FACTORS INFLUENCING THE DISTRIBUTION AND ABUNDANCE OF HELMINTH INFECTIONS:

Model Approaches and Community Studies

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Preface and Acknowledgements

Preface

This dissertation is a record of the research I have carried out during the five years that I spent at the University of Glasgow. I came to Glasgow as a Fulbright scholar, in 1988-89 and investigated host-parasite relationships between tawny owl (*Strix aluco*), common and pygmy shrews (*Sorex araneus* and *S. minutus*, respectively) and the acanthocephalan parasite *Centrorhynchus aluconis*. Some of the results, which are also referred to briefly in Chapter Seven, have been either published or accepted for publication as follows:

Ewald, Crompton, Johnson and Stoddart. 1991. The occurrence of *Centrorhynchus* (Acanthocephala) in shrews (*Sorex araneus* and *Sorex minutus*) in the United Kingdom. *Journal of Parasitology* 77, 485-487.

Ewald and Crompton. 1992. Natural infections of *Centrorhynchus aluconis* (Acanthocephala) and other helminth species in tawny owls (*Strix aluco*) in Great Britain. *Journal of Parasitology* 79,952-954.

McInnes, Crompton and Ewald. 1993. The distribution of *Centrorhynchus aluconis* (Acanthocephala) and *Porrocaecum spirale* (Nematoda) in tawny owls (*Strix aluco*) from Great Britain. Accepted Journal of Raptor Research.

Towards the end of my year as a Fulbright scholar, I decided that I would like to continue research at the University of Glasgow with a view to submission of a dissertation for the PhD degree. My applications for a University of Glasgow Postgraduate Scholarship and Overseas Research Scholarship award were successful. I started investigating transmission mechanisms, particularly by means of model simulations. Some of the results are present in Chapters Eight and Nine and have been presented to the British Society for Parasitology at its Spring meeting in 1993 at Leeds University.

Ewald and Whitehead. 1993. Computer-based simulations of oral transmission in an insect-acanthocephalan system.

In 1991, however, I had the opportunity to participate in an epidemiological survey of human intestinal parasitic infections in Sierra Leone. I was greatly stimulated by the experience not only for its scientific interest but also because of its humanitarian importance. I therefore carried out an extended analysis of my findings (Chapters Three through Six) and it is that effort that has resulted in a somewhat extended research experience and dissertation. Some of my results have been accepted for publication or have been communicated to scientific societies as follows.

Ewald, Bayoh, Crompton and Hodges. 1992. Prevalence and intensity of intestinal helminth infections from three communities in Sierra Leone. *The Journal of the Sierra Leone Medical and Dental Association.*

Ewald, Young, Crompton and Hodges. 1992. Helminthological survey of two locations in Sierra Leone. Presented at the meeting of the Royal Society of Tropical Medicine, Scottish Branch.

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I would like to thank the people who participated in the surveys in Sierra Leone, Gillian and Jayne for either helping to collect the sample or analysing them afterwards and Mary Hodges and Zed for providing wonderful company as well as facilitating the research. This research could not have been undertaken were it not for Mohamed Bayoh who I managed to drag all over Sierra Leone. Adiatu, Sammy and Iris were very helpful in Kroo Bay and the ladies in the office made Bathurst Street a pleasant place to work. Pa Cole deserves a special thanks, he always managed to soothe the

children, charm the women and get us and the vehicle back in one piece. The world is a sadder place without him.

I'd like to thank the members of GULBC, with whom I've rowed throughout the years for keeping me sane and somewhat fit. Thanks go to Jan Meadows for keeping me fed by always throwing a bit of demonstrating my way. I thank my family for letting me go half way around the world.

While at Glasgow I have had the good fortune of having three wonderful friends: Ian Scott, rower and parasitologist, Paul Hagan; whose cups of coffee, lunches and an occasional Haagan Dazs have managed to make the long hours possible and even pleasant, and last, but not least, Fraser J. Hendrie; much more than a friend, but always a friend.

Abstract

An epidemiological survey was carried out in 1991 to study intestinal helminth infections in three human communities in Sierra Leone. Evidence was found for the presence of *Ascaris lumbricoides*, hookworm (probably Neca*tor americanus*), *Trichuris trichiura*, *Schistosoma mansoni* and *Strongyloides stercoralis*. A detailed analysis of the results was undertaken to detect patterns and trends in these human-helminth relationships. Statistical models were constructed to allow predictions to be made about the likely infection status of individuals with intestinal helminth infections. The most important components of the models was the age of the individual in question. The type of data investigation used in this study could be applied to other communities in other countries and could contribute to setting public health priorities, devising control strategies and optimising the use of resources.

The results from the present survey were also compared with those from 24 surveys for intestinal helminth infections carried out in Sierra Leone since 1974. Overall, there is evidence to show that *A. lumbricoides*, though widespread geographically, does not usually occur in high prevalence. Hookworm infection appears to be a serious health problem in rural areas, especially when this information is considered in conjunction with the high rates of malaria found in West Africa. *Trichuris trichiura* shows high prevalence in urban areas and there is some evidence that infection with this helminth is less prevalent in the North of the country.

In the other section of this dissertation, the construction and testing of a simulation model to investigate the mechanism of transmission of *Moniliformis moniliformis* (Acanthocephala) to cockroaches (Periplaneta americana) is described. Construction and testing of the model were based on the results of experiments designed to elucidate how infections of *M. moniliformis* become established in cockroaches. When cockroaches were exposed to different patterns of infective stage distribution (random, clumped and even), over-dispersed distributions of numbers of parasites per host were observed. However, as the distribution of infective stages increased in over-dispersion from even to random to clumped, the variance-to-mean ratio increased. A simulation model of the experimental infections was obtained for each pattern of distribution of infective stages. The even and random distributions were easily modelled, but the results from the clumped distributions of infective stages were not easily modelled. This indicates that there might be other factors involved in these

types of distributions that do not affect the even and random patterns. Such influences might relate to feeding behaviour and the effect that ingesting acanthors may have on this.

The models of the different experimental infections were used to investigate the effect of heterogeneity in inherent susceptibility and changes in acquired susceptibility. The addition of an acquired susceptibility term was seen to have more of an effect than heterogeneity in inherent susceptibility on the over-dispersion of the model cockroaches in models of all three patterns of distributions in infective stages. If 'infected' model cockroaches became easier to infect the over-dispersion rose, if they became harder to infect the over-dispersion fell in comparison to the model before the alterations to simulate differences in susceptibility. This work has implications in epidemiological studies where predisposed individuals have been identified.

Declaration

I declare that the work described in this thesis has been carried out by myself unless otherwise cited or acknowledged. It is entirely of my own composition and has not, in whole or in part, been submitted for any other degree.

Chapter One. Epidemiology of Gastrointestinal Helminths: A Review.

1.1. Introduction

This review will focus on recent epidemiological and public health information available for gastrointestinal helminth infections which are widely distributed in less developed countries (Asaolu, Holland, Jegede, Fraser, Stoddart and Crompton, 1992; Ashford, Craig and Oppenheimer, 1992; Bundy, Cooper, Thompson, Anderson and Simmons, 1987b). The definition of gastrointestinal helminths is expanded here from being those helminths which are parasitic as adult stages in the gastrointestinal tract of humans to include *Schistosoma mansoni*. This helminth, whose eggs are passed in faeces, is often diagnosed at the same time as infection with the common soil-transmitted helminths, *Ascaris lumbricoides*, *Trichuris trichiura*, *Necator americanus* and *Ancylostoma duodenale* by coprological techniques. *Ascaris lumbricoides* infection is estimated to occur in over one billion individuals world-wide (Crompton, 1989b), *T. trichiura* in from 500 million to over 800 million people (World Health Organization, 1987b; Bundy and Cooper, 1989), hookworm infection (*N. americanus* and *A. duodenale* combined) in 900 million individuals (Pawlowski, Schad and Stott, 1991) and *S. mansoni* in 200 million (Doumenge, Mott, Cheung, Villenave, Chapuis, Perrin and Reaud-Thomas, 1987). These infections occur most commonly in the tropical and sub-tropical countries of the world where poverty and malnutrition are widespread.

The health situation is made more serious in that children, who are more at risk of malnutrition because of the energy demands of growth and development, are usually found to be the segment of the population that are most heavily infected with *A. lumbricoides* and *T. trichiura* (Bundy, Hall, Medley and Savioli, 1992). These and other species often co-occur in individuals, with correlations between the intensities of infections (Haswell-Elkins, Elkins and Anderson, 1987; Bundy, Cooper, Thompson, Didier and Simmons, 1987b; Robertson, Crompton, Walters, Nesheim, Sanjur and Walsh, 1989). Polyparasitism has been shown to be a factor affecting the health and nutritional status of children (Robertson, Crompton, Sanjur and Nesheim, 1992). Increasing urbanisation in developing countries, with a third of the population of cities in the developing world living in shanty towns and slums, having poor sanitation and little access to clean water (Harpham and Stephens, 1991) is expected to lead to an increase in the prevalence and intensity of the above helminths most associated with urban conditions, *A. lumbricoides* and *T. trichiura* (Crompton and Savioli, 1993).

Planned control measures for these infections on a large scale, including chemotherapeutic regimes combined with health education and improvements in sanitation at the community level are needed to improve the quality of life of children and adults in the developing world (World Health Organization, 1993). Information gained in epidemiological surveys of the distribution and abundance of helminths in communities (both in hosts and infective stages throughout the environment of the host), the effect of infections on the nutritional status and development of infected individuals and the acute complications arising from infections (Chai, Cho, Lee and Seo, 1991), along with results of controlled studies on the most effective application of chemotherapeutic regimes, will allow the development of control protocols to be drawn up for affected communities. Models simulating the effect of changes in the dynamic parameters of helminth transmission and different control measures on the helminth population within a community can also be used to make suggestions for control programmes.

This review will cover the prevalence and intensity of *A. lumbricoides*, *T. trichiura*, hookworm and *S. mansoni* infections in communities, with reference to differences seen due to host factors that have been investigated (for example, host age, sex, household size, occupation) in studies published recently. The emphasis will be on cross-sectional studies of entire communities, with the views espoused by recent reviews on the distribution of gastrointestinal helminths also considered. Nutritional and developmental effects of infections with the above helminths, especially in children who are infected, will also be covered. These have been reviewed recently for two helminth species of the four being considered (Stephenson, 1993 for infections with *S. mansoni* and Thein Hlaing, 1993 for infections with *A. lumbricoides*) and reviews of the effect of hookworm infection on nutrition (Crompton and Stephenson, 1990) and of *T. trichiura* infection (Bundy and Cooper, 1989) were undertaken in the last five years. Confounding factors that are found to be associated with both helminth infection status and nutritional status will also be discussed. Chemotherapeutic intervention studies on the control of helminth infections which have used information gained from the above epidemiological approaches will be discussed.

1.2. Prevalence and Intensity Profiles of Helminth Infections in Communities

1.2.1. Definition of Prevalence and Intensity

Before considering the differences seen between infections with these four helminth species it is necessary to have a clear definition concerning what is meant by prevalence and intensity. Prevalence of a helminth is understood to be the number of individuals found to be infected with that helminth at a certain time and in a defined locality (Margolis, Esch, Holmes, Kuris and Schad, 1982). This variable is usually expressed as the percentage of a sample that was found to be infected. The sample size examined should be stated, as the larger the sample the better the estimate of the true prevalence of the helminth infection is likely to be. When assessing the prevalence of a helminth infection, selection of individuals for sampling must be done with some care. It is best to use some form of random selection if the entire community cannot be surveyed but also to ensure that this sample contains individuals of all ages and sexes, if it is to be representative of the entire community (Thein Hlaing, 1989a).

Intensity of infection is defined as the mean worm burden of those found to be infected (Margolis *et al.*, 1982). Essentially this is the total number of worms recovered from the individuals sampled in a community divided by the number of individuals found to be positive for infection with that helminth. In the case of surveys using egg counts as a measure of intensity, this is the sum of all the egg counts divided by the number of individuals found to be infected with that helminth species. In some studies, the measure of intensity has been taken to be the sum of the total number of worms (or the sum of egg counts) divided by all the people surveyed regardless of whether they were infected or not. This is now referred to as density (Margolis *et al.*, 1982). Often authors of papers do not specify which method of calculating intensity they have used but this can be determined by the type of transformation they have used for data analysis. Helminth infections are overdispersed with a few individuals harbouring the majority of the worms (Crofton, 1971a; Anderson and Gordon, 1982). This is also true of the distribution of egg counts. In order to perform parametric statistics on the intensity data it is necessary to transform it, usually with a logarithmic transformation. If the authors state they are using log(intensity) transformations, they are most likely to be using only the individuals found to be infected at the time of the survey. If they are using log (intensity + 1) they are probably using all the individuals surveyed in estimations of intensity. The inclusion of individuals

with an intensity of zero would necessitate the use of (intensity + 1) instead of (intensity) as there is no logarithm of zero. This will lead to underestimation of intensities in those actually infected and, if morbidity is related to intensity, to an underestimation of the public health significance of helminth infections for individuals within the community being studied. Using all individuals in a survey, instead of only those found to be infected, assumes that all individuals are at equal risk of having high intensities. If individuals do not have a helminth infection, they are contributing nothing to the helminth community within the host community at this time. Uninfected individuals will not show morbidity effects due to helminth infection. Therefore, the use of only those found to be infected in calculation of intensity appears to give more information on the helminth infections that exist at the time of the survey. It should be noted that in areas of high prevalence, the intensity and density will tend to converge.

1.2.2 Methods of Determining Prevalence and Intensity

The manner of determination of infection will influence both the prevalence and intensity measurements. Two general methods are used to determine frequency of infection and intensity of infection, recovery of worms after treatment and determination of eggs in faeces. Both methods have their draw backs (Hall, 1982). Underestimation of prevalence and to some extent intensity no doubt takes place with both methods, as light infections can be easily missed either with small numbers of eggs or worms being missed. An observer is more likely to miss a worm or egg than count some extraneous object as a worm or egg. The ability to resample the stool for egg counts is possible when a representative sample of the faecal material is taken for testing first, leaving some material for another analysis. If treatment has not yet been given to it is possible to totally resample the individuals in question. In worm recovery studies there is no chance of returning to the individual in question and reworming them, as this method of measuring infection is destructive to the item being measured. This method is useful, however, in estimating both the predisposition to infection and the degree of reinfection after treatment.

Recovery of worms following expulsion chemotherapy cannot be used to determine *S. mansoni* infection, as no worms are passed. The use of recovered worms to measure prevalence and intensity for infections of *T. trichiura* and hookworms runs into difficulty due to the size of these helminths in relation to the amount of faecal material that must be sieved through to recover them.

This problem is not encountered in the recovery of adult *A. lumbricoides*, although the same might be said of small individuals of this species. No anthelmintic drug is 100% effective when used in the field and some inaccuracies will occur due to this (World Health Organization/Pharm, 1986). The effectiveness of the various drugs used is different depending on the species of helminth being treated. The use of one drug as a means of assessing prevalence and intensity for one helminth infection might underestimate the prevalence and intensity of another helminth. The researcher is dependent on the co-operation of the people living in the community to recover all faecal mass they have passed for what is often days following treatment (depending on what anthelmintic is being used) in order to give a reliable count of worms passed. Collection of helminths following expulsion chemotherapy is necessary when certain values of parameters of helminth infections are required for inclusion in models of these infections, such as sex ratio of worms, reproductive potential and estimations of the parameter k for the negative binomial. The logistics of collection and sieving stools and the high level of co-operation required in the community being studied to use collection of helminths passed often make it difficult to use this as a means of estimating prevalence and intensity.

The recognition and counting of helminth eggs in passed stools is the other commonly used method of determining prevalence and intensity of helminth infections. Egg counts rely on individuals producing a sample representative of themselves when they are surveyed, a sample large enough to be characteristic of the number of infective stages being passed by this individual at the time of survey. The use of this method runs into difficulties due to the variability of egg counts from individuals from one day to the next and from any density-dependent effect on fecundity which may be seen in more intense infections (Hall, 1982). The use of egg counts does not allow the discrimination between the two hookworm species commonly found to be parasitic in humans, *A. duodenale* and *N. americanus*. The choice of method of egg counts is open to some debate and this will depend on the species of helminths which are believed to be endemic within the community being studied (Pritchard and Kruse, 1982; Theinpont, Rochett and Vanparijs, 1986; World Health Organization, 1991). Operculate trematode eggs may be more difficult to quantify using techniques used for nematode eggs. The method of counting should be quantitative as well as qualitative in order to give some comparable measure of intensity. Egg counts only give a comparison between the numbers of female worms present. For total worm burden it must be assumed that the sex-ratio does

not differ significantly from one to one. In *S. mansoni* infections in which pairing takes place between the sexes and they essentially become one unit this may be a fair assumption. In other helminth infections, the life span of males may not equal that of females and the number of egg-producing females will not reflect the number of males present.

The choice of methods either worm recovery or egg counts (with the type of procedure used for this) must be determined with the aims of the survey in mind, the species of helminth deemed to be of interest within the community, the technical assistance available, and the amount of co-operation from the community being studied.

1.3. Prevalence and Intensity by Host Age

Comparisons of intensity and prevalence by host age of the three most common gastrointestinal helminth infections indicate some differences (Bundy *et al.*, 1992). In most areas that have been studied, the prevalence of *A. lumbricoides* and *T. trichiura* increases rapidly with age, with peak prevalence being reached by 5 yr to 10 yr of age, with a decrease in prevalence in later years, although this may vary to a degree. If intensity is high, there will be a slower decrease in prevalence with increasing age (Cooper and Bundy, 1990). Examples of prevalence by age profile for infections of *A. lumbricoides* are illustrated in Figure 1.1 (Asaolu, Holland, Jegede, Fraser, Stoddart and Crompton, 1992; Ashford, Craig and Oppenheimer, 1992; Bundy *et al.*, 1987b; Chacia-Bonilla, Bonilla, Parra, Estevez, Morales and Suarez, 1992; Croll, Anderson, Gyorkos and Ghadirian, 1982; Elkins, Haswell-Elkins and Anderson, 1988; Higgins, Jenkins, Kurniawan, Purnomo, Harun and Juwono, 1984; Ratard, Kouemeni, Ekani Bessala, Ndamkou, Sama and Cline, 1991; Thein Hlaing, Than Saw and Myint Lwin, 1987). Age prevalence profiles for *T. trichiura* are displayed on Figure 1.2 (Asaolu *et al.*, 1992; Ashford *et al.*, 1992; Bundy, Cooper, Thompson, Anderson and Didier, 1987a; Chacia-Bonilla *et al.*, 1992; Forrester, Scott, Bundy and Golden, 1988; Higgins *et al.*, 1984; Ratard *et al.*, 1991). The prevalence of hookworm infection increases as well with host age but less rapidly, with peak prevalence being reached in young adulthood. A relatively stable plateau in hookworm prevalence is seen in age classes after adulthood is reached, as illustrated in Figure 1.3 (Asaolu *et al.*, 1992; Ashford, Hall and Babona, 1981; Ashford *et al.*, 1992; Bradley, Chandiwana, Bundy and Medley, 1992; Chacia-Bonilla *et al.*, 1992; Haswell-Elkins, Elkins, Manjula, Michael and Anderson, 1988; Higgins *et al.*, 1984; Marnell, Guillet and Holland, 1992; Schad, Soulsby,

Chowdhury and Gilles, 1975). Profiles for *S. mansoni* (Figure 1.4) show a rise in young adulthood, with a peak in the 10 to 20 yr olds, decreasing in adults (Chandiwana, Taylor and de V. Clarke, 1988; Gryseels, 1990; Gunderson, Birrie, Torvik and Scherbaum, 1990; Jordon, Bartholomew, Grist and Auguste, 1982; Marnell *et al.*, 1992; Ouma, Wijers and Arap Siongok, 1985; Taylor and Makura, 1985).

A rise in intensity with age is also seen in all three infections, although at a slower rate than prevalence. The peak intensities of both *A. lumbricoides* and *T. trichiura* usually occur in children between the ages of 5 and 10 yr old. Intensity then shows a characteristically slow decline in older individuals, with low, but stable levels of infection in adults (Bundy *et al.*, 1987a and Bundy *et al.*, 1987b). There are some instances in the literature, however, where *A. lumbricoides* intensities do not decline with age, but remain around a stable value, near to their peak value found in children (Arfaa, and Ghadirian, 1977). For hookworm infections, the peak intensity which is usually found in adult hosts, remains stable through the later adulthood (Bradley *et al.*, 1992). The intensity by age of *S. mansoni* usually follows a pattern similar to that seen for prevalence in children and young adults (Gryseels, 1990; Taylor and Makura, 1985), with intensity rising in young children reaching a peak in those between 10 and 19 yrs of age and then being seen to decrease in adults. The differences in the relationship between age and prevalence and between age and intensity for these different helminth species, especially for *A. lumbricoides*, *T. trichiura* and hookworm infections have been pointed out in recent papers (Bundy *et al.*, 1992; Bundy, 1990; Ashford *et al.*, 1992).

It has been suggested (Bundy *et al.*, 1987b) that differences in the age-related profiles of *A. lumbricoides* and *T. trichiura* reflect the differences in the absolute size of the worm burden in the two species. This is in regard to the steeper decrease in *A. lumbricoides* prevalence with age after peak prevalence in comparison to prevalence of *T. trichiura*. Prevalence is related to density by the use of the following equation (Anderson, 1982):

$$p(a) = 1 - [1 + M(a)/k]^{-k};$$

where $p(a)$ is the rate of change of prevalence with host age, a; $M(a)$ is the rate of change of mean worm burden with host age; and k is the negative binomial exponent. This equation indicates that for small changes in mean worm burden, when the absolute size of the worm burden is small, there will be a greater change in prevalence in comparison to when the absolute worm burden is high and

prevalence will be less subject to change. The implication from this is that where the worm burden of a helminth species is relatively low (*i.e.* in *A. lumbricoides* infections), the prevalence with increasing age will be seen to decrease with a decrease in mean worm burden but this will not be so if the actual numbers of worms present is high (*T. trichiura* infections). Differences in the worm burden for the two species could be responsible for the observed differences in age-related prevalence.

The type of relationship seen in *S. mansoni* infection and to some extent in infections of *A. lumbricoides* or *T. trichiura* with host age can be taken to indicate either a decrease in transmission as individuals age or a decrease in the amount of parasites which infect a host, due to immunity acquired through exposure to the parasite as an individual ages. Studies on infections with *S. haematobium* and *S. mansoni*, combining water-contact studies and prevalence and intensity of infections have indicated that though contact with water will often remain the same throughout life, after young adulthood an individual will either not acquire infections or will acquire lower intensities of infection. Evidence of involvement of differences in the immune response mounted against *S. haematobium* and *S. mansoni* life-cycle stages have indicated an increase in effective immunological recognition of the host as the host ages (Butterworth, Capron, Cordingley, Dalton, Dunne, Kariuki, Koech, Mugambi, Ouma, Prentice, Richardson, Arap Siongok, Sturrock and Taylor, 1985; Bundy and Blumenthal, 1990; Hagan, Blumenthal, Dunn, Simpson and Wilkins, 1991).

In the case of infections with either *A. lumbricoides* or *T. trichiura*, the influence of immunological responses on the observed epidemiological patterns has not been well studied. Although immune responses are mounted to these helminths, the degree of protection produced is open to debate (Haswell-Elkins, Kennedy, Maizels, Elkins and Anderson, 1989). As infection with these two helminths is spread by faecal contamination, it has been suggested in one study that if other parasites transmitted in a like manner (for example amoebic infections) do not show a decrease in prevalence due to an increase in host age, this is indicative that the amount of contamination does not change with age (Ashford *et al.*, 1992). The decrease seen in prevalence and intensity of *A. lumbricoides* and *T. trichiura* infections is then most likely due to an acquired immune response, not a decrease in transmission due to differences in encounter with infective stages. The use of other infections to determine the amount of faecal contamination present in an individual's environment presupposes that exposure to one of these follows the same pattern as exposure to another. This may

not be true of infection with amoebae and *A. lumbricoides* and *T. trichiura*. In studies which have looked at infections of individuals in houses where there is piped water in comparison to houses where there is no piped water, the prevalence and intensity of gastrointestinal helminths show no difference (Mason, Patterson and Loewenson, 1986), while the prevalence of intestinal amoeba is lower in those houses with piped water. This would seem to indicate a different type of contamination being responsible for infection with these two kinds of parasites. Also, in a study investigating reinfection with *A. lumbricoides* following treatment, differences in rates of reinfection between older versus younger people were not detected (Elkins *et al.*, 1988). If an acquired immune response were responsible for the age prevalence patterns usually seen in infections with *A. lumbricoides*, the reinfection would have been at a lower rate in older people versus younger people. A better test of the environmental exposure/immunity conflict would be to carry out studies similar in nature to water-contact studies involving *S. mansoni*. The examination of other factors influencing infection prevalence and intensity, such as sex, occupation or religion just to name a few, may also shed some light on this subject.

The type of age-profile seen in hookworm infections is one of increasing prevalence and intensity with increasing age until a plateau is reached and is taken to be evidence of no effective immune response in early life and of increasing encounter of infective stages with age. It has been pointed out that in some studies in areas of high transmission with this helminth, a decreasing intensity has been seen with age, after a peak from about 5 to 19 yr of age (Anderson, 1986). In none of the surveys completed recently has this been seen to be the case (see Figure 1.2). In a study of the rate of acquisition of hookworm infection in the Gambia, it has been suggested that there is some immune response involved in the plateau of prevalence and especially intensity of infection (Knight and Merrett, 1981). Again intensity in this study was measured using eggs per gram faeces and density-dependent effects on reproduction have been shown to exist with this helminth, which may lead to spurious results. Information on the actual amount of exposure to infective stages with age and its relation to reinfection on treatment would be necessary before this could be taken as age-related acquired immunity. In the case of hookworm infection, there appear to be many exposure related factors which play a part in the overall picture of prevalence and intensity (Schad, Nawalinski and Kochar, 1983). The examination of other factors involved in prevalence and intensity of infection

will give a better view of what are the components shaping this epidemiological pattern. Studies involving quantifying the amount and distribution of infective stages in the environment would be of benefit in determining what factors are associated with the intensity and prevalence pattern seen with hookworm infections.

1.4. Prevalence and Intensity by Host Sex

Sex of host has also been examined to determine if it has any effect on the prevalence or intensity of infection with these helminth species (Table 1.1). When significant differences are found, females are more likely to be infected with *A. lumbricoides* (Ratard *et al.*, 1991; Arfaa and Ghadirian, 1977; Higgins *et al.*, 1984) and males are more likely to be infected with hookworm or *S. mansoni* (Asaolu *et al.*, 1992; Bradley *et al.*, 1992; Gryseels, 1990), although exceptions to this do occur (Elkins *et al.*, 1988; Haswell-Elkins *et al.*, 1988; Gryseels, 1990). Infections with *T. trichiura* are usually found to be equally prevalent in both males and females (Asaolu *et al.*, 1992; Marnell *et al.*, 1992). Intensity usually follows the same pattern as prevalence in the above infections (Asaolu *et al.*, 1992; Elkins *et al.*, 1988). When significant differences do occur, they appear to indicate differences in transmission parameters most probably due to behavioural differences between the sexes, although hormonal and other physiological differences due to the sex of host cannot be ruled out. A reversal of these rules can usually be associated with local differences in exposure that can be tied to local customs, usually concerning division of labour (Haswell-Elkins *et al.*, 1988; Gryseels, 1990). The finding of significant differences due to host sex can be quite localised, with some communities within an area showing this effect and others not. Examples of these differences are given in Table 1.1 for prevalence and Table 1.2 for intensity. In addition to those studies listed in Tables 1.1 and 1.2, a study in rural Nigerian village, which analysed its results in a combination of EPG x % prevalence to give a measure of what was called 'worm burden', found that females from age 15-30 yr of age had higher 'worm burdens' of *A. lumbricoides* and *T. trichiura* and males had higher 'worm burdens' of hookworm (Nwosu, 1981).

The reasons that have been put forward for the above generalisations about helminth infections include chiefly the matter of contact with areas deemed to be highly contaminated with infective stages of the helminth involved. In general, the studies of *S. mansoni* infection have shown that where infective stages are found in areas involved with fishing, (Gryseels, 1990) and other more

male dominated activities the prevalence and intensity will be higher in males than females. In areas where infective stages are found at areas involved with the washing of clothes and other household tasks (Kvalsvig and Schutte, 1986), females within a community are more at risk of infection. In areas where encounter with infective stages is not related to some activity which is customarily performed by one sex or another, the prevalence and intensity will not vary significantly between the two sexes.

Hookworm infection is sometimes taken to be more prevalent and intense in males due to their involvement in agriculture. The results from a South Indian fishing village (Haswell-Elkins *et al.*, 1988), where females were seen to have more and more intense infections of hookworm, were related to the increased risk of infection that women faced in carrying the fish to market through a highly infected area, while the men of the community faced little risk of infection on their fishing boats. Involvement in agriculture is probably not the only factor responsible for producing the predominance of this infection in men. As anyone who has visited a rural village in the developing world will know, the majority of everyday tasks are carried out by the women and this includes work in the fields. There might be other factors involved, most probably relating to defecation practices. Infective stages have not been found to be randomly distributed and males and females do not share defecation areas (Hominick, Dean and Schad, 1987). The time of the day and the amount of time individuals are involved with agriculture could be crucial to transmission, as defecation usually takes place in the early morning (Hominick *et al.*, 1987). These results from a study similar to the studies of water-contact studies of *S. mansoni*, showed that young adult males often encountered a large number of infective stages in their defecation sites and this could be related to helminth intensity. There was no evidence to suggest how others in the community (i.e. older males) became infected with the numbers of helminths they harboured. Although involvement in agricultural was cited as the behaviour that lead to infection in other age groups, it was not deemed to be the only important feature in contact with infective larvae, as families of farm labourers most at risk also had higher intensities and prevalences of hookworms in comparison to other families, even though these individuals did not contribute significantly to work in the fields (Schad, Nawalinski, and Kochar, 1983)

The higher prevalences of *A. lumbricoides* in females have been remarked upon before (Crompton, 1989b) and this finding has been linked to the additional time that women spend in the fields with greater risk of contamination (World Health Organization, 1967). As this is the usual reason given for the preponderance of hookworm infection in males, it might seem unlikely that it is the same reason for higher prevalence of *A. lumbricoides* in females. A scenario involving a division of labour in the fields in which women were more exposed to *A. lumbricoides* eggs and men to hookworm larvae is highly complicated, but could reflect the importance of micro-environmental factors responsible for transmission patterns (Nelson, 1990). An example of this was believed to be seen in Iran, where it was suspected that females came into greater contact with contaminated night soil and were at higher risk of *A. lumbricoides* infection due to this (Arfaa and Ghadirian, 1977). Another, perhaps more likely scenario is to see *A. lumbricoides* infection as a childhood infection which is picked up from contamination of the micro-environment that children play in. Women and older girls are more liable to pick up infection with *A. lumbricoides*, as they are the people more likely to be involved with children, the age group of the population most heavily infected. They may not be picking up infective stages directly from the children, but as a consequence of child care are more at risk because they share more of the micro-environment of the children, than do their male counterparts.

The fact that *T. trichiura* infections have not been found to show the same relationship in most of the community surveyed may be related to several differences seen between infections with these two helminths. In a study of the contamination of two homes for children with infective stages for *A. lumbricoides* and *T. trichiura*, it was estimated that children on the whole were encountering between 9-20 *A. lumbricoides* eggs per yr and 6-60 *T. trichiura* eggs per yr (Wong, Bundy and Golden, 1991). When this is combined with recent estimates of both the rate of increase and the life span of these two helminth species, it becomes evident that *T. trichiura* infections are more difficult to control and this leads to the conclusion that infections with this helminth species may be more easily picked up (Bundy, Hall, Medley and Savioli, 1992). Therefore men, might be at relatively the same risk as women from *T. trichiura* infection, due to the larger number of infective stages in the environment, higher rate of increase and longer life-span. The difference seen in the relationship of host sex to infection with these two helminths species underlines the fact that they are two different

species and transmission of each species in an endemic environment is likely to differ slightly, leading to different patterns in their epidemiology. In spite of the fact that they appear to infect the same age group most highly, there are differences in their epidemiology which were also mentioned in regards to the prevalence by age profiles seen for each helminth. Although chemotherapuetic regimes might be well suited for combined control of both helminth species, the sanitation and education involved in the control of either helminth might be slightly different. The relative amount of effort required on these two aspects of control might differ depending on which of these two helminths are representing the greatest public health risk in a community at a certain time.

1.5. Prevalence and Intensity by Other Investigated Factors

1.5.1. Climate and Water Resources

Indications from reviews of the prevalence of *A. lumbricoides* (Crompton and Tulley, 1987) and *T. trichiura* (Bundy and Cooper, 1989) are that both of these helminths are less common in arid areas, although this may be compounded by the lower population densities and lower likelihood of reporting of infections. A comparison of villages in Kenya found that all helminth infections studied (hookworm, *A. lumbricoides* and *T. trichiura*) were more common near the coast, in wetter conditions (Ashford, Craig and Oppenheimer, 1993), although within an area, it appeared that there were other factors involved in the distribution of helminth infections. In a survey throughout Cameroon, *T. trichiura* and *A. lumbricoides* infection were most prevalent in wet areas with 20-40% sunshine, mean temperature of 24-26 C, dense vegetation and clay soils (Ratard *et al.*, 1991). *Ascaris lumbricoides* infection was seen to be more common in the cool Highlands of Kenya in a survey of adult male roadworkers, with *T. trichiura* infections being more common in the tropical coastal lowlands (Hall, Latham, Crompton, Stephenson and Wolgemuth, 1982).

Hookworm infection was found to be most prevalent in those areas having greater than 40% humidity in the same survey of Kenyan roadworkers. Similar findings were reported for individuals in Cameroon, where the area of highest rainfall had the highest prevalence of hookworm infection (Ratard, Kouemeni, Ekani Bessala and Ndamkou, 1992). Investigations on the conditions of soil associated with infective hookworm larvae have indicated the need for moisture and shade for the development of larvae (Nwosu and Anya, 1980; Hominick *et al.*, 1987). Another consideration in hookworm infection is the species of hookworm involved, either *Ancylostoma duodenale* or *Necator*

americanus. In Africa, it is believed that *N. americanus* is the most prevalent south of the Sahara and *A. duodenale* North of the Sahara (Kiliama, 1990).

Infections of *S. mansoni* are confined to areas where conditions allow a suitable intermediate host to coexist with humans. In Zimbabwe the distribution of *S. mansoni* infection is seen to reflect the distribution of water, with areas having water bodies existing all year round having the highest prevalence of infection (Taylor and Makura, 1985). The building of dams has been seen to increase the transmission area of a related species *Schistosoma haematobium* (King, Miller, Hussein, Rarkat and Monto, 1982) and the disruption of habitat and increase in amount of standing water due to mining in Sierra Leone has been thought to lead to a spread of *S. mansoni* into areas where it previously did not occur (White, Gbakima and Amara, 1989).

1.5.2. Urban Versus Rural

It is claimed in Africa that infections of *A. lumbricoides* are more prevalent in rural areas than in urban (Crompton and Tulley, 1987), but in Peru higher prevalences are found in urban areas (Lumbreras and Nacquira, 1985). A survey of children in Ethiopia indicated that there were more infections of *A. lumbricoides* in the boroughs of Addis Ababa than in a rural village, the difference being related to over crowding and the disruption of traditional hygienic practises found in the poverty associated with some urban areas (de Carneri, Di Matteo and Tedla, 1992). Hookworm infection is usually found to be more common in rural areas than in urban ones in Africa (Kiliama, 1990) and this is probably due to lack of suitable sites for hookworm larval development. This was also shown by the higher prevalence seen in rural versus urban areas in Cameroon (Ratard *et al.*, 1992) and in the higher prevalences seen between those living in dispersed versus nuclear homestead in Nigerian rural areas (Pugh, Burrows and Bradley, 1981). Infections of *S. mansoni* are usually more prevalent and intense in rural areas than in urban areas, although exceptions to this do exist (Gryseels, 1990). These are related to local conditions which may exist in certain urban locations. If water projects, usually constructed in urban areas, are badly designed and people in the area continue to use natural bodies of water which are contaminated with infective stages of *S. mansoni*, transmission and disease will continue even along side improvements in public services found in an urban area (Kvalsvig and Schutte, 1986).

Recent increases in urbanisation in the developing world have lead to speculation on the effects this will have on the numbers of helminth infections world-wide (Crompton and Savioli, 1993). Attention has been focused on the need for proper sanitation to control infections of especially *A. lumbricoides* and *T. trichiura*. As most of the increasing urbanisation is due to the increase in the size and number of communities with substandard housing, water supply and sanitation, this will no doubt increase both the prevalence and intensity of these two helminth species.

1.5.3. Temporal

There have been some instances in the literature where seasonal transmission of *A. lumbricoides* does occur (Crompton, 1989b). These have been related to either the seasonal use of night-soil (Gelphi and Mustafa, 1967) or to variation in climatic conditions where conditions are suitable for transmission of *A. lumbricoides* only during certain times of the year (Kobayashi, 1980). No evidence in the literature was found for similar differences for *T. trichiura* infection, but as conditions for its transmission would no doubt be influenced by temperature and humidity, this may in fact occur.

Temporal influences on the transmission of hookworm infections have been studied in more detail. In West Bengal, India, hookworm transmission was found to only occur during the rainy season. Owing to mixed infections of *N. americanus* and *A. duodenale* being present, the situation was further complicated by the fact that *A. duodenale* infections would undergo arrested development (Schad, 1990). Thus larvae picked up by the host in one rainy season can delay development until the onset of the next rainy season, with a rise in faecal egg production just preceding the rainy season (Schad, Chowdhury, Dean, Kochar, Nawalinski, Thomas and Tonascia, 1973). In work carried out in rural Gambia, where *N. americanus* is the species of hookworm present, egg counts began to rise eight to nine weeks after the beginning of the rainy season (Knight and Merrett, 1981). The peak rise in egg production was found to be seven and a half months after the start of the rains and this was then followed by a fall, a result taken to indicate a seasonal transmission pattern, since hypobiosis is unknown in this species of hookworm (Schad, 1990). The transmission of hookworm infection was studied in Nigeria where it was shown that the times of the year with the largest number of rainy days were also the times of the year when the largest number of infective larvae were found (Nwosu and

Anya, 1980) and the rainy season correlated with the time when the largest numbers of infective larvae were found (Udonsi, 1983).

Temporal changes in the prevalence and intensity of infections of *S. mansoni* have been correlated with changes in water level in Zimbabwe (Taylor and Makura, 1985). Not only will the amount of water available for the intermediate host be important in the prevalence and intensity of infection, but seasonal variation in human behaviour will be seen to have an influence on the transmission of this parasite. This is related to both the amount of water contact humans may have and the number of suitable intermediate hosts present (Gryseels, 1990), perhaps involving irrigation or other human activities.

1.5.4. Socio-Economics, Social Class and Occupation

Infections with *A. lumbricoides* were studied in an Indian village, where differences were seen between castes in their prevalence and intensity of infection (Haswell-Elkins *et al.*, 1989). This was attributed to the different sizes of households and the placement of houses within the village, both of which appeared to be confounded with caste. In work in Iranian rural villages (Arafaa and Ghadirian, 1977), women were deemed to be more at risk of infection with *A. lumbricoides* due to their increased exposure to contaminated night-soil.

Hookworm infection is often associated with involvement in agriculture and this is often the reason given for any differences in prevalence and intensity between the sexes. This has been studied in detail in India (Schad *et al.*, 1983), where those individuals who were employed in agriculture had the highest intensity of hookworm infection. That this is not simply due to contact with soil is evidenced by the fact that women, who do not actively labour in the fields in this area, also show the same relationship. Those whose family occupation was listed as agricultural had higher intensities of infection than women whose family occupation was not stated to be agricultural. In a South Indian fishing village, women were seen to have the highest intensity and prevalence of hookworm infection (Haswell-Elkins *et al.*, 1988), perhaps related to the particular division of labour in the community. The men of the village were involved in fishing and the women transported the catch of fish to markets in other village, having to traverse through contaminated shaded areas to reach these villages.

Schistosoma mansoni infection is related to water-contact and this is often influenced by occupation. In areas where the contact with infective stages is associated with fishing will show the highest prevalence and intensity in individuals who are involved in this activity, where domestic chores are associated with exposure to infective stages, then people who carry out these domestic chores will be most at risk (Gryseels, 1990). In areas with substandard water facilities, and this is often correlated with low economic status, increased contact with natural bodies of water will increase the likelihood of infection with *S. mansoni* (Kvalsvig and Schutte, 1986).

1.5.5. Family Features

Studies on the clumping of infections of *A. lumbricoides* and *T. trichiura* within certain households have indicated the importance of the family in transmission of these helminths. Extensive work in Mexico showed that some families are more at risk than others from these infections (Forrester *et al.*, 1988), perhaps because of inherited differences in the immunological determinants of susceptibility and/or the importance of the household as a foci of infection. Not only were some families more likely to have more and larger infections, but upon treatment and re-sampling they were seen to be predisposed to more and heavier infections (Forrester, Scott, Bundy and Golden, 1990). A similar result was found in a study of school children in Panama, where in one school infections of *A. lumbricoides*, *T. trichiura* and hookworm were more common in those children whose siblings also were infected (Robertson, Crompton, Walters, Nesheim, Sanjur and Walsh, 1989). Household clustering was seen in an Indian village, where increasing size of household was seen to be associated with increasing intensity of infection (Haswell-Elkins *et al.*, 1989) and a similar result for hookworm infection was found in one of four rural Nigerian villages studied (Asaolu *et al.*, 1992). Investigations into the micro-habitat of areas endemic for *S. mansoni* infections have shown that household clustering is often the result of quite local foci of transmission (Koetzel and de Azevedo Vergetti, 1988) and may have less to do with the family unit *per se* and more to do with increased exposure to infective stages in a very defined area.

1.5.6. Religion and Ethnicity

The distribution of *A. lumbricoides* infection in Malaysia has been seen to differ with regards to ethnicity, with Malays and Indians showing higher intensity and prevalence of infections. These differences are believed to reflect cultural differences, especially in food handling and preparation

(Kan, 1985). These results were collected in groups of similar socio-economic standards. In India, significant differences were found between Hindus and Muslims in intensity of hookworm infection (Nawalinski, Schad and Chowdhury, 1978) and in the prevalences of other helminth infections (Chowdhury, Schad and Schiller, 1968a; Chowdhury, Schad and Schiller, 1968b). Most of the differences associated with ethnicity and religion are probably related to differences in exposure influenced by religious or social customs, rather than differences in physiological or immunological susceptibility to infection.

1.5.7. Sanitation

The importance of sanitation as a determinant of the prevalence and intensity of helminth infections is well established (Kilama, 1985). The provision of latrines and piped water, however, is not always enough to disrupt the transmission of helminths. In Zimbabwe, no difference was found in intensity of hookworm infection and the provision and availability of latrines (Bradley, Chandiwana and Bundy, 1993) and no difference was found in prevalences of helminth infections in areas with piped water versus areas without piped water; the incidence of amoebic infections was reduced following the provision of piped water. The importance of providing socially and culturally acceptable water supplies was pointed out in research carried out in South Africa where even though piped water supplies were provided they were not used and infections of *S. mansoni* were transmitted due to continued use of natural bodies of water (Kvalsvig and Schutte, 1986).

1.6. Helminth Infections and Malnutrition: General Considerations

A detailed review of the evidence for and against the association of childhood malnutrition with infections with gastrointestinal helminths is beyond the scope of this thesis. There are a few general points and recent studies which have some bearing on the following epidemiological surveys and they are presented in the following section.

Studies of the effects of helminth on the nutritional status need to be designed to take into account epidemiological, biological and nutritional factors which may influence both the helminth infections themselves and also the nutritional status of the children being studied. These factors have been summarised (Thein Hlaing, 1989a; Hall, 1993) and are as follows: 1. Cross-sectional surveys which fail to take into account the previous history of infections, socio-economic conditions and diet have a difficult time showing that variations in child nutritional status is due to helminth infection,

either intensity or prevalence; 2. Due to the aggregated nature of helminth intensities, morbidity and disease will be seen in a minority of those found to be infected and children must be stratified based on intensity not on prevalence alone, since nutritional effects would be expected to be present in those with high intensities; 3. The length of infection may have an effect on the extent of malnutrition seen in individuals, with those infected for longer times showing greater effects; 4. Treatment and follow-up need to be designed according to the conditions in which the children live, in areas where transmission pressure is high, repeated treatments may be necessary and if the diet of the children is poor, a longer time period may also be necessary to show significant effects of treatment; 5. Effectiveness of the drug used for treatment must be considered, especially where infections with multiple species of helminths; and 6. Proper untreated control groups must be used, although this may be difficult ethically if malnourished and heavily infected children are detected. Not many of the surveys involving gastrointestinal helminths and malnutrition in children have managed to follow these six guidelines.

1.6.1. Ascariasis

The effect of ascariasis on the nutritional status had recently been reviewed (Thein-Hlaing, 1993). The studies reviewed were divided into two groups, those with and without anthelmintic treatment being given. Those without treatment being given were divided up into cross-sectional studies of helminth epidemiology and follow-up studies. Those in which anthelmintic treatment were given were divided up between those with a randomised intervention and those without randomised intervention. Studies taking place in areas of low *A. lumbricoides* prevalence were excluded from the review as were those intervention studies using a drug of low efficacy and for whom the information was difficult to obtain.

In general, the studies reviewed revealed that children either found to be uninfected with *A. lumbricoides* or who were treated with anthelmintic drugs were found to have better nutritional status. In randomised controlled designs significant improvements in weight or height after anthelmintic intervention was found in areas with high prevalences of *A. lumbricoides* and malnutrition, low prevalence of other confounding helminths and repetitive and regular treatments of children over a sustained period (1 to 2 yrs). The conclusion drawn from this review was of a causal relationship between *A. lumbricoides* infection and childhood malnutrition.

In an example of a well planned intervention to determine the effect of *A. lumbricoides* infection on childhood malnutrition, villages in Burma were selected to give high prevalence of *A. lumbricoides*, low prevalence of other parasitic infections (especially *T. trichiura* and malaria), rice farming as main occupation, high numbers of children between 2-12 yr of age, population stability, no history of flooding and no planned development projects (Thein Hlaing, Than Toe, Than Saw, Myat Lay Kyin and Myint Lwin, 1991). Significant increments of height-for-age were seen among children 2-5 yr of age after 12 m of treatment and in the 6-10 yr of age group, only after 18 m of treatment in intervention children versus non-intervention children. A significant increase in weight-for-age in the treated children versus the untreated children only occurred at the 24th m of the study. The children were also stratified into those with initially higher and lower worm burdens.

1.6.2. Hookworm Infection

The nutritional effect of hookworm infection have been recently reviewed (Crompton and Stephenson, 1990). The dominant conclusion from an earlier review (Roche and Layrisse. 1966) was that hookworm infection was inextricably linked with iron-deficiency anaemia. The authors of the later review could not locate an example of a properly conducted study where treatment of hookworm infection alone was sufficient for improvement in health status. They did conclude that there was sufficient evidence to indicate that hookworm infection decreases appetite and energy status and this is related to a decrease in physical fitness and productivity. They recommended two foci of research: 1. Properly controlled treatment studies to determine the effects on health status of treatment for hookworm infection. 2. Determination of cost-effect chemotherapeutic strategies for community control of hookworm infection.

1.6.3. Trichuriasis

A review of human infections with *T. trichiura* has been recently undertaken and includes a review of conditions associated with infections with this helminth (Bundy and Cooper, 1989). Some evidence of malnutrition due to infections with this helminth has been recorded, with improvements in height-to-weight scores in children who were infected and then treated (Gilman, Chong, Davis, Greenberg, Virik and Dixon, 1983) and correlation of short stature with *T. trichiura* infection has also been recorded in a cross-sectional survey (Cooper and Bundy, 1986).

The influence of *T. trichiura* infection on the cognitive functions of children has received much attention recently. An intervention study, using a double-blind placebo trial, was undertaken on schoolchildren (9-12 yr old) in Jamaica to determine the effect of intensity of *T. trichiura* infection on cognitive function (Nokes, Grantham-McGregor, Sawyer, Cooper, Robinson and Bundy, 1992). Cognitive functions involving attentiveness, with auditory short-term memory and the scanning and retrieval of long-term memory were shown to improve significantly, after 9 weeks, in those infected children given treatment than those given placebo. This was shown to improve more in treated children than in uninfected children. The presence of *A. lumbricoides* infection was also investigated but not found to be significant. In another study of *T. trichiura* infection and development, children with *Trichuris* dysentery syndrome (TDS) were matched with children not having TDS living in close proximity to them, for age and sex (Callender, Grantham-McGregor, Walker and Cooper, 1993). The group with TDS was found to score significantly lower in all of the subscales of development. The development quotient of the children from both groups was subjected to multiple regression, with the only significant variables being the presence of the father in the house ($P \leq 0.05$) and having TDS ($P \leq 0.001$). This indicates a lag in development in those children having TDS in comparison to children matched for other social variables.

1.6.4. Schistosomiasis mansoni

Studies of the impact of infections with *S. mansoni* have been recently reviewed (Stephenson, 1993). The studies reviewed were cross-sectional, not longitudinal and a few of them had been carried out in on either small samples or in areas with low prevalence or intensity of infection. The most interesting study showing an effect on height-for-age scores and skinfold thickness due to intensity of infection with *S. mansoni* (Corbett, Butterworth, Fulford, Ouma and Sturrock, 1992). Intensity of infections was divided into classes revealed that those fount to harbour moderate intensities had higher values of height-for-age and skinfold thickness than those with no infections or light infections and those with heavy infections who had the lowest values. Another area of increasing interest is the effect that infections with *S. mansoni* has on cognitive functions (Stephenson, 1993). The extent to which *S. mansoni* infections aggravate or cause human malnutrition was said to be uncertain. The recommendations of the World Health Organization is

that treatment should be given in areas where surveys have shown that the prevalence of infection in school-age children exceeds 50% (World Health Organization, 1993).

1.7. Use of Anthropometric Data

Anthropometric data is used to determine the effect of intestinal helminth infections on the nutritional status of children. Recommendations for the use of anthropometric data have been published which are designed for cross-sectional surveys and continuous surveillance of nutritional status of children under 10 yr of age (Waterlow, Buzina, Keller, Lane, Nichaman and Tanner, 1977). These recommendations include the use of height-for-age (stunting) and weight-for-height (wasting) as indices for nutritional status. The reference population recommended for use is that of the US National Center of Health Statistics. It is recommended that the sample should include at least 200 individuals in each age and sex group and that the sample should be cross-sectional. Other recommendations relate the clarity of how measurements were taken, how reproducible they were and how reliable. The recommended age groups used to divide data are given, with allowance made for difficulty in sufficient numbers by giving a highly recommended, recommended and permissible divisions. The permissible levels are 0-11.99 m, 1 to 1.99 yr, 2.0 to 3.99 yr, 4.0 to 5.99 yr and 6.0 to 9.99 yr. Standard deviation scores (SD) are recommended for analysis and presentation of results. The formula for calculation of the SD score of individuals with a weight below the median weight for the individual's height is :

$$\text{SD Score of Individual} = \frac{\text{median weight for height - weight of individual}}{\text{1.00 SD Lower}} .$$

Standard deviation scores are especially recommended if relatively undernourished populations are being studied and when height-for-age and weight-for-height measurements are to be related. Individuals under -2 SD are considered to be undernourished.

1.8. Summary

1.8.1. Epidemiological Considerations

Many recent epidemiological studies of gastrointestinal helminth infections have shown that the prevalence and intensity of these infections are often associated with many different factors including both effects due to the individual and local geographic effects. Age of individuals appears to affect the probability of being infected with different helminth infections, with *A. lumbricoides* and

T. trichiura infections of children and young adults, (5 to 15 yr of age), hookworm infecting principally adults and *S. mansoni* young adults (10 to 20 yr of age). Where information is available for the intensity of infection, this is often seen to parallel the prevalence of infection. The factors which generate this observed distribution have not been identified, although differences in exposure, differences in refractivity to establishment and differences in acquired immunity are all postulated to occur. For infections of *S. mansoni* (and *S. haematobium*), it has been shown that both exposure and immunity have some influence in the distribution of these helminths in hosts of varying age.

Differences due to the sex of individuals have been observed. Females are usually seen to have higher prevalence of infection with *A. lumbricoides* and males of hookworm and *S. mansoni* infection. Differences in exposure related to division of labour on the basis of sex is the most commonly cited explanation for this. The same factor comes into play when differences in the intensity or prevalence of a helminth infection are seen due to occupation, for example when agricultural workers are seen to have higher prevalence or intensity of hookworm infection.

Climate and the related factor, availability of water, have been found to be related to the prevalence and intensity of infection with gastrointestinal helminths. People living in wetter areas are seen to have higher prevalence of infections with *A. lumbricoides*, hookworm and *T. trichiura*. In the case of hookworm, this is most likely related to the need for warm, moist and shaded areas needed for development of the larval stages. Transmission of infections of *S. mansoni* are confined to areas where an intermediate host exists and where conditions allow for humans to contact cercariae released into the water.

The effect of urbanisation of the developing world is believed to lead to an increase of *A. lumbricoides* and *T. trichiura* infections. Although it is uncertain if the prevalence of infection with these helminths is higher in rural or urban areas, the creation of large slum areas near metropolitan areas which are ill-equipped to handle the strain of additional people on sanitation systems, will only lead to an increase in prevalence and intensity of infection. Hookworm and *S. mansoni* are considered to be infections more likely to be seen in rural areas. Intensive agricultural practices, which may be needed to feed an expanding population in the developing world, may lead to an increase in prevalence or intensity of these infections.

Transmission of *A. lumbricoides*, hookworm and *S. mansoni* infection has been shown to vary according to the time of the year in some localities. In the case of *A. lumbricoides* these have been related to the seasonal use of contaminated night-soil or to variations in climatic conditions. Hookworm transmission is seen to vary temporally in relation to rainfall and its effect on suitable conditions for larval development and survival. Infections with *S. mansoni* have been shown to vary due to changing water levels.

An individual's occupation may put them at more risk of infections with certain gastrointestinal helminths. Contaminated night-soil is always a danger, especially in terms of infection with *A. lumbricoides*. Agricultural labour increases the risk of hookworm infection and work involving contact with water containing infective cercariae of *S. mansoni* increase the chance of infection with this helminth. Evidence for clumping of infections of *A. lumbricoides* and *T. trichiura* in family groups has been found, as well as for hookworm infections. Larger families have been shown to have heavier intensities of infection with hookworm. Family clustering of *S. mansoni* infections have been shown to be related to micro-habitat and its effect on transmission.

Differences in gastrointestinal helminth prevalence and intensity of infection related to religious affiliation and ethnic group are usually taken to relate to differences in either food handling or preparation. Access to good sanitation is believed to be necessary to control gastrointestinal helminth infections but this must be provided in a culturally acceptable manner or there will be little use made of these facilities. The provision of piped water on its own has been seen to have little effect on the overall prevalence and intensity of infection with gastrointestinal helminth species.

1.8.2. Effects of Infection

In order to distinguish harmful effects of gastrointestinal helminth infections on the health and developmental status of children well though out intervention studies must be carried out. Cross-sectional surveys often have a difficult time controlling for other variables involved in the health of a child. Even intervention trials need to be carefully planned to take into account differences in socio-economics, the distribution of helminth intensity, diet and other conditions. In intervention trials, effective drugs must be used and proper control groups need to be set-up and the intervention needs to be in place for often an extended length of time in order to be effective. In some instances studies

have been carried out which appear to meet these criteria and in most instances deleterious effects have been identified with gastrointestinal helminth infections.

Detrimental effects have been found on weight and height associated with infections with *A. lumbricoides*, hookworm infections have been associated with iron-deficiency anaemia, on height for infections with *T. trichiura* and for height and skin-fold thickness for infections with *S. mansoni*. The effect of gastrointestinal helminth infections on cognitive functions of children is attracting attention recently. Infections with *T. trichiura* (and especially in children with *Trichuris* Dysentery Syndrome) have been associated with decreased cognitive function. The effect of other gastrointestinal helminth infections on this aspect of child development requires further research.

1.9. Conclusion-Prospectus

This thesis involves the investigation of helminth infections and transmission from an epidemiological and an experimental/modelling perspective. The epidemiological section of this work concerned gastrointestinal helminth infections. It sought to ascertain what were the factors within a community associated with different levels of intensity and prevalence of helminth infections. Following on from this the next question investigated was could these factors be combined to enable predictions of helminth status, both prevalence and intensity, which subsequently might be useful for implementation of control measures? The experimental/modelling section investigated first the relationship between distribution of infective stages in space and the resulting distribution of helminths in hosts. Where the two were found to be related and, based on this, could a simulation model be constructed which gave similar results? From the simulation model the effects of differences in susceptibility, both inherent and that based on infection status, on the distribution of helminths in their hosts could be investigated.

The thesis that follows is in two parts. The first of these, reported in volume one, consists of an epidemiological survey of human helminth infections carried out over a 7 week period, from August to October 1991, in three communities in Sierra Leone and the subsequent analysis of this. The second part comprised the construction and manipulation of a simulation model of helminth transmission which investigated various aspects of transmission. This was based on laboratory experiments involving *Periplaneta americana* and *Moniliformis moniliformis* but the results can be extended to be of relevance to those helminth infections which are transmitted via the oral-faecal

route. It is presented in two parts as it naturally falls into two parts. They are related, in that the heterogeneity in host population associated with susceptibility which was investigated in the model, in a human situation, could be related to those variables investigated in the epidemiological survey, especially sex and age of host.

In Chapter Two, an analysis of the recent surveys of helminth infections (including infections with *A. lumbricoides*, hookworm, *T. trichiura*, *S. mansoni* and *S. stercoralis*) is presented, to determine what is the overall picture of these infections in Sierra Leone. Results are analysed in regards to the population on which the survey was carried out (for example, hospital patients, large community surveys or surveys targeted at a certain segment of the population). Chapter Three consists of an analysis of the population structure of the individuals surveyed for infection in comparison to what was expected from the results of the latest census of Sierra Leone, a comparison of the results of infections between the randomly surveyed individuals and those children for which information was available but which were not randomly selected and an analysis of the inter-relatedness between variables investigated further in following chapters (for example, the inter-relatedness of the size of households in different areas within a community). The differences between the three communities in the prevalence and intensity of infection was investigated in Chapter Four, as well as the effect of host age, sex and household conditions including the size of the household and the area of the community in which an individual resided. The effect of one or two concurrent infections on the intensity of infections was also investigated as were the combined effects of age and sex of host on the intensity of infection.

Analysis of variance in combination with covariate analysis was undertaken in Chapter Five to investigate the combined effect of the variables studied on the intensity of infection. Logistic regression was used to construct statistical models to predict infection status and this is reported in Chapter Five. Chapter Six, the last dealing with the survey data, investigated the consequence of helminth infection status, both prevalence and intensity, on anthropometric measurements of the children in the sampled populations.

Chapter Seven, the first in Volume Two, is a review of the relevant literature involved with transmission of helminth parasites and experiments, models and collection of field data that have been constructed to investigate this. In Chapter Eight, the experiments that were used to generate the

model, with varying distributions of infective stages are described and the construction of the model is outlined. In Chapter Nine, the results from simulations of the model to explore the influence of heterogeneity in the host population in inherent and acquired susceptibility are reported. Chapter Ten is a general discussion.

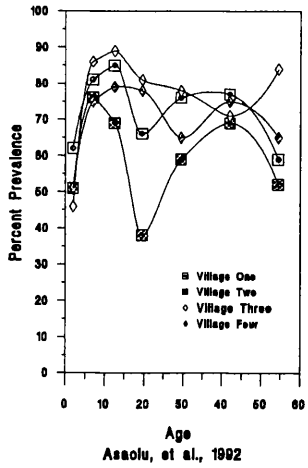
Table 1.1. Differences seen in prevalence of helminth infections related to sex of host.

Helminth Infection	Females greater than Males	No Significant Difference	Males greater than Females
A. lumbricoides	1 village of 4 in Cameroon; females over 5 yr greater than males; (Ratard *et al.*, 1991) Females higher in study of village in Iran, no significance given; (Arfaa and Ghadirian, 1977) Females reinfected quicker, Southern India fishing village; (Elkins *et al.*, 1988) Sumatra, rural village (Higgins *et al.*, 1984)	4 rural Nigerian villages; (Asaolu *et al.*, 1992) 3 of 4 village in Cameroon; (Ratard *et al.*, 1991) Urban community in Malaysia; (Chan *et al.*, 1992) Before treatment in a South India fishing village (Elkins *et al.*, 1988)	
Hookworm	Females higher than males older than 10 yr; (Haswell-Elkins *et al.*, 1988)	3 rural Nigerian villages; (Asaolu *et al.*, 1992) Refugees in Juba, Sudan, no significant difference; (Marnell, *et al.*, 1992) Venezuelan community, no significant difference; (Chacia-Bonilla *et al.*, 1992) Urban area in Nigeria (Udonsi, 1983)	1 rural Nigerian village; (Asaolu *et al.*, 1992) Rural Zimbabwe community (Bradley *et al.*, 1992) Rural Northern Nigerian village (Pugh *et al.*, 1981)
T. trichiura		4 rural Nigerian villages; (Asaolu *et al.*, 1992) 4 rural villages in Cameroon; (Ratard *et al.*, 1991) Venezuelan community, no significant difference; (Chacia-Bonilla *et al.*, 1992)	
S. mansoni	Females higher in Imbo-Sud area of Burundi, no significance value given (Gryseels, 1990)	Refugees, Juba, Sudan; (Marnell *et al.*, 1992) Two rural farming areas; (Chandiwana *et al.*, 1988)	Males higher in Rusizi plain and Cohoha, In Burundi, no significance given; (Gryseels, 1990)

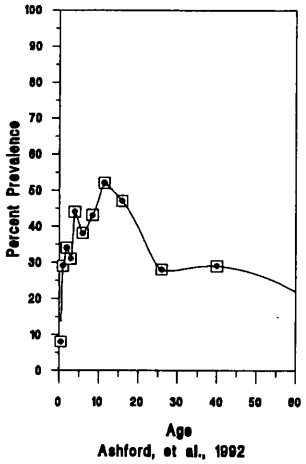
Table 1.2. Differences seen in intensity of helminth infections related to sex of host.

Helminth Infection	Females greater than Males	No Significant Difference	Males greater than Females
A. lumbricoides	Reinfection intensities higher, South India fishing village; (Elkins *et al.*, 1988)	4 rural Nigerian villages; (Asaolu *et al.*, 1992) Urban Malaysian community; (Chan *et al.*, 1992) Before treatment: South Indian fishing village; (Elkins *et al.*, 1988)	
Hookworm	Females higher than males (Haswell-Elkins *et al.*, 1988)	Refugees, Juba, Sudan; (Marnell *et al.*, 1992) Urban area in Nigeria (Udonsi, 1983)	4 rural Nigerian villages; (Asaolu *et al.*, 1992) Rural Zimbabwean village (Bradley *et al.*, 1992)
T. trichiura		4 rural Nigerian villages; (Asaolu *et al.*, 1992)	
S. mansoni		Refugees, Juba, Sudan; (Marnell, *et al.*, 1992) Two rural farming areas; (Chandiwana *et al.*, 1988)	

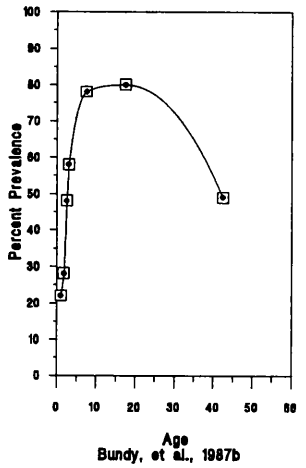
Figure 1.1. Age prevalence profiles for *A. lumbricoides* infections. Numbers refer to graphs from left to right, starting at the top of the page. Graph 1. Four rural Nigerian villages of subsistence and cocoa farmers. 2. Rural villages on the Kenyan coast. 3. Coastal village in St. Lucia. 4. Community in Maracaibo, Venezuela. 5. Rural Iranian villages. 6. Fishing village on Bay of Bengal in India. 7. Three Indonesian villages on Sumatra, Java and Flores, highest prevalence in Java, then Flores and finally Sumatra. 8. Four Cameroon villages, highest prevalence in area with one long rainy season, short dry season, others have two set and two dry seasons. 9. Rural village near Rangoon in Burma (now Yangon in Myanmar).



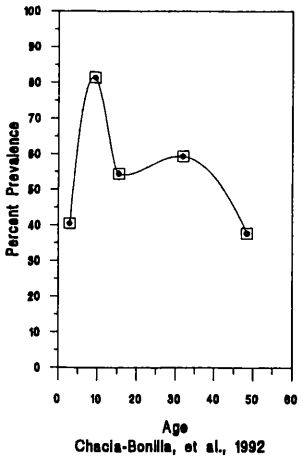
Asaolu, et al., 1992



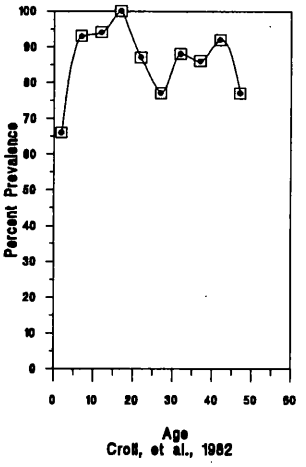
Ashford, et al., 1992



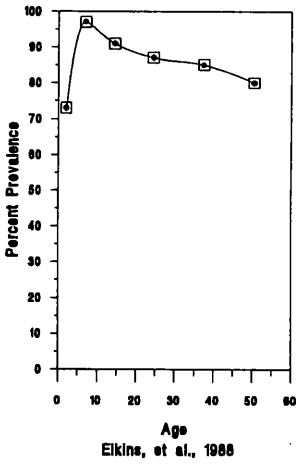
Bundy, et al., 1987b



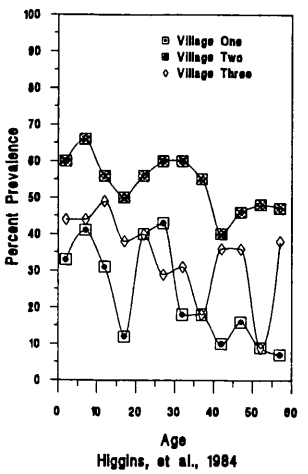
Chacia-Bonilla, et al., 1992



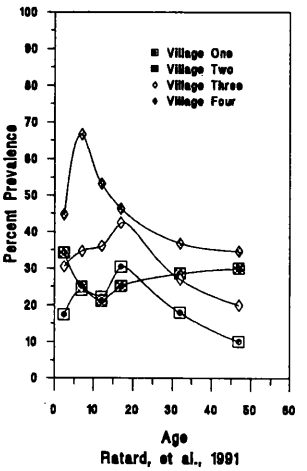
Croll, et al., 1982



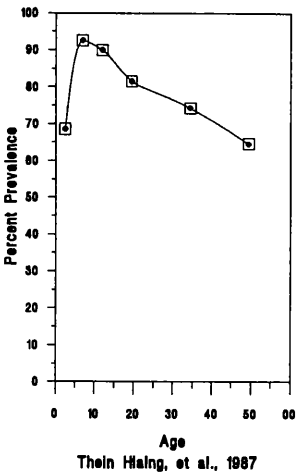
Elkins, et al., 1988



Higgins, et al., 1984

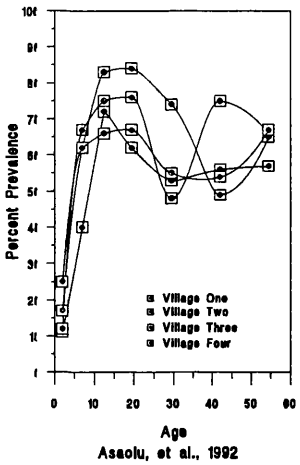


Ratard, et al., 1991

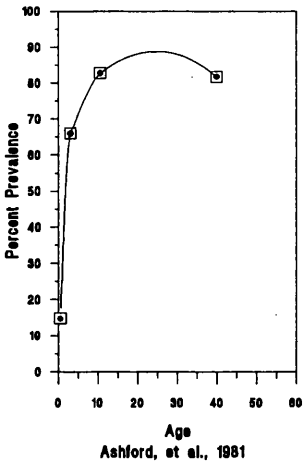


Thein Hlaing, et al., 1987

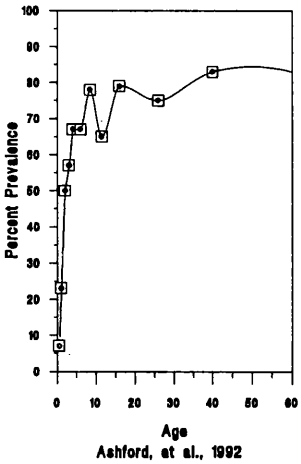
Figure 1.2. Age prevalence profiles for Hookworm infections. Numbers refer to graphs from left to right, starting at the top of the page. Graph 1. Four rural Nigerian villages of subsistence and cocoa farmers. 2. Six rural Papua New Guinea villages. 3. Villages on the Kenyan coast. 4. Farm labourers on a Zimbabwean estate in Eastern Zimbabwe. 5. Community in Maracaibo, Venezuela. 6. Fishing village on Bay of Bengal in India. 7. Three Indonesian villages on Sumatra, Java and Flores, highest prevalence in Java, then Sumatra and finally Flores. 8. Refugees in Juba, Sudan. 9. Rural villages in Bengal, India.



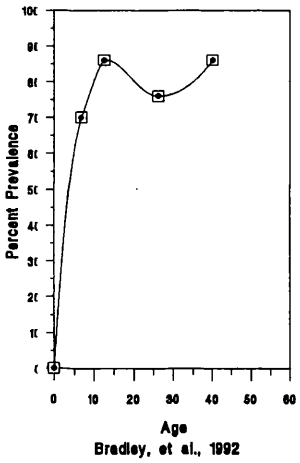
Asaolu, et al., 1992



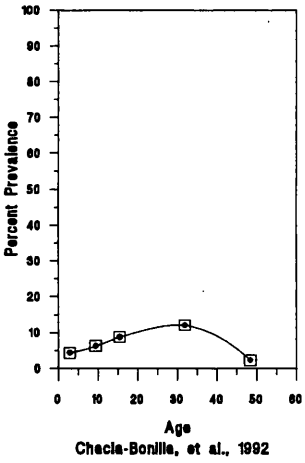
Ashford, et al., 1981



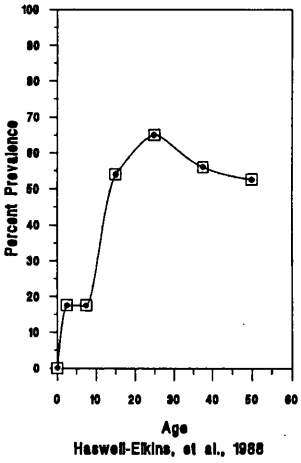
Ashford, et al., 1992



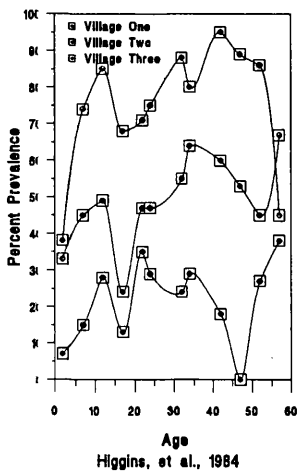
Bradley, et al., 1992



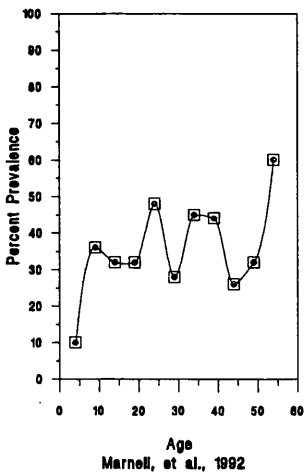
Checla-Bonilla, et al., 1992



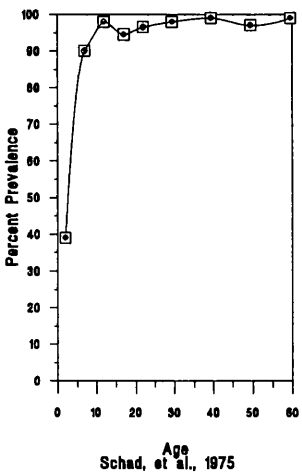
Haswell-Elkins, et al., 1988



Higgins, et al., 1984

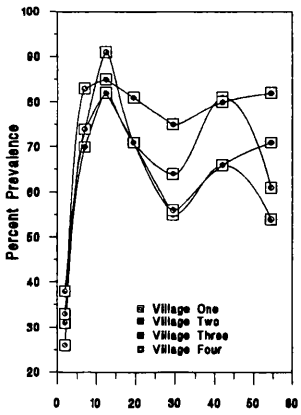


Marnell, et al., 1992

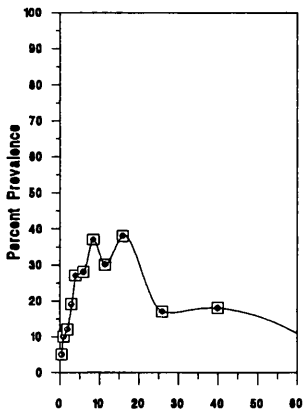


Schad, et al., 1975

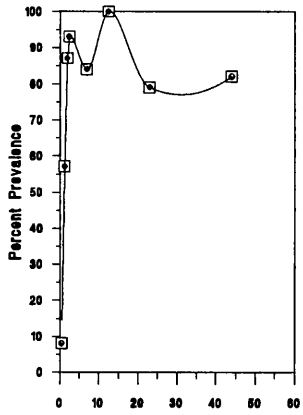
Figure 1.3. Age prevalence profiles for *T. trichiura* infections. Numbers refer to graphs from left to right, starting at the top of the page. Graph 1. Four rural Nigerian villages of subsistence and cocoa farmers. 2. Rural villages on the Kenyan coast. 3. Coastal village in St. Lucia. 4. Community in Maracaibo, Venezuela. 5. Shanty town in Coatzacoalcos, Mexico. 6. Three Indonesian villages on Sumatra, Java and Flores, highest prevalence in Java, then Sumatra and finally Flores. 7 Four Cameroon villages, lowest prevalence in area with one long rainy season, short dry season, others have two set and two dry seasons.



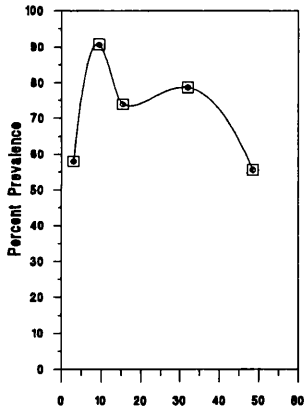
Asaolu, et al., 1992



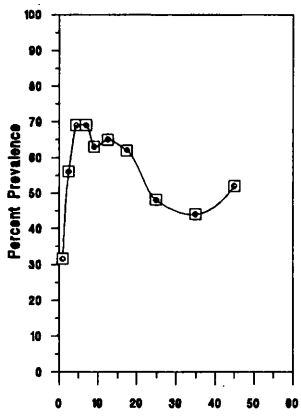
Ashford, et al., 1992



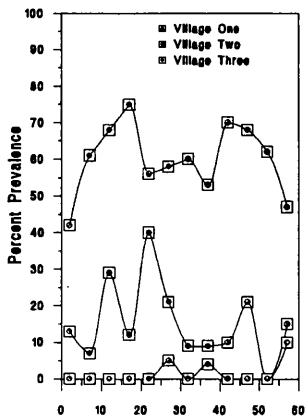
Bundy, et al., 1987a



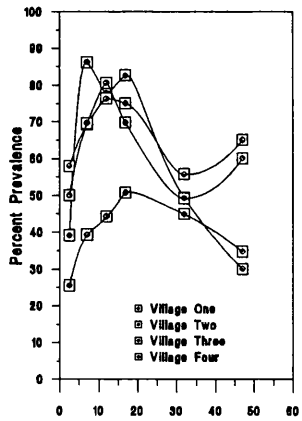
Chacia-Bonillo, et al., 1992



Forrester, et al., 1988

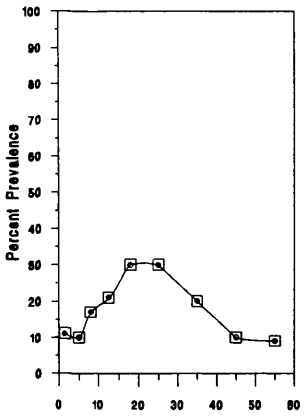


Higgins, et al., 1984

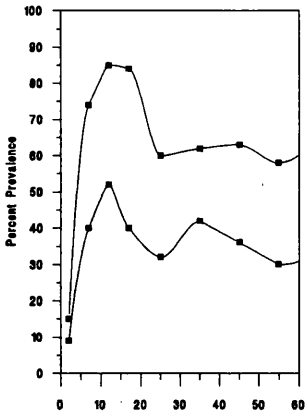


Retard, et al., 1991

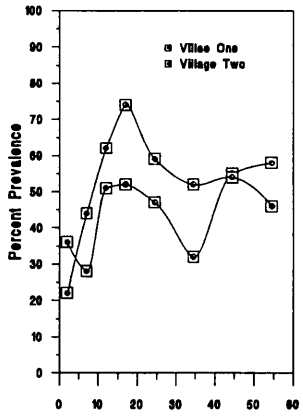
Figure 1.4. Age prevalence profiles for *S. mansoni* infections. Numbers refer to graphs from left to right, starting at the top of the page. Graph 1. Rural Zimbabwean villages. 2. Two groups of communities in the Rusizi plain (Burundi) with dispersed houses and farms. 3. Blue Nile Valley in Ethiopia, two villages. 4. Marquis Valley in St. Lucia, villages of high and low transmission. 5. Refugees in Juba, Sudan. 6. Machakos District, Kenya; river valley with few dams and over 6000 individuals. 7 Four Zimbabwean villages.



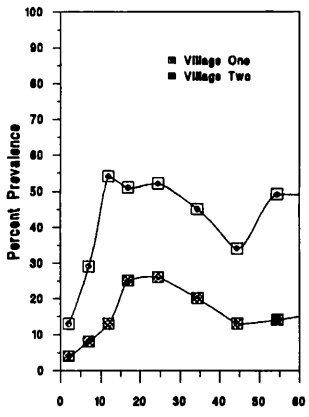
Chandiwana, et al., 1988



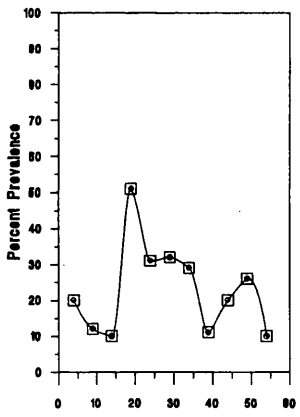
Gryseels, 1990



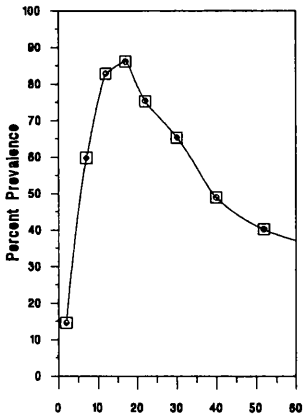
Gunderson, et al., 1990



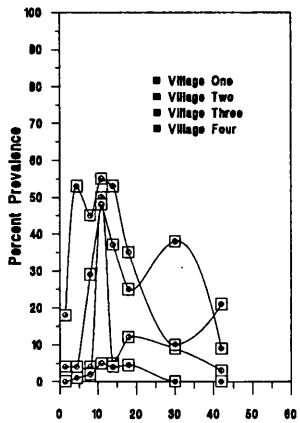
Jordan, et al., 1982



Marnell, et al., 1992



Ouma, et al., 1985



Taylor and Makura, 1985

Chapter Two. An Analysis of the Distribution and Abundance of Gastrointestinal Helminth Infections in Sierra Leone.

2.1. Introduction.

Sierra Leone is located on the West Coast of Africa, between Guinea on the North and East and Liberia on the South. It has some of the lowest quality-of-life statistics in reports on the world's nations, with high child mortality, low life expectancy and low *per capita* income (UNICEF, 1990). In the National Nutrition Survey of under-fives published in 1989, the under-fives death rate was reported as 235.3 per 1000 live births. Life expectancy at birth was reported as 41 yr, equal lowest in the world with Ethiopia, and gross national product as US$ 300 *per capita* in a recent report of the State of the World's Children (UNICEF, 1990). The combination of tropical climate and wide spread poverty offers the perfect setting for parasitic disease. Several surveys of intestinal helminthic infection have been carried out in the recent past in Sierra Leone and many of them have been documented elsewhere (Crompton, Kamara, Ferret, Hodges and Stoddart, in press). The definition of gastrointestinal helminth infection has been expanded to include *Schistosoma mansoni* infection where it has been reported because it is typically diagnosed by examination of faecal samples. The results of recent surveys are summarised here in Tables 2.1 to 2.7 and Figures 2.1 to 2.5. An investigation of these results was carried out using Chi-square analysis and Bonferoni confidence intervals to examine the differences in prevalences seen between different surveys.

2.2. Surveys Summarised

Surveys were classified into three basic categories based upon the protocol used for collecting the data. The protocols were: (1) examination of hospital records for the results of any parasitological tests that were carried out on patients when they were in hospital, (2) large scale research projects where a cross-section of the entire community is sampled but in which parasitic infections other than the three main gastrointestinal helminth infections (*Ascaris lumbricoides*, *Trichuris trichiura* and hookworm) are of main interest, and (3) small research projects sampling a limited portion of the community with the sample population being limited by considerations which are other than scientific.

2.3. Statistical Methods

Bonferoni confidence intervals have been used to determine differences between count data, allowing differences indicated by a significant Chi-squared value to be pin-pointed (Neu, Byers and Peek, 1974). A significant Chi-squared value is not necessarily a prerequisite for the use of Bonferoni

confidence intervals, however, in the following analysis, a Chi-squared value was calculated before Bonferoni confidence intervals were constructed. The following formula was adopted to construct confidence intervals which were then used to compare the prevalence values of the different helminths from the different surveys

$$p_i \pm z_{(1 - a/2k)}\sqrt{p_i(1-p_i) / n} \quad .$$

In this equation, p_i refers to the proportion of the sample which were found to be infected with the helminth in question, n is the sample size, i.e. the number of people surveyed, a is the probability error rate, and k is the number of simultaneous estimates being made of the prevalence of a helminth. The z statistic is obtained from tabled values (Steel and Torrie, 1980).

Bonferoni confidence intervals offer the investigator a method of determining where significant differences lie when a many-celled Chi Square analysis is done and the result indicates that some of the locations have statistically different prevalences. This method of constructing confidence intervals is sensitive to the fact that when estimating two or more parameters simultaneously, the probability that any one interval estimate is incorrect increases beyond a and is partially dependent upon the number of simultaneous estimates being made. In order to bound the probability error rate at a, a scaling down of the significance level of each estimate is required. Therefore the z statistic used is $z_{(1-a/2k)}$ instead of $z_{(1-a/2)}$, the Bonferoni normal statistic (Miller, 1966).

2.4. Prevalence data

2.4.1. Hospital records

The hospital records investigated reported prevalences of *A. lumbricoides*, *T. trichiura*, hookworm (most probably *Necator americanus* (Bayoh, 1991 and Whitworth, Morgan, Maude, McNicholas and Taylor, 1991)) and *Schistosoma mansoni* (Table 2.1). Two of these reports were based on records of the Connaught Hospital in Freetown, one in the 1970's (1970 to 1972) and the other in the 1980's (1986 to 1988). The other two were from different hospitals, one in Bo Government Hospital in the southern part of Sierra Leone, and the one in Masanga Leprosy Hospital in the Northern part of Sierra Leone. Information gained in this manner must be interpreted with regard to the fact that the people sampled are not a random survey, but are presenting themselves at hospital. Ill-health may have influenced these people's chances of being infected with helminths,

although the reason for their hospitalisation may not have been parasite related. Information reported in this way often fails to include any details regarding age of host and prevalence, seasonal trends or intensity of infections; this is true in most of these studies, excepting that of Bayoh (1991), where positive diagnosis was classified as to whether the host was a child (aged under 12 yr of age) or adult.

The work of Williams (1974) was based on the records of the parasitology section at the Connaught Hospital in Freetown from September 1970 to December 1972. During this time, 9203 faecal specimens were examined from patients in the hospital. A similar approach was also carried out at the Masanga Leprosy Hospital (Hodges, 1988) with the evaluation of 5550 patient records. Bayoh (1991) reported information on geohelminthiasis prevalence in 1652 patients at Bo Government Hospital from January 1990 to December 1990. Duncan (1991) reported results from 12345 samples analysed in Connaught Hospital during 1986 to 1988. Chi-square analysis performed on the numbers of infected and uninfected persons reported at each hospital indicate that these prevalences are significantly different for each of the helminth species investigated. Bonferoni confidence intervals were calculated for the prevalences of *A. lumbricoides* (Chi-square = 780.722, d.f. = 3, $P \leq 0.01$), hookworm (Chi-square = 1407.709, d.f. = 3, $P \leq 0.01$), *T. trichiura* (Chi-square = 815.625, d.f. = 3, $P \leq 0.01$ and *Strongyloides stercoralis* (Chi-square = 225.683, d.f. = 3, $P \leq 0.01$) in all four of these surveys. *Schistosoma mansoni* (Chi-square = 2979.384 d.f. = 2, $P \leq 0.01$) prevalence was reported in only three of the four surveys, therefore only three confidence intervals were calculated.

The prevalence of *A. lumbricoides* was observed to be lowest in the Masanga Leprosy Hospital patients (Table 2.1), followed by the patients in Connaught Hospital in the 1970's and those in Bo Government Hospital, where the prevalences are not significantly different from one another at the $P \leq 0.01$ level. The patients at Connaught Hospital in the 1980's showed the highest prevalence of *A. lumbricoides.* These confidence intervals suggest a lower prevalence of *A. lumbricoides* in the North of Sierra Leone than the South and an increase in the prevalence of *A. lumbricoides* between the time of the two surveys in Freetown. The increase seen in the Freetown surveys could be due to the increasing urbanisation which is taking place all over the developing world and is no doubt contributing to the spread of helminths due to the over-stretching of sanitation facilities and the overcrowding of habitation within urban areas (Crompton and Savioli, 1993).

In contrast, the prevalence of hookworm was found to be significantly lowest ($P \leq 0.01$) in the 1980's survey data from Connaught Hospital, followed by the survey results from the 1970's at Connaught. Both of the hospitals serving more rural areas showed significantly higher prevalences ($P \leq 0.01$) of hookworm infections than those attending Connaught Hospital, with those people attending Bo Government Hospital having a significantly lower prevalence of hookworm ($P \leq 0.01$) than those attending the Masanga Leprosy Hospital (Table 2.1). It is expected that people in a rural area, engaged in agriculture, would have higher prevalences of hookworm and this is borne out by this result. The differences seen in the results from the records of the Connaught Hospital would tie in with increasing urbanisation of Freetown, and a decrease in agriculture-based employment and a subsequent decreased risk of hookworm infection. The differences seen between the two rural areas might indicate differences in farming practises or differences in the availability of sanitation facilities, although the latter is not borne out by the *Ascaris* or *Trichuris* prevalence data. Another possibility might be different environmental factors leading to different survivability's of the infective stages of hookworm, hence the observed prevalences.

The *T. trichiura* prevalences reflect the same pattern as those of *A. lumbricoides* (Table 2.1). The lowest prevalence was seen in the patients at the Masanga Leprosy Hospital which is significantly lower ($P \leq 0.01$) than that seen in the patients at the Bo Government Hospital. Prevalences of *T. trichiura* in patients seen at Connaught Hospital are significantly higher ($P \leq 0.01$) than those seen in the rural hospitals, with the prevalence increasing from the 1970's to the 1980's. This increase over time could be taken, again, to indicate increasing urbanisation of the Freetown area, with a decrease in sanitation facilities and an increase in overcrowding. The low level of *T. trichiura* in the patients at the Masanga Leprosy Hospital will be considered later in regards to the results of a survey in Foria (Chater Four).

Schistosoma mansoni prevalence was not reported in the survey of the records of the patients at Bo Government Hospital. The prevalence of this helminth was found to be very low in the patients attending Connaught Hospital in the 1970's, increasing slightly but significantly ($P \leq 0.01$) in those attending this hospital in the 1980 survey. This trend may be due to an influx of infected people from areas outside the Freetown area, as little transmission of this parasite would be likely to take place in this urban setting. There are consequences not only for the spread of this parasite into the Freetown

area but also for its introduction into areas through which these people will pass on their way to Freetown, where conditions might be more favourable for the transmission for *S. mansoni* and where suitable intermediate hosts may be found. The significantly ($P \leq 0.01$) greater prevalences of this parasite seen in the patients attending the Masanga Leprosy Hospital indicate that conditions are favourable for transmission of *S. mansoni* in this area, with a combination of suitable intermediate hosts and human activities (either agriculture or swimming and bathing) which bring people into contact with cercarial stages in the water.

The prevalence of *Strongyloides stercoralis* was found to be low in all of the surveys of hospital patients. The survey of patients at Connaught Hospital in the 1970's showed a significantly higher prevalence ($P \leq 0.01$) of *S. stercoralis* than any of the following surveys. The decrease in prevalence from the 1970's to the 1980's in Freetown may be related to the increase in urbanisation of the area, in a similar fashion to what might have happened to the hookworm prevalence, as transmission occurs in a similar manner for these helminths. The corresponding higher prevalences seen in rural areas with hookworm are not seen with *S. stercoralis*, indicating that differences in urbanisation may not be as important in prevalence of this parasite as compared with hookworm.

2.4.2. Large Surveys

Some survey work (Table 2.2) has been carried out in the course of studies designed to collect information on other aspects of people's lives in Sierra Leone and not specifically on the epidemiology of gastrointestinal helminths. The smaller sample sizes of these surveys, in comparison to the data from patients records, results in larger confidence intervals and less of a chance of seeing clear cut differences between prevalences of the helminths spatially or temporally. White (1977), in the course of an investigation concerned with the level of schistosomiasis in rice farmers, reported results about various intestinal helminth infections. These were taken from 38 villages surrounding Kenema. In each village, households were selected at random and all members of the households were sampled. No information was given regarding age of respondents. The results of this survey were not included in the Chi-square analysis or in the construction of Bonferoni confidence intervals.

Results of a longitudinal study of the epidemiology of schistosomiasis in Sierra Leone (Alghali, Gage, Blockarie, Collier, Terry and Bangura, 1990) included prevalences of *A. lumbricoides*, hookworm and *T. trichiura*. This survey, carried out between June 1987 and November

1989, was performed on random samples of villages in each sub-district in Moyamba District with random individuals (in the age group of 5 to 40 yr) in random households being selected for sampling. The results for each village are reproduced in Table 2.2. A preliminary sample of children 0 to 5 yr was undertaken and the results of that are reported in Table 2.2 and also in detail in Table 2.5, along with details on results of surveys of other children in Sierra Leone.

Whitworth, Morgan, Maude, McNicholas and Taylor (1991) surveyed villagers participating in a placebo-controlled trial of Ivermectin (Merck Sharp and Dohme) for the control of onchocerciasis. People were allocated to groups (placebo or drug) at random. Those who could not be tested because of the manufacturers specification (*i.e.* under five yr old, pregnant women or lactating women with babies under one mo old or persons with neurological disease or severe systemic illness) were excluded from the drug group. People who had been given the placebo and those who had never received Ivermectin either because of absence, refusal or failure to meet the manufacturers specifications were considered the control group for the trial. The prevalence of gastrointestinal helminths in this group were taken as representative of those in the entire trial. The prevalences of infection with gastrointestinal helminths were reported for these 461 individuals from six villages located along the Tabe river in Sierra Leone. Fifty faecal samples were cultured to identify the species of hookworm present, all of these showed positive for *Necator americanus.*

Bonferoni confidence intervals were calculated for the prevalences of *A. lumbricoides* (Chi-square = 144.198, d.f. = 7, $P \leq 0.01$), hookworm (Chi-square = 672.43, d.f. = 7, $P \leq 0.01$) and *T. trichiura* (Chi-square = 213.933, d.f. = 7, $P \leq 0.01$) in all of eight of the survey locations. *Strongyloides stercoralis* (Chi-square = 17.548 , d.f. = 6, $P \leq 0.01$) prevalence was reported for seven surveys. *Schistosoma mansoni* prevalence (Chi-square = 205.621 d.f. = 3, $P \leq 0.01$) was reported in four of the survey locations.

The larger confidence intervals involved in these surveys, in comparison to the hospital surveys, make interpretation of these results more difficult (Table 2.2). The lowest prevalences of *A. lumbricoides* were seen in White's survey in 1977, Alghali *et al.* in 1990 of 148 children under 5 yr of age, and Whitworth *et al.* in 1991 which showed a higher prevalence than the other two but not significantly so ($P \leq 0.01$). Most of the prevalences for each chiefdom studied by Alghali *et al.* (1990) survey show a significantly higher ($P \leq 0.01$) prevalence of *A. lumbricoides* than found by White

(1977) and Alghali *et al.* (1990) in children and also by Whitworth *et al.* (1991), except for the prevalence of *A. lumbricoides* in the Kaiyamba chiefdom.

Hookworm prevalence tended to aggregate into three levels. Relatively low prevalences were seen by White (1977) and by Alghali *et al.* (1990), both in children and in people in Bumpe, Bagruwa, Kongbora, Banta, and Kagbora chiefdoms (Table 2.1). Significantly higher prevalences ($P \leq 0.01$) were seen in those people in the Kaiyamba chiefdom survey (Alghali *et al.*, 1990) which were significantly lower ($P \leq 0.01$) than those detected by Whitworth *et al.* (1991).

Trichuris trichiura prevalence was found not to be significantly different in most of the surveys except for the significantly higher ($P \leq 0.01$) results seen in those people surveyed in Kaiyamba chiefdom by Alghali *et al.*, (1990). This does not correspond with the *A. lumbricoides* prevalence as in the preceding hospital record surveys where higher *T. trichiura* prevalences were found in areas that had higher *A. lumbricoides* prevalences. Of the available *Schistosoma mansoni* prevalence figures, low levels were seen in the Whitworth survey and in the Banta and Kaiyamba chiefdoms examined by Alghali *et al.* (1990). Significantly higher ($P \leq 0.01$) prevalences were found by Alghali *et al.* (1990) in the people in Bagruwa chiefdom (Table 2.2). This helminth is often quite local in distribution, with foci of infection in an endemic area corresponding to areas of human contact with contaminated water. *Strongyloides stercoralis* prevalence values were all uniformly low (under 10%) with no significant differences being apparent between the surveys. This was indicated also by the Chi-square value for prevalence of this helminth which was very close to the non-significant level.

2.4.3. Small Surveys

Several small scale surveys, specifically looking at the level of gastrointestinal helminths in Sierra Leone have been undertaken. Most of these have centred around Freetown and have looked at the prevalence of infection in children, most commonly children under 5 yr of age. The results of these are presented on Table 2.3. Awasika-Sekoni (1987) examined faecal samples collected from 111 children, aged from 3-14 yr of age, at Fourah Bay College School in Freetown. No information was given of the prevalence based on the age or the intensity of infection. Williams (1988) reported soil-transmitted helminth infections from a study on malnutrition in a group of 70 children under 5 yr of age attending a clinic of the Army Medical Services, Freetown. No information was given on

intensity of infection or prevalence by age. Grant (1989), in a survey of factors influencing health status of 148 children 0-5 yr of age in Freetown, reported prevalences of geohelminthiases. No information was reported on age-prevalence profiles or on intensity of infections. Webster, Hodges, Crompton and Walters (1990) surveyed 343 Freetown children between the ages of 5-9 yr at four different locations within the city. These four locations were the Royal Sierra Leone Military Forces (RSLMF) barracks at Juba (n = 96) and Murraytown (n = 167) and two civilian residential areas; First Street, Kissy (n = 39) and Old Railway Line, Brookfields (n = 41). Prevalence figures for age and sex of child and study site are given and are reproduced in Table 2.4. Mean EPG faeces were reported for these variables and are also reproduced on Table 2.4. Bayoh (1991) reported information on the prevalences of geohelminthiasis among children between the ages of 4-12 yr at four different locations within Freetown. These locations were Juba (n = 99), Murraytown (n = 52), Fulatown (n = 55) and Brookfields (n = 66). Results were analysed with respect to location, age class and site, with both prevalence and intensity reported (Table 2.5). He also reported information gained on the identity of the hookworm species with which children in his survey were infected, which he determined to be *Necator americanus*. Wilson, Lindsay, Crompton and Hodges (1991) carried out a survey on intestinal helminth infections of mothers and their infants. Two areas were selected for study, Freetown and Alicalia (Koindugu District, Northern Province). The samples from Freetown were collected from 8 areas; Murraytown Barracks clinic (n = 21 mother/child pairs), Wilburforce barracks clinic (n = 29 mother/child pairs), Juba Barracks clinic (n = 9 mother/child pairs), Marie Stopes clinic (n = 18 mother/child pairs), Georgebrook (n = 8 mother/child pairs), Brookfields (n = 17 mother/child pairs), Bombay (n = 7 mother/child pairs) and Kroo Bay (n = 22 mother/child pairs). Information was reported from Freetown (samples from the areas within the city being combined) and Alicalia (n = 60 mother/child pairs) on prevalences of geohelminthiases and intensity (EPG) (Table 2.6). The Sierra Leone National Nutrition Survey May 1990 (Sierra Leone National Nutrition Survey, 1990 (SLNNS, 1990) attempted to gain information concerning the geohelminthiasis in children of 0-5 yr of age. A survey was carried out in October 1989 in Moyamba District, Southern Province on 421 children, most of whom lived in Moyamba town, Banta or Ribbi. Duplicates of some of the samples (n = 305) were sent to Glasgow University for examination (Crompton, Kamara, Reret, Hodges and Stoddart, in press).

Bonferoni confidence intervals were calculated for the prevalence of *A. lumbricoides* (Chi-square = 190.36, d.f. = 10, $P \leq 0.01$), hookworm (Chi-square = 115.127, d.f. = 10, $P \leq 0.01$) and *T. trichiura* (Chi-square = 760.356, d.f. = 10, $P \leq 0.01$) in all of eleven of the survey locations. *Strongyloides stercoralis* (Chi-square = 55.857, d.f. = 6, $P \leq 0.01$) was reported in seven of the surveys. *Schistosoma mansoni* prevalence was reported in four of the survey locations, however, Chi-square analysis could not be performed on this data, due to 2 cells of the 4 by 2 chi square table having less than five expected infected individuals.

The *A. lumbricoides* prevalences show little clear-cut pattern. Low prevalences are seen in both the Freetown infants and the Alicalia infants (Wilson, 1991), though not significantly different from the prevalences seen in Williams' survey in 1988, which is not significantly less than the prevalences seen in Grant's 1989 survey, Lindsay's 1991 survey of Alicalia mothers, the Awosika-Sekoni 1987 survey, the SLNNS/Crompton *et al.* survey in 1990 and Lindsay's 1991 survey of women of child-bearing age in Freetown (which show prevalence intervals where the lowest limit of the interval increases in the above order, although they are not significantly different at the $P \leq 0.01$ level). Both the Webster *et al.* (1990) and the Bayoh (1991) surveys of 5-9 yr-olds and 4-12 yr-olds, respectively, showed the highest confidence intervals, though not significantly so in regards to the surveys of Awosika-Sekoni (1987), who admittedly sampled children in the age groups that both Webster *et al.* (1990) and Bayoh (1991) sampled, with no information given on age group and prevalence (Table 2.3). They were also not significantly different from Lindsay's 1990 sample of women of child-bearing age (a small sample size, 129 in Freetown and 60 in Alicalia in regards to Webster *et al.* (1990) and Bayoh's (1991) 343 and 267, respectively) and the Crompton *et al.* survey (in press), though not the NNS (1990) data (again reflecting both the smaller sample size of the Crompton *et al.* survey (in press) with the larger confidence intervals this leads to and the larger prevalence value seen in this survey). The confidence intervals indicate there is a tendency for these age groups (5-9 yr-olds and 4-12 yr-olds) to have higher prevalences of *A. lumbricoides* infection, though not significantly so ($P \leq 0.01$) from other age groups sampled (Table 2.3).

Hookworm infection was not found in Wilson's survey of Freetown infants and its prevalence was low in her survey of Alicalia infants (Wilson, 1991) and in Awosika-Sekoni's 1987 survey, Williams' 1988 survey and Grant's survey of 1989. Lindsay's survey of Freetown mothers (Lindsay,

1991) showed a low prevalence of hookworm infection, not being significantly different from the above children's surveys (Table 2.3). The surveys of Webster *et al.* (1990), Bayoh, (1991) and the SLNNS (1990)/Crompton, *et al.* (in press) all showed similar prevalence figures for hookworm which were all significantly higher ($P \leq 0.01$) than the prevalences seen in Awosika-Sekoni's (1987) and Williams' (1988) surveys. Lindsay's survey of mothers in Alicalia (Lindsay, 1991) indicated a significantly ($P \leq 0.01$) higher prevalence of hookworm in these rural women. The accepted pattern of hookworm prevalence is of a low prevalence in younger people, with an increasing prevalence associated with an increase in age. This rise is believed to be associated with higher infection potential linked to increased time spent involved in agriculture with its related exposure to infective larvae of hookworms. Evidence of this association is found in these results, with the mothers in Alicalia being the most likely of those surveyed to be involved directly in agriculture. Evidence for lower prevalences in urban versus rural communities is also seen in these results with the mothers in Freetown having a lower prevalence than the rural women surveyed.

Trichuris trichiura prevalences were found not to be significantly different in the surveys of Awosika-Sekoni (1987), Williams (1988), Grant (1989), and Lindsay's survey of Freetown infants (Lindsay, 1991), Wilson's survey of Alicalia mothers (Wilson, 1991), and that of the SLNNS (SLNNS, 1990)/Crompton *et al.* (in press). No evidence for infections with this helminth were found in Wilson's survey of Alicalia infants (Wilson, 1991). Prevalence of *T. trichiura* was significantly higher ($P \leq 0.01$) in the surveys of Webster *et al.* (1990), Bayoh (1991) and in Lindsay's survey of Freetown women (Lindsay, 1991) in comparison to these surveys (Table 2.3). This may indicate a serious health threat to older urban children and adults due to infection with this helminth (Bundy and Cooper, 1989).

Schistosoma mansoni infection was reported in only a few of the surveys, reflecting its more patchy distribution in Sierra Leone. Results of the surveys in Alicalia, of both infants (Wilson, 1991) and mothers (Lindsay, 1991), appear to indicate that this helminth is common in this locality.

Strongyloides stercoralis and *S. fuellebourni* have both been reported in these surveys; *S. fuellebourni* was reported in the survey of Crompton *et al.* (in press) which was a duplicate of the SLNNS (1990) material. This helminth was not reported in the SLNNS results, most probably being misdiagnosed as *S. stercoralis* infection. The same may be true of the other surveys, leading to some

uncertainty regarding the current prevalence of these two helminths in Sierra Leone. The prevalence, where reported, of *Strongyloides* infections appears to be quite low, especially in Freetown (Table 2.3). No infection with this helminth was found in Alicalia in the North (Wilson, 1991; Lindsay, 1991), but a small and significant amount was found in the SLNNS (1990)/Crompton *et al.* (in press) surveys in under-fives in the South of the country. This parasite is believe to be a health threat chiefly in young children whose immune system might not be fully functional. More survey work in the southern portion of Sierra Leone would be necessary to determine the extent that the SLNNS (1990) /Crompton *et al.* (in press) surveys reflect the prevalence of *S. fuellebourni* in this area.

2.4.4. Children Surveys

The surveys reporting prevalences of the three major gastrointestinal helminths (*Ascaris lumbricoides*, hookworm (probably *Necator americanus*) and *Trichuris trichiura*) in children were examined in more detail (Table 2.7). The smallest reported group was used where information was given as to age and prevalence, except in the case of Alghali *et al.* (1990), where the children from the 0-6 mo category and the 6-12 mo category were combined. Bonferoni confidence intervals were calculated for the prevalences of *A. lumbricoides* (Chi-square = 324.977, d.f. = 21, $P \leq 0.01$), hookworm (Chi-square = 482.505, d.f. = 21, $P \leq 0.01$) and *T. trichiura* (Chi-square = 901.802, d.f. = 21, $P \leq 0.01$) in all of twenty-two of the survey locations. *Strongyloides stercoralis* (Chi-square = 53.25 , d.f. = 10, $P \leq 0.01$) was reported in eleven of the survey sites and age groups. *Schistosoma mansoni* infection was reported in four of the survey locations, however the prevalence was so low that the expected number of infected in the four cells for the infected counts were all under five and chi-square analysis could not be completed.

The *A. lumbricoides* data indicated that there is a tendency for younger children under five, and especially under one yr of age, to not be infected with this helminth, however the 99% confidence intervals did overlap and, in spite of a significant Chi-square result ($P \leq 0.01$), there was no clear cut pattern in the prevalence data. The highest prevalences seen were in the 5-9 age group (Whitworth *et al.*, 1991) with a 78% prevalence and the 7-9 age group (Bayoh, 1991) with 64.2% prevalence (Table 2.7).

Hookworm was most prevalent in one of the rural surveys done (Whitworth *et al.*, 1991) with a prevalence ranging from 70% in the 1-4 yr old age group to 93% in the 10-19 yr old age group. The

confidence intervals of these groups did not overlap with any other groups except the 1-4 yr-olds overlapped with the 9-yr olds of Webster *et al.* (1990) and the 7-9 yr olds of Bayoh (1991), the two groups with the highest prevalence of the remaining surveys (Table 2.7). The rural children surveyed by Alghali *et al.* (1990) appeared to have a similar prevalence of hookworm to the urban children. Bayoh's survey of patients 0-12 yr of age at Bo's Government Hospital indicated that these children had a hookworm prevalence similar to those living in urban Freetown. No information was given as to whether the children at Bo hospital were from an urban or rural background but some may be expected to have come from a rural setting.

Trichuris trichiura prevalence was highest in the survey of Webster *et al.* (1990), where the prevalence ranged from 74.7% in the 6 yr old group to 85.9% in the 9 yr-old group, and Bayoh's survey (1991), where the prevalence showed the opposite trend with the 10-12 yr olds having a prevalence of 36.9% and the 4-6 yr olds a prevalence of 62.0% (Table 2.7). These were not significantly different from one another but all of them, except for Bayoh's 10-12 yr olds, showed a significantly higher prevalence of *T. trichiura* ($P \leq 0.01$) from the other surveys within Freetown. Whitworth's *et al.* (1991) survey indicated results similar to Webster *et al.* (1990), where the prevalence was highest in the 5-9 yr olds, although in this case not significantly so ($P \leq 0.01$). This data appears to indicate that the age group most at risk from *T. trichiura* infection is also that which is most at risk from *A. lumbricoides* infection, i.e. those in the 5-9 yr age class. This is in agreement with most studies which have pin-pointed similar results in other surveys (see Figure 1.1 and 1.3). If hookworm prevalence is also high in the community, this will be the age that youngsters will start to pick up infections with this helminth as well, leading to the compounding of any pathology associated with these gastrointestinal helminths.

Schistosoma mansoni was rarely reported in the children's surveys and *Strongyloides* spp. was reported at a low level in most of the surveys, with none of these showing a significantly higher prevalence of this helminth, in spite of the generally higher prevalence seen in the SLNNS (1991) and Crompton *et al.* (in press) results of children 0-5 yr of age in Moyamba District (Table 2.7).

2.5. Intensity Data

Intensity is defined as the mean number of worms per infected persons. This was not reported in any of the reviewed surveys. An indirect method of estimating intensity, based on egg

counts, was reported in a small number of surveys. These were the surveys by Webster *et al.* (1990) (Table 2.4), Bayoh (1991) (Table 2.5), Lindsay (1991) (Table 2.6) and Wilson (1991) (Table 2.6). Mean intensity values are of limited applicability, as most helminth infections are overdispersed, with the variance greater than the mean (Crofton, 1971) and parametric statistics and the associated parameters are not valid without data transformation. They do give a rough idea of the relationship between prevalence and intensity. They are also influenced by the method of determining egg counts. Bayoh (1991) used direct faecal smears to determine the egg count. Webster *et al.* (1990) and Lindsay (1991)/Wilson (1991) examined the faecal samples in their surveys using a modified Kato-Katz technique (World Health Organization, 1985; Robertson, Crompton, Walters, Nesheim, Sanjur and Walsh, 1989).

Webster *et al.* (1990) found, in an urban area, that there were no significant differences of intensity by sex, site or socio-economic factors in *A. lumbricoides*, hookworm or *T. trichiura* infections (Table 2.4). Some evidence was found to suggest that the intensity of *A. lumbricoides* decreased as age increased, from 5 yr to 9 yr.

Bayoh, (1991) in contrast, found the opposite relationship for the children in his survey, the older children had higher intensities of infection with the pre-school children having lower intensities (Table 2.5). Significant differences ($P \leq 0.05$) in intensities were found in all the infection between the 4-6 yr old age group vs. the 7-9 yr old and 10-12 yr old age groups, which were not significantly different from one another ($P \leq 0.05$). He found a significant difference between the intensities of hookworm for the children living in Juba and Brookfields, with Brookfields having significantly lower mean intensities ($P \leq 0.05$). There was also a significant difference between the sexes for *T. trichiura* infection ($P \leq 0.025$) but not for *A. lumbricoides* and hookworm infections (Table 2.5).

Lindsay (1991) and Wilson (1991) found that the intensity was much lower in the infants surveyed (Table 2.6). This is not surprising considering the rather limited possibilities that children of this age have of being infected. They did not find any association with intensity of infection and study site with any of the helminth species investigated for either the mothers or the infants.

The observation by Webster *et al.* (1990) that there was a decrease in intensity of *A. lumbricoides* by age is in disagreement with Bayoh's (1991) findings that the 4-6 yr olds have the lowest intensity, with the 7-9 and 10-12 yr olds having intensities which are not significantly different

from one another, but are higher than the 4-6 yr age group (Tables 2.4 and 2.5). The localities sampled by these two investigators were almost identical and some of the children sampled by Webster *et al.* (1990) may have been included in Bayoh's survey (Bayoh, 1991). The higher intensity of *T. trichiura* seen in females in the study by Bayoh (1991) is somewhat unexpected, as there is no difference seen in the prevalence by sex for this helminth nor is there believed to be any discrimination by sex in Sierra Leone that would account for this difference (Bayoh, 1991). This difference may be due to some young girls playing closer to their houses, where infective stages of *T. trichiura* may be more common. This could not apply to all the girls in the survey or there would be a significant difference in the prevalences between the two sexes. The surveys results by Lindsay (1991) and Wilson (1991) which indicate no significant differences in intensity despite differences in prevalences (Table 2.6) is interesting, as there is evidence for the correlation of prevalence with intensity of infections in *A. lumbricoides* (Guyatt, Bundy, Medley and Grenfell, 1990); *T. trichiura* (Guyatt and Bundy, 1991) and hookworm (Lwambo, Bundy and Medley, 1992).

2.6. Overall Patterns

The results of the surveys reviewed here (Tables 2.1 through 2.7) have been summarised in Figures 2.1 through 2.6 to give an overall picture of the prevalence of infection in different age groups and localities in Sierra Leone. *Ascaris lumbricoides* (Figure 2.1) infection shows little significant pattern as regards differences in prevalence based on difference in age class and area. The highest prevalences seen were in rural areas, especially the surveys of Alghali *et al.* (1990) and in children in the age group of 5-9 yr, both in rural and urban areas. In general, hookworm infection (Figure 2.2) is much more common in the rural areas than in the urban areas, although no evidence of a higher intensity has been found (Table 2.6). The majority of the surveys have hookworm prevalence confidence intervals not greater than 40 percent prevalence, with those with high prevalences(greater than 60 percent prevalence) being chiefly from rural areas (both children and adults). The species of hookworm has been identified as *N. americanus* in those surveys (Whitworth *et al.*, 1991; Bayoh, 1991) which have attempted to identify it. *Trichuris trichiura* infection appears to be most common amongst the urban children (Figure 2.3) and infections with this helminth in the northern part of the country appear to be less common. *Schistosoma mansoni* infection also appears to be quite local in distribution (Figure 2.4) with areas of endemicity being found in the north (Koinadugu District)

(Lindsay, 1991; Wilson, 1991) and in the south (Moyamba District) (Alghali *et al.*, 1990). *Stongyloides stercoralis* appears to be widespread, but with quite low prevalence, usually less than 10% (Figure 2.5). The finding of *S. fuellebourni* in one survey in Moyamba District (Crompton *et al.*, in press) has not been confirmed by others working in this area and further studies must be undertaken to determine the true extent of this helminth's distribution in Sierra Leone.

Information concerning the population of the districts of Sierra Leone is displayed in Table 2.8. This is preliminary information from the 1985 population census. The number of surveys which were undertaken (if any) in each district is noted as well as the mean prevalence from these surveys for each of the three gastrointestinal helminths; *A. lumbricoides*, hookworm and *T. trichiura*. There is no information available for seven of the thirteen districts in Sierra Leone regarding the prevalence of the three major species of gastrointestinal helminths. This represents 47.8% of the population of Sierra Leone. Most information has been reported from Freetown and Moyamba district, with most of the studies in Freetown concentrating on children.

Estimations of the overall prevalence of gastrointestinal helminths were made by first finding the mean prevalence of the surveys carried out by district, disregarding any differences in ages or sexes which might have existed. Those districts for which no information is available were matched by province to one where information was available and the prevalence from this district was used. The number of people expected to be infected in each district was then calculated and these were summed to find the overall prevalence for the total population of Sierra Leone (Table 2.8). As most information has been reported for children under five yr of age, these estimated prevalences will most likely be underestimations, especially for hookworm prevalence. In those surveys which have investigated prevalence by age (notably Whitworth *et al.*, 1991), prevalence values for hookwom infection have increased with age and children who are older than five have shown higher prevalences than the under-fives for *A. lumbricoides* and *T. trichiura* infections. These values do give rough figures to gauge the impact of gastrointenstinal helminths on the health of the people of Sierra Leone.

The prevalences of the three major gastrointestinal in each survey were compared using non-parametric Spearman Rank correlation to gauge the similiarity of their distributions (Booth and Bundy, 1992). If high prevalences of more than one helminth species are found in an area, the use of broad-spectrum anthelmintics may be feasible to control these infections more cheaply than treatment

targeted at each of several infections. Table 2.9 presents information concerning the 24 surveys investigated in this chapter, not including breakdown of prevalence by age when it was reported.

Table 2.9. Results of Spearman rank tests between the prevalence of the three major gastrointestinal helminth infections in Sierra Leone, in the surveys reviewed here.

Comparisons	Correlation Coefficients	P
A. lumbricoides vs. Hookworm	0.3988	0.054
Hookworm vs. *T. trichiura*	0.3441	0.100
A. lumbricoides vs. *T. trichiura*	0.3953	0.056

Figures 2.6 through 2.8 are scattergrams illustrating the relationship between prevalences of the three major gastrointestinal helminth infections. None of the helminth species pairs showed a significant correlation between their prevalences in this sample of 24 surveys. Figure 2.6 illustrates the relationship between *A. lumbricoides* and hookworm prevalence, Figure 2.7 illustrates that between *A. lumbricoides* and *T. trichiura*, and Figure 2.8 that between hookworm and *T. trichiura*.

Previous work involving similiar investigations in many different countries had found significant correlations between the prevalence of *A. lumbricoides* and *T. trichiura* in countries as far apart as Brazil, India, Indonesia and Cameroon (Booth and Bundy, 1992) but no significant correlation between the prevalence of these two infections in East Africa (Tanzania and Kenya). Significant correlations were also found when comparing prevalences of *A. lumbricoides* and hookworm infections in surveys carried out in Brazil, India and Indonesia but again not in East Africa. Hookworm and *T. trichiura* prevalences were only significantly correlated in surveys carried out in India but not in Brazil, Indonesia or East Africa. In East Africa, the lack of correlation in the prevalences was believed to be due to the rarity of *A. lumbricoides* and *T. trichiura* infections in comparison to hookworm infection.

The results of this work indicate that high prevalences of *A. lumbricoides* are associated with low prevalences of both hookworm (Figure 2.6) and *T. trichiura* (Figure 2.7) but low prevalences of *A. lumbricoides* are associated with low prevalences of the other two helminths (Figures 2.6 and 2.7). The surveys of high *A. lumbricoides* with low prevalences of the other two gastrointestinal helminths were all done in Moyamba District (Alghali *et al.*, 1990, see Table 2.2). Figure 2.8 illustrates that in most cases of low hookworm prevalence there is also low *T. trichiura* prevalence, except for three cases where low hookworm prevalence is associated with high *T. trichiura* prevalence, all reported

from surveys completed in Freetown (Webster *et al.*, 1990, Bayoh, 1991; Lindsay, 1991 see Table 2.3). There are also two cases where high hookworm prevalence is associated with low *T. trichiura* prevalence, both in rural areas (Lindsay, 1991 in Koinadugu District and Whitworth *et al.*, 1991 in Moyamba and Bo Districts, see Tables 2.3 and 2.2 respectively) and one case where both helminth species have relatively high prevalences (Moyamba District, Alghali *et al.*, 1990, see Table 2.2).

The lack of correlation between the prevalence of the three gastrointestinal helminths indicates that their distributions are independent of one another in Sierra Leone overall. Thus the application of broad-spectrum anthelmintics to control more than one helminth species at a time may not be the most practical approach to gastrointestinal helminth control for the whole of Sierra Leone. From Figures 2.6 through 2.8 it is apparent that certain localities may benefit from this approach and local conditions concerning prevalence should be assesed.

2.7. Suggestions for Future Work

The Western Area and the Southern Province have been the localities for most of the surveys carried out in Sierra Leone. It is necessary for more work to be done in the north and east, as little is known of the helminth status of the people living in these areas. Economic and safety constraints often appear to be the deciding factor as to where and whom will be surveyed. The survey work undertaken would be of more value for planning public health measures if these decisions were made with improvements in the public health of the entire country in mind. It would also be of help in making public health decisions if the intensities and prevalences were reported in regards to age and sex, so that any contributing factors due to these may be accounted for. Morbidity data related to helminth infection in children might also be of use in determining public health policy as regards the introduction of control measures for helminth infections.

2.8. Summary

The review of epidemiological surveys of gastrointestinal helminth infection in Sierra Leone has given some picture of the prevalence of these infections in this West African country. In general, the prevalence of *A. lumbricoides* infection appears to be higher in the South of the country than in the North, with some evidence of an increase in prevalence of infection. There is a suggestion of higher prevalence in the 5-9 yr olds and 10-12 yr olds, but this is often not shown by statistically significant differences. An interesting result was seen in the analysis of women of child-bearing age

who did not vary in prevalence from the children, perhaps a suggestion that child-care is an activity that carries with it a risk of infection with *A. lumbricoides.*

Hookworm prevalence was found to be higher in rural rather than urban areas. There is evidence for adults having a higher prevalence of infection than children in rural areas. Infection with *T. trichiura* was found to be more common in young adults and women of child-bearing age in Freetown than in younger children. There is some indication that in the North of Sierra Leone infection with this helminth may be less common than in the South and the Western Area. Reports of *S. mansoni* infection were not comparable to those from the other gastrointestinal infections. Often no mention of the prevalence of this infection was given in the publications reviewed here. When evidence was given, the prevalence was often quite low, with some evidence for a patchy distribtuioon.

Few surveys report intensity data for gastrointestinal helminth infection. Although some intrepretation of prevalence of infection as an indicator of morbidity has been recentlly attempted (Guyatt and Bundy, 1991), the usual means of accessing morbidity is through intensity, with those individuals who ar the most heavily infected being likely to show the most serious detrimental effects due to infection (Anderson and May, 1985). Those surveys that have reported intensity information have been contradictory in the effect of age of the host on the intensity of *A. lumbricoides.* Some have indicated there may be a decrease in intensity as children age from five to 10 years and other the opposite. There was insufficient data available on the intensity of gastrointestinal infection to make many deductions regarding these in Sierra Leone.

Table 2.1. Review of hospital surveys reporting prevalences of gastrointestinal helminths in Sierra Leone, within the last 20 years. Prevalences and 99% Bonferoni confidence intervals.

Source	Sample Size	Location	Patient age	*Ascaris lumbricoides*	Hookworm	*Trichuris trichiura*	*Schistosoma mansoni*	*Strongyloides stercoralis*
Williams 1974 (1)*	9203	Connaught Hospital, Freetown	mixed	18.5%(1706) (17.37-19.73)	13.3% (1207) (12.22-14.38)	12.3% (1131) (11.26-13.34)	0.6% (55) (0.36-0.84)	9.7% (897) (8.76-10.64)
Hodges 1988 (2)	5550	Masanga Leprosy Hospital	mixed	9.0% (499) (7.83-10.17)	31.6% (1754) (29.70-33.50)	3.5% (196) (2.75-4.25)	19.4% (1076) (17.84-20.96)	4.5% (252) (3.65-5.35)
Bayoh 1991 (3)	1652	Bo Government Hospital, Bo	mixed	20.5% (339) (17.31-23.19)	17.6% (291) (15.12-20.08)	8.8% (146) (6.68-10.92)	NR**	3.9% (145) (2.45-5.34)
Duncan 1991 (4)	12345	Connaught Hospital, Freetown	mixed	26.9% (3321) (25.69-28.11)	10.1% (1247) (9.28-10.92)	18.7% (2309) (17.64-19.76)	2.0% (247) (1.63-2.37)	5.3% (654) (4.69-5.91)

* Numbers are used to identify surveys in Figure 1-4.

** NR. No information given on the prevalence of this helminth.

Table 2.2. Review of large surveys reporting prevalences of gastrointestinal helminths in Sierra Leone, within the last 20 years. Prevalences and 99% Bonferoni confidence intervals.

Source	Sample Size	Location of Study	Patient age (yrs)	*Ascaris lumbricoides*	Hookworm	*Trichuris trichiura*	*Schistosoma mansoni*	*Strongyloides stercoralis*
White, 1977 (5)*	38 Villages	Kenema District	Mixed	37.6% (19.40-55.80)	24.8% (8.70-40.90)	13.1% (4.40-21.80)	NA**	NA
Alghali *et al.* 1990 (6)	148	Moyamba District	0-5	35.3% (52) (22.57-48.07)	16.2% (24) (6.36-26.04)	8.1% (12) (0.81-15.39)	NR †	NR
Alghali *et al.* 1990 (7)	200	Bumpe Cfdm, Moyamba District	5-40	80.0% (160) (70.81-89.19)	30.0% (60) (19.47-40.53)	8.0% (16) (1.77-14.23)	NR	1.0% (2) (0.00-3.25)
Alghali *et al.* 1990 (8)	220	Bagruwa Cfdm, Moyamba District	5-40	75.0% (165) (65.51-84.49)	27.0% (59) (17.27-36.73)	13.0% (29) (5.63-20.37)	42.0% (92) (31.89-52.12)	7.0% (15) (1.50-12.50)
Alghali *et al.* 1990 (9)	280	Kongbora Cfdm, Moyamba District	5-40	76.0% (213) (67.71-84.29)	15.0% (42) (8.07-21.93)	5.0% (14) (0.77-9.23)	NR	3.0% (8) (0.00-6.26)
Alghali *et al.* 1990 (10)	196	Banta Cfdm, Moyamba District	5-40	77.0% (151) (67.23-86.77)	11.0% (22) (3.74-18.26)	3.0% (6) (0.00-6.96)	8.0% (16) (2.11-13.89)	2.0% (4) (0.00-5.20)
Alghali *et al.* 1990 (11)	210	Maiyamba Cfdm, Moyamba District	5-40	72.0% (151) (61.93-82.07)	60.0% (126) (49.01-70.99)	45.0% (95) (33.84-56.16)	10.0% (21) (3.71-16.30)	5.0% (11) (0.19-9.81)
Alghali *et al.* 1990 (12)	114	Kagboro Cfdm, Moyamba District	5-40	78.0% (89) (65.39-90.61)	8.0% (9) (0.00-16.26)	20.0% (23) (7.82-32.18)	NR	3.0% (3) (0.00-8.11)
Whitworth *et al.* 1991 (13)	461	6 villages, Moyamba and Bo Districts	mixed	56.0% (258) (48.49-63.51)	85.0% (392) (79.59-90.40)	23.0% (106) (16.63-29.37)	3.0%(14) (0.59-5.41)	6.0% (28) (2.46-9.54)

* Numbers are used to identify surveys in Figure 1-4.

** NA. Information on the prevalence of this helminth was not available.

† NR No data reported on the presence of this helminth at this location.

Table 2.3. Prevalences and 99% Bonferoni confidence intervals of gastrointestinal helminths in the small scale surveys.

Source	Sample Size	Location of Study	Patient age (yrs)	*Ascaris lumbricoides*	Hookworm	*Trichuris trichiura*	*Schistosoma mansoni*	*Strongyloides stercoralis*
Awosika-Sekoni 1987 (14)*	111	Freetown	3-15 years	34.2% (38) (19.25-49.15)	5.4% (6) (0.00-12.48)	18.0% (20) (5.97-30.03)	NA**	3.6% (4) (0.00-9.26)
Williams 1988 (15)	70	Freetown	0-5 years	10.0% (7) (0.00-21.90)	4.3% (3) (0.00-12.30)	5.7% (4) (0.00-14.84)	NA	NA
Grant 1989 (16)	148	Freetown	0-5 years	17.6% (26) (7.21-27.99)	16.2% (24) (6.21-26.19)	8.1% (12) (0.70-15.50)	NA	1.4% (2) (0.00-4.49)
Webster *et al.* 1990 (17)	343	Freetown	5-9 years	43.4% (149) (34.52-52.28)	20.7% (71) (13.48-27.96)	80.5% (276) (73.44-87.56)	1.0% (4) (0.00-2.36)	4.7% (16) (1.04-8.36)
Bayoh 1991 (18)	267	Freetown	4-12 years	50.9% (136) (40.74-61.06)	27.7% (74) (18.66-36.74)	55.4% (148) (45.36-65.44)	NR †	3.7% (9) (0.00-7.40)
Lindsay 1991 (19)	129 mothers	Freetown	16-40 years	38.8% (50) (24.56-53.04)	11.6% (15) (2.30-20.90)	47.3% (61) (32.79-61.81)	4.7% (6) (0.00-10.36)	0.8% (1) (0.00-3.31)
Wilson 1991 (20)	130 infants	Freetown	0-1 year	1.5% (2) (0.00-5.04)	0.0%	2.3% (3) (0.00-6.64)	0.0%	0.0%
Lindsay 1991 (21)	60 mothers	Alicalia, Koinadugu District	16-40 years	40.0% (24) (19.00-61.00)	58.3% (35) (37.29-79.31)	10.0% (6) (0.00-22.78)	31.7% (19) (13.44-49.96)	0.0%
Wilson 1991 (22)	61 infants	Alicalia, Koinadugu District	0-1 year	1.6% (1) (0.00-6.93)	1.6% (1) (0.00-6.90)	0.0%	1.6% (1) (0.00-6.48)	0.0%
NNS 1990 (23)	421	Moyamba District	0-5 years	26.7% (113) (19.54-33.86)	20.0% (84) (13.57-26.43)	10.2% (43) (5.33-15.07)	NR	9.3% (39) (4.77-13.83)
Crompton *et al.* in press (24)	305 ††	Moyamba District	0-5 years	28.2% (86) (19.65-36.75)	19.3% (59) (11.84-26.76)	10.8% (33) (4.94-16.66)	NR	13.1% (40)‡

* Numbers are used to identify surveys in Figure 1-4.

** NA. Information on the prevalence of this helminth was not available.

† NR. No data reported on the presence of this helminth at this location.

†† Replicates of 305 of the samples of the National Nutrition Survey.

‡ Combination of 13 (4.3%) samples positive for *Strongyloides stercoralis* and 27 (8.9%) positive for *Strongyloides fuelleborni*.

Table 2.4. Summary of results of Webster *et al.* (1990): prevalence / mean intensity (EPG).

	NUMBER IN EACH GROUP	*Ascaris lumbricoides*	Hookworm	*Trichuris trichiura*
Juba	96	44.8%/1733	26.0%/151	77.1%/221
Murraytown	167	37.1%/2737	19.8%/137	83.2%/325
First Street	39	53.8%/4028	12.8%/129	87.2%/388
Old Railway Line	41	56.1%/2617	19.5%/42	70.7%/255
Male	180	45.0%/2688	22.8%/76	82.2%/260
Female	163	41.7%/2630	18.4%/140	78.5%/324
aged 5	68	41.2%/4877	13.2%/88	76.5%/290
aged 6	79	43.0%/3224	19.0%/177	74.7%/363
aged 7	58	34.5%/2031	17.2%/61	81.0%/198
aged 8	67	49.3%/2417	20.9%/84	85.1%/309
aged 9	71	47.9%/1722	32.4%/143	85.9%/321
Total	343	43.4%/2662*	20.7%/103*	80.5%/290*

* Total mean intensities calculated from group mean intensities.

Table 2.5. Summary of results of Bayoh (1991): prevalences / mean intensities ± standard error (EPG).

	NUMBER IN EACH GROUP	*Ascaris lumbricoides**	Hookworm	*Trichuris trichiura*
Juba	94	61.7%/3037±440	34.0%/1541±235	57.4%/ 955±173
Murray Town	52	53.8%/3073±821	28.8%/1233±407	61.5%/1107±341
Fula Town	55	43.6%/3139±796	23.6%/1133±378	52.7%/ 764±219
Brookfields	66	39.4%/2628±545	21.2%/ 803±240	50.0%/ 811±139
Male	128	46.9%/2988±489	28.1%/1307±253	57.0%/ 664±110
Female	139	54.7%/2981±410	27.3%/1229±203	53.9%/1177±230
4-6 years	121	52.9%/2191±395	32.3%/ 898±144	62.0%/ 711± 82
7-9 years	81	64.2%/3414±511	34.6%/1448±274	60.5%/1185±169
10-12 years	65	30.8%/4406±999	10.8%/2360±892	36.9%/1055±215
Totals	267	50.9%/2984**	27.7%/1267**	55.4%/924**

* Prevalences (%) and mean intensities (EPG) standard error.

** Total mean intensities calculated from group mean intensities. Therefore no standard errors are reported.

Table 2.6. Summary of the results of Lindsay (1991) and Wilson (1991) on the helminth infections of mothers and infants: prevalence / mean intensity (EPG).

GROUP	NUMBER IN EACH GROUP	*Ascaris lumbricoides*	Hookworm	*Trichuris trichiura*	*Schistosoma mansoni*
Mothers/ Freetown	129	38.8%/ 164	16.6%/ 14	47.3%/ 11	4.7%/ 12
Infants/ Freetown	130	1.5%/ 38*	0.0%	2.3%/ 32	0.0%
Mothers/ Alicalia	60	40.0%/ 100	58.3%/ 21	10.0%/ 15	31.7%/ 10
Infants/ Alicalia	61	1.6%/ 38*	1.6%/ 32	0.0%	1.6%/ 8

* Mean intensities (EPG) were reported for the infants from Alicalia and Freetown together.

Table 2.7. Prevalences and 99% Bonferoni confidence intervals of gastrointestinal helminths in children in those studies reporting data for age profiles.

Study	Patient Age (yrs)	Numbers in each group	Survey Site	*Ascaris lumbricoides*	Hookworm	*Trichuris trichiura*	*Schistosoma mansoni*	*Strongyloides* spp.
Awosika-Sekoni 1987	3-15 years	111	Freetown	34.2% (38) (17.99-50.41)	5.4% (6) (0.00-13.12)	18.0% (20) (4.91-31.09)	NA**	3.6% (4) (0.00-9.47)
Williams 1988	0-5 years	70	Freetown	10.0% (7) (0.00-22.91)	4.2% (3) (0.00-12.93)	5.7% (4) (4.25-15.65)	NA	NA
Grant 1989	0-5 years	148	Freetown	17.6% (26) (6.33-28.87)	16.2% (24) (5.30-27.10)	8.1% (12) (0.05-16.15)	NA	1.4% (2) (0.00-4.61)
Alghali *et al.* 1990 (25)*	0-1 years	19	Moyamba District	5.26% (1) (0.00-23.69)	5.26% (1) (0.00-23.69)	0.0%	0.0%	NR †
Alghali *et al.* 1990 (26)	1-3 years	27	Moyamba District	22.0% (6) (0.00-50.70)	11.0% (3) (0.00-32.68)	7.5 % (2) (0.00-25.70)	0.0%	NR
Alghali *et al.* 1990 (27)	3-5 years	102	Moyamba District	18.6% (19) (4.73-32.47)	19.6% (20) (5.45-33.75)	9.8% (10) (0.00-20.37)	0.0%	NR
Webster *et al.* 1990 (28)	5 years	68	Freetown	41.2% (28) (19.71-62.69)	13.2% (9) (0.00-27.98)	76.5% (52) (58.04-94.96)	NR	NR
Webster *et al.* 1990 (29)	6 years	79	Freetown	43.0% (34) (22.95-63.05)	19.0% (15) (3.11-34.89)	74.7% (59) (57.14-92.26)	NR	NR
Webster *et al.* 1990 (30)	7 years	58	Freetown	34.5% (20) (12.03-56.97)	17.2% (10) (0.00-35.04)	81.0% (57) (62.51-99.49)	NR	NR
Webster *et al.* 1990 (31)	8 years	67	Freetown	49.3% (33) (27.31-71.29)	20.9% (14) (3.02-38.78)	85.1% (57) (69.48-100.0)	NR	NR
Webster *et al.* 1990 (32)	9 years	71	Freetown	47.9% (34) (26.56-69.24)	32.4% (23) (12.41-52-39)	85.9% (61) (71.07-100.0)	NR	NR
Bayoh 1991 (33)	4-6 years	121	Freetown	52.9% (64) (36.56-69.23)	32.2% (39) (16.91-47.49)	62.0% (75) (46.16-77.84)	NR	2.5% (3) (0.00-7.21)

Table 2.7 (cont.). Prevalences and 99% Bonferoni confidence intervals of gastrointestinal helminths in children in those studies reporting data for age profiles.

Study	Patient Age (yrs)	Numbers in each group	Survey Site	*Ascaris lumbricoides*	Hookworm	*Trichuris trichiura*	*Schistosoma mansoni*	*Strongyloides* spp.
Bayoh 1991 (34)	7-9 years	81	Freetown	64.2% (52) (45.02-83.38)	34.6% (28) (15.57-53.63)	60.5% (49) (41.00-80.00)	NR	6.2% (5) (0.00-15.10)
Bayoh 1991 (35)	10-12 years	65	Freetown	30.8% (20) (10.19-51.14)	10.8% (7) (0.00-24.66)	36.9% (24) (15.41-58.39)	NR	1.5% (1) (0.00-6.51)
Bayoh 1991 (36)	0-12 years	261	Bo Gvnmt. Hospital, Bo	29.4% (105) (19.25-39.55)	17.4% (62) (8.95-25.85)	10.9% (39) (3.97-17.83)	NR	2.0% (7) (0.00-4.88)
Whitworth *et al.* 1991 (37)	1-4 years	82	Moyamba/Bo Districts	60.0% (49) (40.52-79.18)	70.0% (57) (51.78-88.22)	16.0% (13) (1.47-30.53)	2.0% (2) (0.00-6.70	2.0% (2) (0.00-7.13)
Whitworth *et al.* 1991 (38)	5-9 years	64	Moyamba/Bo Districts	78.0% (50) (59.36-96.64)	89.0% (57) (74.92-100.0)	41.0% (26) (18.93-63.07)	2.0% (1) (0.00-7.32	6.0% (4) (0.00-15.86)
Whitworth *et al.* 1991 (39)	10-19 years	58	Moyamba/Bo Districts	48.0% (28) (24.84-71.62)	93.0% (54) (80.93-100.0)	28.0% (16) (6.83-49.17)	3.0% (2) (0.00-9.81	2.0% (1) (0.00-8.10)
Wilson 1991	infants under 12 months	130	Freetown	1.5% (2) (0.00-5.34)	0.0%	2.3% (3) (0.00-7.02)	0.0%	0.0%
Wilson 1991	infants under 12 months	61	Alicalia	1.6% (1) (0.00-7.38)	1.6% (1) (0.00-7.42)	0.0%	1.6% (1) (0.00-6.48	0.0%
NNS 1991	0-5 years	421	Moyamba	26.7% (113) (18.92-34.48)	20.0% (84) (12.98-27.02)	10.2% (43) (4.91-15.49)	0.0%	9.3% (39) (4.60-14.00)
Crompton *et al.*,in press	0-5 years	305 ††	Moyamba	28.2% (86) (18.92-37.48)	19.3% (59) (11.17-27.43)	10.8% (33) (4.42-17.18)	0.0%	13.1% (40)‡ (6.69-19.51)

* Numbers are used to identify surveys in Figure 1-4.

** NA. Information on the prevalence of this helminth was not available.

† NR. No data reported on the presence of this helminth at this location.

†† Replicates of 305 of the samples of the National Nutrition Survey.

‡ Combination of 13 (4.3%) samples positive for *Strongyloides stercoralis* and 27 (8.9%) positive for *Strongyloides fuelleborni*.

Table 2.8. Distribution of the population of Sierra Leone and estimated prevalences of *A. lumbricoides*, hookworm and *T. trichiura*.

District/ Province*	Population	% of Total Population	Number of Reviewed Surveys**	Estimated Prevalence of *A. lumbricoides*†	Number with *A. lumbricoides*	Estimated Prevalence of Hookworm	Number with Hookworm	Estimated Prevalence of *T. trichiura*	Number with *T. trichiura*
Bo / S	268671	7.6	2	38.3	102901	51.3	137828	15.9	42719
Bonthe / S	105007	3.0	0	59.3	62269	34.1	35807	15.2	15961
Moyamba / S	250514	7.1	9	64.0	160329	30.2	75655	15.0	37577
Pujehun / S	117185	3.3	0	59.3	69491	34.1	39960	15.2	17812
Kailahun / E	233839	6.7	0	37.6	87923	24.8	57992	13.1	30633
Kenema / E	337055	9.6	1	37.6	126733	24.8	83590	13.1	44154
Kono / E	389657	11.1	0	37.6	146511	24.8	96635	13.1	51045
Bombali / N	317729	9.0	0	16.9	53696	30.5	96907	4.5	14298
Kambia / N	186231	5.3	0	16.9	31473	30.5	56800	4.5	8380
Koinadugu / N	183286	5.2	2	20.8	38123	30.0	54986	5.0	9164
Port Loko / N	329344	9.4	0	16.9	55659	30.5	100450	4.5	14820
Tonkolili / N	243051	6.9	1	9.0	21875	31.6	76804	3.5	8507
Western Area	554243	15.8	9	26.9	149091	12.4	67310	27.6	152909
Total	3515812	100	24	31.5%	1106074	27.9%	980724	12.7%	447979

* S = Southern Province; E = Eastern Province; N = Northern Province.

** Surveys in Tables 1, 2 and 3.

† See text for method of estimation.

Figure 2.1. Prevalence (99% Bonferoni confidence intervals) of *Ascaris lumbricoides* infection for the surveys analysed. Survey code refers to the surveys as numbered in Tables 2.1-2.3 and Table 2.7. Letters in front of the number refer to the locality of the survey and the age of the people being surveyed. R = rural area; U = urban area; C = children of mixed ages; A = children with a defined age group; M = mixed adults and children; G = adults only; S = Southern Province of Sierra Leone; W = Western Area; N = Northern Province of Sierra Leone; E = Eastern Province of Sierra Leone; H = data from hospital records.

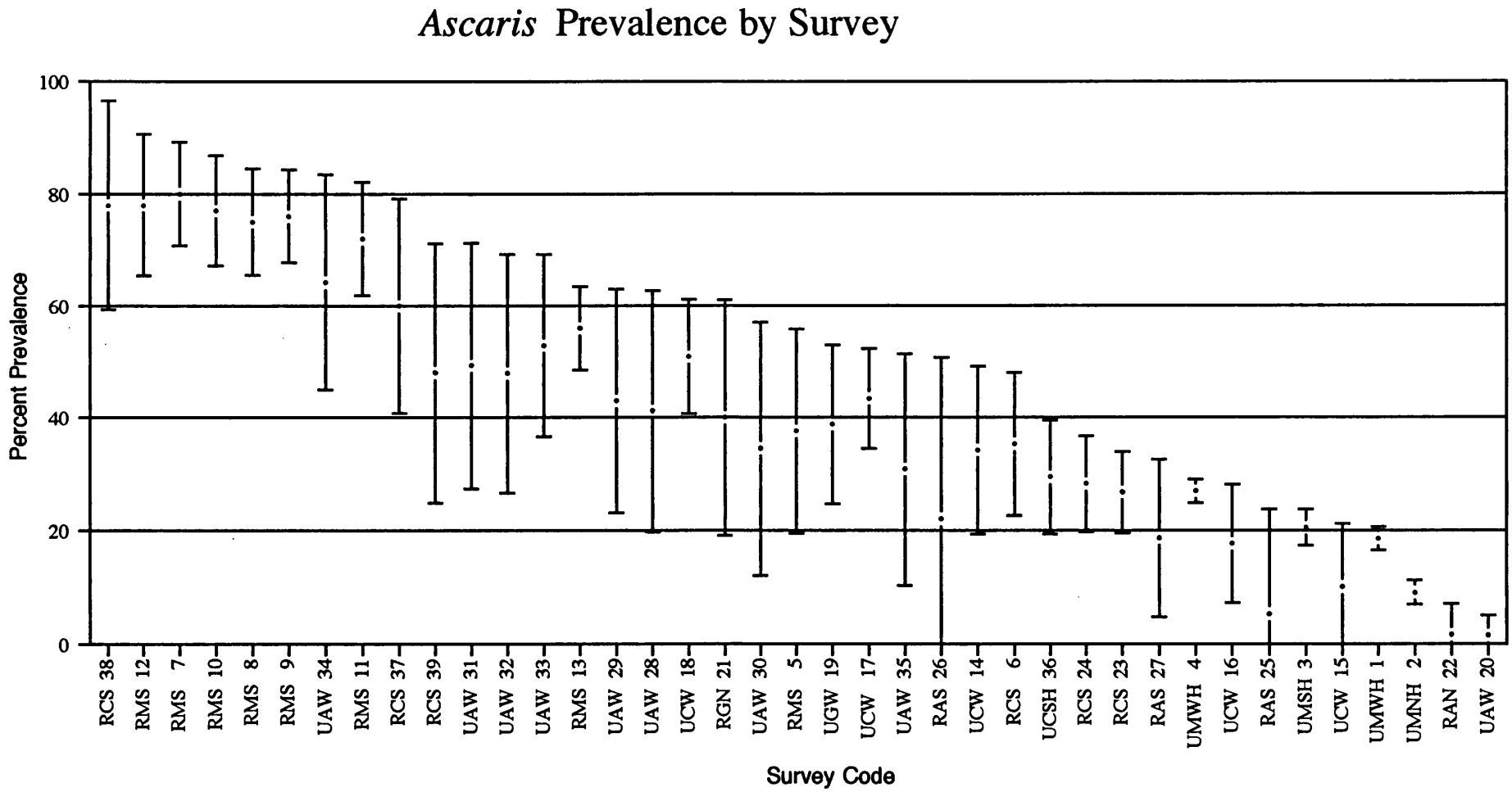

Ascaris Prevalence by Survey
Percent Prevalence
100
80
60
40
20
0
RCS 38
RMS 12
RMS 7
RMS 10
RMS 8
RMS 9
UAW 34
RMS 11
RCS 37
RCS 39
UAW 31
UAW 32
UAW 33
RMS 13
UAW 29
UAW 28
UCW 18
RGN 21
UAW 30
RMS 5
UGW 19
UCW 17
UAW 35
RAS 26
UCW 14
RCS 6
UCSH 36
RCS 24
RCS 23
RAS 27
UMWH 4
UCW 16
RAS 25
UMSH 3
UCW 15
UMWH 1
UMNH 2
RAN 22
UAW 20
Survey Code

Figure 2.2. Prevalence (99% Bonferoni confidence intervals) of hookworm infection for the surveys analysed. Survey code refers to the surveys as numbered in Tables 2.1-2.3 and Table 2.7. Letters in front of the number refer to the locality of the survey and the age of the people being surveyed. R = rural area; U = urban area; C = children of mixed ages; A = children with a defined age group; M = mixed adults and children; G = adults only; S = Southern Province of Sierra Leone; W = Western Area; N = Northern Province of Sierra Leone; E = Eastern Province of Sierra Leone; H = data from hospital records.

Hookworm Prevalence by Survey

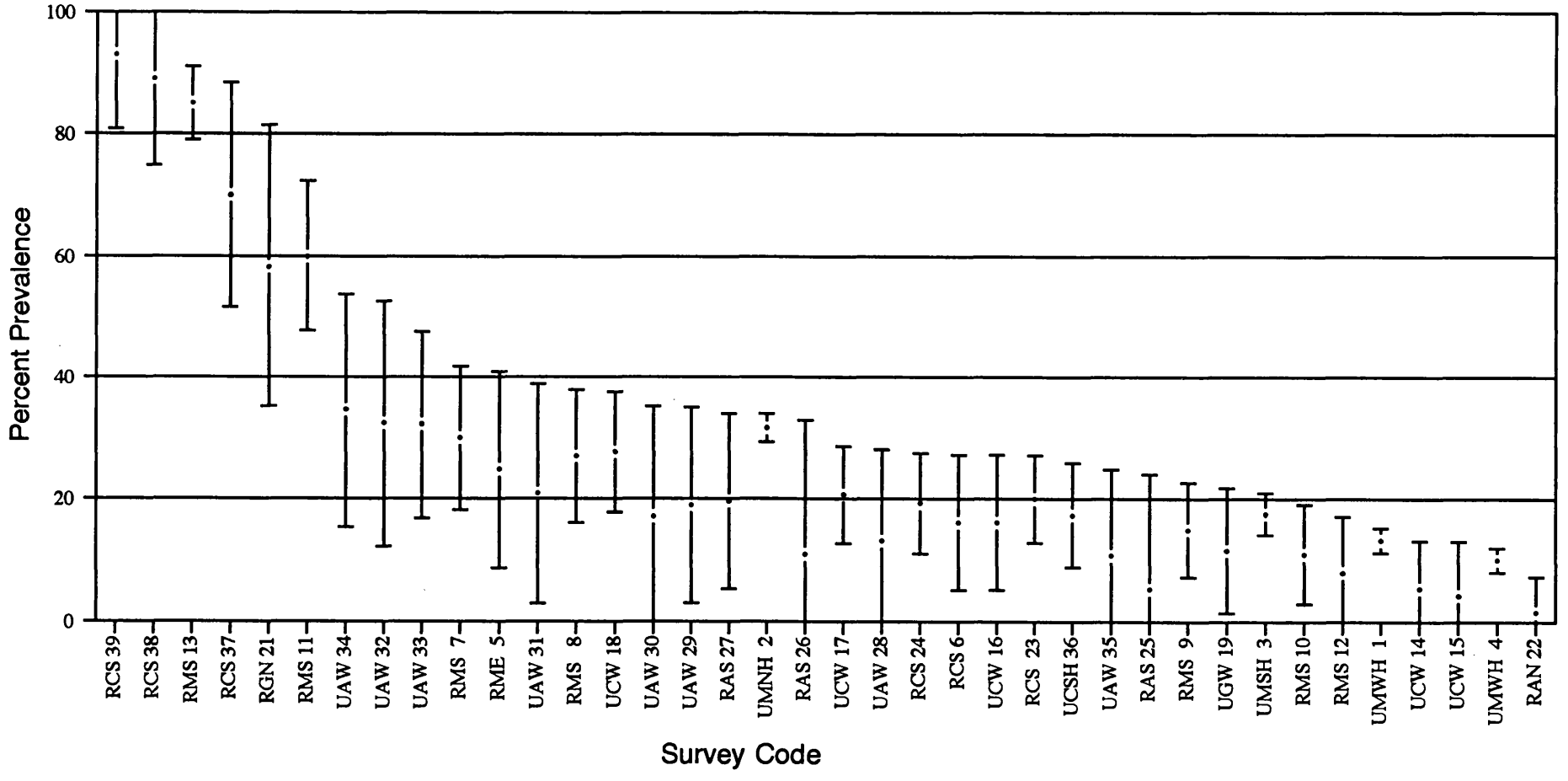


Figure 2.3. Prevalence (99% Bonferoni confidence intervals) of *Trichuris trichiura* infection for the surveys analysed. Survey code refers to the surveys as numbered in Tables 2.1-2.3 and Table 2.7. Letters in front of the number refer to the locality of the survey and the age of the people being surveyed. R = rural area; U = urban area; C = children of mixed ages; A = children with a defined age group; M = mixed adults and children; G = adults only; S = Southern Province of Sierra Leone; W = Western Area; N = Northern Province of Sierra Leone; E = Eastern Province of Sierra Leone; H = data from hospital records.

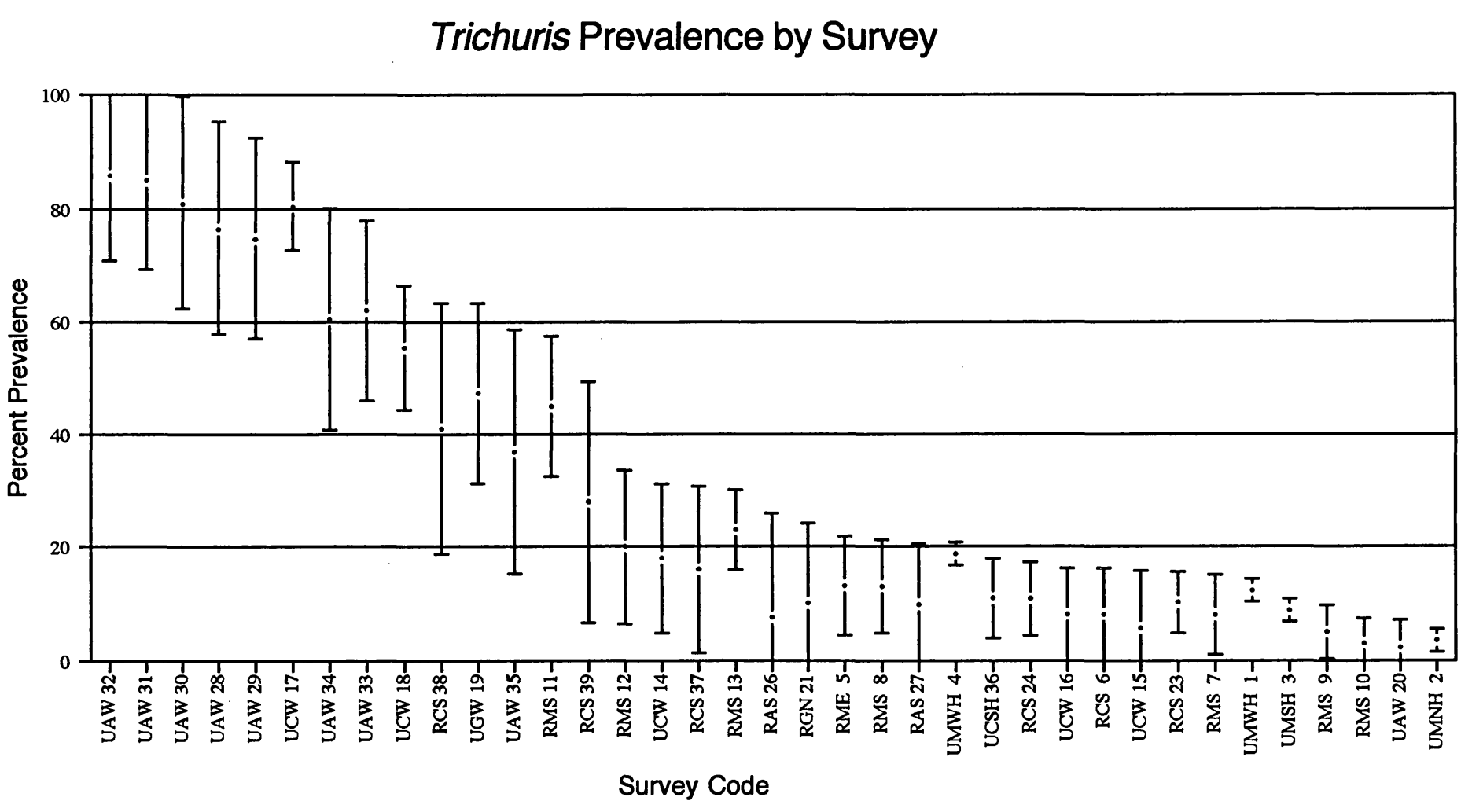

Trichuris Prevalence by Survey
Percent Prevalence
100
80
60
40
20
0
UAW 32
UAW 31
UAW 30
UAW 28
UAW 29
UCW 17
UAW 34
UAW 33
UCW 18
RCS 38
UGW 19
UAW 35
RMS 11
RCS 39
RMS 12
UCW 14
RCS 37
RMS 13
RAS 26
RGN 21
RME 5
RMS 8
RAS 27
UMWH 4
UCSH 36
RCS 24
UCW 16
RCS 6
UCW 15
RCS 23
RMS 7
UMWH 1
UMSH 3
RMS 9
RMS 10
UAW 20
UMNH 2
Survey Code

Figure 2.4. Prevalence (99% Bonferoni confidence intervals) of *Schistosoma mansoni* infection for the surveys analysed. Survey code refers to the surveys as numbered in Tables 2.1-2.3 and Table 2.7. Letters in front of the number refer to the locality of the survey and the age of the people being surveyed. R = rural area; U = urban area; C = children of mixed ages; A = children with a defined age group; M = mixed adults and children; G = adults only; S = Southern Province of Sierra Leone; W = Western Area; N = Northern Province of Sierra Leone; H = data from hospital records.

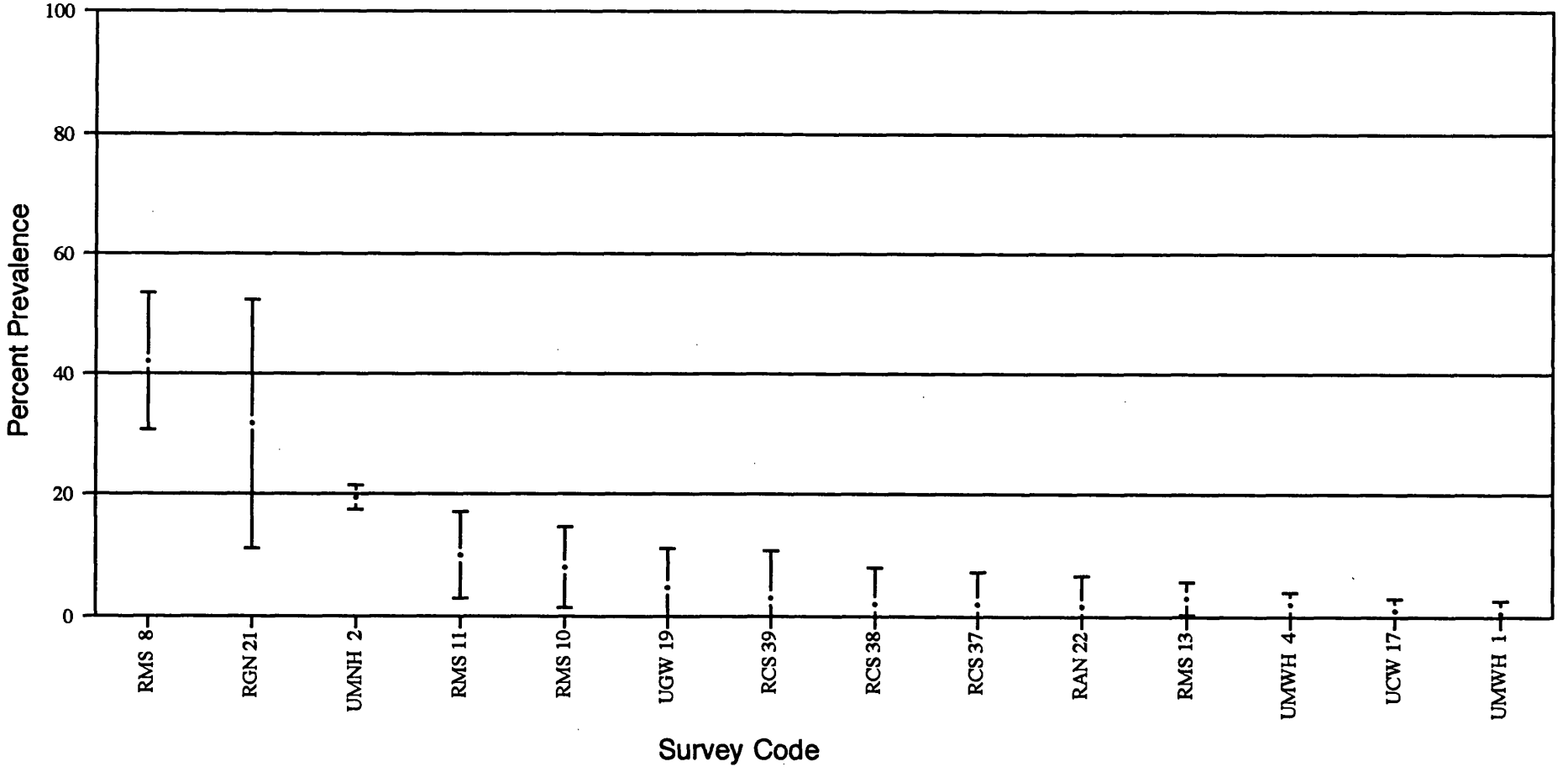

Schistosoma Prevalence by Survey
Percent Prevalence
100
80
60
40
20
0
RMS 8
RGN 21
UMNH 2
RMS 11
RMS 10
UGW 19
RCS 39
RCS 38
RCS 37
RAN 22
RMS 13
UMWH 4
UCW 17
UMWH 1
Survey Code

Figure 2.5. Prevalence (99% Bonferoni confidence intervals) of *Strongyloides stercoralis* infection for the surveys analysed. Survey code refers to the surveys as numbered in Tables 2.1-2.3 and Table 2.7. Letters in front of the number refer to the locality of the survey and the age of the people being surveyed. R = rural area; U = urban area; C = children of mixed ages; A = children with a defined age group; M = mixed adults and children; G = adults only; S = Southern Province of Sierra Leone; W = Western Area; N = Northern Province of Sierra Leone; H = data from hospital records.

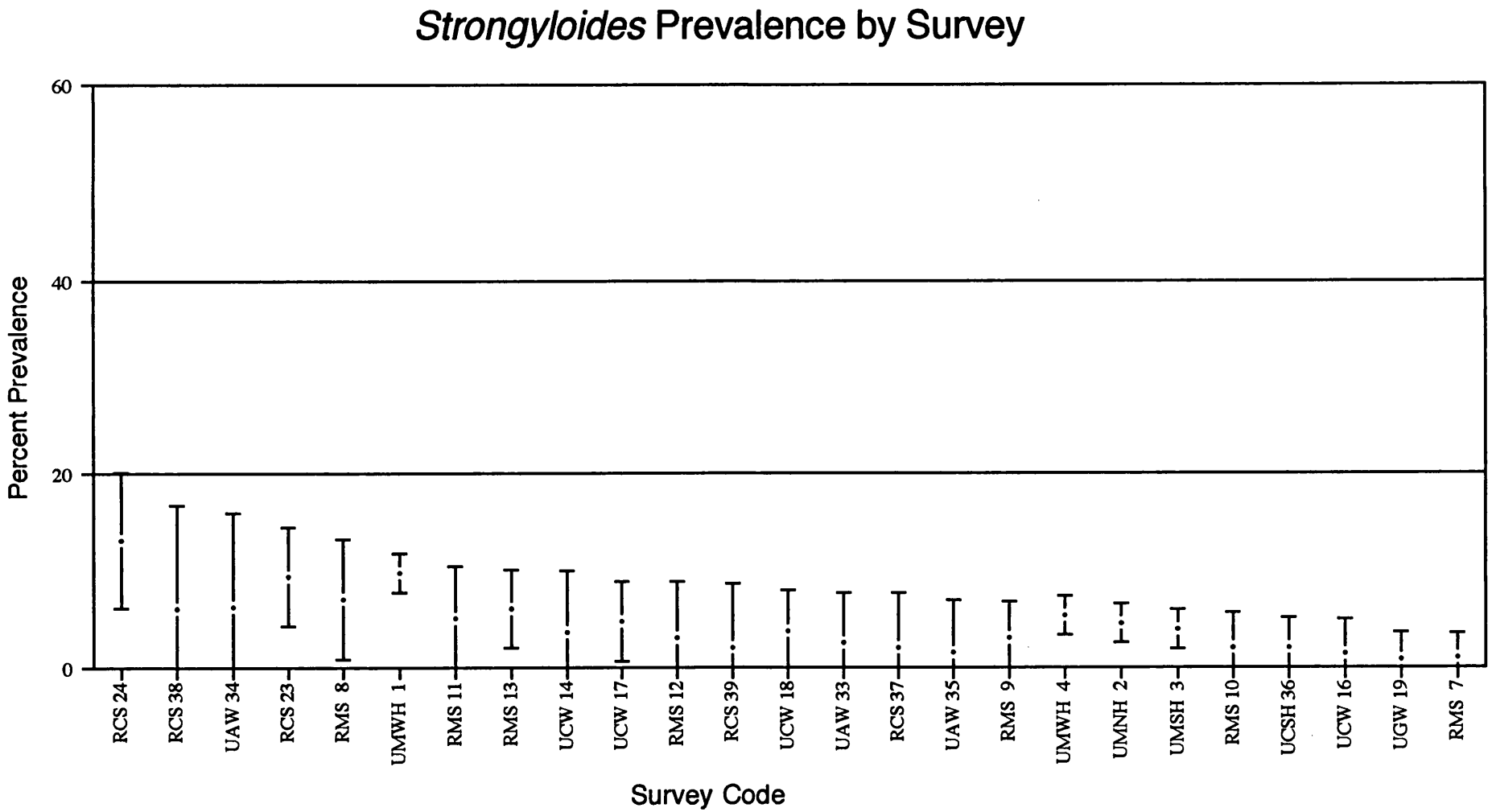

Strongyloides Prevalence by Survey
Percent Prevalence
60
40
20
0
RCS 24
RCS 38
UAW 34
RCS 23
RMS 8
UMWH 1
RMS 11
RMS 13
UCW 14
UCW 17
RMS 12
RCS 39
UCW 18
UAW 33
RCS 37
UAW 35
RMS 9
UMWH 4
UMNH 2
UMSH 3
RMS 10
UCSH 36
UCW 16
UGW 19
RMS 7
Survey Code

Figure 2.6. Comparisons of prevalence of *A. lumbricoides* and hookworm in each survey.

Figure 2.7. Comparisons of prevalence of *A. lumbricoides* and *T. trichiura* in each survey.

Figure 2.8. Comparisons of prevalence of hookworm and *T. trichiura* in each survey.

Figure 2.6

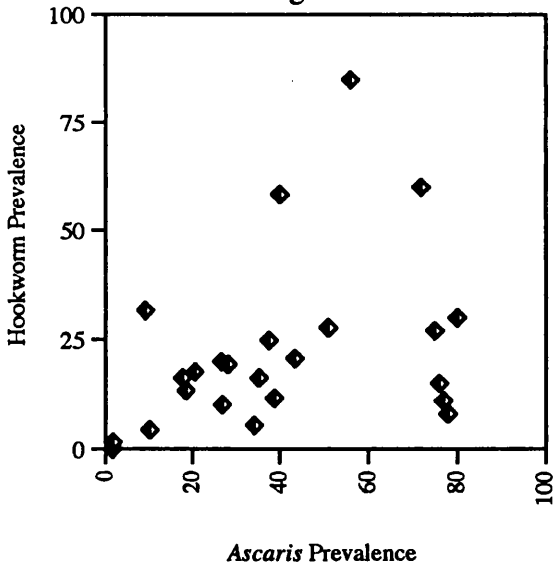


Figure 2.7

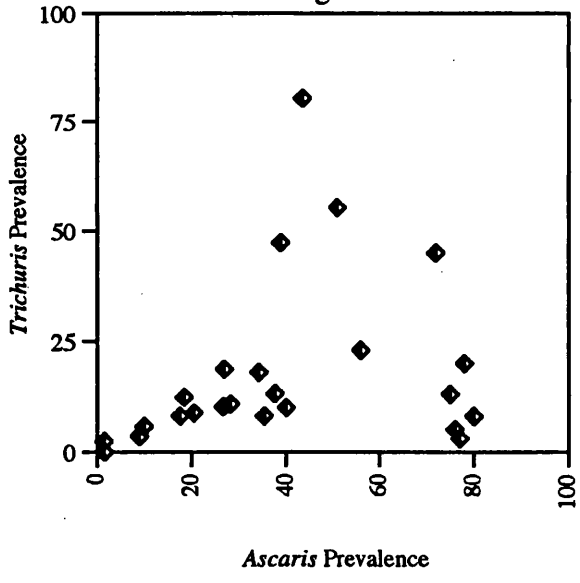
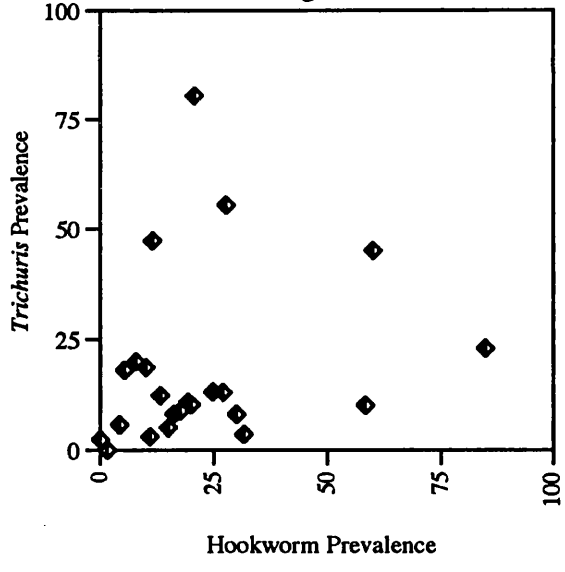


Figure 2.8



Chapter Three. Epidemiology of Gastrointestinal Helminth Infections in Sierra Leone: Description of the Localities Sampled and Demographic Analysis.

3.1 Introduction

Previous helminth surveys and information gathered from hospital records (Chapter Two) have indicated that *Ascaris lumbricoides*, hookworm (probably *Necator americanus*) and *Trichuris trichiura* are widespread in the population of Sierra Leone. *Schistosoma mansoni*, *Strongyloides stercoralis* and *Strongyloides fullebourni* have also been reported. These surveys, however, have often failed to give reliable data regarding: (1) the distribution of the infections throughout a community, (2) the factors that are associated with their persistence and (3) their public health significance. Accordingly, new surveys were designed and conducted to investigate the distribution of helminth infections in three communities. The field work for these was carried out from August to October in 1991. An extensive statistical analysis of the results obtained from the survey carried out in Sierra Leone follows in Chapters Three through Six. It must be borne in mind that the survey took place over 7 weeks only. It only represents the situation at that time and does not contain any information regarding the status of helminth infections over time in the areas surveyed. In this regard, the extensive analysis carried out here may be viewed to be unwarranted. This survey does, however, contain the only recent information on the prevalence and intensity of helminth infections in all age groups in the Northern Province and in the Western Area.

Random selection of households was used to obtain a representative sample of individuals of all ages in the communities studied. The distribution of people in the surveys was compared to the 1974 census data to determine if they were representative of the region from which they were drawn, both in terms of age structure and sex ratio. Subsequent analysis was performed on the individuals surveyed, first to determine if non-targeted individuals differed significantly from individuals targeted by the sampling procedure and also to determine if categorical variables were distributed equally amongst one another, for example, if both sexes were equally represented across all age groups. The overall distribution of intensity of helminths (eggs per gram faeces) was investigated in each community and comparisons were undertaken for differences in helminth intensity and prevalence.

The distribution of helminth prevalence and intensity as regards host sex and age, household size and area within the village are investigated for each village separately, in the following chapter. The effect of all the factors simultaneously on intensity and prevalence was investigated to aid in the design of control measures. Morphometric data obtained from the children was analysed to identify

any effects on childhood health that may be related to community, sex, age, household size, area or helminth infection within a community.

3.2 Materials and Methods

3.2.1. Study Sites and Populations

Three communities of approximately 1000 individuals each were selected: an urban site, Kroo Bay, a shanty settlement near downtown Freetown, in the urban Western Area; Rowollon, a low-lying village on the Great Scarcies River, dependent on subsistence farming and fishing in the Northwest of Sierra Leone near Mambolo, in Kambia District in the Northern Province; Foria, a highland rural village of subsistence farmers and hunters in the Northeast of Sierra Leone near Alikalia, in Koinadugu District, also in the Northern Province. Households were randomly selected in each community to obtain representative samples of people of all ages over five yr. In addition, every household was invited to obtain stool samples from all children under five yr. Subjects reported to the collection point at a given time, where they were all weighed. The height of children 25 kg and under and their percentile score on a weight-for-height chart was recorded. All individuals in the study were examined by a primary health care worker. Anthelmintic treatment (Ketrax [=levamisole] Zeneca Pharmaceuticals, U.K.) was given to all subjects, according to the manufacturer's instructions. Other primary health care treatment was given.

3.2.2. Parasitological Procedures

Faecal material was examined using a modified Kato-Katz technique (W.H.O., 1985; Robertson, Crompton, Walters, Nesheim, Sanjur and Walsh, 1989). Stool samples were centrifuged for 5 min at 2000 RPM. The supernatant fluid was poured off into a 10% bleach solution. A 100 mesh steel sieve was used to remove large pieces of rough material from the faecal pellet by forcing material through the sieve with a clean steel spatula. A stainless steel template was used to measure out approximately 50 mg of sieved faecal material on a clean microscope slide. A solution of 3% malachite green in 50% glycerol (Martin and Beaver, 1968) was added (2-3 drops) to the faecal material and a coverslip placed on the sample. This preparation was allowed to stand for at least 30 min but not longer than 36 hr in which time the parasite ova and larva were stained. After 36 hr, the preparation started to dry out and was difficult to examine. Examination was done at x100 magnification. Eggs and larvae of helminths were counted and an indirect method of measuring

intensity (eggs/larvae per gram faeces) was recorded for each specimen found to be positive for helminth eggs +/or larvae. Mean intensity is defined as the sum of all the egg/larvae counts divided by the number of people found to be infected (Margolis, Esch, Holmes, Kuris and Schad, 1982).

Differences in prevalence of the helminths among the three communities were investigated using Chi-square analysis. Bonferoni confidence intervals (Neu, Byers and Peek, 1974) were constructed for the prevalence of each helminth in each community. Differences in intensity were analysed using one-way analysis of variance for differences between three communities or t-tests for differences between two communities, on intensity data which were transformed using base ten logarithms. Correlation of intensity was completed using a Spearman rank correlation. Intensity data was checked to determine whether parametric analysis was correct using Levene's test for homogeneity of variances and Kolmorgorov-Smirnov's test to determine if the distributions differed significantly from a normal distribution. When assumptions of equality of variances or normality were violated, nonparametric tests (Kruskal-Wallis analysis of variance, Mann-Whitney U tests and Median tests) were used.

3.2.3. Categorical Variables

These are variables which are either categories in their own right or are interval data that had been lumped into categories for analysis. The manner of combining age and household size into categories for each community is explained here. Analysis is performed later to determine if the various categories were not represented equally between each other, for example if there are more males than females in a certain age class.

3.2.3a. Age

Host age was divided into the following classes: from birth through to four yr-of-age and any proportion of four yr was age class 1; 5 through 9 yr and any proportion of 9 yr, age class 2; 10 through 19 yr and any proportion of 19 yr, age class 3; 20 through 39 yr and any proportion of 39 yr of age, age class 4; and over 40 yr-of-age, age class 5.

3.2.3b. Area

Area of households is illustrated in Figure 3.1 for Kroo Bay, in Figure 3.2 for Rowollon and in Figure 3.3 for Foria. In each of the communities, the selection of area was done to reflect differences in the quality or the age of houses. In Kroo Bay, those houses in area 1 were often made

out of corrugated steel in comparison to area 2 which where made out of more stable building materials. In Rowollon, area 1 consisted of houses that appeared to be older than those in area 2, and they were spaced more densely. In Foria, area 1 houses were older and more densely spaced in comparison to area 2.

3.2.3c. Household Size

3.2.3c.*i.* Kroo Bay

Information on the number of people within a household was only available for the targeted households in Kroo Bay, a sample of 261 individuals. Numbers of people living in a household ranged from three to 50. Households were divided into three groups, those in group 1 contained one to fourteen individuals, those in group 2 contained 15 to 24 individuals and those in group 3 had more than 24 individuals per household.

3.2.3c.*ii.* Rowollon

Household size was investigated using the total number of people in the houses (gathered when the primary health care worker visited households) which were randomly selected and using the number of individuals under 15 and under 5. These were found to be highly correlated using Spearman rank correlation (r_S = .942 for the overall number in the household and the number of those under 15, r_S = .926 for the overall number in the household and the number under 5 and r_S = .947 for the number under 15 and the number under 5), with the different numbers essentially measuring the same thing, degree of crowding in a house. It was decided to use the number of under-fives to divide the households, as this information was available for all households in Rowollon, to determine if size of the household had any influence on the prevalence or intensity of helminth infection. The number of under-fives ranged from 0 to 10. Houses were grouped into those with no under-fives to three under-fives, group 1; 4 through 6 under-fives, group 2; and seven or more under-fives, group 3.

3.2.3c.*iii.* Foria

Information on the size of households was only available for the randomly chosen individuals, 397 in total. Numbers ranged from one individual in a household to 47. Households were divided into three groups, those containing one to fourteen individuals, group 1, those containing fifteen to twenty-four individuals, group 2 and those households where more than twenty-four individuals lived, group 3.

3.3. Description of Sample Analysed

The description of the samples analysed is presented in Table 3.1 for all three communities. Chi-square analysis was used to test the level of people's response to being asked to contribute to the survey. No significant difference was found (Chi-square = 3.32, df = 1, $P > 0.05$). All information is not available for all the communities (Table 3.1).

3.3.1. Kroo Bay

Details of the individuals surveyed in this community are presented on Table 3.1. The Kroo Bay survey was the most difficult to carry out. This community is a district within urban Freetown and people from without the community attended the clinic and provided samples. It was difficult to contact people and to get reliable information on the number of individuals in a household due to transient residency within a household. The survey in Kroo Bay was carried out with the assistance of the St. Andrew's Clinic for Children, which had run an under-fives and maternal health care clinic in this community for sometime. The clinic's emphasis on under-fives and maternal health care could have biased the response towards younger children and mothers.

3.3.2. Rowollon

Table 3.1 provides details on the individuals surveyed in this community. The best information was obtained about the population in Rowollon, where information on most of the under-fives in the community and the most reliable data on the number of people living in each household was available. Of the entire population of under-fives, 218 individuals, 71 (32.6%) were included in the random sample of Rowollon. If it is assumed that individuals in all age classes complied with the request for a faecal sample with an equal response and that analysis was undertaken on similar percentages of other age classes the total population of the community could be estimated. The random survey was made up of 341 individuals, which should be 32.6% of the entire population of Rowollon. If 341 is divided by .326 this gives the population of Rowollon as 1046, very close to the local health care worker's original estimate of 1000 individuals.

3.3.3. Foria

Information on the number of individuals participating in the survey in the targeted household in Foria is presented in Table 3.1. Information on the individuals in the non-targeted

households was not available, although the local health care worker attempted to encourage all children under five yr of age in the community to participate.

3.4. Comparison of the Randomly Selected Survey Sample with Information from the 1974 Census

The 1974 population census of Sierra Leone (Sierra Leone Government, 1989) is the latest data set available concerning the distribution of the population of districts with regard to age and sex. Chi-square analysis was used to determine if the survey samples taken from each community differed significantly from the situation in 1974 in terms of age class and sex ratio.

3.4.1. Kroo Bay

The Kroo Bay sample was checked to determine if the distribution of individuals amongst the age classes differed from that which was found in the 1974 census. Table 3.2 displays data from both the random sample of Kroo Bay and the 1974 census.

Table 3.2. Data from the 1974 census of the Western Area and the random sample of people living in Kroo Bay.

	1974 Census			Kroo Bay Sample		
Age Groups	Population	% of Pop.	Male / Female	N	% of Sample	Male / Female
0 - 4.9	47838	15.2	0.995 23858/23980	93	35.6	0.661 37/56
5 - 9.9	44269	14.0	0.894 20895/23374	44	16.9	0.833 20/24
10 - 19.9	68232	21.6	1.020 34457/33775	30	11.5	0.429 9/21
20 - 39.9	99163	31.4	1.269 55450/43713	46	17.6	0.122 5/41
40 +	55960	17.7	1.253 31122/24838	48	18.4	0.231 9/39
Total	315462	99.9*	1.108 165782/149680	261	100	0.442 80/181

* 550 people did not state their age.

3.4.1.a. Age Class

The results of Chi-square analysis (Table 1, Appendix I) of the distribution by age groups in the Kroo Bay sample in comparison with the 1974 census indicated that there was a statistical difference between the two samples in the distribution of the population in the five different age groups (Chi-square value equalled 101.74, df = 4, $P \leq 0.01$). The Chi-square table was collapsed to determine where the significant differences lay. The age classes were ordered by the difference in the percentage of the sample found in each age class in comparison to the census data. This gave the

following order, age class 3 (with 11.5% of the sample compared to 21.6% of the census population), age class 4, age class 5, age class 2 and age class 1.

Table 3.3. Comparisons to locate the differences between the Kroo Bay random survey and the 1974 census.

Comparisons	Chi-square Value*	*P*
3 vs. 4	0.05	$P > 0.05$
3 & 4 vs. 5	12.30	$P \leq 0.01$
5 vs. 2	0.50	$P > 0.05$
5 & 2 vs. 1	27.25	$P \leq 0.01$

* The degree of freedom for each of the comparisons is one

Significant differences (Table 3.3) were found between the combined age classes of 3 and 4 and age class 5 and the combined age classes of 5 and 2 and age class 1. This indicated that age classes 3 and 4 had fewer people in them in the Kroo Bay survey than in the 1974 census and age class 1 had more than would be expected in comparison to the 1974 census. The method of targeting households in Kroo Bay and the history of the St. Andrew's Clinic involvement in the community were both geared towards the treatment of individuals under five yr of age and perhaps this had influenced the response of individuals in coming forward for examination.

3.4.1.b. Sex Ratio

Chi-square analysis was used to determine if the male to female ratios in each age group were different than those seen in the 1974 census (Table 3.4). Chi-square tables for those age classes found to be significantly different from the 1974 census in their sex ratio are presented in Tables 2 through 4, Appendix I.

Table 3.4. Comparisons in the sex ratio between the Kroo Bay sample and the 1974 census data.

Comparisons	Chi-square Value*	*P*
Age Class 1, KB vs. Age Class 1, Census	3.78	$P > 0.05$
Age Class 2, KB vs. Age Class 2, Census	0.06	$P > 0.05$
Age Class 3, KB vs. Age Class 3, Census	5.05	$P \leq 0.05$
Age Class 4, KB vs. Age Class 4, Census	26.40	$P \leq 0.01$
Age Class 5, KB vs. Age Class 5, Census	37.88	$P \leq 0.01$
All Ages, KB vs. All Ages, Census	50.16	$P \leq 0.01$
Age Class 5, KB vs. Age Class 4, Census	26.88	$P \leq 0.01$
Age Class 4, KB vs. Age Class 1-3, Census	28.89	$P \leq 0.01$

* There is one degree of freedom for all comparisons.

No significant differences were found in the male to female ratios in age group 1 and in age group 2 (Table 3.4). However there were significant differences between the 1974 census and the Kroo Bay

sample in age groups 3, 4, 5 and also in the overall male to female ratio (Table 5, Appendix I). By comparing the observed and expected values in the Chi-square tables (Tables 2 to 5, Appendix I) it may be seen that these findings are due to fewer males than would be expected from the 1974 census being represented in the sample. This may indicate a different attitude towards health and the perception of parasitological problems of adult males within this urban community.

The 40 yr and over group in the Kroo Bay sample was then compared to the 20 to 39 yr olds in the 1974 census (Table 3.4 and Table 6, Appendix I), essentially comparing members of the same cohort after a period of 18 yr. Those who had been in the 1974 census at ages 20 through 39 would now presumably make up a majority of the 40 yr and over group. The male to female ratios of these two groups were significantly different and significant differences were seen when similar analysis was undertaken for the 20 to 39 yr olds in the sample in comparisons to those aged 0 to 19 yr of age in the 1974 census (Table 3.4 and Table 7, Appendix I).

The number of individuals in the different age classes in this survey and the numbers of males and females is probably not representative of the urban Western Area from the above analysis. It appears that the sample is heavily weighted towards individuals under age five and towards females. The parasitological results from the survey described here must be interpreted with this weighting in mind. This underlies some of the problems to be overcome when attempting to sample randomly from a defined area.

3.4.2. Rowollon.

The Rowollon sample was examined in the same manner and the relevant data are displayed in Table 3.5.

Table 3.5. Data from the 1974 census of Northern province and the random sample of people living in Rowollon.

	1974 Census			Rowollon Sample		
Age Groups	Population	Percent of Population	Male / Female	N	Percent of Sample	Male / Female
0 - 4.9	181356	17.3	0.9799 89758/ 91598	72	21.1	0.800 32/40
5 - 9.9	183288	17.5	1.0554 94112/89176	46	13.5	1.706 29/17
10 - 19.9	189766	18.1	0.9828 94062/95704	64	18.7	0.6842 26/38
20 - 39.9	274096	26.2	0.6700 109963/164133	81	23.7	0.2462 16/65
40 +	215934	20.6	1.0249 109297/106637	79	23.1	0.580 29/50
Total	1046158	99.7*	0.9085 497192/547248	342	100	0.6316 132/209

* 1718 individuals did not state their age.

3.4.2a. Age Class

Chi-square analysis of the age group distribution in the Rowollon sample, in comparison to the 1974 census, indicated that there was no statistical difference in the distribution of the population in the five different age groups (Chi-square value equalled 7.532, df = 4, $P > 0.05$). The Chi-square table for this is presented in Table 8, Appendix I.

3.4.2b. Sex Ratio

Results of Chi-square analysis undertaken to determine if the male to female ratios in each age group were different than those seen in the 1974 census is presented in Table 3.6. The Chi-square tables for those comparisons found to be significant are presented in Tables 9 to 11, Appendix I.

Table 3.6. Comparisons in the sex ratio between the Rowollon sample and the 1974 census data.

Comparisons	Chi-square Value*	*P*
Age Class 1, RW vs. Age Class 1, Census	0.55	$P > 0.05$
Age Class 2, RW vs. Age Class 2, Census	2.52	$P > 0.05$
Age Class 3, RW vs. Age Class 3, Census	2.05	$P > 0.05$
Age Class 4, RW vs. Age Class 4, Census	13.98	$P \leq 0.01$
Age Class 5, RW vs. Age Class 5, Census	6.11	$P \leq 0.01$
All Ages, RW vs. All Ages, Census	11.03	$P \leq 0.01$
Age Class 5, RW vs. Age Class 4, Census	0.38	$P > 0.05$
Age Class 4, RW vs. Age Class 1-3, Census	29.90	$P \leq 0.01$

* There is one degree of freedom for all comparisons.

No significant differences were found between the male to female ratios in age groups 1, 2 and 3 in the Rowollon survey and the 1974 census data (Table 3.6). There were significant differences

between the 1974 census and the Rowollon sample in age groups 4, 5 and for all the age classes combined. It can be seen from the Chi-square tables in Appendix I (Tables 9 to 11) that there were fewer males in regards to the number of females in these groups in the Rowollon survey than in the 1974 census.

The 40 yr and over group in the Rowollon sample was then compared to the 20 to 39 yr olds in the 1974 census, essentially comparing the same cohort 18 yr later. The male to female ratios of these two groups were not significantly different (Table 3.6). However, when the 20 to 39 yr olds in the Rowollon survey were compared to the 0 to 19 yr old age classes in the 1974 census a significant difference was revealed between the male to female (Table 3.6 and Table 12, Appendix I).

If it be assumed that Rowollon is representative of the population of Kambia district, it appears that there has been a loss of men from the population of Rowollon, occurring as they age from under 20 yr into the group of 20 to 39 yr. From the data on the male to female ratio on older people in Rowollon (40 yr and over) in comparison to the ratio 18 yr ago, it appears that the majority of this loss from the population has been completed by the time people reach age 40. The grouping of people into age groups has no doubt obscured when exactly this loss takes place, but it is probably a gradual process that begins as individuals start to reach young adulthood in their teens and twenties.

3.4.3. Foria

The Foria sample was also examined and the relevant data are displayed in Table 3.7.

Table 3.7. Data from the 1974 census of the Northern Province and the random sample of people living in Foria.

	1974 Census			Foria Sample		
Age Groups	Population	Percent of Pop.	Male / Female	N	Percent of Sample	Male / Female
0 - 4.9	181356	17.3	0.9799 89758/ 91598	82	20.7	.7826 36 / 46
5 - 9.9	183288	17.5	1.0554 94112/89176	68	17.1	.7000 28 / 40
10 - 19.9	189766	18.1	0.9828 94062/95704	94	23.7	.9583 46 / 48
20 - 39.9	274096	26.2	0.6700 109963/164133	108	27.2	.5652 39 / 69
40 +	215934	20.6	1.0249 109297/106637	45	11.3	0.4516 14 / 31
Total	1017440	99.7	0.9085 497192/547248	397	100	0.6966 163 / 234

* 1718 individuals did not state their age.

3.4.3a. Age Class

The results of Chi-square analysis (see Table 13 in Appendix I) of the distribution by age groups in the Foria sample in comparison to the 1974 census indicated that there was a statistical difference between the two samples in the distribution of the population in the five different age groups (Chi-square value equalled 26.131, df = 4, $P \leq 0.01$). The Chi-square table was collapsed to determine where the difference lay (Table 3.8). The age classes were ordered in sequence of the difference in the percentage of the sample found in each age class in comparison to the census data. This resulted in the following order; age class 5 (with 11.3% of the sample compared to 20.6% of the census data), age class 2, 4, 1 and 3.

Table 3.8. Comparisons to locate the differences between the Foria random survey and the 1974 census.

Comparisons	Chi-square Value*	*P*
5 vs. 2	9.26	$P \leq 0.01$
2 vs. 4	2.11	$P > 0.05$
2 & 4 vs. 1	2.97	$P > 0.05$
2 & 4 & 1 vs. 3	4.47	$P \leq 0.05$

* There is one degree of freedom for each of the comparisons.

Age class 5 differed from age class 2. Age classes 2, 4 and 1 were not significantly different and age class 3 was significantly different from these three age classes. This indicates that age class 5 has fewer than expected people in it in comparison to the 1974 census data and that age class 3 has more people in it than would be expected, but the other age classes are comparable, in the proportion of individuals in them, with the 1974 census.

3.4.3b. Sex Ratio

Analysis undertaken to determine if the male to female ratios in each age group were different than those seen in the 1974 census indicated that there were no significant differences in the male to female ratios in age groups 1, 2, 3 and 4 but there were significant differences between the 1974 census and the Foria sample in age group 5, those 40 yr and older, and also in the overall male to female ratio (Table 3.9). Chi-square tables for analyses found to be significantly different are presented in Tables 14 and 15, Appendix I.

Table 3.9. Comparisons in the sex ratio between the Foria sample and the 1974 census data.

Comparisons	Chi-square Value*	*P*
Age Class 1, FR vs. Age Class 1, Census	1.03	$P > 0.05$
Age Class 2, FR vs. Age Class 2, Census	2.82	$P > 0.05$
Age Class 3, FR vs. Age Class 3, Census	0.02	$P > 0.05$
Age Class 4, FR vs. Age Class 4, Census	0.72	$P > 0.05$
Age Class 5, FR vs. Age Class 5, Census	6.93	$P \leq 0.01$
All Ages, FR vs. All Ages, Census	6.84	$P \leq 0.01$
Age Class 5, FR vs. Age Class 4, Census	1.52	$P > 0.05$
Age Class 4, FR vs. Age Class 1-3, Census	8.49	$P \leq 0.01$

* There is one degree of freedom for all comparisons.

Age classes 1, 2, 3 and 4 were found not to be significantly different from the 1974 Census data in their male to female ratios. Age class 5 was significantly different where it can be seen from Table 14. in Appendix I that there were fewer males in this age class in regards to the number of females when compared to the 1974 census. Comparing the Foria sample over all age classes to the 1974 census in terms of male to female ratio indicated that there was a significant difference between the survey of Foria and the 1974 Census, again with males being under-represented in the Foria sample.

The 40 yr and over group in the Foria sample was then compared to the 20 to 39 yr olds in the 1974 census, essentially comparing the same group after a time period of 18 yr. The male to female ratios of these two groups were not significantly different (Table 3.9). Comparing the 20 through 39 yr olds in the Foria survey with the 0 through 19 yr old age groups in the 1974 census revealed significant differences between the male to female ratios of these groups (Table 3.9). From Table 16 in Appendix I it can be seen that this reflects that there were fewer males in the Foria sample than would be expected looking at their same cohort in the 1974 Census.

If it is assumed that Foria is representative of the population of the Northern province this indicates that there is a loss from the population of Foria of men, occurring as they age from under 20 yr of age into the age group of 20 through 39. From the data on the male to female ratio on older people in Foria (40 yr and over) in comparison to the ratio 18 yr ago, it appears that the majority of this loss from the population has been completed by the time people reach age 40. The grouping of people into age groups has no doubt obscured when exactly this loss is taking place, but it is probably a gradual process that begins as individuals start to reach young adulthood in their teens and continues into their twenties.

3.5. Selection of Individuals for Analysis

The analysis of the data from the children not living in the randomly chosen households in Foria and Rowollon, from individuals outwith the study area in Kroo Bay and from those living in non-targeted households presented difficulties. The question of whether to include the non-random and non-targeted individuals in further analysis was settled by investigating whether or not their infections differed in prevalence or intensity from the randomly chosen children. If the intensity or prevalence was found to differ in the non-randomly selected individuals or in the individuals from non-targeted households, the subsequent analysis only used those individuals which were randomly selected or targeted.

3.5.1. Kroo Bay

Individuals outwith the study area of Kroo Bay were dropped from analysis. The objective of this survey was to focus on communities in different parts of Sierra Leone and the helminth infections within the people living in these communities. It was decided to concentrate on those individuals which actually lived in Kroo Bay at the time of the survey.

3.5.1a. Prevalence Data

Chi-square analysis was performed on the prevalence of *A. lumbricoides*, hookworm and *T. trichiura* to determine if there were any significant differences according to whether the samples had been chosen at random or not. It had been decided if no significant differences were found ($P \leq 0.05$) the results from the samples would be combined and the proceeding analysis would be undertaken on all of the data. If there were significant differences, only the data collected from the random sample would be used.

Table 3.10. Comparisons of helminth prevalence between targeted and non-targeted households in Kroo Bay.

Helminth Infection	Chi-square Value*	P
A. lumbricoides	0.51	$P > 0.05$
Hookworm	0.71	$P > 0.05$
T. trichiura	11.56	$P \leq 0.01$

* There is one degree of freedom for all the comparisons.

Ascaris lumbricoides and hookworm prevalence in people living in targeted households versus those in non-targeted households was not significant different (Table 3.10). The prevalence of *T. trichiura* in people living in targeted households versus those in non-targeted households did show

a significant difference (Table 3.10). The Chi-square table of the observed and expected counts is found in Table 17, Appendix I. This significant result, where the non-targeted households had a lower percentage of people infected with *T. trichiura* (65.1% versus 46.6%), indicated that the analysis of results would be restricted to only those from the targeted households in any analysis concerning *T. trichiura* infections.

3.5.1b. Intensity Data

Analysis was undertaken on the transformed intensities (EPG) of the *A. lumbricoides* and hookworm infection in order to determine if results from the individuals from the non-targeted household were significantly different from those in targeted households. Levene's tests for homogeneity of variances were first calculated to determine if parametric statistics could be used for this analysis. Results of these are presented in Table 18 in Appendix I. Comparisons between the intensities in the targeted and non-targeted households are presented in Table 3.11.

Table 3.11. Comparisons of helminth intensities (EPG) between targeted and non-targeted households in Kroo Bay.

Helminth Infection	Test Statistic	df	*P*
A. lumbricoides	t = 1.87	97	$P = 0.065$
Hookworm	Chi-square = 0.13	1	$P \leq 0.722$

No significant difference was found between the groups in their intensity (EPG) of *A. lumbricoides.* The comparison of intensities of hookworm infection between individuals in targeted versus non-targeted households was undertaken using a median test, as the two samples had unequal variances (Levene's $F = 7.115$, $p \leq 0.009$), a feature which precluded using a t-test or a Mann-Whitney test. No significant differences were found in the distribution of the intensity of individuals from the two sets of houses. Previous analysis of the prevalence of *T. trichiura* had revealed significant differences between individuals in targeted and non-targeted households and the individuals in the non-targeted households had therefore been dropped from subsequent analysis. Analysis of *A. lumbricoides* and hookworm intensity was undertaken on the data set of 379 individuals from targeted and non-targeted households from the Kroo Bay area. Any analysis of concurrent infections concerning *T. trichiura* was undertaken on the 261 individuals from the targeted households.

3.5.2. Rowollon

3.5.2a. Prevalence Data

Chi-square analysis was performed on the prevalence values of *A. lumbricoides*, hookworm and *T. trichiura* in both age class 1 and age class 2 separately to determine if there were any significant differences according to whether the samples had been chosen at random or not. If there were no significant differences ($P > 0.05$) the samples would be combined and the proceeding analysis would be undertaken on all of the data. If there were significant differences, only the data collected from the random sample would be used.

The prevalence of *A. lumbricoides* by age class in random versus non-random samples revealed no significant difference in the first age class (from birth to 4 yr of age). Significant differences were seen in those children aged 5 to 9 yr of age (Table 3.12). The Chi-square table for this is presented in Table 19 in Appendix I. The 34 non-random samples from children aged 5 to 9 were not included in the analyses concerned with both the prevalence and intensity of this parasite.

Table 3.12. Comparisons of helminth prevalence between randomly chosen and non-randomly chosen children in Rowollon.

Helminth Infection	Age Class	Chi-square Value*	*P*
A. lumbricoides	One	1.51	$P > 0.05$
	Two	3.93	$P \leq 0.05$
Hookworm	One	0.28	$P > 0.05$
	Two	4.50	$P \leq 0.05$
T. trichiura	One	1.09	$P > 0.05$
	Two	2.33	$P > 0.05$

* There is one degree of freedom for all the comparisons.

Hookworm prevalence by age class in random versus non-random samples revealed no significant difference in the first age class (from birth to 4 yr of age). Significant differences were seen in those children aged 5 to 9 yr of age (Table 3.12). The Chi-square table for this is presented in Table 20 in Appendix I. The 34 non-random samples from children aged 5 to 9 were not included in the analyses concerned with both the prevalence and intensity of this parasite.

The prevalence of *T. trichiura* when examined by age class in random versus non-random samples revealed no significant difference in the first age class (from birth to 4 yr of age) and also no significant difference in those children aged 5 to 9 yr of age. Consequently all the children sampled were included in further analysis of the prevalence of this parasite.

3.5.2b. Intensity Data

Analysis was undertaken in the case of the transformed intensity data (EPG) of *A. lumbricoides* and hookworm in age class 1 to determine if the non-random samples were significantly different from the random samples. Levene's tests for homogeneity of variances were carried out to determine if parametric statistics could be carried out (Table 21, Appendix I). This indicated that the randomly and non-randomly selected children in age class 1 had significantly different variances for *A. lumbricoides* intensity. A median test was used to determine if there were any differences between the intensity of *A. lumbricoides* in the two groups of children in age class 1. No significant difference was found between the mean intensity of *A. lumbricoides* from random versus non-random samples nor between hookworm intensity. All subsequent analysis was carried out on the entire data set for age class 1 for both infection for random and non-random samples.

Table 3.13. Comparisons of helminth intensities (EPG) between randomly chosen and non-randomly chosen children in Rowollon.

Helminth Infection	Test Statistic	df	*P*
A. lumbricoides Age Class One	Chi-square = 0.03	1	$P > 0.050$
Hookworm Age Class One	t = -1.58	55	$P \leq 0.119$
T. trichiura Age Class One	t = 0.34	33	$P \leq 0.738$
T. trichiura Age Class Two	t = 0.29	48	$P \leq 0.776$

T-tests were undertaken in the case of the transformed *T. trichiura* intensity (EPG) in age classes 1 and 2 to determine if the non-random samples were statistically different from those taken randomly and if this varied from 1 age class to another. This showed no significant differences in *T. trichiura* intensity between randomly and non-randomly chosen children in the two age classes. All subsequent analysis was carried out on the entire data set for *T. trichiura* intensity.

3.5.3. Foria

3.5.3a. Prevalence Data

The prevalence of *A. lumbricoides* by age class in random versus non-random samples revealed no significant difference in the first age class or in the second age class. The same result was found for the prevalence of hookworm in the two groups in each age class (Table .14). *Schistosoma mansoni* prevalence by age class in random versus non-random samples was not investigated due to the small numbers found to be infected in each group.

Table 3.14. Comparisons of helminth prevalence between randomly chosen and non-randomly chosen children in Foria.

Helminth Infection	Age Class	Chi-square Value*	*P*
A. lumbricoides	One	1.62	$P > 0.05$
A. lumbricoides	Two	0.11	$P > 0.05$
Hookworm	One	0.05	$P > 0.05$
Hookworm	Two	0.91	$P > 0.05$

* There is one degree of freedom for all the comparisons.

3.5.3b. Intensity Data

T-tests were undertaken in the case of the transformed *A. lumbricoides* and hookworm intensity data (EPG) in age classes 1 and 2 to determine if the results from the non-random samples were significantly different from those obtained randomly in each age class. Levene's tests for homogeneity of variances were used to determine if parametric statistics could be used for this analysis and are presented on Table 22 in Appendix I. A significant difference was found in intensity in age class 1 in *A. lumbricoides* infections between random and non-random samples but not between random versus non-random samples in age class 2. No significant difference was found between the mean intensity of hookworm from random versus non-random samples in age class 1 nor between the two samples in age class 2 . A t-test could not be completed on *S. mansoni* intensity in age class 1 of random versus non random children due to small sample size but was used to test for differences in age class 2, where no significant difference was found between the two groups of children (Table 3.15).

Table 3.15. Comparisons of helminth intensities (EPG) between randomly chosen and non-randomly chosen children in Foria.

Helminth Infection	Test Statistic	df	*P*
A. lumbricoides Age Class One	$t = 3.20$	$df = 39$	$P = 0.003$
A. lumbricoides Age Class Two	$t = -0.47$	$df = 33$	$P = 0.643$
Hookworm Age Class One	$t = 1.62$	$df = 24$	$P = 0.118$
Hookworm Age Class Two	$t = 1.61$	$df = 58$	$P = 0.113$
S. mansoni Age Class Two	$t = 0.08$	$df = 3$	$P = 0.945$

Subsequent analysis of *A. lumbricoides* intensity data (EPG) was carried out on the data set but children in age class 1 from the non-random sample were excluded. For analysis of all helminth infections, non-random children from age class 1 were not included. Analysis of *S. mansoni* and hookworm intensity (EPG) was undertaken on the total data set of 450 individuals.

3.6. Associations between Categorical Variables

Log-linear analysis was used to determine if the categorical variables of sex and area as well as the data which had been classed into categories, age and number of people in a household were distributed randomly (Norusis and SPSS Inc., 1990a).

3.6.1. Kroo Bay

Analysis was carried out using the 261 individuals from the targeted households. All possible two-way interaction between categorical variables were entered into hierarchical log-linear analysis and backward elimination was used to determine which of these was statistically significant. This analysis revealed that there were significant effects due to the interaction between the area of a community where a household was and category of the size of household (Chi-square = 76.35, df = 1, $P \leq 0.0001$; and the distribution of the number of males and females in the different age classes (Chi-square = 21.44, df = 4, $P \leq 0.0003$).

3.6.1a. Area by Size of Household

Analysis of the distribution of size of household by area was completed using Chi-square analysis. This analysis indicated that there were significant differences in the number of individuals in the survey from households with different numbers of people when comparing area 1 to area 2 (Chi-square = 58.76, df = 2, $P \leq 0.01$; Table 23, Appendix I). The Chi-square table was collapsed (Table 3.16), with the categories of household size being ordered as 3, 2, 1 in relation to the percentage of individuals in area 1 for each of the categories.

Table 3.16. Comparisons to locate the differences in the distribution household size between the areas in Kroo Bay.

Comparisons	Chi-square Value*	*P*
3 vs. 2	26.49	$P \leq 0.01$
2 vs. 1	11.32	$P \leq 0.01$

* There is one degree of freedom for each of the comparisons.

Categories 3 and 2 were statistically different from one another. Category 2 was then compared to category 1 and these two categories were found to be significantly different. This indicates that area 1 had significantly more individuals from the large category of households than area 2, and area 2 had significantly more individuals from smaller houses. Significantly different results seen as a consequence of area or household size may be confounded with one another due to this interaction.

3.6.1b. Age Class and Sex

The effect of the proportion of females to males by age class was investigated using Chi-square analysis. This indicated a significant difference in the distribution of the sexes in the different age classes (Chi-square = 19.86, df = 4, $P \leq 0.0005$: Table 24, Appendix I). The Chi-square table was collapsed to find where the significant differences were (Table 3.17). The age classes were ordered in ascending order by the percentage of females in each age class, resulting in the following order; age class 2, 1, 3, 5 and 4.

Table 3.17. Comparisons to locate the differences in the distribution sex between the age classes in Kroo Bay.

Comparisons	Chi-square Value*	*P*
Age Class 2 vs. 1	0.39	$P > 0.05$
Age Classes 2 & 1 vs. 3	1.39	$P > 0.05$
Age Classes 2 & 1 & 3 vs. 5	7.08	$P \leq 0.01$
Age Class 5 vs. 4	1.15	$P > 0.05$

* There is one degree of freedom for each of the comparisons.

Age classes 2 and 1 were compared to one another and found not to be significantly different (Table 3.17). They were combined and compare to age class 3 and were found not to be significantly different. These three age classes were then combined and compared to age class 5. They were found to be significantly different. Age class 5 was then compared to age class 4 and they were found not to be significantly different.

3.6.2. Rowollon.

Hierarchical log linear analysis was carried out on the 431 individuals in Rowollon, the group that included all those which were included in all analyses of prevalence. This revealed that significant effects were due to the interaction between sex and age class (Chi-square = 25.81, df = 1, $P \leq 0.0001$) and between area of households and category of number of under fives (Chi-square = 76.32, df = 1, $P \leq 0.0001$), using backward elimination of effects from the log-linear model.

3.6.2a. Age Class and Sex

The sample was broken down into age classes and sex to determine if either sex was more highly represented in a certain age class; a feature which might lead to differences in prevalence between age classes if one of the sexes showed a higher prevalence of a helminth infection. Chi-

square analysis revealed a significant difference between the sexes in their representation in the five age classes (Chi-square value of 26.27, df = 4, $P \leq 0.01$; see Table 25, Appendix I).

The Chi-square table was collapsed to determine where the differences lay (Table 3.18). The cells were ordered by the percentage of females present in ascending order, age classes 2, 1, 3, 5 and 4.

Table 3.18. Comparisons to locate the differences in the distribution sex between the age classes in Kroo Bay.

Comparisons	Chi-square Value*	*P*
Age Class 1 vs. 2	4.67	$P \leq 0.05$
Age Classes 1 vs. 3	0.42	$P > 0.05$
Age Classes 1 & 3 vs. 5	1.29	$P > 0.05$
Age Class 1 & 3 & 5 vs. 4	13.30	$P \leq 0.01$

* There is one degree of freedom for each of the comparisons.

Age classes 2 and 1 were seen to have significantly different proportion of females to males. Age classes 1 and 3 were not found to be significantly different and they were combined and compared with age class 5 where no significant difference was found. Age classes 1, 3 and 5 were then combined and compared with age class 4 to reveal a significant difference between the proportion of females to males in these two groups.

3.6.2b. Area by Size of Household

The distribution of categories of numbers of under-fives by area was investigated. This revealed significant differences in the distribution of the households throughout the community and the size of the households (Chi-square = 31.29, df = 2, $P \leq 0.01$; see Table 26, Appendix I). The Chi-square table was collapsed as before, with the categories of under-fives being ordered as 3, 2 and 1 in relation to the percentage of individuals in area 1 for each of the categories.

Table 3.19. Comparisons to locate the differences in the distribution household size between the areas in Rowollon.

Comparisons	Chi-square Value*	*P*
3 vs. 2	3.62	$P > 0.05$
3 & 2 vs. 1	27.66	$P \leq 0.01$

* There is one degree of freedom for each of the comparisons.

Categories 3 and 2 were not statistically different from one another and they were combined and compared to category 1. The combination of 2 and 3 was found to be statistically different from

category 1 in the distribution of individuals among area. In area 1, there were more people from larger households than in area 2, which had more people from smaller households.

3.6.3. Foria

Hierarchical log-linear analysis on the sample of the 397 randomly selected individuals revealed that the only significant effect was due to the interaction between area of households and size of household (Chi-square = 9.88, df = 1, $P \leq 0.0072$), using backward elimination of effects from the log-linear model.

3.6.3a. Area by Size of Household

The distribution of size of household by area was investigated using Chi-square analysis. The Chi-square value was 9.56, df = 2, $P \leq 0.01$ (Table 27, Appendix I). The Chi-square table was collapsed as before, with the categories of household size being ordered as 2, 1 and 3 in relation to the percentage of individuals in area 1 for each of the categories. Categories 2 and 1 were not statistically different from one another and they were combined and compared to category 3. The combination of 2 and 1 was found to be statistically different from category 3 in the distribution of individuals among area. Area 2 had more individuals in smaller households than did area 1, where more individuals were found in larger households.

Table 3.20. Comparisons to locate the differences in the distribution household size between the areas in Rowollon.

Comparisons	Chi-square Value*	*P*
2 vs. 1	0.57	$P > 0.05$
2 & 1 vs. 3	8.95	$P \leq 0.01$

* There is one degree of freedom for each of the comparisons.

3.7. Distribution of helminth intensities in the three communities

The results of measurements of the intensity of infection (mean number of eggs per gram of those found to be positive for a helminth infection) were investigated. The faecal egg counts were found to be over-dispersed, with a variance-to-means ratio greater than one. Consequently they were transformed, using a base ten logarithmic transformation. Both the non-transformed and transformed data were checked to see if they varied significantly from a normal distribution, using the Kolmogorov-Smirnov one-sample goodness of fit test. Variance to mean ratios were also calculated for comparison between the various distributions and are presented in Table 3.21. The intensity of *T.*

trichiura infection in Rowollon differed significantly from a normal distribution, even after transformation.

3.8. Discussion

The demography and social structure of the three communities surveyed and the manner of the data collection and its subsequent investigation have been described in this chapter. The form of the random sample of subjects from each of the communities was compared with data for the 1974 census of Sierra Leone. The Kroo Bay sample was seen to vary significantly from the census sample, with a greater than expected proportion of the sample being made up of children under the age of five and with fewer people from age 10 to 19 and 20 to 39 than would be expected. By comparing the sex ratios in the survey with those in the census data, it seems that the difference lay in the fact that many adult males failed to participate in the survey. The Kroo Bay survey thus provides a better indication of the helminth infection status of under-fives than of the other age classes and gives less reliable information on adult males and their helminths.

The Rowollon sample did not differ from that of the 1974 census, indicating that population distribution probably reflected the actual distribution in this area. This survey, therefore, was assumed to give good information about the status of helminth infections for all age groups and for both sexes. It also indicates that male migration away from the area, probably into an urban setting, is a long established occurrence, although the extent of this may be increasing.

The Foria sample also differed significantly from the 1974 census, with fewer individuals of 40 yr and over than expected, and more individuals aged between 10 and 19 yr of age than would have been expected. Part of this may be because one of the randomly targeted houses was involved in teaching young adults Arabic and the Koran and there were a large number of individuals in this age group in this household, often from surrounding communities. All these individuals were included in the survey. The random sample should reflect the composition of the community at the time of the survey, in spite of the significant differences seen.

The selection of individuals for analysis was determined for each of the three predominant infections in each community separately. Analysis was completed for all 379 individuals living in the Kroo Bay area for infections of *A. lumbricoides* and hookworm. Analysis was completed on the 261 individuals from targeted households on information concerning *T. trichiura*. Information on all

three infections was analysed using only the 261 individuals from the targeted households. In Rowollon, analysis of *A. lumbricoides* and hookworm infection was completed on 408 individuals, those randomly selected in all age classes and those non randomly selected in age class 1 (under five yr of age). For *T. trichiura*, analysis was undertaken on the total sample of 465 individuals. Analysis of information concerning all three helminth infections was undertaken on the 408 individuals identified previously. For the analysis of the Foria data, results on *A. lumbricoides* were investigated on the sample of randomly selected individuals and the non-randomly selected children in age class 2 (five to nine yr of age) numbering 397 individuals. The analysis of hookworm and *S. mansoni* was carried out on the full sample of 450 individuals. Analysis of all three common helminth infections together was carried out on the sample of 397 individuals.

Association between categorical variables was found in all three communities. There were significant differences in the representation of males and females in the different age classes in Kroo Bay and Rowollon. In Kroo Bay, there were more females than expected in the age classes over 20 yr of age. In Rowollon, there were fewer females than expected in age class 2, (5 to 9 yr of age). There were also more females than expected in age class 4. These findings should be remembered if any significant results are found by age and sex of host as the different numbers of each in each age class may influence the results. In all the communities, there were also significant differences found in the distribution of the sizes of households within the community. This also indicates that the two categorical variables of area and household size are confounded with one another in all the communities, as are sex and age in Kroo Bay and Rowollon and this may lead to problems when attempting to measure the effect of these two variables on helminth infections.

The distribution of the intensity (EPG) of all the helminth infections in the communities was found to be over-dispersed (variance-to-mean ratio greater than one) and to be significantly different from a normal distribution. The use of base ten logarithms on the intensity data allowed the transformation of the distributions to ones approximating a normal distribution, except for that of *T. trichiura* in Rowollon, for which the transformation did not work.

3.9. Summary

Comparisons with 1974 census data

Kroo Bay

1. Fewer people aged 10 to 39 yr and more aged 0 to 5 yr than expected.
2. Fewer males, overall and aged from 10 yr and older than expected.

Rowollon

1. No statistical differences in peoples ages from the sample versus the 1974 Census.
2. Fewer males, overall and aged from 20 yr and older than expected.

Foria

1. Fewer people aged 40 yr and over and more aged 10 to 19 yr than expected.
2. Fewer males, overall and aged from 40 yr and older than expected.

Selection of individuals for analysis

Kroo Bay

1. Individuals used from targeted and non-targeted households in analysis of *A. lumbricoides* and hookworm prevalence, but only from targeted households for *T. trichiura* prevalence.

2. Individuals used from targeted and non-targeted households in analysis of *A. lumbricoides* and hookworm intensity, but only from targeted households for *T. trichiura* intensity.

Rowollon

1. Individuals used from randomly selected households and children aged from birth to 4 yr in non-randomly selected households in analysis of *A. lumbricoides* and hookworm prevalence, and all individuals used for *T. trichiura* prevalence.

2. Individuals used from randomly selected households and children aged from birth to 4 yr in non-randomly selected households in analysis of *A. lumbricoides* and hookworm intensity, and all individuals used for *T. trichiura* intensity.

Foria

1. All individuals used from randomly and non-randomly selected households for analysis of *A. lumbricoides*, *T. trichiura* and *S. mansoni* prevalence.

2. All individuals used from randomly and non-randomly selected households for analysis of *T. trichiura* and *S. mansoni* intensity, only those individuals from randomly selected households and those aged 5 to 9 yr of age from non-randomly selected households for *A. lumbricoides* intensity.

Association Between Categorical Variables

Kroo Bay

1. Significantly more individuals from larger households in area 2; significantly more individuals from smaller households in area 1.

2. Age classes one, two and three had lower female to male ratio than age classes four and five.

Rowollon

1. Age class two had significantly the lowest number of females to males, then came age classes one, three and five who were significantly lower in the number of females to males than age class four.

2. In area one there were more individuals in larger households, in area two, there were more individuals in smaller households.

Foria

1. Area two had more individuals in smaller households than did area one, where more were in larger households.

Distribution of Helminth Intensities in the three communities

1. Distributions of intensities of all helminth species were over-dispersed in all three communities.

2. Log-transformations successfully transformed all distributions to normal except for that of the intensity of *T. trichiura* infections in Rowollon.

Table 3.1. Information available for the samples collected and analysed in the three communities.

Community	Number in Targeted Households	Number Analysed from Targeted Households (%*)	Number in Nontargeted Households	Number Analysed from Nontargeted Households (%‡)	Total Number Analysed
Kroo Bay	328	261 (79.6%)	†	50 individuals from outside Kroo Bay 118 individual from inside Kroo Bay	429
Rowollon	411	342(83.2)	150	123 (82.0%)	465
Foria	463	397(85.7%)	†	53	450

* Percentage analysed of the people found to be living in the targeted households

‡ Percentage analysed of the number of individuals found to be living in the nontargeted households, if known.

† No reliable information was available on the numbers of people living in the nontargeted households

Table 3.21. Distribution of the intensity (EPG) of the three major helminth infections in each community.

			Non Transformed Intensity (EPG)		Transformed Intensity (EPG)	
Helminth Infection	Community	N	Variance/ Mean	Kolmogorov-Smirnov	Variance/ Mean	Kolmogorov-Smirnov
A. lumbricoides	Kroo Bay	99	11287	2.4947*	0.134	0.4201
Hookworm	Kroo Bay	84	3940	3.1889*	0.162	0.6773
T. trichiura	Kroo Bay	170	999	3.3802*	0.126	0.7953
A. lumbricoides	Rowollon	90	10040	2.4547*	0.146	0.5230
Hookworm	Rowollon	287	2949	4.5879*	0.121	0.4852
T. trichiura	Rowollon	230	311	4.0036*	0.100	1.4517*
A. lumbricoides	Foria	131	14711	2.9401*	0.099	0.5070
Hookworm	Foria	278	2269.7	4.5423*	0.151	0.9564
S. mansoni	Foria	58	565.9	2.1548*	0.165	0.9333

* Values that indicated the distributions being tested were significantly different ($p \leq 0.05$) from normal.

Figure 3.1. Map of Kroo Bay, with targeted households numbered. The wide black line divides areas 1 and 2. Houses in area 1 were mostly made from corrugated tin, those in area 2 from more robust materials.

FIGURE 3.1. KROO BAY

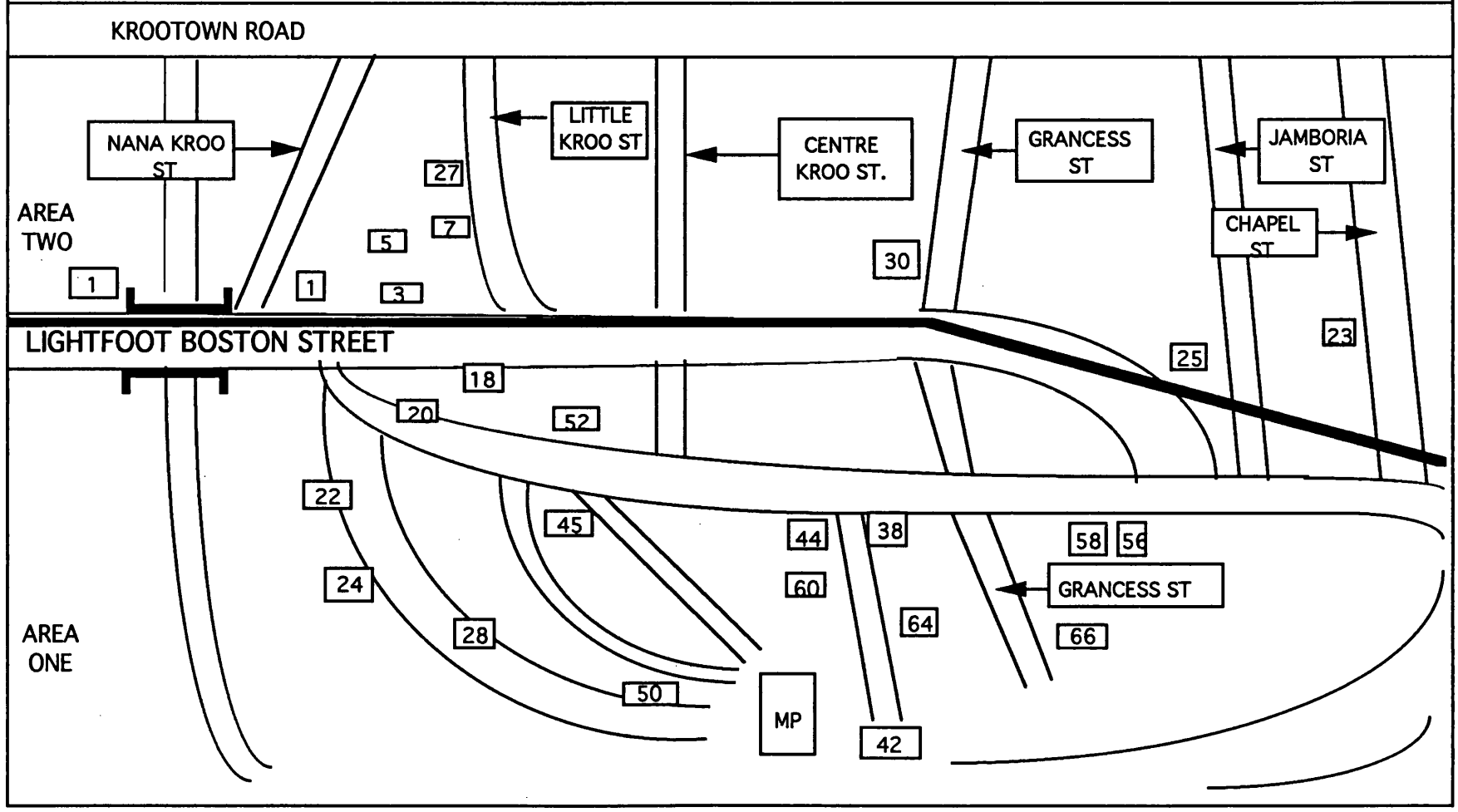


Figure 3.2. Map of Rowollon with households numbered. The wide black line divides the community into area 1 and area 2. The houses in area 1 appeared to be older but were made of better materials (concrete walls) than the houses in area 2 (earthen walls). Area 1 was closer to the river and the swamps.

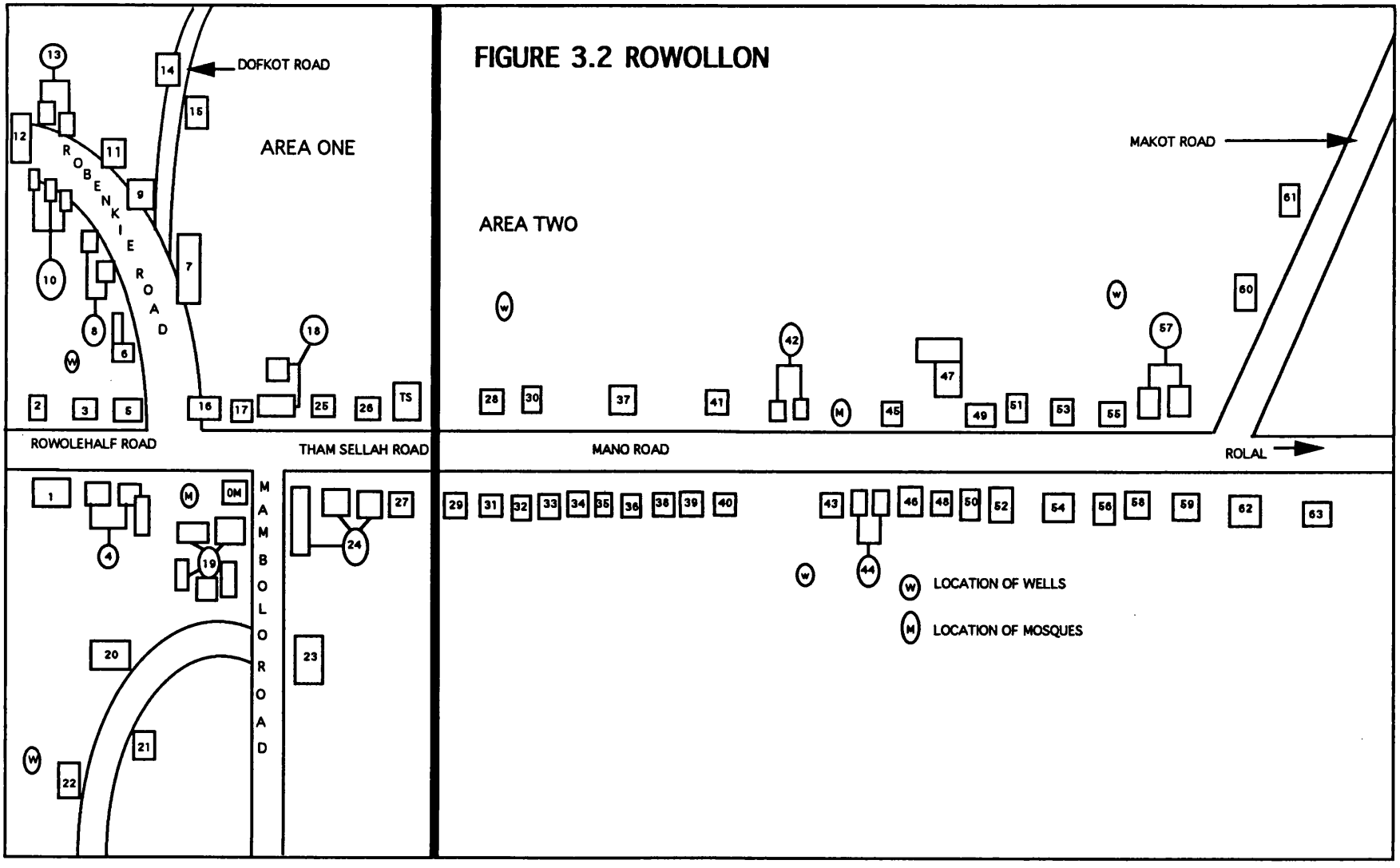


FIGURE 3.2 ROWOLLON
AREA ONE
AREA TWO
DOFKOT ROAD
MAKOT ROAD
ROBENKIE ROAD
MAMBOLO ROAD
ROWOLEHALF ROAD
THAM SELLAH ROAD
MANO ROAD
ROLAL
LOCATION OF WELLS
LOCATION OF MOSQUES

Figure 3.3. Map of Foria with targeted households numbered. Houses in area 1 appeared to be older than those in area 2.

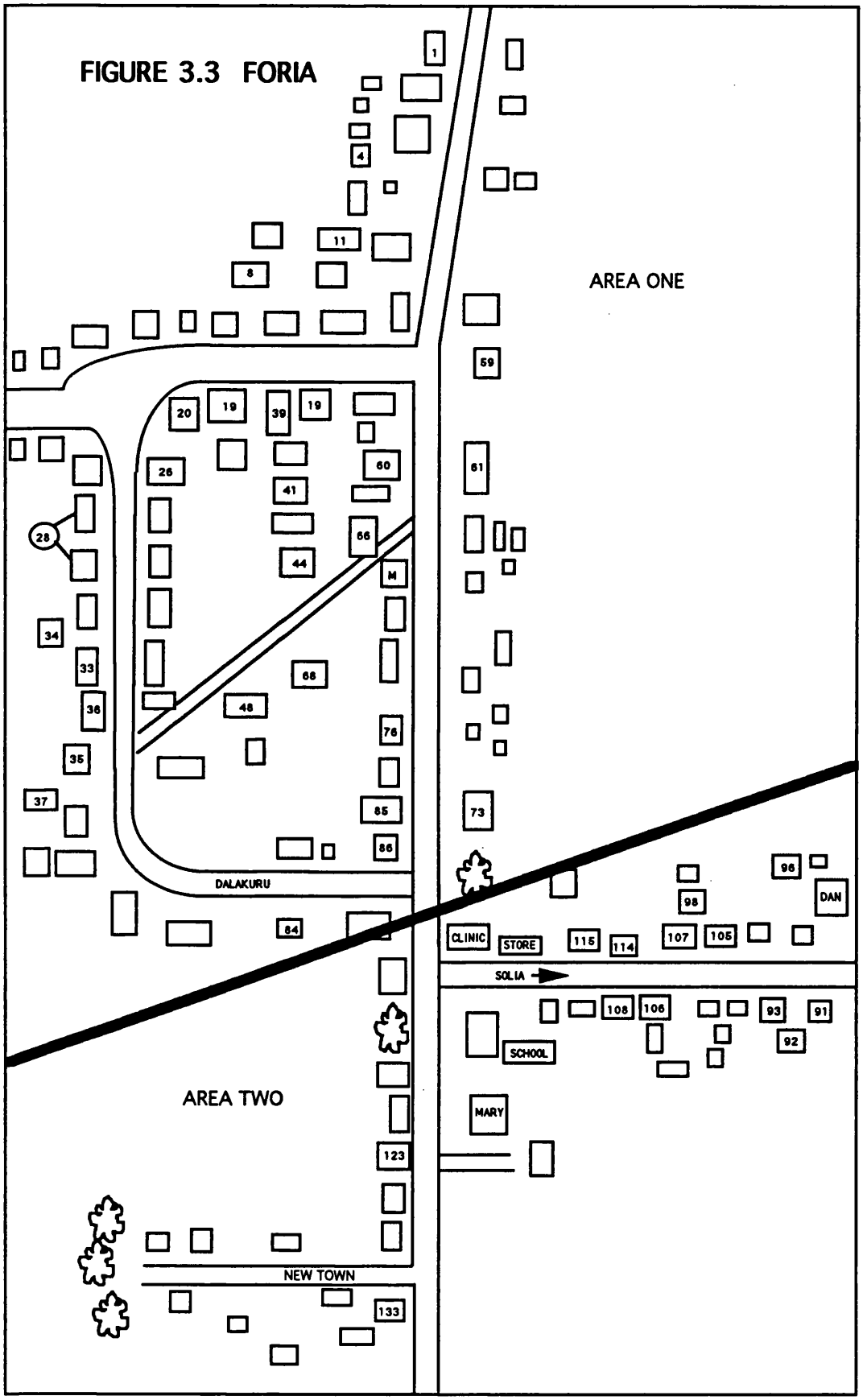


FIGURE 3.3 FORIA
AREA ONE
AREA TWO
DALAKURU
NEW TOWN
SOLIA
CLINIC
STORE
SCHOOL
MARY
DAN
1
4
11
8
59
20
19
39
19
26
60
41
61
28
66
44
M
34
33
68
36
48
76
35
37
65
73
86
64
96
98
115
114
107
105
108
106
93
91
92
123
133

Chapter Four. Basic Epidemiological Analyses of Infections with Gastrointestinal Helminths in Three Communities in Sierra Leone.

4.1. Introduction

Analysis was undertaken of the results of the surveys in the three communities, Kroo Bay, Rowollon and Foria according to sex of individuals, age of individuals, areas houses were located in and size of the household in which an individual lived (i.e. number of other individuals sharing the house). Results are presented in the following sections for straightforward analysis of differences between groups, without taking into account the influence of other factors on prevalence and intensity of helminths, except for analysis of the dual effects of sex of host and age of host on intensity, when it was possible to analyse both.

4.2. Methods

Statistical investigation was undertaken using SPSS/PC+ for DOS and SPSS for Windows, release 5.02. Prevalence was examined using Chi-square analysis with presentation of the results as numbers in each category and as the expected values if infected individuals were distributed evenly throughout all categories being analysed. Association of infections was investigated using Chi-square analysis. Intensity was studied using base ten logarithms of the eggs per gram faeces values, with exclusion of the individuals found to be uninfected for the helminth infection at the time of the survey. This procedure allowed parametric analysis to be carried out after confirming that the groups being analysed did not violate assumptions regarding equality of variances and normality. Consequently t-tests and analysis of variances, either one-way or two-way anova where used for analysis of sex, age, location of house and size of household of host in regards to intensity of infection. If the data violated the assumptions of equality of variances, the median test was used for determining if there were differences in the overall distributions between groups (Sprent, 1993). Correlation between intensities of different helminth infections was investigated using Spearman rank correlation.

4.3. Results

Results are presented as follows: First, the prevalence and intensity of helminth infection between the different communities are compared. Secondly, the prevalences are investigated with regard to sex of host, age (classed as in Section 3.2.3a), areas of houses within a community (see Figures 3.1, 3.2 and 3.3) and according to the number of individuals within a household (Section 3.2.3c). Thirdly, the association of prevalence of the different helminth infections is then described. Fourthly, the effect of concurrent infections on the intensity of helminth infections is presented

Finally, the differences in intensity due to the preceding factors are reported. The effects of sex of host and age of host are analysed using a two-way analysis of variance. Appendix II contains all the Chi-square tables that were found to be significant ($P \leq 0.05$) and the values needed for distinguishing differences for multiple means tests of intensity data. The results of tests for equality of variance in the intensity analysis are also presented in Appendix II.

4.4. Comparisons between communities.

Information on the prevalence of each of the helminths in each of the communities is given in Table 4.1. where 95% Bonferoni confidence intervals are also shown. The back transformed intensities (EPG) and the 95% confidence intervals are given for each community in Table 4.2.

4.4.1. Prevalence of infections

Differences between the prevalence of the major helminths in each community were investigated using a Chi-square analysis. Results for each of the helminth infections investigated are presented in Table 4.3. Chi-square tables for each of the infections are presented in Tables 1 through 5 in Appendix II. Chi-square tables were collapsed and ordered by the percentage of helminth infection present. Communities which had the most similar prevalences were compared to one another first. If they were found to be significantly different, the remaining community was compared to the community which had the prevalence that fell closest to it's prevalence. If the first two communities were not statistically different in their prevalences, they were combined and compared to the remaining community. Results of this analysis are presented in Table 4.4.

Table 4.3. Chi-square values for comparisons of prevalence of the different helminth infections

Helminth Infection	Chi-square Value*	P
A. lumbricoides	13.64†	$P \leq 0.01$
Hookworm	189.91†	$P \leq 0.01$
T. trichiura	376.77†	$P \leq 0.01$
S. mansoni	55.09†	$P \leq 0.01$
S. stercoralis	10.19†	$P \leq 0.01$

* The degrees of freedom for each of the comparisons is 2, except for *S. mansoni* infections where there is one degree of freedom..

† Indicates where comparisons were found to be significantly different at $P \leq 0.01$.

All the helminth infections showed significant differences in the prevalence between the communities. *Schistosoma mansoni* infection was only identified in two of the communities, Foria and Rowollon. There was no need to collapse a Chi-square table to determine which community had

the highest prevalence. Individuals living in Foria were seen to have significantly higher prevalences of this infection.

Table 4.4. Comparisons to locate the difference between prevalence by age class.

Helminth Infection	Comparisons	Chi-square Value*	*P*
A. lumbricoides	RW vs. KB	3.10	$P > 0.05$
	RW & KB vs. FR	10.79†	$P \leq 0.01$
Hookworm	RW vs. FR	2.22	$P > 0.05$
	RW & FR vs. KB	186.55†	$P \leq 0.01$
T. trichiura	KB vs. RW	16.60†	$P \leq 0.01$
	RW vs. FR	280.10†	$P \leq 0.01$
S. stercoralis	RW vs. KB	1.16	$P > 0.05$
	RW & KB vs. FR	9.61†	$P \leq 0.01$

* The degrees of freedom for each of the comparisons is 1.

† Indicates where comparisons were found to be significantly different at $P \leq 0.01$.

Rowollon and Kroo Bay were compared first for *A. lumbricoides* infections, as they differed least in helminth prevalence. They were shown not to be significantly different and so were combined and compared with the value from Foria. A significant difference was found between the prevalence of *A. lumbricoides* in Foria and its prevalence in Rowollon and Kroo Bay (Table 4.4), indicating that there was more *A. lumbricoides* infection found in Foria than in the other two communities.

Hookworm infection showed a significant difference among the three communities (Table 4.3). The Chi-square table was collapsed to determine where the differences lay. The communities were ordered in increasing prevalence of hookworm infection, Kroo Bay had the lowest prevalence followed by Foria and then Rowollon. Rowollon and Foria had prevalence close to one another and on comparison (Table 4.4) they were found not to be significantly different. They were combined and compared with Kroo Bay, which was found to be significantly different from the other two. There was evidence of significantly more hookworm infection in Rowollon and Foria, which were the rural communities under investigation.

The prevalence of *Trichuris trichiura* showed a significant difference among the three communities (Table 4.3). The Chi-square table was collapsed, as before, to determine where the differences lay. The communities were ordered by the prevalence of *T. trichiura*, Foria, Rowollon, and Kroo Bay. Kroo Bay and Rowollon had close prevalence values and so were compared first. They were found to be significantly different as regards the prevalence of *T. trichiura* (Table 4.4).

Rowollon was then compared to Foria and these two communities were found to be significantly different as regards the prevalence of *T. trichiura*.

No *S. mansoni* infections were identified in Kroo Bay. The prevalence of *S. mansoni* differed between the Rowollon and Foria, with significantly more of this parasite being found in Foria (Table 4.3).

The prevalence of *Strongyloides stercoralis* was found to be significantly different between the three communities (Table 4.3). The communities were ordered by prevalence of *S. stercoralis*, Rowollon, Kroo Bay, and Foria. Rowollon and Kroo Bay were compared first, as they were closest in prevalence, and found not to be significantly different (Table 4.4). They were combined and compared to Foria, where they were found to be significantly different.

4.4.2. Numbers uninfected, single, double and triply infected

The prevalence of uninfected, single, double and triple infections differed among the three communities (Chi-square = 228.74, df = 6, $P \leq 0.01$; Table 4.5). It is difficult to collapse a Chi-square table that has greater than two rows (Siegel and Castellan, 1988). The 95% confidence intervals for each of the infections were compared to determine where the differences were in the distribution of uninfected individuals and those infected with one, two and three of the three major helminths at each of the three areas (Table 4.6).

Table 4.5. The prevalence of uninfected, single , double and triple infections in the three communities.

Community	Uninfected (Expected)	Single (Expected)	Double (Expected)	Triple (Expected)	Totals
Kroo Bay	76 (55.30)	186 (86.62)	75 (101.34)	21 (17.74)	261
Rowollon	117 (86.44)	104 (135.41)	146 (158.42)	64 (27.73)	408
Foria	100 (80.29)	169 (125.79)	130 (147.16)	9 (25.76)	379
Totals	293	459	537	94	1383

The 95% confidence intervals can be used to help determine where the significant differences lie. From these it appears than the three communities do not differ in regard to the percentage of the population that are uninfected. Foria appears to have more individuals with single infections than Rowollon but Kroo Bay does not differ from the other two communities in this respect. No significant differences were apparent in the three communities in regards to the prevalence of double infections,

but at Rowollon there were more people with triple infections than at Foria, with Kroo Bay having an intermediate percentage of triple infections.

Table 4.6. The prevalence and 95% confidence intervals of uninfected, single, double and triple infections in the three communities.

Community	Uninfected	Single	Double	Triple
Kroo Bay	29.12 (22.4 - 35.9)	34.10 (27.1 - 41.1)	28.74 (22.0 - 35.4)	8.05 (4.0 - 12.1)
Rowollon	28.68 (23.3 - 34.0	25.49 (20.3 - 30.7)	35.78 (30.1 - 41.5)	15.69 (11.4 - 20.0)
Foria	26.39 (21.0 - 31.8)	44.91 (38.1 - 50.3)	34.30 (28.5 - 40.1)	2.37 (0.5 - 4.2)

4.4.3. Intensity

Differences between mean intensities in the three communities were investigated using one-way analysis of variance, a median test, and a t-test. Results are presented in Table 4.7. Levene's tests were used to determine if the variances of the groups being compared were statistically different and whether a median test should be used (see Table 6, Appendix II). When significant differences were found in one-way Anovas, a least significant test was used to determine which means were different from one another.

Table 4.7. Intensity of helminth infections between communities.

Helminth	Test Statistic	Degrees of Freedom	*P*
A. lumbricoides	F = 5.0392	df = 2, 317	$P \leq 0.007$
Hookworm	F = 14.555	df = 2, 646	$P \leq 0.0001$
T. trichiura	Chi-square = 41.71	df = 1	$P \leq 0.01$
S. mansoni	t = -0.59	df = 59	$P \leq 0.557$
S. stercoralis	F = 0.2024	df = 2, 16	$P \leq 0.8189$

* Significantly different at $P \leq 0.05$.

A significant difference was seen between the three communities in the intensity (EPG) of *A. lumbricoides*. Least significant difference tests for unequally replicated means were used to determine where the differences lay. Table 4.8 presents the results of these tests and indicates that the difference lay between the intensity of the infections (EPG) in Rowollon and Foria with Foria having significantly higher intensities of infection, and that the intensities in the other comparisons were not significantly different from one another at the $P \leq 0.05$ level. Values needed for significant differences are displayed in Table 7, Appendix II.

Table 4.8. Comparisons between means of *A. lumbricoides* intensity in the different communities.

	Communities		
Communities	Kroo Bay	Rowollon	Foria
Kroo Bay	-	0.1157	0.1566
Rowollon		-	0.2723*
Foria			-

*Means that were found to be significantly different ($P \leq 0.05$).

The three communities were seen to be significantly different in their intensities (EPG) of hookworm. The three means were compared using least significant difference tests and the results are presented in Table 4.9. All the comparisons showed significant differences in the mean intensities, with Rowollon having the highest mean intensity, followed by Foria and then Kroo Bay.

Table 4.9. Comparisons between means of hookworm intensity in the different communities.

	Communities		
Communities	Kroo Bay	Rowollon	Foria
Kroo Bay	-	0.3886*	0.2397*
Rowollon		-	0.1489*
Foria			-

*Means that were found to be significantly different ($P \leq 0.05$).

The five infected individuals from Foria were not included in the test for differences in the intensity of *T. trichiura* between the three communities, because the sample sizes between the three communities were highly different. A median test was undertaken on the intensity of *T. trichiura* in Kroo Bay and Rowollon, as Levene's test for homogeneity of variances indicated that there was a significant difference in the variances in the two communities (Table 6, Appendix II). This indicated that the two communities were significantly different in the numbers of individuals that had intensities above and below the overall median of 130 eggs per gram for *T. trichiura.* Table 4.10 displays the results of the median test and indicates that Kroo Bay had more intense infections of *T. trichiura* than did Rowollon (Table 4.2.).

Table 4.10. Results of a median test on intensity (EPG) of *T. trichiura* in Kroo Bay and Rowollon.

	Kroo Bay	Rowollon
> Median	117	82
< Median	53	48

The mean intensity of *S. mansoni* infections in Foria and Rowollon were compared using a t-test and were found to be not significantly different (Table 4.7). The intensity (larva per gram faeces)

of *S. stercoralis* was compared and found not to be significantly different between the three communities (Table 4.7).

4.5. Overall Values by Categorical Variables in All the Communities

The prevalence (%) of the three major helminths in all three communities, by sex, by area within a community, by age class and by size of household is given in Table 4.1, together with the appropriate 95% confidence intervals. The back transformed mean intensities (EPG) and the 95% confidence intervals for the means are given in Table 4.2, again overall for a community and also by the categorical variables of sex, area within a community, size of household and age of individual. Differences between categorical variables within a community are investigated and discussed in the following sections. The number of samples analysed and the number found to be infected are presented in Table 4.11 for the three major helminth infections in the communities.

The prevalence and mean intensity of the less common helminths in a community are given in Table 4.12 and Table 4.13, respectively. The number of individuals found to be infected with the less common helminths, as well as the total number of samples analysed, are presented in Table 4.14. The numbers of single, double and triple infections are presented in Table 4.15 for Kroo Bay, Table 4.16 for Rowollon and Table 4.17 for Foria. Information on the individuals not used in the analysis because the results differed significantly from the randomly chosen targeted individuals is displayed in Table 4.18 for prevalence and in Table 4.19 for intensity. These tables include data on all helminth infections for individuals living outside Kroo Bay and the *T. trichiura* data for those within Kroo Bay, but not in targeted households, *A. lumbricoides* and hookworm data for those in Rowollon in age class 2 not in randomly chosen households and *A. lumbricoides* data for those individuals in Foria in age class 1 and not in randomly chosen households. The number of individuals found to be positive for each helminth infection and the total number of samples examined are presented in Table 4.20.

4.5.1. Prevalence of Helminth Infections by Sex

The results of Chi-square analysis on differences in prevalence of helminth infections by sex of individual are presented in Table 4.21. No significant differences were found between prevalence for *A. lumbricoides* and hookworm in Kroo Bay, Rowollon or Foria. No significant differences were found for the prevalence by sex of *T. trichiura* infections in Kroo Bay or Rowollon or for *S. mansoni* in Foria (Table 4.21).

Table 4.21. Chi-square values of analysis of prevalence by sex.

Community	Helminth Infections	Chi-square Value*
Kroo Bay	*A. lumbricoides*	2.43
Kroo Bay	Hookworm	0.01
Kroo Bay	*T. trichiura*	0.09
Rowollon	*A. lumbricoides*	0.60
Rowollon	Hookworm	0.01
Rowollon	*T. trichiura*	2.30
Foria	*A. lumbricoides*	0.02
Foria	Hookworm	1.71
Foria	*S. mansoni*	0.99

* The degrees of freedom is one for all comparisons and $P > 0.05$.

An individual's sex was not found to influence the possibility of becoming infected with any of the three most common helminths found in the three communities studied.

4.5.2. Prevalence of Helminth Infections by Age Class

Differences in the prevalence of helminth infections in the different age classes were examined using Chi-square analysis (Table 4.22). The Chi-square tables for the results reported in Table 4.22 are presented in Tables 9 through 17 in Appendix II.

Table 4.22. Chi-square values for comparisons of prevalence by age class.

Helminth and Community	Chi-square Value*	*P*
A. lumbricoides in Kroo Bay	11.49†	$P \leq 0.05$
A. lumbricoides in Rowollon	17.77†	$P \leq 0.05$
A. lumbricoides in Foria	8.32	$P > 0.05$
Hookworm in Kroo Bay	26.38‡	$P \leq 0.01$
Hookworm in Rowollon	118.88‡	$P \leq 0.01$
Hookworm in Foria	121.42‡	$P \leq 0.01$
T. trichiura in Kroo Bay	30.36‡	$P \leq 0.01$
T. trichiura in Rowollon	84.08‡	$P \leq 0.01$
S. mansoni in Foria	22.64‡	$P \leq 0.01$

* The degrees of freedom for each of the comparisons is 4.
† Indicates where comparisons were found to be significantly different at $P \leq 0.05$.
‡ Indicates where comparisons were found to be significantly different at $P \leq 0.01$

If the Chi-square value was found to be significant, the Chi-square tables were collapsed by ordering the age classes in ascending order of the prevalence the helminth infection under investigation. Chi-square values were calculated to compare the first and second age class in the ordered sequence. If they were found to be significantly different ($P \leq 0.05$), the second one was compared to the third ordered age class and so on. If they were found not to differ significantly, they were combined and compared to the third ordered age class. This continued until the last age class, with the highest prevalence, was reached. The results of this analysis are presented in Table 4.23.

4.5.2a. *Ascaris lumbricoides*

Differences were seen in the prevalence of *A. lumbricoides* in the different age classes in Kroo Bay and Rowollon but not in Foria (see Table 4.22 for Chi-square values). When the Chi-square tables were collapsed for the Kroo Bay data (Table 4.23), age classes 2 and 3 were seen to have significantly higher prevalence than the other age classes. In Rowollon, age class 2 was seen to have a significantly higher prevalence of *A. lumbricoides* than the other age classes.

4.5.2b. Hookworm

The Chi-square analysis of all the prevalences indicated significant differences in the three communities with regard to hookworm infection in the different age classes (Table 4.22). When the Chi-square tables were collapsed (Table 4.23) individuals in each of the communities were shown to have similar prevalence by age class, with children in age class 1 in all of the communities having a significantly lower prevalence of hookworm infection. The other age classes were indistinguishable from one another in their prevalence.

4.5.2c. *Trichuris trichiura*

Chi-square analysis of *T. trichiura* prevalence by age revealed significant differences in prevalence in the two communities for which this was studied (Table 4.22). After collapse of the Chi-square table for Kroo Bay, it could be seen that age class 1 had significantly fewer infections of *T. trichiura* than the other age classes (Table 4.23). In Rowollon, not only did age class 1 have significantly fewer infections of *T. trichiura* but age class 3 was seen to have a significantly higher number of infections than age class 4, 5 and 2 (Table 4.23).

4.5.2d. *Schistosoma mansoni*

Chi-square analysis of *S. mansoni* prevalence by age revealed a significant differences in prevalence (see Table 4.22). The Chi-square table was collapsed and age classes 1, 2 and 5 were seen to have significantly lower prevalence of infection with *S. mansoni* than age classes 3 and 4.

4.5.3. Prevalence of Helminth Infections by Area

Area of households within the community was investigated to determine if this had any influence on the prevalence of helminth infections. Areas for each community were defined in Chapter Three (see Figures 3.1 to 3.3). No significant differences were seen between the different

areas in any of the three communities as regards the prevalence of any of the helminth infections investigated. Chi-square values from this analysis are presented in Table 4.24.

Table 4.24. Chi-square values of analysis of prevalence by area.

Community	Helminth Infections	Chi-square Value*
Kroo Bay	*A. lumbricoides*	0.74
Kroo Bay	Hookworm	1.53
Kroo Bay	*T. trichiura*	0.68
Rowollon	*A. lumbricoides*	0.31
Rowollon	Hookworm	1.99
Rowollon	*T. trichiura*	1.23
Foria	*A. lumbricoides*	0.82
Foria	Hookworm	0.36
Foria	*S. mansoni*	0.25

* The degrees of freedom is one for all comparisons and $P > 0.05$.

Areas were based on quality of houses and density of houses to one another. From this analysis, it appears that these factors have no influence on the prevalences of helminth infections.

4.5.4. Prevalence of Helminth Infections by Household Size

The only significant difference found in prevalence of helminth infections between the different categories of household size was that of *S. mansoni* in Foria. The prevalences of all the other helminth infections studied did not show significant differences, based on differences in household size in any of the communities studied. The results of the Chi-square analysis are presented in Table 4.25.

Table 4.25. Chi-square values of analysis of prevalence by household size.

Community	Helminth Infections	Chi-square Value*
Kroo Bay	*A. lumbricoides*	2.03
Kroo Bay	Hookworm	1.12
Kroo Bay	*T. trichiura*	2.09
Rowollon	*A. lumbricoides*	3.47
Rowollon	Hookworm	4.02
Rowollon	*T. trichiura*	1.12
Foria	*A. lumbricoides*	1.69
Foria	Hookworm	1.47
Foria	*S. mansoni*	7.50‡

* The degrees of freedom is one for all comparisons.

‡ Significant differences at $P \leq 0.05$.

A significant difference was detected in the prevalence of *S. mansoni* (Chi-square = 7.50, df = 2, $P \leq 0.05$) in households of different sizes. The Chi-square table for this is presented in Table 18, Appendix II. The categories of household size were ordered in increasing prevalence of *S. mansoni*,

the Chi-square table was collapsed and the results of the comparisons are displayed in Table 4.26. Households of smaller size were shown to have a significantly higher prevalence of *S. mansoni* than households of larger size.

Table 4.26. Comparisons of *S. mansoni* prevalence between the different households size in Foria.

Helminth	Comparisons	Chi-square Values*	*P*
S. mansoni	2 vs. 3	0.63	$P > 0.05$
	2 & 3 vs. 1	7.00†	$P \leq 0.01$

* There is one degree of freedom for each comparison.

† Significantly different $P \leq 0.01$.

4.5.5. Co-occurrence of Helminth Infections

The prevalences of the various helminth infections were investigated to determine if combinations of infections were more or less likely to occur together than would be expected by chance alone. Infections which occur together more often than would be expected by chance alone might indicate similar processes in transmission, or susceptibility while those which occur together less often than would be expected by chance might indicate differences in these processes. This aspect was investigated using Chi-square analysis and the results are presented in Table 4.27.

Table 4.27. Chi-square values for co-occurrence of helminths.

Helminths	Communities	Chi-square Values*	*P*
A. lumbricoides and Hookworm	Kroo Bay	13.51†	$P \leq 0.01$
	Rowollon	18.66†	$P \leq 0.01$
	Foria	8.23†	$P \leq 0.01$
A. lumbricoides and *T. trichiura*	Kroo Bay	13.86†	$P \leq 0.01$
	Rowollon	31.64†	$P \leq 0.01$
A. lumbricoides and *S. mansoni*	Foria	7.62†	$P \leq 0.01$
Hookworm and *T. trichiura*	Kroo Bay	21.96†	$P \leq 0.01$
	Rowollon	125.21†	$P \leq 0.01$
Hookworm and *S. mansoni*	Foria	4.44‡	$P \leq 0.05$

* The degrees of freedom is one for all comparisons.

† Significant at $P \leq 0.01$.

‡ Significant differences, $P \leq 0.05$.

The differences between observed and expected values must be examined in order to determine if the helminth infections are occurring together more or less often than would be expected by chance alone. This is done by reference to the Chi-square tables which are presented in Table 19 through 28 in Appendix II. These results indicated that all the species occurred together more often than would be expected by chance alone, except for *A. lumbricoides* and *S. mansoni* in Foria. In this

case, it appears that those individuals who are infected with one of these species are unlikely to be infected with the other.

4.5.6. Intensity of Helminth Infections by Concurrent Infections

Concurrent infections were common and numbers of each are presented in Tables 4.1, 4.16 and 4.17. Intensity of infection was investigated in relation not only to the type of infection, but also in relation to the presence of either single, double, or triple infections to determine if higher intensities are associated with concurrent infections. The double infections were lumped together and intensities were subjected to an analysis of variance (Levene's tests for differences in variances are presented in Table 29, Appendix II). Results of these tests are presented in Table 4.28. The back transformed means and 95 % confidence intervals, as well as the number in each group, are presented in Table 4.29. When significant differences were found in the analysis of all the groups, a least significant test for unequally replicated means was used to determine where the differences were to be found. The means were determined to be different if the difference between them exceeded the value calculated for significance at $P \leq 0.05$. The calculated values for significant differences are presented in Tables 30 to 34, Appendix II.

No significant differences were seen in individuals living in Foria, infected with *A. lumbricoides*, hookworm or *S. mansoni*, or in individuals, living in Kroo Bay infected with hookworm. Significant differences were seen in the remainder of the infections and they are compared in Tables 4.30 to 4.34.

Table 4.28. Intensity of helminth infections by concurrent infections.

Helminth and Community	F Value	Degrees of Freedom	*P*
A. lumbricoides in Kroo Bay	8.55*	2,96	$P \leq 0.0004$
A. lumbricoides in Rowollon	4.08*	2,87	$P \leq 0.0202$
A. lumbricoides in Foria	0.50	2,128	$P \leq 0.6093$
Hookworm in Kroo Bay	0.05	2,81	$P \leq 0.9534$
Hookworm in Rowollon	14.69*	2,284	$P \leq 0.0001$
Hookworm in Foria	1.23	2,266	$P \leq 0.2933$
T. trichiura in Kroo Bay	5.10*	2,167	$P \leq 0.0071$
T. trichiura in Rowollon	4.67*	2,206	$P \leq 0.0104$
S. mansoni in Foria	0.25	2,53	$P \leq 0.7763$

* Significantly different at $P \leq 0.05$.

Differences were found to be significant between single versus double infections and between single infections versus triple infections in *A. lumbricoides* infections in people living in Kroo Bay (Table 4.30).

Table 4.30. Comparisons between means of *A. lumbricoides* intensity in single, double and triple infections in Kroo Bay.

	Infections		
Infections	Single	Double	Triple
Single	-	0.6511*	0.8389*
Double		-	0.1878
Triple			-

*Means that were found to be significantly different ($P \leq 0.05$).

People infected with only *A. lumbricoides* were found to have less intense infections than those infected with one or two other helminths. Double and triple infections were found not to be significantly different.

In those individuals infected with *A. lumbricoides* in Rowollon, the intensity was found to be significantly different between single and triple infections (Table 4.31), with single infections of *A. lumbricoides* being less intense than infections of *A. lumbricoides* when it occurred with two other of the most common species of helminth present in Kroo Bay. However, the single and double infections and the double and triple infections were not significantly different from one another.

Table 4.31. Comparisons between means of *A. lumbricoides* intensity in single, double and triple infections in Rowollon.

	Infections		
Infections	Single	Double	Triple
Single	-	0.0862	0.4917*
Double		-	0.3553
Triple			-

*Means that were found to be significantly different ($P \leq 0.05$).

In people infected with hookworm in Rowollon, all three means, single, double and triple, were seen to differ significantly from one another. Individuals with all three infections were found to have the highest intensities of hookworm infections (Table 4.32). Those found to harbour two helminth infections had the next highest intensities and people found to have only hookworm infections had the lowest intensities.

Table 4.32. Comparisons between means of hookworm intensity in single, double and triple infections in Rowollon.

	Infections		
Infections	Single	Double	Triple
Single	-	0.2566*	0.4897*
Double		-	0.2331*
Triple			-

* Means which were found to be significantly different ($P \leq 0.05$).

In the people infected with *T. trichiura* in Kroo Bay, those found to be infected with only *T. trichiura* or with *T. trichiura* and hookworm or *A. lumbricoides* did not have significantly different intensities of infection (Table 4.33). Those individuals infected with all three helminths were seen to have the highest infections.

Table 4.33. Comparisons between means of *T. trichiura* intensity in single, double and triple infections in Kroo Bay.

	Infections		
Infections	Single	Double	Triple
Single	-	0.1289	0.4117*
Double		-	0.2828*
Triple			-

* Means which were found to be significantly different ($P \leq 0.05$).

A similar result was found in those people infected with *T. trichiura* in Rowollon (Table 4.34).

Table 4.34. Comparisons between means of *T. trichiura* intensity in single, double and triple infections in Rowollon.

	Infections		
Infections	Single	Double	Triple
Single	-	0.0769	0.2630*
Double		-	0.1861*
Triple			-

* Means which were found to be significantly different ($P \leq 0.05$).

4.5.7. Intensity of Helminth Infections by Sex

Differences between intensities of *Ascaris lumbricoides*, hookworm, *S. mansoni* and *T. trichiura* infection due to host sex were investigated by use of t-tests (Levene's test results are presented in Table 35, Appendix II). The results are presented in Table 4.35. The only significant difference seen in intensity of helminth infections with regard to host sex was seen in those people found to be infected with hookworm in Rowollon.

Table 4.35. Intensity of helminth infections by sex of host.

Helminth and Community	t Value	Degrees of Freedom	*P*
A. lumbricoides in Kroo Bay	1.22	97	$P \leq 0.224$
A. lumbricoides in Rowollon	1.17	88	$P \leq 0.091$
A. lumbricoides in Foria	-0.46	129	$P \leq 0.645$
Hookworm in Kroo Bay	-1.52	82	$P \leq 0.131$
Hookworm in Rowollon	-3.12*	285	$P \leq 0.002$
Hookworm in Foria	-0.98	276	$P \leq 0.328$
T. trichiura in Kroo Bay	0.55	168	$P \leq 0.586$
T. trichiura in Rowollon	1.57	228	$P \leq 0.117$
S. mansoni in Foria	-0.26	56	$P \leq 0.800$

* Significantly different at $P \leq 0.05$.

Back-transformed means and 95 % confidence intervals from males and females infected with hookworm in Rowollon are presented in Table 4.36, indicating that males were found to have more intense infections of hookworm.

Table 4.36. Means and 95% confidence intervals of hookworm intensity by sex of host in Rowollon.

	Number Infected	Mean* (95% Confidence Intervals)
Female	172	411.2 (336-503)
Male	115	668.8 (568-840)

* Back transformed from transformed results.

4.5.8. Intensity of Helminth Infections by Age Class

One-way analysis of variance was used to investigate the relationship of *A. lumbricoides*, hookworm and *T. trichiura* intensity with the age of the host (Table 4.37). The results of Levene's tests for similarities in variances are presented in Table 36, Appendix II.

Table 4.37. Intensity of helminth infections by age of host.

Helminth and Community	F Value	Degrees of Freedom	*P*
A. lumbricoides in Kroo Bay	3.08	4,94	$P \leq 0.020$
A. lumbricoides in Rowollon	0.81	4,85	$P \leq 0.522$
A. lumbricoides in Foria	2.41	4,126	$P \leq 0.053$
Hookworm in Kroo Bay	1.20	4,79	$P \leq 0.320$
Hookworm in Rowollon	2.70*	4,282	$P \leq 0.032$
Hookworm in Foria	6.24	4,273	$P \leq 0.001$
T. trichiura in Kroo Bay	2.46*	4,165	$P \leq 0.047$
T. trichiura in Rowollon	2.18	4,225	$P \leq 0.073$
S. mansoni in Foria	0.35	4,53	$P \leq 0.845$

* Significantly different at $P \leq 0.05$.

Significant differences were found in *A. lumbricoides* infections in Kroo Bay, in hookworm infection in Rowollon and Foria and in *T. trichiura* infections in Kroo Bay. When significant

differences were found in the analysis of variance, least significant tests for unequally replicated means were used to determine where the differences were located. The values needed to establish significant differences ($P \leq 0.05$) are presented in Tables 37 through 40, Appendix II. The differences between means, with indication of which are significantly different from one another, are presented in Tables 4.38 to 4.41.

For people living in Kroo Bay, significant differences were seen between the mean intensity of *A. lumbricoides* infections in those individuals in age class 1 and those in age classes 3 and 5 (Table 4.38). The individuals infected with *A. lumbricoides* in age class 1 were seen to have less intense infections than those people in age class 3 and 5. No other means were found to be significantly different.

Table 4.38. Comparisons between means of *A. lumbricoides* intensity in the different age classes in Kroo Bay.

	Age Classes				
Age Class	One	Two	Three	Four	Five
One	-	0.35	0.66*	0.28	0.48*
Two		-	0.31	0.08	0.13
Three			-	0.38	0.18
Four				-	0.21
Five					-

* Means which were found to be significantly different ($P \leq 0.05$).

Significant differences were found between the mean intensities of those in age class 1 and those in age classes 2, 3 and 5 of people living in Rowollon, found to be infected with hookworm (Table 4.39).

Table 4.39. Comparisons between means of hookworm intensity in the different age classes in Rowollon.

	Age Classes				
Age Class	One	Two	Three	Four	Five
One	-	0.24*	0.30*	0.20	0.29*
Two		-	0.06	0.04	0.03
Three			-	0.10	0.01
Four				-	0.09
Five					-

* Means which were found to be significantly different ($P \leq 0.05$).

People under five yr of age who were infected with hookworm had significantly lower mean intensities of hookworm infection than those in age class 2, 3 and 5. In Foria (Table 4.40) a similar

result was seen except all of the other age classes, 2 to 5, were seen to differ significantly from age class 1.

Table 4.40. Comparisons between means of hookworm intensity in the different age classes in Foria.

	Age Classes				
Age Class	One	Two	Three	Four	Five
One	-	0.39*	0.56*	0.63*	0.55*
Two		-	0.17	0.24*	0.16
Three			-	0.07	0.01
Four				-	0.08
Five					-

* Means which were found to be significantly different ($P \leq 0.05$).

Children under five yr of age were seen to have the lowest mean intensities of hookworm. In addition, individuals in age class 2 was seen to have significantly lower mean intensities than individuals in age class 4.

In people infected with *T. trichiura* in Kroo Bay, individuals in age class 1, 4 and 5 were seen to have significantly lower mean intensities than children in age class 2 (Table 4.41).

Table 4.41. Comparisons between means of *T. trichiura* intensity in the different age classes in Kroo Bay.

	Age Classes				
Age Class	One	Two	Three	Four	Five
One	-	0.25*	0.12	0.10	0.04
Two		-	0.14	0.36*	0.30*
Three			-	0.22	0.16
Four				-	0.06
Five					-

* Means which were found to be significantly different ($P \leq 0.05$).

The mean intensity of *T. trichiura* infection of those in age class 3 did not differ significantly from either those in age class 2 or those of the other group.

4.5.9. Intensity of Helminth Infections by Sex and Age

Interactions between the sex and age of the host in regards to intensity of helminth infection were investigated using a two-way analysis of variance. (Cochran's and Bartlett's tests for homogeneity of variances were carried out and results are presented in Tables 41 and 42 respectively in Appendix II). If the interaction between sex and age of host was found to be significant, the effects of age and sex alone could not be investigated. If the interaction was not significant, the effects of sex and age of host alone could be investigated. Results of these analyses are presented in Table 4.42.

Individuals infected with *S. mansoni* in Foria were not included in this analysis as there were not enough males and females infected in all age classes for this to be meaningful. Two-way analysis of variance could not be carried out for people infected with hookworm in Rowollon due to the variance of the groups being significantly different (Table 41 and 42, Appendix II). One-way analysis of variance of the effect of age class on intensity of infection on males and females infected with hookworm separately could not be carried out as significant differences were seen in the variances between groups in this case as well (Table 43, Appendix II). A median test was used to analyse this data.

Significant differences were seen in the effect of age on *A. lumbricoides* and hookworm infections and the age by sex interaction in *T. trichiura* infections in Kroo Bay. In Rowollon, significant differences were seen in both the effect of sex and age on *T. trichiura* intensity. Hookworm intensity was seen to be significantly different due to age of host in Foria.

Table 4.42. Two-way analysis of variance for sex and age of host.

Helminth	Community	Groups	F Value	df	*P*
A. lumbricoides	Kroo Bay	sex	0.70	1,89	$P \leq 0.406$
		age	3.83*	4,89	$P \leq 0.006$
		sex x age	1.23	4,89	$P \leq 0.302$
	Rowollon	sex	1.95	1,80	$P \leq 0.167$
		age	0.65	4,80	$P \leq 0.632$
		sex x age	0.11	4,80	$P \leq 0.979$
	Foria	sex	0.00	1,121	$P \leq 0.980$
		age	2.57*	4,121	$P \leq 0.041$
		sex x age	1.67	4,121	$P \leq 0.162$
Hookworm	Kroo Bay	sex	3.04	1,75	$P \leq 0.085$
		age	2.52*	4,75	$P \leq 0.048$
		sex x age	2.55	3,75	$P \leq 0.062$
	Foria	sex	1.36	1,268	$P \leq 0.244$
		age	6.08*	4,268	$P \leq 0.000$
		sex x age	0.63	4,268	$P \leq 0.643$
T. trichiura	Kroo Bay	sex	2.15	1,160	$P \leq 0.145$
		age	3.95†	4,160	$P \leq 0.004$
		sex x age	2.97*	4,160	$P \leq 0.021$
	Rowollon	sex	6.18*	1,220	$P \leq 0.014$
		age	2.88*	4,220	$P \leq 0.024$
		sex x age	0.62	4,220	$P \leq 0.650$

* Indicates where there were significant differences ($P \leq 0.05$).

† Significant difference in main effect ($P \leq 0.05$), but the interaction term is also significant.

On the finding of significant results ($P \leq 0.05$) in the two-way analysis of variance, *post hoc* contrasts (Steel and Torrie, 1980) were used to determine where the differences were. Scheffe's

correction for tabled F-values was used, as these were *post hoc* comparisons (Tobachnick and Fidell, 1989). The contrasts that were tested were those that were suggested when earlier one-way analysis of variance for age class data had detected significant differences or if t-tests for differences based on sex of host had been significant. Other contrasts tested were those suggested by the means of the different groups. Contrasts are presented in Tables 4.43 to 4.47.

Analysis of the differences between the mean intensities of *A. lumbricoides* in Kroo Bay by host age (Table 4.43) revealed that the differences seen in the one-way analysis of variance between age class 1 and age classes 3 and 5 were also found when analysed using contrasts. Hookworm intensities by age class of host (Table 4.44) were found to be significantly lower in age class 1 than in age classes 2 to 5. The analysis of the interaction of age and sex of host on the intensity of *T. trichiura* infection in females and males showed that both sexes had the highest intensities in individuals in age class 2 and 3 (Table 4.45). However, in males, the intensity of infection in individuals in age class 3 was higher than that of age class 2 and in females the opposite was observed, with individuals in age class 2 having higher intensities than those in age class 3.

In individuals living in Rowollon, contrast analysis of the intensity of *T. trichiura* infection as regards sex of host indicated that females had significantly higher intensities of this helminth than males (Table 4.46). Analysis of intensity of *T. trichiura* by age class indicated that individuals in age class 2 and 3 had significantly higher intensities than individuals in age class 1, 4 and 5.

Hookworm infections in Foria were seen to be significantly lower in individuals of age class 1 than in the other age classes. Age class 2 was also seen to have a higher mean intensity of hookworm than age class 4 (Table 4.47).

A median test was used to analyse the differences between age classes for males and females separately in individuals infected with hookworm in Rowollon (Table 4.48). The median test does not assume that each sample has the same distribution (Sprent, 1993), which is known in this case not to be a valid assumption considering the significant differences in variances shown. This test merely states that one or more of the groups differ in their medians.

Table 4.48. Results of median tests for differences in hookworm intensity between males and females.

Host Sex	Overall Median	Chi-square*	P
Female	400.5	5.76	$P \leq 0.218$
Male	727.0	10.43	$P \leq 0.034$

* Degrees of freedom for each of the tests was four.

No significant difference was found in the median intensity of hookworm in the different age classes in the females infected, but significant differences were found in the male data. Table 4.49 depicts the results of the median test for the male data.

Table 4.49. Frequency less than or greater than the overall median of the hookworm intensity in the different age classes.

	Age Class				
Intensity	ONE	TWO	THREE	FOUR	FIVE
〉MEDIAN	7	12	16	5	17
〈MEDIAN	16	16	9	9	8

Subgroups of two or more samples may be analysed using the median test until the differences have been isolated (Conover, 1980). This sorting out of the samples by repeatedly testing subgroups of the data distorts the true level of significance of all the tests but the first, Conover (1980). In this case, males in age classes 1, 2, and 4 were tested for any differences and males in 3 and 5 were tested for differences, as the above table appeared to indicate that the data fell into these two groups. For the age classes 1, 2 and 4 (Table 4.50), the overall median was 426.6 (EPG), with a Chi-square of 1.0937, df = 2, and $P \leq 0.5788$.

Table 4.50. Frequency less than or greater than the median of the hookworm intensity in age classes 1, 2 and 4.

	Age Class		
Intensity	ONE	TWO	FOUR
〉MEDIAN	9	15	7
〈MEDIAN	14	13	7

For age classes 3 and 5 (Table 4.53), the overall median was 883.1 (EPG), with a Chi-square of 0.00001, df = 1, and $P \leq 1.000$, essentially being indistinguishable from one another.

Table 4.51. Frequency less than or greater than the median of the hookworm intensity in age classes 3 and 5.

	Age Class	
Intensity	THREE	FIVE
〉MEDIAN	12	13
〈MEDIAN	13	12

Adding in either age class 3 or 5 to the median test of differences among 1, 2 and 4 resulted in an overall median of 587.5 (EPG) or 651.6 (EPG) respectively with df = 3 and Chi-squares of 5.5133 and $P \leq 0.1378$ or 7.5419 and $P \leq 0.0565$, neither of which gave a significant result. The medians and inter quartile ranges are presented in Figure 4.1 for intensities of infection in both males and females for the five age classes.

4.5.10. Intensity of Helminth Infections by Area

The influence of the area in which an individual lived on intensity of helminth infection was investigated in most cases using a t-test (Table 4.52). In the case of *T. trichiura* infection in Kroo Bay, a median test was used as a Levene's test of the variances indicated that there were significant differences in the variances between the areas (Results of Levene's tests for all comparisons are presented in Table 44, Appendix II.). This median test indicated that there were no significant differences in the numbers of individuals with intensities above and below the overall median intensity between the two areas (Chi-square = 0.1193, df = 1, $P \leq 0.7298$).

Table 4.52. Intensity of helminth infections by area in which individuals lived.

Helminth and Community	t Value	Degrees of Freedom	*P*
A. lumbricoides in Kroo Bay	2.49*	97	$P \leq 0.014$
A. lumbricoides in Rowollon	-0.16	88	$P \leq 0.873$
A. lumbricoides in Foria	0.73	124	$P \leq 0.465$
Hookworm in Kroo Bay	-1.52	82	$P \leq 0.131$
Hookworm in Rowollon	0.07	285	$P \leq 0.945$
Hookworm in Foria	0.04	260	$P \leq 0.967$
T. trichiura in Rowollon	2.35*	228	$P \leq 0.020$
S. mansoni in Foria	-0.26	56	$P \leq 0.800$

* Significantly different at $P \leq 0.05$.

A significant difference was detected in the intensity of *A. lumbricoides* in Kroo Bay and *T. trichiura* in Rowollon. The means and 95% confidence intervals are displayed in Table 4.53, where it can be seen that individuals in area 1 have higher intensities of *A. lumbricoides* in Kroo Bay and that individuals in area 1 in Rowollon have higher intensities of *T. trichiura*.

Table 4.53. Back transformed means and 95% confidence intervals helminth intensity by area.

Helminth	Area	N	Mean Intensity	95% Confidence Interval
A. lumbricoides in Kroo bay	One	47	2945.8	1921 - 4517
	Two	52	1395.7	914 - 2131
T. trichiura in Rowollon	One	136	105.51	89.4 - 124.5
	Two	94	76.70	61.7 - 95.4

4.5.11. Intensity of Helminth Infections by Household Size

The intensity of the three helminth infections was investigated in regards to the categories of household size using one-way analysis of variance. Levene's tests for equality of variances were undertaken on all the comparisons (Table 45, Appendix II). Results of the analysis of variance are presented in Table 4.54.

Table 4.54. Intensity of helminth infections by categories of household size.

Helminth and Community	F Value	Degrees of Freedom	*P*
A. lumbricoides in Kroo Bay	0.389	2,68	$P \leq 0.679$
A. lumbricoides in Rowollon	1.083	2,87	$P \leq 0.343$
A. lumbricoides in Foria	4.833*	2,123	$P \leq 0.010$
Hookworm in Kroo Bay	0.410	2,58	$P \leq 0.666$
Hookworm in Rowollon	4.930*	2,282	$P \leq 0.008$
Hookworm in Foria	0.372	2,259	$P \leq 0.690$
T. trichiura in Kroo Bay	0.919	2,167	$P \leq 0.401$
T. trichiura in Rowollon	0.220	2,227	$P \leq 0.800$
S. mansoni in Foria	0.702	2,53	$P \leq 0.500$

* Significantly different at $P \leq 0.05$.

When significant differences were found using one-way analysis of variance, least significant tests for unequally replicated means were used to determine between which means the differences occurred. Significant differences were found between the means of the different household categories in the people infected with *A. lumbricoides* in Foria and in those infected with hookworm in Rowollon.

The differences between the means of those infected with *A. lumbricoides* in Foria are presented in Table 4.55. From this it can be seen that individuals living in households with the lowest numbers of people in them have significantly higher intensities of *A. lumbricoides* than those living in households with the largest number of people in them. Values needed for significant differences are presented in Table 46, Appendix II.

Table 4.55. Comparisons between means of *A. lumbricoides* intensity in categories of household size in Foria.

	Households		
Households	One	Two	Three
One	-	0.1401	0.3735*
Two		-	0.2334
Three			-

* Means which were found to be significantly different ($P \leq 0.05$).

When means of hookworm intensity were examined, individuals in the middle category of household size were found to have significantly higher intensities of infection than those in small and large households. Differences are presented in Table 4.56 and values needed for significant differences are presented in Table 47, Appendix II.

Table 4.56. Comparisons between means of hookworm intensity in categories of household size in Rowollon.

	Households		
Households	One	Two	Three
One	-	0.1401	0.3735*
Two		-	0.2334
Three			-

* Means which were found to be significantly different ($P \leq 0.05$).

4.5.12. Correlation between Intensity of Helminth Infections

Spearman rank correlation analysis was used to investigate the association of intensity of helminth species with one another. Results of these are presented in Table 4.57, which gives r values for each comparison, degrees of freedom and the appropriate significance value.

Table 4.57. Correlation between intensities of helminth infections.

Community	Helminth Infections	DF	r	Significance level
Kroo Bay	*A. lumbricoides* & Hookworm	35	0.0405	$P > 0.05$
Kroo Bay	Hookworm & *T. trichiura*	55	0.1215	$P > 0.05$
Kroo Bay	*A. lumbricoides* & *T. trichiura*	59	0.4342*	$P \leq 0.001$
Rowollon	*A. lumbricoides* & Hookworm	77	0.3052*	$P \leq 0.007$
Rowollon	Hookworm & *T. trichiura*	194	0.2153*	$P \leq 0.004$
Rowollon	*A. lumbricoides* & *T. trichiura*	68	0.3463*	$P \leq 0.003$
Foria	*A. lumbricoides* & Hookworm	105	0.1484	$P > 0.05$
Foria	Hookworm & *S. mansoni*	42	0.0469	$P > 0.05$
Foria	*A. lumbricoides* & *S. mansoni*	10	0.7236*	$P \leq 0.01$

* Comparisons which were found to be significantly different ($P \leq 0.05$).

These results indicate that the intensities of all three species are correlated with one another in Rowollon as well as the intensities of *A. lumbricoides* and *T. trichiura* in Kroo Bay and *A. lumbricoides* and *S. mansoni* in Foria. Significant correlations in intensity of infections would indicate the use of anthelmintics with broad effectiveness to control several infections with one treatment.

4.6. Discussion

4.6.1. Prevalence and Intensity of Helminth Infections Between Communities

Prevalence of the three helminth infections in the three communities was investigated to determine if certain helminth infections were more common in one community as compared with another. *Ascaris lumbricoides* infection was found to be more common in Foria than in the other two communities. This supports, to some extent, the claim that *A. lumbricoides* infections are more common in rural areas in Africa (Crompton and Tulley, 1987), though one might have expected the people surveyed in Rowollon to have had more infections with this helminth than Kroo Bay if this is always the case. Hookworm infection was found to be more common in the rural communities (Foria and Rowollon) than in the urban community (Kroo Bay), as would be expected (Kiliama, 1990). There were significantly more infections of *T. trichiura* in Kroo Bay than in Rowollon where there were significantly more infections with *T. trichiura* than in Foria. In Foria, *T. trichiura* was not common and was replaced by *S. mansoni* in a list of the three most common helminth infections. There was some indication from the reports of hospital records in the North (Hodges, 1988) cited in Chapter Two, that infections with this helminth is less common in the North of Sierra Leone. *Schistosoma mansoni* was not found in Kroo Bay and was found in only 3 individuals in Rowollon where there was a significantly lower prevalence of this parasite in comparison to Foria. Foria had significantly more *S. stercoralis* than either Rowollon or Kroo Bay. Foria had more single and fewer triple infections than the other two communities and Rowollon had fewer single infections and more triple infections. This may relate to the means of transmission, water contact, of *S. mansoni* in Foria in comparison to the three helminths found in Rowollon. Kroo Bay would, as an urban site, be expected to have fewer hookworm infections and this would influence the number of triple infections found there.

The intensity of infections was investigated for those individuals found to be infected in each community. Rowollon had significantly higher *A. lumbricoides* intensity than Foria, with the intensity of this helminth at Kroo Bay falling somewhere between the two. It is usually assumed that areas with higher prevalence will have higher intensity and this result differs from what is expected (Guyatt and Bundy, 1991). The intensity of hookworm was significantly highest in Rowollon, followed by Foria and then Kroo Bay. This may be as expected, with the lowest intensity being in the

urban setting. There is no obvious explanation for the significant difference seen between the intensity of *A. lumbricoides* at Rowollon and Foria. The intensity of *T. trichiura* was seen to be highest in Kroo Bay, significantly different from that in Rowollon. No significant differences were seen in the intensity of *S. mansoni* and *S. stercoralis*, despite the significant differences seen in the prevalence of these helminths between the three communities.

4.6.2. Prevalence and Intensity of Helminth Infections Within Communities

4.6.2a. *Ascaris lumbricoides*

The prevalence of *A. lumbricoides* was found to be significantly different between the age classes in Kroo Bay, with the highest prevalence in age classes 2 and 3. A significant difference was also seen in Rowollon, where individuals of age class 2 were seen to have the highest prevalence of *A. lumbricoides*. No significance difference was found between the age classes in Foria. The results from Kroo Bay and Rowollon indicate that the age classes with the highest risk of *A. lumbricoides* infection are those individuals aged from 5 to 9 yr and 10 to 19 yr (Compare to the surveys reviewed in Chapter and illustrated in Figure 1.1). It is noteworthy that in Foria which showed the highest prevalence of *A. lumbricoides* no significant difference in prevalence was found between age classes. Targeted control programmes in communities where *A. lumbricoides* is endemic (Asaolu, Holland and Crompton, 1991), have successfully directed anthelmintic treatment at the age groups seen here to have the highest intensity, with an overall decrease in prevalence of untreated individuals as well as treated individuals. It would be interesting to target these age groups in a community where the overall prevalence of the infection is low, but that of the targeted age groups is significantly higher than other age groups and compare it to a community where there is no significant difference in the targeted age class prevalence. It is possible that the community where the targeted age classes were significantly different would show the greatest response to this kind of targeted treatment.

There were no other significant differences seen in the prevalence of *A. lumbricoides* by sex of individual, by area of households within the community and by the size of household in which an individual lived. Higher levels of co-occurrence of *A. lumbricoides* with hookworm infection were found in Kroo Bay, Rowollon and Foria than would be expected by chance alone. This may indicate similarities in the manner in which these two helminth infections are transmitted and in susceptibility to these two helminths. A similar result was seen in the prevalence of co-occurrence of *A.*

lumbricoides and *T. trichiura* in Kroo Bay and Rowollon. This co-occurrence may indicate that combined control of infections with these helminth species is possible in these locations in contrast to what has been suggested elsewhere for *A. lumbricoides*, *T. trichiura* and hookworm infection (Booth and Bundy, 1992). However, the analysis of co-occurrence of *S. mansoni* and *A. lumbricoides* in Foria indicated that those individuals infected with one of these infections appeared not to be likely to be infected with the other. It is interesting that one of the age classes seen to be the most likely to be infected with *A. lumbricoides* in Kroo Bay (age class 3) was one of those (age classes 3 and 4) most likely to be infected with *S. mansoni* in Foria, although in this community there were no significant differences seen between age classes in *A. lumbricoides* prevalence.

Differences in intensity of *A. lumbricoides* were seen in the analysis of single, double, and triple infections in Kroo Bay and Rowollon. In Kroo Bay, single infections of *A. lumbricoides* were less intense than those infections of *A. lumbricoides* seen to occur with one or two other infections. In Rowollon, single infections were less intense than those infections occurring with two other infections. No differences were found in intensity of single, double and triple infections in Foria. The results from Kroo Bay and Rowollon indicate that individuals with three infections, who may be expected to have the highest possibility for pathology and morbidity due to infection, may also have the highest number of helminths (Keymer and Pagel, 1990). That would only add to the health risks which are associated with infections with more than one helminth. Conversely, since the measurement of intensity in this study was made by counting and comparing egg counts (EPG), individuals who are infected with more than one helminth species may present a better habitat to the helminth and this may increase the number of infective stages that each individual worm produces. The only way to determine the effect of multiple infections on helminth fecundity would be to combine collections of all helminths passed after dosage with anthelmintic with counts of eggs per gram faeces to determine the inter-relatedness of the two factors. The important factor to point out is that those individuals responsible for distributing infective stages of all helminth or at least more than one species of helminth are also responsible for spreading more infective stages of *A. lumbricoides*.

Age of host was seen to have an important effect on the intensity of infection with *A. lumbricoides* in people from Kroo Bay. Those hosts aged under five yr were seen to have lower intensities of infection than those aged between 10 yr and 19 yr and those over 40 yr of age. This is

most likely an indication that younger individuals in age class 1 are just beginning to pick up infections of *A. lumbricoides* and will have less intense infections because of this. The higher intensities seen in age class 3 are not surprising because individuals of this age class were among those found to have the highest prevalence of *A. lumbricoides* in Kroo Bay and it would be expected that these individuals would also have the highest intensity, especially if there was something in their behaviour that increased the possibility of becoming infected (Guyatt and Bundy, 1991). The higher intensities in those infected with *A. lumbricoides* in age class 5 are interesting as this age class is not one of those with the highest prevalence of *A. lumbricoides* infection. This result may reflect the presence of certain individuals in this age class which are especially susceptible to infection with this helminth, either through behavioural or perhaps ill health predisposing them to infection. The size of household was seen to influence the intensity of infection with *A. lumbricoides* in Foria, with those living in smaller households having higher intensities of infections than those in the largest households.

Correlation was seen between the intensity of *A. lumbricoides* and *T. trichiura* in Kroo Bay, between *A. lumbricoides* and hookworm and *T. trichiura* in Rowollon and *A. lumbricoides* and *S. mansoni* in Foria in those few individuals infected with both of these helminths. Significant correlation in the intensities and significant results of co-occurrence data indicate that combined treatment of both infections involved might be possible if there is a drug that has good efficacy against both infections being studied. These results indicate that treatment of those infected with *A. lumbricoides* in Kroo Bay could also treat those infected with *T. trichiura* and the same result would be possible in Rowollon with both *T. trichiura* and hookworm. The treatment for *A. lumbricoides* is not effective against *S. mansoni*, whose drug of choice (Praziquantel) is more expensive than that used against *A. lumbricoides*. The results of co-occurrence studies on these two helminths indicate that combined treatment would not be the most efficient means of treating these infections, even if it were possible.

4.6.2b. Hookworm

The analyses of differences of prevalence of hookworm by the different age classes revealed that, in all the study sites, hookworm infections were most prevalent in age classes 2, 3, 4 and 5 (compare to those surveys reviewed in Chapter One and illustrated in Figure 1.2). This suggests that

control of this helminth should be directed at individuals over five yr of age. It should be noted that the prevalence of hookworm infection did not vary significantly from age class 2 through age class 5, indicating that it is not just the adults, who might be expected to be involved in agriculture, especially in the rural communities of Rowollon and Foria, who are infected but also young adults and children from 5 yr of age and older. It also indicates that the overall profile of hookworm infection with age is similar in both urban and rural settings, where hookworm is found in both low and high overall prevalence, respectively. This may indicate a component of hookworm transmission that occurs outside the general picture of infection believed to take place in an agricultural setting. This may be due to contamination of the environment around housing due to spread of eggs and/or larvae. In India it has been found that women, married to men who are actively involved in agriculture, and who do not work in the fields had higher intensities than women married to men involved in other types of labour (Schad *et al.*, 1983)

Hookworm infection was found to co-occur with *A. lumbricoides* infection in all three communities studied. This indicates similarity in exposure and susceptibility. It may be influenced by the fact that hookworm infection is very common in Rowollon and Foria, where over 60% of individuals were found to be infected with this parasite. Co-occurrence was also found between *T. trichiura* and hookworm infection in Kroo Bay and Rowollon and *S. mansoni* and hookworm infection in Foria. This may be due to similarity in exposure and susceptibility but may also be explained by the fact that hookworm infection is very common in Rowollon and Foria (over 60% prevalence) and *T. trichiura* is very common in Kroo Bay (over 60% prevalence).

Hookworm intensity in Rowollon, the community where this parasite was the most prevalent, was seen to be significantly higher in males than in females (see Table 1.2 for a review of sex differences in intensity) and to be significantly higher in individuals infected with the two other helminth species than in individuals infected with hookworm and one other species of helminth. There was also significant correlation between the intensity of hookworm (EPG) and *A. lumbricoides* and *T. trichiura* indicating that individuals that were shedding large numbers of hookworm eggs were also shedding large number of eggs of other helminths (Keymer and Pagel, 1990).

Intensities of hookworm infection were seen to be higher in age classes 2, 3 and 5 in comparison to age class 1. When age and sex of host were considered at the same time and the

intensity of hookworm was analysed for females and males separately, it was seen that there were no significant differences between the age classes in females but there were significant differences between the intensity of the different age classes in the males, with age classes 3 and 5 having significantly higher intensities. This indicates that the individuals responsible for spreading most of the eggs of hookworm are the males in these age classes. Individuals infected with more than one species of helminth are thus also spreading eggs for more than one helminth and will be responsible for the largest percentage of contamination of the environment with infective stages. These individuals represent appropriate groups for intervention, either through treatment or through education directed at curtailing the amount of contamination they may be causing in the environment.

Individuals living in the medium sized households in Rowollon were found to have more intense infections of hookworm than those living in smaller sized and larger sized households. This result may reflect that there were more infected males of age class 3 and 5 in these households than in other sized households. This proposition was tested by using Chi-square analysis to determine if there were relatively more infected males of age classes 3 and 5, the more intensely infected male age classes, in the households of medium size than in the other sized households. This indicated that there was a significant difference in the distribution of males of this age in the households (Chi-square = 8.80, df = 2, $P \leq 0.05$). The Chi-square table was collapsed with the different sizes of households ordered by the percentage of the infected individuals that were males of age class 3 and 4. This revealed no significant differences between the number of males of these age classes in the large and small sized households (Chi-square = 3.37, df = 1, $P > 0.05$) but did reveal a difference between the medium sized households and the other two (Chi-square = 6.03, df = 1, $P \leq 0.05$). This indicated that there were significantly more infected males of age class 3 and 5 in the medium sized household than would be expected by chance alone. The reason for the higher intensities in these males could be due to some factor involved in the size of household. However, most conventional thinking would suggest that the contributing element to this higher intensity is due to greater exposure from involvement in agriculture that the males in this age group might experience. Why the males in age class 4 did not show significantly higher mean intensity is an interesting question and the answer to this could be related to the movement of males out of this community, once they reach this age group.

A similar result in the intensity of hookworm by age class was seen in Foria, where individuals in age class 1 had significantly less intense infections than individuals in other age classes and where age class 2 had significantly lower intensity infections than those individuals in age class 4.

4.6.2c. *Trichuris trichiura*

Only five individuals living in Foria were found to be infected with *T. trichiura*, with the three most common helminths in this community being hookworm, *A. lumbricoides* and *S. mansoni*, in that order. No detailed analysis of *T. trichiura* infection in people from Foria was undertaken because of this. The North of Sierra Leone may have little T. trichiura infection when this and the results of an analysis of records from Masanga Eye Hospital (Hodges, 1988) are taken together. The prevalence of infection with this helminth needs to be examined further in this part of the country.

No significant differences in the prevalence of *T. trichiura* in Rowollon or Kroo Bay were observed due to sex of individuals. Differences in the prevalence of this parasite were observed between the different age classes. In Kroo Bay, individuals in age class 1 were seen to have significantly fewer infections of *T. trichiura*, with the remaining age classes having similar prevalence. In Rowollon, individuals in age class 1 again showed significantly fewer infections with this helminth. People in age classes 2, 4 and 5 had prevalence of *T. trichiura* which were not significantly different but those individuals in age class 3; ten through 19 yr of age; were seen to have the highest prevalence between the different age classes in Rowollon. These results compare well to those reviewed in Chapter One and illustrated in Figure 1.3.

There were no differences seen in the prevalence of *T. trichiura* based on the areas within the village in which people lived or on the size of household in which they resided. Associations were seen between infections of *T. trichiura* and *A. lumbricoides* and between *T. trichiura* and hookworm infections in both Kroo Bay and Rowollon. This indicated that individuals infected with *T trichiura* in both these communities were also likely to be infected with these other helminths and that combined control of these helminths may be possible in these communities.

The intensity of *T. trichiura* was seen to differ between individuals which were found to be infected with only *T. trichiura* and those found to be infected with one other helminth infection versus those found to be infected with two other helminth infections, with those individuals found to harbour

three infections showing significantly higher intensities of *T. trichiura* infections. This was found to occur in both Kroo Bay and Rowollon, indicating that those individuals spreading infective stages for the highest number of species of helminths were also spreading the highest number of infective stages for *T. trichiura.*

No overall differences were found between individuals of different sexes in any of the communities. Analysis of age alone on the intensity of *T. trichiura* indicated that, in Kroo Bay, individuals infected with *T. trichiura* in age class 2 had more intense infections than individuals in age class 1 and 4. No significant differences were seen in Rowollon when age alone was analysed. Analysis of the effects of sex and age of individual together on the intensity indicated that, in Rowollon, males and females showed different age classes to have significantly higher intensity infections of *T. trichiura.* In females, the highest intensity was seen in those individuals in age class 2 and, in males, in those individuals in age class 3. This analysis revealed that, on average over the different age classes, males had less intense infections than females. This also revealed that adults of both males and females (age class 4 and 5) had significantly less intense infections of *T. trichiura* than the young adults and children of their respective sexes. This indicates that the largest percentage of the *T. trichiura* population is located in the young adults and children and this is also where there will be the greatest chance of morbidity due to infection.

The area of the household was seen to have a significant effect on the intensity of *T. trichiura* in Rowollon. This indicates that individuals in the households in area 1, the area where the houses were older, had higher intensities of infection of *T. trichiura.* This result could be due to some aspect of the houses in this area but might have been due to a larger number of infected young adults and children living in these houses, with the higher intensity infections these individuals have been shown to harbour. This was shown not to be the case by Chi-square analysis (Chi-square = 1.57, df = 1, $P > 0.05$), indicating that there could be some condition in area 1, for example crowding together of houses forcing children to play in heavily infected areas in comparison to area 2, where houses were spread out along the road, with much space in between for children to play in.

Correlation was found between the intensity of *A. lumbricoides* and *T. trichiura* in Kroo Bay and the intensity of *A. lumbricoides* and *T. trichiura* and hookworm and *T. trichiura* in Rowollon. This information, combined with the associations seen in the prevalence of these helminths in these

communities, indicates that combined control of these helminths could be a possibility in these two communities.

4.6.2d. *Schistosoma mansoni*

Large numbers of infections with *S. mansoni* were seen in Foria but not in the other two communities studied. Prevalence of this helminth is often not reported in helminth surveys (Chapter Two) but needs to be monitored as it is believed to be spreading within Sierra Leone (White, Gbakima and Amara, 1989). Analysis of factors associated with infection with this parasite and in the intensity of infection with *S. mansoni* was only carried out on the information available for this community. In Foria, *S. mansoni* was seen to have the highest prevalence in age classes 3 and 4 (compare to the surveys reviewed in Chapter One and illustrated in Figure 1.4) and to be more prevalent in smaller households. This significant result may have resulted from more individuals in the age classes 3 and 4 living in the smaller households than in the larger households. This was found not to be true (Chi-square = 1.09, df = 1, $P > 0.05$). Individuals living in the smaller households appear to have a higher chance of being infected with *S. mansoni* than those living in larger households. This may be a reflection of household income as treatment for *S. mansoni* infection was available from the local clinic for a price and was perceived as a health problem by the people living in Foria. Often important members of the community, who will probably have more money, have large numbers of people living in their houses. Another indication of relatively higher income for males is having more than one wife, which will in turn lead to larger households.

Schistosoma mansoni and *A. lumbricoides* were seen to occur together less often than by chance alone. However, in those few individuals who did have both infections, there was a significant correlation in the intensity of infections of these two. For these individuals, the chance of higher morbidity may be significant but the combined treatment of both infections leads to many complications. Anthelmintics used against *A. lumbricoides*, hookworm and *T. trichiura* are not effective against *S. mansoni*, for which the drug of choice is Praziquantel. Problems may exist when attempting to treat these infections at the same time as treating *S. mansoni*. It has been accepted practise not to administer treatment for other helminths when giving treatment for *S. mansoni*. Praziquantal is not believed to be effective against nematode parasites (Davis, 1993) and therefore control aimed at a combination of *A. lumbricoides*, hookworm and *S. mansoni* is not deemed possible.

4.7. Summary

Between Communities

Ascaris Lumbricoides.

1. More prevalent in Foria than in Rowollon or Kroo Bay.
2. Significantly higher intensity in Rowollon in comparison to Foria, Kroo Bay between the two.

Hookworm.

1. More prevalent in Rowollon and Foria than in Kroo Bay.
2. Intensity significantly higher in Rowollon, then Foria and then Kroo Bay.

Trichuris trichiura.

1. More prevalent in Kroo Bay than in Rowollon; very little in Foria.
2. Intensity significantly higher in Kroo Bay compared to Rowollon. Foria not compared.

Schistosoma mansoni.

1. Not found in Kroo Bay, very low prevalence in Rowollon significantly highest in Foria.
2. No significant differences in intensity between Foria and Rowollon.

Strongyloides stercoralis.

1. More prevalent in Foria than in Rowollon and Kroo Bay.
2. No significant differences in intensity.

Combined Infections.

1. More triple infections in Rowollon and fewer single infections, Foria fewer triple infections and more single.

Kroo Bay

Ascaris lumbricoides.

1. Age Class 2 and 3 significantly higher prevalence.
2. Significant co-occurrence with hookworm and *T. trichiura.*
3. Singly infected significantly less intense infections than doubly or triply infected.
4. Age class 1 significantly less intense infections than age classes 3 and 5.
5. Area 1 significantly more intense infections.
6. Intensity significantly correlated with *T. trichiura.*

Hookworm.

1. Age class 1 significantly lower prevalence.
2. Significant co-occurrence with *A. lumbricoides* and *T. trichiura.*
3. Age class 1 significantly less intense infections.

Trichuris trichiura.

1. Age class 1 significantly lower prevalence.
2. Significant co-occurrence with *A. lumbricoides* and hookworm.
3. Singly and doubly infected significantly less intense infections than triply infected.
4. Overall, age class 2 significantly higher intensity than age classes 1, 4 and 5.
5. In females, most intense infections in age class 2, in males age class 3.
6. Intensity significantly correlated with *A. lumbricoides.*

Rowollon

Ascaris lumbricoides.

1. Age class 2 significantly higher prevalence.
2. Significant co-occurrence with hookworm and *T. trichiura.*
3. Singly infected significantly less intense infections than triply infected.
4.. Intensity significantly correlated with hookworm and *T. trichiura.*

Hookworm.

1. Age class 1 significantly lower prevalence.
2. Significant co-occurrence with *A. lumbricoides* and *T. trichiura.*
3. Singly infected significantly less intense infections than doubly infected significantly less intense than triply infected.
4. Males higher intensity than females.
5. Overall, age class 1 significantly lower intensity than age classes 2, 3, 4 and 5.
6. In females, no difference in intensity by age, in males age class 3 and 5 most intense.
7. Intensity significantly correlated with *A. lumbricoides* and *T. trichiura.*

Trichuris trichiura.

1. Age class 1 significantly lower prevalence and age class 3 significantly higher.
2. Significant co-occurrence with *A. lumbricoides* and hookworm.

3. Singly and doubly infected significantly less intense infections than triply infected.
4. Females higher intensity and age class 2 and 3 significantly more intense.
5. Area 1 significantly more intense infections.
6. Intensity significantly correlated with *A. lumbricoides* and hookworm.

Foria

Ascaris lumbricoides.

1. Co-occurrence with hookworm & significant non-occurrence with *S. mansoni.*
2. Smaller households less intense infections.
3. Intensity significantly correlated with *S. mansoni.*

Hookworm.

1. Age class 1 significantly lower prevalence.
2. Significant co-occurrence with *A. lumbricoides* and *S. mansoni.*
3. Overall, age class 1 significantly lower intensity than age classes 2, 3, 4 and 5; age class 2 significantly lower than age class 4..

Schistosoma mansoni.

1. Age classes 3 and 4 significantly higher prevalence than 1, 2 and 5.
2. Co-occurrence with hookworm and significant non-occurrence with *A. lumbricoides.*
3. Smaller households higher prevalence.
4. Intensity significantly correlated with *A. lumbricoides.*

Table 4.1. Prevalence (%) and 95% Bonferoni confidence intervals of the three most common helminth infections in the three communities studied.

COMMUNITY	HELMINTH	OVERALL PREVALENCE	FEMALE	MALE	LOCATION ONE	LOCATION TWO
Kroo Bay	*A. lumbricoides*	26.1 20.7 - 31.5	28.5 21.1 - 35.9	21.0 11.1 - 30.9	24.2 16.1 - 32.3	28.1 19.4 - 36.8
Rowollon	*A. lumbricoides*	20.9 16.2 - 25.6	22.1 15.3 - 28.9	19.1 11.2 - 27.0	21.8 14.8 - 28.8	19.7 12.0 - 27.4
Foria	*A. lumbricoides*	32.1 26.6 - 37.6	32.1 24.1 - 40.1	32.2 22.8 - 41.6	33.1 25.7 - 40.5	28.3 17.1 - 39.5
Kroo Bay	Hookworm	22.2 17.1 - 27.3	22.3 15.5 - 29.1	21.8 11.8 - 31.8	24.7 16.5 - 32.9	19.5 11.8 - 27.2
Rowollon	Hookworm	66.6 61.2 - 72.0	66.7 59.0 - 74.4	66.5 57.0 - 76.0	63.8 55.7 - 71.9	70.2 61.4 - 79.0
Foria	Hookworm	61.8 56.3 - 67.3	59.2 51.1 - 67.2	65.3 56.2 - 74.4	65.1 57.6 - 72.6	68.1 56.5 - 79.7
Kroo Bay	*T. trichiura*	65.1 58.5 - 71.7	64.6 55.7 - 73.5	66.3 53.1 - 79.5	49.5 57.5 - 77.3	44.1 51.5 - 73.5
Rowollon	*T. trichiura*	49.5 44.3 - 54.7	46.6 39.1 - 54.1	53.7 44.6 - 62.8	52.1 44.4 - 59.8	46.1 37.4 - 54.8
Foria	*S. mansoni*	12.9 9.8 - 16.0	11.5 7.1 - 15.9	14.7 8.9 - 20.5	13.0 8.5 - 17.5	15.0 7.5 - 22.5

Table 4.1 (cont.). Prevalence (%) and 95% Bonferoni confidence intervals of the three most common helminth infections in the three communities studied.

COMMUNITY	HELMINTH	AGE CLASS ONE	AGE CLASS TWO	AGE CLASS THREE	AGE CLASS FOUR	AGE CLASS FIVE	SIZE ONE	SIZE TWO	SIZE THREE
Kroo Bay	*A. lumbricoides*	19.1 9.4 - 28.8	37.7 19.5 - 56.0	38.9 15.0 - 62.8	21.9 6.7 - 37.1	27.3 12.4 - 42.2	27.9 17.0 - 38.8	24.4 11.6 - 37.2	30.4 11.7- 49.1
Rowollon	*A. lumbricoides*	14.3 6.2 - 22.4	41.3 20.0 - 62.6	25.0 9.1 - 40.9	23.5 9.6 - 37.4	16.5 4.2 - 28.8	15.6 7.0-24.2	22.5 12.8 - 32.2	24.0 14.5 - 33.5
Foria	*A. lumbricoides*	29.3 14.5 - 44.1	44.3 27.9 - 60.7	34.0 19.6 - 48.4	27.8 15.1 - 40.5	22.2 4.0 - 40.4	33.6 21.5 - 45.7	27.7 17.3 - 38.1	34.3 23.2 - 45.4
Kroo Bay	Hookworm	9.2 2.0 - 16.4	31.1 13.7 - 48.5	41.7 17.5 - 65.9	23.4 7.8 - 39.0	28.6 13.5 - 43.7	24.0 13.6 - 34.4	22.1 9.7 - 34.5	23.9 6.5 - 41.3
Rowollon	Hookworm	35.4 24.3 - 46.5	91.3 79.1 - 100	90.6 79.9 - 100	74.1 59.8 - 88.4	88.6 78.1 - 99.1	73.3 62.8 - 83.8	63.4 52.2 - 74.6	63.6 52.9 - 74.3
Foria	Hookworm	21.0 10.2 - 31.8	75.9 61.8 - 90.0	79.8 67.6 - 92.0	75.0 62.8 - 87.3	80.0 62.5 - 97.5	62.1 49.6 - 74.5	66.0 55.0 - 77.0	69.3 58.35- 80.1
Kroo Bay	*T. trichiura*	45.2 30.7 - 59.7	84.1 68.6 - 99.6	86.7 69.3 - 100	71.7 53.0 - 90.4	66.7 47.6 - 85.8	69.8 59.1 - 80.5	57.0 42.9 -71.1	67.4 49.2 - 85.6
Rowollon	*T. trichiura*	21.7 12.6 - 30.8	62.5 47.3 - 77.7	79.7 65.6 - 93.8	56.8 41.3 - 72.3	60.8 45.4 - 76.2	47.6 38.9 - 56.3	53.3 40.6 - 66.0	49.6 37.9 - 61.3
Foria	*S. mansoni*	2.4 0.0 - 5.9	6.3 0.0 - 13.3	19.1 8.7 - 29.5	25.0 14.3 - 35.7	11.1 0.0 - 23.2	20.7 11.7 - 29.7	9.2 3.4 - 15.0	12.1 5.5 - 18.7

Table 4.2. Mean intensities (EPG) and 95% confidence intervals for the three most common helminth infections in the three communities studied.

COMMUNITY	HELMINTH	N	OVERALL INTENSITY	FEMALE	MALE	LOCATION ONE	LOCATION TWO
Kroo Bay	*A. lumbricoides*	99	1989.8 1467 - 2700	2219.2 1589 - 3099	1441.1 698 - 2975	2945.8 1921 - 4517	1395.7 914 - 2131
Rowollon	*A. lumbricoides*	90	1524.4 1097 -2118	1885.8 1265 - 2811	1056.0 591 - 1885	1490.7 954 - 2330	1574.0 949 - 2610
Foria	*A. lumbricoides*	131	2853.6 2262 - 3601	2724.6 2066 - 3593	3042.3 2017 - 4588	2941.0 2216 - 3903	2401.6 1531 - 3769
Kroo Bay	Hookworm	84	203.9 150 - 277	174.5 124 - 246	288.5 152 - 547	205.8 134 - 315	201.3 128 - 318
Rowollon	Hookworm	287	499.8 429 - 582	411.2 336- 503	668.8 534 - 839	502.2 412 -612	496.8 391 - 632
Foria	Hookworm	278	354.1 299 - 419	328.4 264 - 408	388.8 298 - 508	385.1 313 - 473	382.1 280 - 521
Kroo Bay	*T. trichiura*	170	216.2 179 - 261	224.0 86 - 120	200.0 139 - 288	243.8 185 - 321	185.7 144 - 239
Rowollon	*T. trichiura*	230	92.6 81 - 106	101.7 86 - 120	82.2 66 - 102	105.5 89 - 125	76.7 62 - 95
Foria	*S. mansoni*	58	103.1 73 - 146	99.7 59 - 164	108.0 65 - 180	91.5 59 - 141	116.0 56 - 241

Table 4.2 (cont.). Mean intensities (EPG) and 95% confidence intervals of the three most common helminth infections in the three communities studied.

COMMUNITY	HELMINTH	AGE CLASS ONE	AGE CLASS TWO	AGE CLASS THREE	AGE CLASS FOUR	AGE CLASS FIVE	SIZE ONE	SIZE TWO	SIZE THREE
Kroo Bay	*A. lumbricoides*	958.5 522 - 1759	2161.7 1055 - 4428	4394.4 1864 - 10359	1814.7 1059 - 3108	2914.7 1521 - 5587	2134.0 1281 - 3555	2319.0 1245 - 4321	3260.6 1143 - 9303
Rowollon	*A. lumbricoides*	2328.1 1109 - 4888	1690.8 892 - 3203	990.1 475 - 2063	1276.1 624 - 2609	1366.8 414 - 4510	1285.6 657 - 2517	1218.7 708 - 1644	2038.0 1168 - 3554
Foria	*A. lumbricoides*	4433.0 2392 - 8217	3754.9 2371 - 5946	2057.8 1336 - 3170	1881.5 1111 - 3186	3774.0 2098 - 6787	4283.5 2803 - 6548	3102.4 2093 - 4598	1812.6 1215 - 2705
Kroo Bay	Hookworm	103.8 49 - 218	229.9 113 - 466	165.6 102 - 270	252.1 97 - 658	273.1 142 - 525	179.8 126 - 257	209.4 103 - 425	268.8 88 - 817
Rowollon	Hookworm	311.0 210 - 461	535.1 350 - 817	623.7 470 - 827	487.1 344 - 689	600.6 448 - 806	428.4 332 - 553	748.7 534 - 927	426.6 328 - 554
Foria	Hookworm	114.8 70 - 188	280.2 202 - 388	416.9 296 - 588	487.5 358 - 663	408.9 257 - 650	421.9 307 - 580	392.8 297 - 520	351.0 260 - 473
Kroo Bay	*T. trichiura*	194.9 141 - 269	349.5 228 - 535	255.4 155 - 420	153.9 100 - 237	176.4 106 - 292	210.3 165 - 267	258.4 175 - 382	176.9 108 - 290
Rowollon	*T. trichiura*	95.1 64 - 142	102.8 76 - 138	118.2 87 - 160	66.4 52 - 85	86.5 66 - 113	88.5 73 - 108	108.6 84 - 140	86.8 66 - 113
Foria	*S. mansoni*	178.6 2 - 12915	97.3 20 - 466	97.0 50 - 188	112.5 65 - 196	61.1 15 - 241	120.6 67 - 215	100.9 48 - 213	72.9 36 - 147

Table 4.11. Numbers infected over number analysed of the three most common helminth infections in the three communities studied.

COMMUNITY	HELMINTH	OVERALL PREVALENCE	FEMALE	MALE	LOCATION ONE	LOCATION TWO
Kroo Bay	*A. lumbricoides*	99/379	78/260	25/119	47/194	52/185
Rowollon	*A. lumbricoides*	90/431	57/258	33/173	53/243	37/188
Foria	*A. lumbricoides*	131/408	76/237	55/171	94/284	32/113
Kroo Bay	Hookworm	84/379	58/260	26/119	48/194	36/185
Rowollon	Hookworm	287/431	172/258	115/173	155/243	132/188
Foria	Hookworm	278/450	154/260	124/190	185/284	77/113
Kroo Bay	*T. trichiura*	170/261	117/181	53/80	95/141	75/120
Rowollon	*T. trichiura*	230/465	129/277	101/188	136/261	94/204
Foria	*S. mansoni*	58/450	30/260	28/190	37/284	17/113

Table 4.11(cont.). Numbers infected over number analysed of the three most common helminth infections in the three communities studied.

COMMUNITY	HELMINTH	AGE CLASS ONE	AGE CLASS TWO	AGE CLASS THREE	AGE CLASS FOUR	AGE CLASS FIVE	SIZE ONE	SIZE TWO	SIZE THREE
Kroo Bay	*A. lumbricoides*	27/141	23/61	14/36	14/64	21/77	10/50	15/49	29/86
Rowollon	*A. lumbricoides*	23/161	19/46	16/64	19/81	13/79	21/135	32/142	37/154
Foria	*A. lumbricoides*	24/82	35/79	32/94	30/108	10/45	39/116	39/141	48/140
Kroo Bay	Hookworm	13/141	19/61	15/36	15/64	22/77	14/50	10/49	21/86
Rowollon	Hookworm	57/161	42/46	58/64	60/81	70/79	99/135	90/142	98/154
Foria	Hookworm	26/124	60/79	75/94	81/108	36/45	72/116	93/141	97/140
Kroo Bay	*T. trichiura*	42/93	37/44	26/30	33/46	32/48	35/50	34/49	56/86
Rowollon	*T. trichiura*	35/161	50/80	51/64	46/81	48/79	110/231	57/107	63/127
Foria	*S. mansoni*	3/124	5/79	18/94	27/108	5/45	24/116	13/141	17/140

Table 4.12. Prevalence (%) and 95% Bonferoni confidence intervals of the less common helminth infections in the three communities studied.

COMMUNITY	HELMINTH	OVERALL PREVALENCE	FEMALE	MALE	LOCATION ONE	LOCATION TWO
Rowollon	*S. mansoni*	0.65 0.0 - 1.4	0.72 0.0 - 1.9	0.53 0.0 - 1.7	0.77 0.0 - 2.0	0.49 0.0 - 1.6
Foria	*T. trichiura*	1.11 0.1 - 2.1	1.54 0.0 - 3.3	0.53 0.0 - 1.7	0.70 0.0 - 1.8	2.65 0.0 - 6.0
Kroo Bay	*S. stercoralis*	1.06 0.0 - 2.3	1.15 0.0 - 2.9	0.84 0.0 - 3.0	1.03 0.0 - 2.9	1.08 0.0 - 2.9
Rowollon	*S. stercoralis*	0.43 0.0 - 1.2	0.72 0.0 - 2.0	-	-	0.98 0.0 - 2.8
Foria	*S. stercoralis*	2.89 1.0 - 4.8	4.23 1.0 - 7.4	1.05 0.0 - 3.0	3.17 0.0 - 5.8	2.65 0.0 - 6.5

Table 4.12 (cont.). Prevalence and 95% Bonferoni confidence intervals of the less common helminth infections in the three communities studied.

COMMUNITY	HELMINTH	AGE CLASS ONE	AGE CLASS TWO	AGE CLASS THREE	AGE CLASS FOUR	AGE CLASS FIVE	SIZE ONE	SIZE TWO	SIZE THREE
Rowollon	*S. mansoni*	-	2.5 0.0 - 6.4	1.6 0.0 - 5.1	-	-	-	-	2.4 0.0 - 5.1
Foria	*T. trichiura*	0.81 0.0 - 2.8	1.27 0.0 - 4.4	1.06 0.0 - 3.7	1.85 0.0 - 5.1	-	0.86 0.0 - 2.8	2.84 0.0 - 6.0	-
Kroo Bay	*S. stercoralis*	0.71 0.0 - 2.7	1.64 0.0 - 6.3	2.78 0.0 - 10.6	1.56 0.0 - 6.0	-	-	-	2.33 0.0 - 6.5
Rowollon	*S. stercoralis*	0.62 0.0 - 2.4	-	-	-	1.3 0.0 - 4.9	0.87 0.0 - 2.4	-	-
Foria	*S. stercoralis*	4.03 0.0 - 9.0	2.53 0.0 - 7.5	4.26 0.0 - 10.2	0.93 0.0 - 3.6	2.22 0.0 - 8.5	3.45 0.0 - 7.8	4.26 0.0 - 8.6	1.43 0.0 - 4.0

Table 4.13. Mean intensities (EPG)and range for the less common helminth infections in the three communities studied.

COMMUNITY	HELMINTH	N	OVERALL INTENSITY	FEMALE	MALE	LOCATION ONE	LOCATION TWO
Rowollon	*S. mansoni*	3	217.3 75 - 447	288.5 130 - 447	75 -	102.5 75 - 130	447 -
Foria	*T. trichiura*	5	30.2 19 - 56	28.3 19 - 56	38 -	28.5 19 - 38	31.3 19 - 56
Kroo Bay	*S. stercoralis*	4	581.5 38 - 1932	756.7 38 - 1932	56 -	47 38 - 56	1116 300 - 1932
Rowollon	*S. stercoralis*	2	270.5 75 - 466	270.5 75 - 466	-	-	270.5 75 - 466
Foria	*S. stercoralis*	13	459 19 - 3977	537.3 19 - 3977	28.5 19 - 38	615 19 - 3977	62.7 19 - 131

Table 4.13 (cont.). Mean intensities (EPG) and range of the less common helminth infections in the three communities studied.

COMMUNITY	HELMINTH	AGE CLASS ONE	AGE CLASS TWO	AGE CLASS THREE	AGE CLASS FOUR	AGE CLASS FIVE	SIZE ONE	SIZE TWO	SIZE THREE
Rowollon	*S. mansoni*	-	102.5 75 - 130	447 -	-	-	-	-	217.3 75 - 447
Foria	*T. trichiura*	19 -	38 -	19 -	37.5 19 - 56	-	38 -	28.3 19 - 56	-
Kroo Bay	*S. stercoralis*	56 -	1932 -	300 -	38 -	-	-	-	178 56 - 300
Rowollon	*S. stercoralis*	466 -	-	-	-	75 -	270.5 75 - 466	-	-
Foria	*S. stercoralis*	896.8 19 - 3977	140.5 56 - 225	56.5 19 - 131	882 -	94 -	65.8 38 - 131	212.8 19 - 882	2091.5 206 - 3977

Table 4.14. Numbers infected over number analysed of the less common helminth infections in the three communities studied.

COMMUNITY	HELMINTH	OVERALL PREVALENCE	FEMALE	MALE	LOCATION ONE	LOCATION TWO
Rowollon	*S. mansoni*	3/465	2/277	1/188	2/261	1/204
Foria	*T. trichiura*	5/450	4/260	1/190	2/284	3/113
Kroo Bay	*S. stercoralis*	4/379	3/260	1/119	2/194	2/185
Rowollon	*S. stercoralis*	2/265	2/277	0/188	0/261	2/204
Foria	*S. stercoralis*	13/450	11/260	2/190	9/284	3/113

Table 4.14(cont.). Numbers infected over number analysed of the less common helminth infections in the three communities studied.

COMMUNITY	HELMINTH	AGE CLASS ONE	AGE CLASS TWO	AGE CLASS THREE	AGE CLASS FOUR	AGE CLASS FIVE	SIZE ONE	SIZE TWO	SIZE THREE
Rowollon	*S. mansoni*	0/161	2/80	1/64	0/81	0/79	0/231	0/107	3/127
Foria	*T. trichiura*	1/124	1/79	1/94	2/108	0/45	1/116	4/141	0/140
Kroo Bay	*S. stercoralis*	1/141	1/61	1/36	1/64	0/77			
Rowollon	*S. stercoralis*	1/161	0/46	0/64	0/81	1/79	2/231	0/107	0/127
Foria	*S. stercoralis*	5/124	2/79	4/94	1/108	1/45	4/116	6/141	2/140

Table 4.15. Concurrent infections of gastrointestinal helminths in Kroo Bay in total and by age, sex, size of households and location.

	Uninfected	Single	Single	Single	Double			Triple
		A. lumbricoides	Hookworm	*T. trichiura*	*A. lumbricoides* / Hookworm	*A. lumbricoides* / *T. trichiura*	Hookworm / *T. trichiura*	
Age Class								
One	43	6	1	25	1	10	4	3
Two	6	0	1	14	0	9	8	6
Three	4	0	0	8	0	6	6	6
Four	11	1	0	17	1	5	9	2
Five	12	2	1	13	1	8	7	4
Sex								
Female	52	6	3	51	3	30	22	14
Male	24	3	0	26	0	8	12	7
Location								
One	39	4	1	45	2	18	18	14
Two	37	5	2	32	1	20	16	7
Household size								
One	34	3	1	40	1	21	18	11
Two	28	5	2	25	2	9	10	5
Three	14	1	0	12	0	8	6	5
Total	76	9	3	77	3	38	34	21

Table 4.16. Concurrent infections of gastrointestinal helminths in Rowollon in total and by age, sex, size of households and location.

	Uninfected	Single	Single	Single	Double			Triple
		A. lumbricoides	Hookworm	*T. trichiura*	*A. lumbricoides* / Hookworm	*A. lumbricoides* / *T. trichiura*	Hookworm / *T. trichiura*	
Age Class								
One	91	7	24	5	5	1	18	10
Two	3	0	10	1	1	0	13	18
Three	2	1	11	2	0	1	33	14
Four	13	1	18	5	3	2	26	13
Five	8	0	19	1	4	0	38	9
Sex								
Female	67	6	54	10	10	3	70	38
Male	50	3	27	4	3	1	59	26
Location								
One	71	7	34	8	6	2	77	38
Two	46	2	47	6	7	2	52	26
Household Size								
One	30	1	32	5	5	0	47	15
Two	41	4	20	5	3	2	44	23
Three	46	4	29	4	5	2	38	26
Total	117	9	81	14	13	4	129	64

Table 4.17. Concurrent infections of gastrointestinal helminths in Foria in total and by age, sex, size of households and location.

	Uninfected	Single	Single	Single	Double			Triple
		A. lumbricoides	Hookworm	*S. mansoni*	*A. lumbricoides* / Hookworm	*A. lumbricoides* / *S. mansoni*	Hookworm / *S. mansoni*	
Age Class								
One	49	16	9	0	7	0	0	1
Two	14	3	26	2	31	0	2	1
Three	12	2	34	5	28	0	11	2
Four	18	3	39	5	21	1	16	5
Five	7	1	23	1	9	0	4	0
Sex								
Female	66	13	73	10	57	1	12	5
Male	34	12	58	3	39	0	21	4
Location								
One	71	19	89	9	68	0	21	7
Two	27	6	40	2	23	1	12	2
Non-Random	2	0	2	2	5	0	0	0
Household Size								
One	26	9	33	8	24	1	10	5
Two	42	5	49	1	32	0	10	2
Three	30	11	47	2	35	0	13	2
Non-Random	2	0	2	2	5	0	0	0
Total	100	25	131	13	96	1	33	9

Table 4.18. Prevalence (%) and 95% Bonferoni confidence intervals for the data not used in analysis.

COMMUNITY	HELMINTH	OVERALL PREVALENCE	FEMALE	MALE	Age Class One	Age Class Two	Age Class Three	Age Class Four	Age Class Five
Kroo Bay (outside area)	*A. lumbricoides*	22.00 (10.5 - 33.5)	28.13 (10.3 - 45.9)	11.11 (0.0 - 27.7)	13.34 (0.0 - 32.0)	30.00 (0.0 - 67.3)	40.00 (0.0 - 96.4)	33.33 (0.0 - 82.9)	14.29 (0.0 - 48.4)
Kroo Bay (outside area)	Hookworm	10.00 (1.7 - 18.3)	6.25 (0.0 - 15.8)	16.67 (0.0 - 36.3)	13.34 (0.0 - 30.7)	-	-	16.67 (0.0 - 53.1)	14.29 (0.0 - 46.0)
Kroo Bay (outside area)	*T. trichiura*	58.00 (44.3 - 71.7)	59.38 (39.9 - 78.8)	55.56 (29.3 - 81.8)	36.36 (6.6 - 58.0)	100.0 -	60.00 (3.6 - 100.0)	83.33 (44.1 - 100)	42.86 (0.0 - 9.0)
Kroo Bay (outside area)	*S. mansoni*	4.00 (0.0 - 9.4)	6.25 (0.0 - 14.6)	-	-	-	20.00 (0.0 - 60.1)	-	14.29 (0.0 - 43.9)
Kroo Bay (outside area)	*S. stercoralis*	2.00 (0.0 - 5.9)	-	5.56 (0.0 - 16.1)	4.55 (0.0 - 13.3)	-	-	-	-
Kroo Bay (non-targeted)	*T. trichiura*	46.61 (37.6 - 55.6)	50.63 (38.0 - 63.2)	38.46 (21.0 - 55.9)	33.33 (15.8 - 50.9)	64.71 (34.9 - 94.6)	66.67 (17.1 - 100)	55.56 (25.4 - 85.7)	48.28 (24.4 - 72.2)
Rowollon (non-random)	*A. lumbricoides*	20.59 (7.0 - 34.2)	15.79 (0.0 - 34.5)	26.67 (1.1 - 52.2)	-	20.59 (7.0 - 34.2)	-	-	-
Rowollon (non-random)	Hookworm	73.53 (58.7 - 88.4)	57.89 (32.5 - 83.3)	93.33 (78.9 - 100)	-	73.53 (58.7 - 88.4)	-	-	-
Foria (non-random)	*A. lumbricoides*	40.48 (25.6 - 55.3)	43.48 (20.3 - 66.6)	36.84 (20.3 - 66.6)	40.48 (25.6 - 55.3)	-	-	-	-

Table 4.19. Mean intensities (EPG) and 95% confidence intervals for the data not used in analysis.

COMMUNITY	HELMINTH	OVERALL INTENSITY	FEMALE	MALE	Age Class One	Age Class Two	Age Class Three	Age Class Four	Age Class Five
Kroo Bay (outside area)	*A. lumbricoides*	1283.21 (436.5 - 3772.2)	1879.75 (602.4 - 5865.4)	230.20 (113.0 - 469.0)*	871.6 (2.8 - 273842.0)	2643.63 (167.6 - 41706.1)	281.51 (169.0 - 469.0)*	1577.97 (488.0 - 5102.7)*	6434.28
Kroo Bay (outside area)	Hookworm	425.01 (176.1 - 1025.7)	449.99 (300 - 675)*	409.07 (42.1 - 3971.0)	409.07 (42.1 - 3971.0)	-	-	300.0	675.0
Kroo Bay (outside area)	*T. trichiura*	185.87 (121.7 - 283.8)	134.09 (76.5 - 234.9)	345.54 (209.0 - 571.3)	408.70 (145.3 - 1149.5)	229.19 (132.6 - 396.0)	146.76 (11.5 - 1873.3)	66.63 (21.2 - 209.4)	79.09 (37.6 - 166.3)
Kroo Bay (outside area)	*S. mansoni*	70.55 (38 -131)*	70.55 (38 -131)*		-	-	131	-	38
Kroo Bay (outside area)	*S. stercoralis*	497	-	497	497	-	-	-	-
Kroo Bay (non-targeted)	*T. trichiura*	267.30 (197.2 - 362.5)	317.83 (219.1 - 461.0)	168.46 (102.2 - 277.7)	281.64 (139.7 - 567.9)	334.27 (185.9 - 601.2)	118.80 (7.5 - 1892.3)	385.48 (181.2 - 820.0)	205.07 (122.8 - 342.6)
Rowollon (non-random)	*A. lumbricoides*	2789.97 (1017.2 - 7652.4)	1710.80 (45.6 - 64165.3)	4026.24 (1247.1 - 13001.7)	-	2789.97 (1017.2 - 7652.4))	-	-	-
Rowollon (non-random)	Hookworm	591.83 (330.1 - 1061.2)	670.50 (239.0 - 1881.0)	536.54 (244.3 - 1178.4)	-	591.83 (330.1 - 1061.2)	-	-	-
Foria (non-random)	*A. lumbricoides*	1097.49 (577.8 - 2084.5)	1253.43 (483.9 - 3246.4)	907.82 (300.8 - 2739.7)	1097.49 (577.8 - 2084.5)	-	-	-	-

* Range of values not the 95% confidence intervals.

Table 4.20. Numbers infected over number analysed for the data not used in analysis.

COMMUNITY	HELMINTH	OVERALL PREVALENCE	FEMALE	MALE	Age Class One	Age Class Two	Age Class Three	Age Class Four	Age Class Five
Kroo Bay (outside area)	*A. lumbricoides*	11/50	9/32	2/18	3/22	3/10	2/5	2/6	1/7
Kroo Bay (outside area)	Hookworm	5/50	2/32	3/18	3/22	0/10	0/5	1/6	1/7
Kroo Bay (outside area)	*T. trichiura*	29/50	19/32	10/18	8/22	10/10	3/5	5/6	3/7
Kroo Bay (outside area)	*S. mansoni*	2/50	2/32	0/18	0/22	0/10	1/5	0/6	1/7
Kroo Bay (outside area)	*S. stercoralis*	1/50	0/32	1/18	1/22	0/10	0/5	0/6	0/7
Kroo Bay (non-targeted)	*T. trichiura*	55/118	40/79	15/39	16/48	11/17	4/6	10/18	14/29
Rowollon (non-random)	*A. lumbricoides*	7/34	3/19	4/15	-	7/34	-	-	-
Rowollon (non-random)	Hookworm	25/34	11/19	14/15	-	25/34	-	-	-
Foria (non-random)	*A. lumbricoides*	17/42	10/23	7/19	17/42	-	-	-	-

Table 4.23. Comparisons to locate the difference between prevalence by age class.

Helminth and Community	Comparisons	Chi-square Value*	*P*
A. lumbricoides in Kroo Bay	4 vs. 1	0.21	$P > 0.05$
	4 & 1 vs. 5	1.73	$P > 0.05$
	4 & 1 & 5 vs. 3	5.02†	$P \leq 0.05$
	3 vs. 2	0.01	$P > 0.05$
A. lumbricoides in Rowollon	1 vs. 5	0.15	$P > 0.05$
	1 & 5 vs. 4	2.62	$P > 0.05$
	1 & 5 & 4 vs. 3	2.00	$P > 0.05$
	1 & 5 & 4 & 3 vs. 2	13.00‡	$P \leq 0.01$
Hookworm in Kroo Bay	1 vs. 4	7.54‡	$P \leq 0.01$
	4 vs. 5	0.51	$P > 0.05$
	4 & 5 vs. 2	0.27	$P > 0.05$
	4 & 5 & 2 vs. 3	2.60	$P > 0.05$
Hookworm in Rowollon	1 vs. 4	36.22‡	$P \leq 0.01$
	4 vs. 5	3.80	$P > 0.05$
	4 & 5 vs. 3	1.81	$P > 0.05$
	4 & 5 & 3 vs. 2	0.93	$P > 0.05$
Hookworm in Foria	1 vs. 4	67.82‡	$P \leq 0.01$
	4 vs. 2	0.02	$P > 0.05$
	4 & 2 vs. 3	0.67	$P > 0.05$
	4 & 2 & 3 vs. 5	0.21	$P > 0.05$
T. trichiura in Kroo Bay	1 vs. 5	5.87†	$P \leq 0.05$
	5 vs. 4	0.28	$P > 0.05$
	5 & 4 vs. 2	3.47	$P > 0.05$
	5 & 4 & 2 vs. 3	2.21	$P > 0.05$
T. trichiura in Rowollon	1 vs. 4	26.49‡	$P \leq 0.01$
	4 vs. 5	0.25	$P > 0.05$
	4 & 5 vs. 2	3.00	$P > 0.05$
	4 & 5 & 2 vs. 3	7.83†	$P \leq 0.05$
S. mansoni in Foria	1 vs. 2	1.96	$P > 0.05$
	1 & 2 vs. 5	3.81	$P > 0.05$
	1 & 2 & 5 vs. 3	16.00‡	$P \leq 0.01$
	3 vs. 4	1.00	$P > 0.05$

* The degrees of freedom for each of the comparisons is 1.

† Indicates where comparisons were found to be significantly different at $P \leq 0.05$.

‡ Indicates where comparisons were found to be significantly different at $P \leq 0.01$.

Table 4.29. Back-transformed means, 95% confidence intervals and numbers in each group for single, double and triple infection.

Helminth	Community	Single		Double		Triple	
		n	Mean (95% CI)	n	Mean (95% CI)	n	Mean (95% CI)
A. lumbricoides	Kroo Bay	13	472.5 (209 - 1070)	55	2115.9 (1423 - 3147)	31	3260.5 (1974 - 5386)
	Rowollon	9	656.5 (168 - 2566)	17	800.6 (479 - 1337)	64	2036.6 (1369 - 3030)
	Foria	25	2560.4 (1479 - 4432)	97	3033.9 (2302 - 3999)	9	1994.3 (819 - 4858)
Hookworm	Kroo Bay	9	188.5 (79 - 452)	44	213.2 (139 - 328)	31	195.7 (113 - 340)
	Rowollon	82	290.7 (217 - 390)	141	525.0 (423 - 651)	64	897.8 (691 - 1166)
	Foria	131	334.6 (258 - 433)	129	403.9 (321 - 508)	9	632.4 (229 - 1743)
T. trichiura	Kroo Bay	77	169.6 (128 - 224)	72	228.2 (171 - 304)	31	438.5 (287 - 646)
	Rowollon	14	68.9 (44 - 107)	131	82.3 (69 - 98)	64	126.3 (99 - 161)
S. mansoni	Foria	13	121.2 (57 - 260)	34	95.2 (61 - 150)	9	82.0 (25 - 270)

Table 4.43. Contrasts for the mean intensities of *A. lumbricoides* infection in Kroo Bay, by age of host.

	Age Classes					Statistics				
	Age One	Age Two	Age Three	Age Four	Age Five	Q	$\sum r_i c_i^2$	$Q^2 / \sum r_i c_i^2$	F	df
Numbers	27	23	14	14	21					
Sum	80.50	76.70	51.00	45.62	72.76					
Contrast	2	0	-1	0	-1	37.24	143	9.698	24.12*	1,89

* Table F (1,220): F .05 = 3.84; For 5-1 comparisons *post hoc* F.05 = 15.80.

Table 4.44. Contrasts for the mean intensities of hookworm infection in Kroo Bay, by sex of host.

						Statistics				
	Age One	Age Two	Age Three	Age Four	Age Five	Q	$\sum r_i c_i^2$	$Q^2 / \sum r_i c_i^2$	F	df
Numbers	13	19	15	15	22					
Sum	26.21	44.87	33.29	36.02	53.60					
Contrast	4	-1	-1	-1	-1	-62.94	279	14.20	41.76*	1,75

* Table F (1,75): F .05 = 3.95; For 5-1 comparisons *post hoc* F.05 = 19.75.

Table 4.45. Contrasts for the mean intensities of *T. trichiura* infection in Kroo Bay, by the interaction of sex and age of host.

	Groups										Statistics				
	F1	F2	F3	F4	F5	M1	M2	M3	M4	M5	Q	$\sum r_i c_i^2$	$Q^2 / \sum r_i c_i^2$	F	df
Numbers	27	19	17	30	24	15	18	9	3	8					
Sum	63.20	50.62	37.97	66.77	56.42	32.97	43.49	24.62	5.41	15.47					
Contrast 1	2	-3	-3	2	2	0	0	0	0	0	107.01	648	17.67	65.45*	df
96.63	0	0	0	0	0	2	-3	-3	2	2	96.63	347	26.91	99.66*	1,160
3	0	-1	1	0	0	0	0	0	0	0	-12.65	36	4.45	16.46*	1,160
4	0	0	0	0	0	0	1	-1	0	0	18.87	27	13.19	48.84*	1,160

Table F (1,160): F .05 = 3.88 For (5-1) x (2-1) comparisons *post hoc* F.05 = .15.52

Table 4.46. Contrasts for differences between the intensity of *T. trichiura* infection in Rowollon by sex and age of host.

	Age Classes					Sex		Statistics				
	Age One	Age Two	Age Three	Age Four	Age Five	Female	Male	Q	$\sum r_i c_i^2$	$Q^2 / \sum r_i c_i^2$	F	df
Numbers	35	50	54	46	48	129	101					
Sum	69.24	100.59	105.71	83.82	92.97	258.95	193.39					
Contrast	-	-	-	-	-	-1	1	65.57	230	18.69	97.86*	1,220
	2	-3	-3	2	2	-	-	126.85	1425	11.29	59.12*	1,220

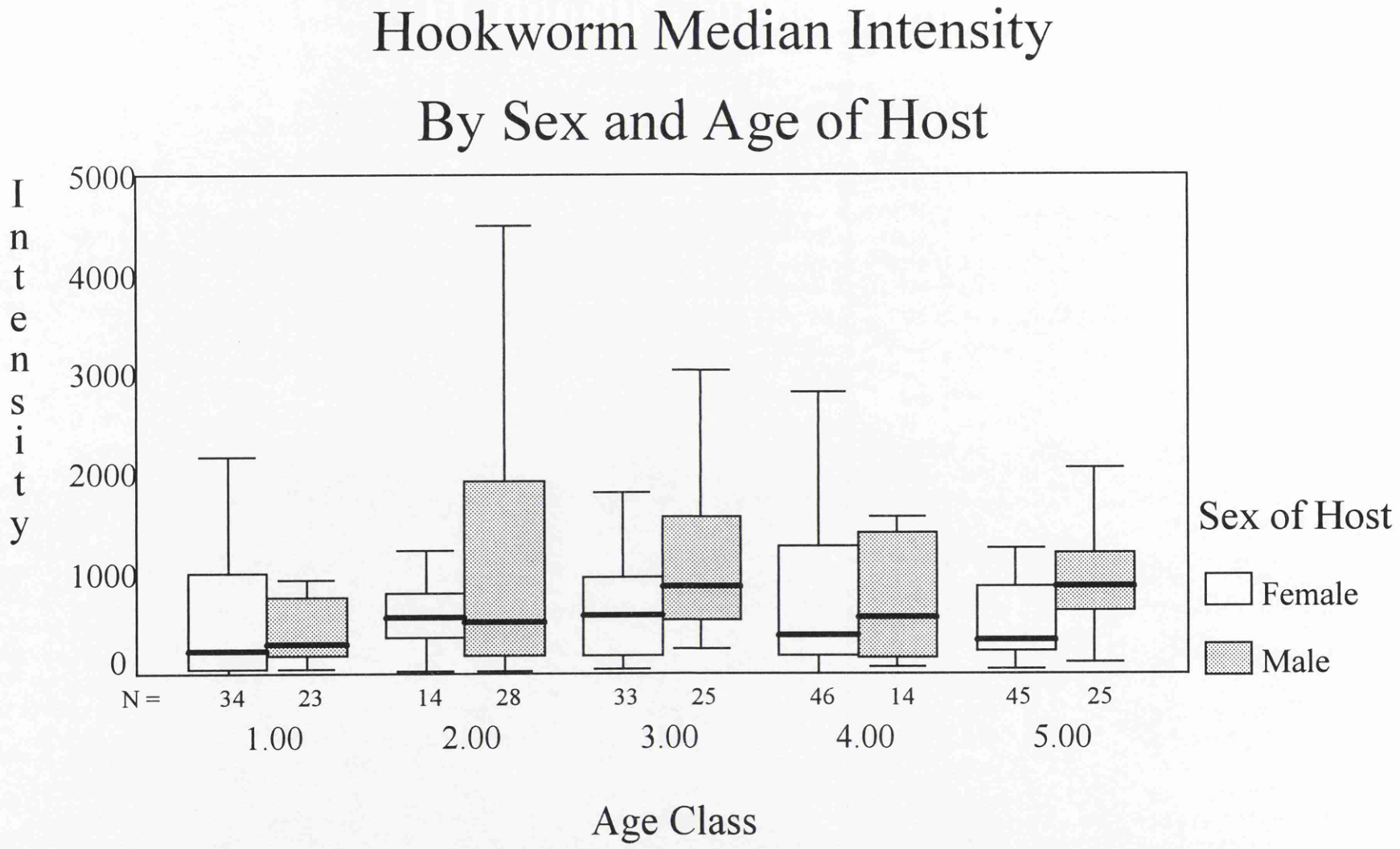
* Table F (1,220): F .05 = 3.84; For (5-1) comparisons *post hoc* F.05 = 15.80 or for (2-1) comparisons *post-hoc* F .05 = 3.84.

Table 4.47. Contrasts for the mean intensities of hookworm infection in Foria, by age of host.

	Age Classes					Statistics				
	Age One	Age Two	Age Three	Age Four	Age Five	Q	$\sum r_i c_i^2$	$Q^2 / \sum r_i c_i^2$	F	df
Numbers	26	60	75	81	36					
Sum	53.55	146.85	196.50	217.73	94.02					
Contrasts	4	-1	-1	-1	-1	-440.9	668	291.01	810.61*	1,268
	0	-1	0	1	0	70.88	141	35.63	99.25*	1,268

* Table F (1,268): F .05 = 3.84; For 5-1 comparisons *post hoc* F.05 = 15.80.

Figure 4.1. Median hookworm intensity (EPG) by age class for males and females found to be infected in Rowollon and the inter-quartile ranges. Males in age classes 3 and 5 have significantly higher medians than males in age classes 1, 2 and 4.


Hookworm Median Intensity
By Sex and Age of Host
Intensity
5000
4000
3000
2000
1000
0
N =
34
23
14
28
33
25
46
14
45
25
1.00
2.00
3.00
4.00
5.00
Age Class
Sex of Host
Female
Male

Chapter Five. Analyses of Prevalence and Intensity of Gastrointestinal Helminth Infections: Combination of All Measured Factors Associated With Infection.

5.1. Introduction

In Chapter Four, the effects of factors on the prevalence and intensity of helminth infections in the three communities in Sierra Leone were investigated separately. In this chapter an attempt is made to combine the factors of age, sex, area in which individuals live and number of individuals in a household to develop models of intensity and prevalence of helminth infections. By combining these components together it is hoped that an overall picture of infection will appear, to enable health care workers to design better helminth control programmes. In Chapter Three it was shown that not all factors were equally sampled within the survey population, *i.e.* the ratio of females to males sampled in the higher age classes in Kroo Bay was higher than expected. An unrepresentative sampling of one sex and/or age classes may have influenced the overall helminth intensity found in this sample if one or the other group had higher intensity of infections and this should be borne in mind when interpreting the results of the surveys.

5.2. Materials and Methods

Intensity of helminth infections was investigated first using multiple regression to determine if there were any significant relationships between increasing age of host or numbers of individuals in a household and intensity of infections. Three different curves, linear, polynomial and logarithmic, were tested to determine how well they described the relationship between age and household size and intensity of helminth infection. Then combinations of the curves for age and households size were investigated. The line that best fit the data (had the lowest P value) was then used in covariance analysis as the regression line or covariate. Covariance analysis is used here to separate out the noise of any effect due to age of host or size of the host's household and determine if other effects are associated with differences in intensity of infection (Tabachnick and Fidell, 1989). This allowed the other factors, of sex of host and area in which the host lived, to be included in the model. The residuals from the regression lines were checked for normality using normal probability plots. In the covariance analysis, Cochran's C and Bartlett's B tests were done to check homogeneity of variances.

Prevalence of helminth infections in the different communities was modelled using logistic regression (Hosmer and Lemeshow, 1989; Norusis and SPSS Inc., 1990a). Logistic regression is a multivariate technique for estimating the probability of whether an event will occur or not. In this case the event that is of interest is infection with a certain helminth species. In logistic regression, the

parameters associated with an event happening are selected from all those entered into the analysis. The equation that results from logistic regression allows for the interpretation of the probability of an event occurring based on an individual's values for the relevant parameters.

In order to build a model and test a model using logistic regression, it is necessary to have both a set of data to generate the model and one to test the ability of the model to predict an event taking place. To do this the survey population was split randomly into two groups, with one half being used to generate the model and the other being used to test the model. Forward elimination using the Wald statistic was used to generated the models. The predicted probabilities of being infected were saved and the number of individuals found to be infected and uninfected with each percentile of predicted probabilities was recorded. The model generated would allow health workers to determine what percentage of the population would have to be treated in order to reach a certain percentage of individuals predicted to be infected with the helminth in question. All of the analysis for this was completed on SPSS for Windows, Version 4.01.

5.3. Modelling Helminth Intensity Using Multiple Regression

Regression analysis of the logarithmic transformations of the intensities of *A. lumbricoides*, hookworm (*N. americanus*) and *T. trichiura* was carried out, using the two continuous variables that were measured in this survey; number of individuals in a household and age of host. This was done to find the best fitting curve to describe the relationship between these variables and helminth intensity (EPG). Simple linear curves were tested, as well as polynomial and logarithmic curves. The results of these and the equations for the lines are presented in Table 1 in Appendix II. As well as describing the intensity in relation to these variables individually, the intensity was also examined using both of the variables, to determine if the combination of the two variables explained more of the variation in the intensity data than one of them on its own. Results of these are presented in Tables 3 and 4, Appendix II, for *A. lumbricoides*, Table 5 and 6, Appendix II for hookworm infections and Table 7 and 8, Appendix II, for *T. trichiura* and *S. mansoni* infections. The equations that showed the lowest *P* values for the age and number data separately, for each helminth infection are presented in Table 5.1 and Table 5.2. The equations that showed the lowest *P* values for the combination of the two variables of age and number of individuals in each household are presented in Table 5.3.

Scatter graphs of the intensity data (EPG) are presented in Figures 5.1 to 5.10 for the regression lines in Tables 5.1 to 5.3 that were found to be statistically significant. The equations for regression lines that showed the lowest *P* values (either the most highly significant, $P \leq 0.05$ or the closest thing to significance) were used in covariance analysis with the two categorical variables that were measured on the individuals in the survey, *i.e.* their sex and the location within the community in which they lived.

These results indicate that, for the data on the age of host, *A. lumbricoides* intensity is best described by a curve using the logarithm of the age of the host in both Kroo Bay and Rowollon. In Foria, a polynomial curve using age, age squared and the cube of the host's age best describes the distribution of intensity by host age. It should be pointed out that the only regression equation of these three to be statistically significant ($P \leq 0.05$) is that of *A. lumbricoides* in Kroo Bay (Figure 5.1), and this regression line explained only 3.3% of the variance in the intensity data. Hookworm intensity, investigated with regards to the age of the host, showed the best fit using the logarithm of the age for all three communities. This was found to be significant in Rowollon and Foria, not Kroo Bay. In Rowollon (Figure 5.2), this regression equation explained only 2.5% of the data while in Foria (Figure 5.3) the regression equation explained 5.9% of the data. *Trichuris trichiura* intensity was best described by a polynomial curve containing the age of host, the square of the age and the cube of the age, in Kroo Bay and Rowollon. Neither of these regression equations was found to be statistically significant. The equation of best fit for *S. mansoni* intensity by age was a polynomial including the age of host, the square of the age and the cube of the age. This was not found to be statistically significant however.

Table 5.1. Types of equations which best describe helminth infection intensity (EPG) in relation to age of hosts .

Helminth	Community	Best Type of Equation	F Value	df	*P*	Adjusted r^2
A. lumbricoides	Kroo Bay	Logarithmic	4.42885	1,97	0.0379	0.03381
	Rowollon	Logarithmic	1.43508	1,88	0.2342	0.00486
	Foria	Polynomial	2.25129	3,127	0.0856	0.02807
Hookworm	Kroo Bay	Logarithmic	2.97775	1,82	0.0882	0.02327
	Rowollon	Logarithmic	8.19880	1,285	0.0045	0.02455
	Foria	Logarithmic	18.43051	1,276	0.00001	0.05920
T. trichiura	Kroo Bay	Polynomial	1.27868	3,166	0.2834	0.00492
	Rowollon	Polynomial	1.93853	3,226	0.1242	0.01215
S. mansoni	Foria	Polynomial	0.44196	3,54	0.7239	-0.03026

In the analysis of the intensity for the number of people living in the host's household (Table 5.2), it can be seen that for A. *lumbricoides*, a regression equation including the logarithm of the number of individuals is the line of best fit for the data from Kroo Bay and Foria. A simple regression equation, with just the number in each household, describes the intensity data from Rowollon better. The only equation to be statistically significant is that for the data from people living in Foria, where the regression equation is seen to explain almost 7% of the variation in the intensity data (Figure 5.4).

Table 5.2. Types of equations which best describe helminth infection intensity (EPG) in relation to number of hosts in households

Helminth	Community	Type of Equation	F value	df	*P*	Adjusted r^2
A. lumbricoides	Kroo Bay	Logarithmic	0.35703	1,69	0.5521	-0.00927
	Rowollon	Simple	1.05799	1,88	0.3065	0.00065
	Foria	Logarithmic	10.37754	1,124	0.0016	0.06979
Hookworm	Kroo Bay	Polynomial	0.87152	3,57	0.4613	-0.00647
	Rowollon	Polynomial	1.73892	3,283	0.1592	0.00769
	Foria	Polynomial	1.70895	3,258	0.1656	0.00808
T. trichiura	Kroo Bay	Simple	1.66335	1,168	0.1989	0.00391
	Rowollon	Polynomial	0.57230	3,226	0.6338	-0.00563
S. mansoni	Foria	Simple	1.53871	1,52	0.2204	0.01006

In all three communities, the hookworm intensity is best explained by a polynomial curve including the number of people in a household and the square and cube of this. However none of these were seen to be statistically significant. For the data on the intensity of *T. trichiura* infections, in Kroo Bay, the equation that showed the lowest *P* value was a simple line containing only the numbers of people living in a household. For *T. trichiura* infection in Rowollon, the equations that showed the lowest *P* values was a polynomial containing the number of people in a household, the square and the cube of this. In Foria, *S. mansoni* infection intensity was best described using a simple equation with only the number of individuals in each household. However, none of these was statistically significant.

The equations that showed the lowest *P* values, when the effects of both host age and the number of people in a household were combined, are presented in Table 5.3. The *A. lumbricoides* intensity was best explained by a combination of the logarithm of the age and the logarithm of the number of people in the household in both Kroo Bay and Foria. In Rowollon, the equation that showed the lowest *P* values used the logarithm of the age and the number of people in each

household. The only one of these to be statistically significant was the equation for the people living in Foria, where the regression line explained 8.7% of the variation in the data (Figures 5.5 and 5.6).

Table 5.3. Types of equations which best describe helminth infection intensity (EPG) in relation to a combination of age of host and number of hosts in households.

Helminth	Community	Age Equation	Number Equation	F value	df	*P*	Adjustedr^2
A. lumbricoides	Kroo Bay	Logarithmic	Logarithmic	1.801	2,68	0.1728	0.02239
	Rowollon	Logarithmic	Simple	0.987	2,87	0.3767	-0.00028
	Foria	Logarithmic	Logarithmic	7.006	2,123	0.0013	0.08768
Hookworm	Kroo Bay	Simple	Polynomial	0.946	4,56	0.4441	-0.00359
	Rowollon	Logarithmic	Polynomial	3.202	4,282	0.0136	0.02989
	Foria	Logarithmic	Logarithmic	4.668	2,259	0.0102	0.02735
T. trichiura	Kroo Bay	Polynomial	Simple	1.436	4,165	0.2240	0.01023
	Rowollon	Polynomial	Simple	1.590	4,225	0.1777	0.01021
S. mansoni	Foria	Polynomial	Simple	1.544	4,49	0.2039	0.03950

Hookworm intensity was best described in those people living in Kroo Bay by an equation including the age of the host and a polynomial curve consisting of the number of individuals in a household, the square and the cube of the number in a household. For those individuals living in Rowollon, the hookworm intensity was best described by an equation including the logarithm of the age of the host and a polynomial curve for the numbers living in a household. The hookworm intensity in people living in Foria was best described by an equation including the logarithms of both age and the number of individuals in a household. These regression equations were found to be significant in Rowollon (Figures 5.7 and 5.9) and in Foria (Figures 5.9 and 5.10), where they explained about 3% and 2.7%, respectively, of the variation in the intensity of hookworm. The *T. trichiura* intensity data was best described in both Kroo Bay and Rowollon by an equation containing a polynomial curve of the age of host and a simple curve of the number of people living in the households. Neither of these were found to be statistically significant. For the *S. mansoni* infection intensity in Foria, the equation that showed the lowest *P* value was one combining a polynomial curve for the age of hosts and a simple curve for the number of individuals in a household, but the fit was found not to be statistically significant.

5.4. Covariance Analysis

Covariance analysis combined with a two-way analysis of variance was attempted to determine the overall influence of all of these factors on helminth intensity. The two factors in the analysis of variance were sex and location, with age and number of people in the household being the

covariates. In covariance analysis, the slopes of the regression lines are first investigated to determine if they differ in their slopes. If they do, no further analysis of their elevations is possible. If they do not differ in their slopes, the elevations of the regression lines can then be investigated to determine if there are differences in groups, taking into account differences in covariates. In addition to this Cochran's C and Bartlett's Box tests were used to determine if the groups being compared differed in their variances. The results of these are presented in Tables 9 and 10, Appendix II.

5.4.1. *Ascaris lumbricoides*

5.4.1a. Kroo Bay

The regression line that showed the highest significance for *A. lumbricoides* intensity in Kroo Bay was that of the logarithm of the age. This was used as the covariate in covariance analysis. *Ascaris lumbricoides* intensity showed no significant variation in the slopes of the logarithm of the age by sex of infected individual (Table 5.4) or by the area of Kroo Bay in which the individual lived. This allowed the comparison of the differences in elevation of the regression lines.

However, no significant effect of the covariate on the intensity of *A. lumbricoides* infections by age and area in which people lived was found (Table 5.4) although the *P* value was close to being significant. Significant differences were seen in the intensity of *A. lumbricoides* infections which were due to the area of Kroo Bay in which hosts lived. There was no difference found between male and female hosts in their intensity of *A. lumbricoides* when analysed in this manner. Figure 5.11 displays the relationship between the intensity of *A. lumbricoides* by age in the different areas. Hosts living in area 1 had higher intensities, regardless of their age than those living in area 2.

Table 5.4. Results of analysis of covariance of age of host, sex of host and area of the community in which an individual lived on the intensity (EPG) of *A. lumbricoides* infections in Kroo Bay.

Differences Tested	F Value	df	*P*
Slopes of Intensity by Logarithm of Age for the Different Sexes	0.76	1, 92	$P \leq 0.386$
Slopes of Intensity by Logarithm of Age for the Different Areas	0.72	1, 92	$P \leq 0.397$
Significance of Regression Line for Logarithm of Age	3.19	1, 94	$P \leq 0.077$
Interaction of Sex of Host and Area	1.63	1,94	$P \leq 0.205$
Main Effect of Sex of Host	1.10	1,94	$P \leq 0.297$
Main Effect of Area	8.32	1,94	$P \leq 0.005$

5.4.1b. Rowollon

The covariate used in the covariance analysis of *A. lumbricoides* intensity in hosts living in Rowollon was the logarithm of the age of host. The slopes of the logarithm of the age of host were

not found to differ between the different sexes of host or between the different areas of the community where the hosts lived (Table 5.5). The regression line of the logarithm of the age was not statistically significant, nor were there any differences seen between the sexes or areas of the community in the intensity of *A. lumbricoides* infection.

Table 5.5. Results of analysis of covariance of age of host, sex of host and area of the community in which an individual lived on the intensity (EPG) of *A. lumbricoides* infections in Rowollon.

Differences Tested	F Value	df	*P*
Slopes of Intensity by Logarithm of Age for the Different Sexes	0.17	1,83	$P \leq 0.678$
Slopes of Intensity by Logarithm of Age for the Different Areas	0.02	1,83	$P \leq 0.889$
Significance of Regression Line for Logarithm of Age	1.94	1,85	$P \leq 0.167$
Interaction of Sex of Host and Area	0.93	1,85	$P \leq 0.337$
Main Effect of Sex of Host	2.68	1,85	$P \leq 0.105$
Main Effect of Area	0.20	1,85	$P \leq 0.653$

5.4.1c. Foria

The lowest *P* value for a regression line for the intensity of *A. lumbricoides* in Foria was that for the curve of the logarithm of the host's age combined with the logarithm of the number of individuals in the host's household. This was combined and used as the covariate in covariance analysis (Table 5.6).

Table 5.6. Results of analysis of covariance of age of host, number of people living in the house with an individual, sex of host and area of the community in which an individual lived on the intensity (EPG) of *A. lumbricoides* infections in Foria.

Differences Tested	F Value	df	*P*
Slopes of Intensity by Logarithm of Age for the Different Sexes	1.20	1,116	$P \leq 0.275$
Slopes of Intensity by Logarithm of Number of Individuals in House for the Different Sexes	0.00	1,116	$P \leq 0.998$
Slopes of Intensity by Logarithm of Age for the Different Areas	1.11	1,116	$P \leq 0.295$
Slopes of Intensity by Logarithm of Number of Individuals in House for the Different Areas	0.13	1,116	$P \leq 0.716$
Significance of Regression Line for Logarithm of Age and Logarithm of Number of Individuals in House	6.94	2,120	$P \leq 0.001$
Interaction of Sex of Host and Area	0.63	1,120	$P \leq 0.430$
Main Effect of Sex of Host	0.27	1,120	$P \leq 0.606$
Main Effect of Area	0.39	1,120	$P \leq 0.533$

This analysis indicated a significant effect due to the regression line as illustrated in Figures 5.5 and 5.6. There were no differences in the elevation of the slopes between the different levels of sex or area for the two components of the regression line. There were also no significant differences found between the interaction of sex and area or between the two areas or sexes in their intensity of *A. lumbricoides*.

5.4.2. Hookworm

5.4.2a. Kroo Bay

The logarithm of the age was used as the covariate in the analysis of the hookworm intensity in hosts living in Kroo Bay. The slopes of the logarithm of age did not differ significantly between the different sexes (Table 5.7) or between the different areas of Kroo Bay where the hosts lived.

Table 5.7. Results of analysis of covariance of age of host, sex of host and area of the community in which an individual lived on the intensity (EPG) of hookworm infections in Kroo Bay.

Differences Tested	F Value	df	*P*
Slopes of Intensity by Logarithm of Age for the Different Sexes	1.74	1,77	$P \leq 0.192$
Slopes of Intensity by Logarithm of Age for the Different Areas	0.41	1,77	$P \leq 0.524$
Significance of Regression Line for Logarithm of Age	4.23	1,79	$P \leq 0.043$
Interaction of Sex of Host and Area	0.18	1,79	$P \leq 0.670$
Main Effect of Sex of Host	3.81	1,79	$P \leq 0.054$
Main Effect of Area	0.00	1,79	$P \leq 0.947$

Hookworm intensity showed a significant covariate effect of the logarithm of age. Females and males were almost significantly different in their hookworm intensities when analysed in this manner, with a *P* value very close to $P \leq 0.05$. This is illustrated in Figure 5.12. However, there were no significant differences in the intensity of hookworm infections due to the area in which a host lived, when host age was taken into consideration.

5.4.2b. Rowollon

The lowest *P* value for a regression line for hookworm intensity in Tables 5.1 to 5.3 was for that of the logarithm of the age of host. This was used as the covariate in covariance analysis of the intensity of infections with this helminth (Table 5.8).

Table 5.8. Results of analysis of covariance of age of host, sex of host and area of the community in which an individual lived on the intensity (EPG) of Hookworm infections in Rowollon.

Differences Tested	F Value	df	*P*
Slopes of Intensity by Logarithm of Age for the Different Sexes	0.36	1,280	$P \leq 0.549$
Slopes of Intensity by Logarithm of Age for the Different Areas	1.98	1,280	$P \leq 0.161$
Significance of Regression Line for Logarithm of Age	11.24	1,282	$P \leq 0.001$
Interaction of Sex of Host and Area	0.24	1,282	$P \leq 0.628$
Main Effect of Sex of Host	12.22	1,282	$P \leq 0.001$
Main Effect of Area	0.01	1,282	$P \leq 0.927$

The slopes of the relationship between age and intensity were not found to be significantly different, but the regression line for age of host was significant and the sexes differed in their intensities, even when differences in intensity due to the age of host were taken into account (Figure 5.13). There were

no significant differences between hosts living in the different areas of the community in their mean intensity of hookworm infection.

5.4.2c. Foria

The regression line which showed the lowest *P* value for the intensity of hookworm in Foria was that of the logarithm of the age of host. This was used as the covariate in covariance analysis. The slopes of the regression lines for logarithm of host age were not significantly different between males and females or between hosts living in the different areas. This allowed for the elevation of the slopes in these categories to be compared to one another. No significant differences in hookworm intensity were found in the interaction of sex of host and area in which the host lived. No significant differences were found between males and females or between those living in area 1 versus area 2 in their intensity of hookworm (Table 5.9).

Table 5.9. Results of analysis of covariance of age of host, sex of host and area of the community in which an individual lived on the intensity (EPG) of hookworm infections in Foria.

Differences Tested	F Value	df	*P*
Slopes of Intensity by Logarithm of Age for the Different Sexes	0.21	1,255	$P \leq 0.645$
Slopes of Intensity by Logarithm of Age for the Different Areas	0.48	1,255	$P \leq 0.490$
Significance of Regression Line for Logarithm of Age	10.67	1,257	$P \leq 0.001$
Interaction of Sex of Host and Area	0.65	1,257	$P \leq 0.422$
Main Effect of Sex of Host	1.22	1,257	$P \leq 0.271$
Main Effect of Area	0.65	1,257	$P \leq 0.422$

5.4.3. *Trichuris trichiura*

5.4.3a. Kroo Bay

The regression line used for the analysis of *T. trichiura* intensity was the number of individuals in the household where a host lived, as this was shown to be the regression line with the lowest *P* value. The slopes of the regression lines for the number of individuals per household between the levels of sex and area were not found to be significantly different (Table 5.10).

Table 5.10. Results of analysis of covariance of number of people living in the house with an individual, sex of host and area of the community in which an individual lived on the intensity (EPG) of *T. trichiura* infections in Kroo Bay.

Differences Tested	F Value	df	*P*
Slopes of Intensity by # in Households for the Different Sexes	0.00	1,163	$P \leq 0.946$
Slopes of Intensity by # in Households for the Different Areas	0.01	1,163	$P \leq 0.943$
Significance of Regression Line for # in Households	3.17	1,165	$P \leq 0.077$
Interaction of Sex of Host and Area	0.19	1,165	$P \leq 0.668$
Main Effect of Sex of Host	0.24	1,165	$P \leq 0.623$
Main Effect of Area	2.61	1,165	$P \leq 0.108$

Trichuris trichiura showed an almost significant covariate effect number of people in the household. Neither sex and nor location were significantly different in their intensities when the number of individuals in each household were taken into account.

5.4.3b. Rowollon

The regression line that showed the lowest *P* value for the intensity of *T. trichiura* in Rowollon was that of a polynomial curve of age of host. This was used as the covariate in covariance analysis of the intensity of infection with this helminth (Table 5.11). The regression line of the polynomial curve for age was not significant, but the hosts living in different areas were found to differ significantly in their intensity of infections with *T. trichiura* (Figure 5.14). This was shown before, where it was seen that hosts living in area 1 had more intense infection of this helminth.

Table 5.11. Results of analysis of covariance of age of host, sex of host and area of the community in which an individual lived on the intensity (EPG) of *T. trichiura* infections in Rowollon.

Differences Tested	F Value	df	*P*
Slopes of Intensity by the Polynomial Age for the Different Sexes	2.89	1,223	$P \leq 0.091$
Slopes of Intensity by the Polynomial Age for the Different Areas	2.66	1,223	$P \leq 0.104$
Significance of Regression Line for the Polynomial Age	0.11	1,225	$P \leq 0.745$
Interaction of Sex of Host and Area	1.07	1,225	$P \leq 0.301$
Main Effect of Sex of Host	2.99	1,225	$P \leq 0.085$
Main Effect of Area	5.95	1,225	$P \leq 0.016$

5.4.4. *Schistosoma mansoni*

The regression line which was used for the covariate in the analysis of *S. mansoni* intensity was that of a combination of a polynomial of the age of the host and a simple curve of the number of individuals living in the host's household (Table 5.12). The slopes of these were not found to differ between the two sexes of the hosts or between individuals living in area 1 versus 2.

Table 5.12. Results of analysis of covariance of age of host, sex of host and area of the community in which an individual lived on the intensity (EPG) of *S. mansoni* infections in Foria.

Differences Tested	F Value	df	*P*
Slopes of Intensity by the Polynomial of the Age of Host for the Different Sexes	2.76	1,44	$P \leq 0.104$
Slopes of Intensity by Number of Individuals Living in the Same House as the Host for the Different Sexes	1.05	1,44	$P \leq 0.312$
Slopes of Intensity by the Polynomial of the Age of Host for the Different Areas	2.76	1,44	$P \leq 0.104$
Slopes of Intensity by Number of Individuals Living in the Same House as the Host for the Different Areas	1.07	1,44	$P \leq 0.306$
Significance of Regression Line for the Polynomial of the Age of Host & Number of Individuals Living in Same House as the Host	0.54	2,48	$P \leq 0.586$
Interaction of Sex of Host and Area	3.14	1,48	$P \leq 0.083$
Main Effect of Sex of Host	1.03	1,48	$P \leq 0.314$
Main Effect of Area	1.52	1,48	$P \leq 0.224$

No significant effect was seen from the analysis of the covariate, the interaction of the sex of host and the area in which the host lived, or the main effects of sex of host and area in which the host lived.

5.5. Model Building Using Logistic Regression

Stepwise logistic regression was used to determine the factors important in being infected with a certain helminth species and the factors important in any helminth infection. The models generated should be judged on both the number of individuals correctly identified as infected when they were in fact infected, and the proportion of the overall intensity of those infected placed in the uninfected group. If the goal of this analysis is to determine groups for targeted treatment within a village, then the cost of the treatment must be weighed against the cost of not treating individuals when they are in fact infected. The total sample was divided into two groups, with individuals assigned randomly to one of these two groups. The first group was used to construct a model of the prevalence of the helminths and give coefficients for each of the factors included in the model. The second group was used to test the model generated on the first group, in order to determine how well it predicted prevalence of the helminth infections under consideration.

Predicted values for each individual are generated from the model, giving the probability of being infected for each individual. The percentile breakdown for each of the models is reported, with information on how many infected and uninfected individuals are in each percentile. This can serve as a guide for targeted treatment of groups based on these models of prevalence. A health care worker with limited resources can then decide, based on these models, what proportion of the population she or he can afford to give treatment to and have some ides how effective this treatment will be, *i.e.* what

percentage of the total numbers infected the treatment would reach and how many uninfected people would be treated unnecessarily. Spearman rank correlation between predicted probabilities and intensity of infection was also completed. A significant correlation between predicted values and intensity would indicate that those found to be most highly infected would have high probabilities of being infected according to the model and treating those with high probabilities of being infected would remove those individuals spreading the most infective stages into the environment from the infected population.

The variables investigated were: the age of an individual, sex of an individual, logarithm of the age of an individual, the square of the age of an individual, the cube of the age of an individual, the number of individuals in the household the logarithm of the number of individuals in a household, the square of the number of individuals in a household, the cube of the number of individuals in a household and the location of the house within the community studied.

5.5.1. *Ascaris lumbricoides* Models

5.5.1a. Kroo Bay

Initial logistic regression of *A. lumbricoides* prevalence indicated that the important factors in predicting infection with this helminth were the location of an individual's household within Kroo Bay and the logarithm of the individual's age. The sample was then randomly divided into two, with a predictive model being generated from 148 individuals of which 40 (27.0%) were infected with *A. lumbricoides* and 1087 were not, similar to the prevalence of 25.5% for the entire sample. The model equation included the logarithm of an individual's age. The equation was Z = -1.5489 + 0.5827 (logarithm of an individual's age), where: $1/(1+e^{-Z})$ equals the probability of being infected with *A. lumbricoides* in Kroo Bay. Percentiles of probabilities are presented in Table 5.13 with number of individuals who are infected in each of the 10% intervals reported as well. They provide a tool for health care workers working within Kroo Bay and similar areas to use for choosing groups to target in selected treatment regimes. This model did not predict any individuals to have over 50% of a chance of being infected with *A. lumbricoides*, either in the group for which the model was generated for or in the group on which it was tested.

Table 5.13. Percentiles of predicted probabilities of being infected with *A. lumbricoides* in Kroo Bay from the generated model.

Percentiles	Probabilities	Number Infected	Percent of Infected	Number Uninfected	Percent of Total Sample
> 0.90	> 0.373	10	10.1	27	9.8
0.90 - 0.80	0.373 - 0.351	10	10.1	23	8.7
0.80 - 0.70	0.351 - 0.332	8	8.1	35	11.3
0.70 - 0.60	0.332 - 0.293	10	10.1	28	10.0
0.60 - 0.50	0.293 - 0.265	17	17.2	17	9.0
0.50 - 0.40	0.265 - 0.242	17	17.2	36	14.0
0.40 - 0.30	0.242 - 0.224	7	7.1	20	7.1
0.30 - 0.20	0.224 - 0.197	15	15.2	23	10.0
0.20 - 0.10	0.197 - 0.169	4	4.0	28	8.4
< 0.10	< 0.169	1	1.0	43	11.6

A scatter graph of predicted probabilities versus age, the factor shown to be important in this analysis, was constructed to demonstrate the relationship between age and the probability of being infected with *A. lumbricoides* in Kroo Bay (Figure 5.15). From Figure 5.15 it can be seen that this model predicts increasing probability of being infected with *A. lumbricoides* with increasing age.

5.5.1b. Rowollon

The Rowollon sample of 431 individuals was split into two at random. The model was generated on 219 individuals, of which 45 (20.5%) were found to have been infected with A. lumbricoides. The model generated from this analysis was tested on the remaining 212 individuals, of which 45 (21.2%) were found to have been infected. The model correctly predicted only 13.33% of those found to be infected but correctly predicted 97.13% of those found to be uninfected in the sample used to generate the model. In the sample used to test the model, it again only predicted 13.33% of those found to be infected correctly but again was better at predicting those who were uninfected (94.61%). The model generated was Z = -7.0189 + 18.8417 (logarithm of an individual's age) -1.4746 (age of individuals) + 0.0320 (age squared) - 0.0003 (age cubed), where: $1/(1+e^{-Z})$ equals the probability of being infected with *A. lumbricoides* in Rowollon. From this it appears that the model works best at predicting those found to be uninfected, with relatively little success at predicting those that are infected with *A. lumbricoides*. If, however, a health care worker was to treat those with a predicted probabilities greater than that defining the upper 50% of the number infected (Table 5.14) this would result in 51.1 % of the infected individuals being treated, with only 33.2% of the total sample being treated.

Table 5.14. Percentiles of predicted probabilities of being infected with *A. lumbricoides* in Rowollon from the model generated.

Percentiles	Probabilities	Number Infected	Percent of Infected	Number Uninfected	Percent of Total Sample
> 0.90	> 0.467	18	20.0	25	10.0
0.90 - 0.80	0.467 - 0.342	14	15.6	33	10.9
0.80 - 0.70	0.342 - 0.275	10	11.1	23	7.7
0.70 - 0.60	0.275 - 0.254	4	4.4	16	4.6
0.60 - 0.50	0.254 - 0.205	15	16.7	55	16.2
0.50 - 0.40	0.205 - 0.174	8	8.9	38	10.7
0.40 - 0.30	0.174 - 0.102	15	16.7	56	16.5
0.30 - 0.20	0.102 - 0.015	4	15.6	46	11.6
0.20 - 0.10	0.015 - 0.003	0	0.0	7	1.6
< 0.10	< 0.003	2	2.2	42	10.2

Figure 5.16 illustrates the change in predicted probabilities for change in age.

5.5.1c. Foria

The model generated for predicting *A. lumbricoides* infection in those individuals sampled in Foria was generated on 196 individuals selected from the 408 in the sample at random. This sample included 70 (35.7%) found to be infected with *A. lumbricoides*. The model generated was tested on the remaining 201 in the Foria sample, of which 56 (27.9%) were found to be infected. The model failed to successfully predict any individuals as being infected with *A. lumbricoides*. The model equation was Z = -0.4022 - 0.0000099 (an individual's age cubed), where: $1/(1+e^{-Z})$ equals the probability of being infected with *A. lumbricoides* in Foria. Control measures can be planned by using the model for selection and Table 5.15 to determine both what proportion of the infected population would be treated and what proportion of the total population would be treated. Figure 5.17 illustrates the change in predicted probability by the change in age of possible host.

Table 5.15. Percentiles of predicted probabilities of being infected with *A. lumbricoides* in Foria from the model generated.

Percentiles	Probabilities	Number Infected	Percent of Infected	Number Uninfected	Percent of Total Sample
0.80 - 0.70	> 0.400	41	32.5	80	30.5
0.70 - 0.60	0.400 - 0.398	19	15.1	24	10.8
0.60 - 0.50	0.398 - 0.393	7	5.6	21	7.1
0.50 - 0.40	0.393 - 0.387	17	13.5	25	10.6
0.40 - 0.30	0.387 - 0.364	17	13.5	31	12.1
0.30 - 0.20	0.364 - 0.326	5	4.0	25	7.6
0.20 - 0.10	0.326 - 0.261	15	11.9	38	13.4
< 0.10	< 0.261	5	4.0	27	8.1

5.5.2. Hookworm Models

5.5.2a. Kroo Bay

The sample was again divided into two, at random, to generate a model to predict which individuals were infected with hookworm. The model was generated using 136 people and 125 people to compare the predictive power of this model. The model failed to predict correctly any individuals that were found to be infected. It performed better in the testing sample on predicting infected individuals correctly (21.74% versus 2.63%) than in the sample for which it was generated. Factors shown to be important in the prevalence of hookworm infection in Kroo Bay were the logarithm of the age of an individual, the area in which an individual lived, and the age of an individual. The equation was Z = -2.6970 - 0.0563 (an individual's age) + 2.7534 (logarithm of an individual's age). Again $1/(1+e^{-Z})$ equals the probability of being infected, this time with hookworm, in Kroo Bay. Percentile breakdowns of the predicted probabilities of having hookworm infections for the individuals surveyed are presented in Table 5.16. As age was seen to be a major contribution to the distribution of hookworm prevalence in Kroo Bay, a scatter graph of the predicted values versus age of individuals is presented in Figure 5.18. It can be seen that the probability of infection with hookworm increases with the age of an individual and then decreases with age.

Table 5.16. Percentiles of predicted probabilities of being infected with hookworm in Kroo Bay from the generated model.

Percentiles	Probabilities	Number Infected	Percent of Infected	Number Uninfected	Percent of Total Sample
> 0.90	> .0.425	7	8.3	29	9.5
0.90 - 0.80	0.425 - 0.397	10	11.9	31	10.8
0.80 - 0.70	0.397 - 0.360	15	17.9	15	7.9
0.70 - 0.60	0.360 - 0.302	15	17.9	33	12.7
0.60 - 0.50	0.302 - 0.258	11	13.1	33	11.6
0.50 - 0.40	0.258 - 0.213	11	13.1	17	7.4
0.40 - 0.30	0.213 - 0.166	9	10.7	31	10.6
0.30 - 0.20	0.166 - 0.102	3	3.6	33	9.5
0.20 - 0.10	0.102 - 0.049	3	3.6	29	8.4
< 0.10	< 0.049	0	0.0	44	11.6

5.5.2b. Rowollon

The sample from Rowollon was divided into two, at random, to generate a model to predict which individuals were infected with hookworm. The model was generated using 206 people and 225 people to compare the predictive power of this model. The model predicted correctly 80.58% of the

sample for which it was generated and 80.00% of the testing sample. It performed better in predicting infected individuals correctly (96.15% in the sample with which it was generated and 95.54% for the comparison sample) than in predicting those that were uninfected (53.95% in the generating sample and 44.12% in the testing sample). Factors shown to be important in the prevalence of hookworm infection in Rowollon were the logarithm of the age of an individual, the age of an individual, the square of the age of an individual and the cube of the age. The equation was Z = -3.1965 - 0.7937 (an individual's age) + 11.9310 (logarithm of an individual's age) + 0.0139 (the square of an individual's age) - 0.000085 (age cubed). Again $1/(1+e^{-Z})$ equals the probability of being infected, this time with hookworm, in Rowollon. Percentile breakdowns of the predicted probabilities of having hookworm infections for the individuals surveyed are presented in Table 5.17.

As age was seen to be a major contribution to the distribution of hookworm prevalence in Rowollon, a scatter graph of the predicted values versus age of individuals is presented in Figure 5.19. It can be seen that, as found in all three study sites, the probability of infection with hookworm increases with the age of an individual.

Table 5.17. Percentiles of predicted probabilities from the model generated for being infected with hookworm in Rowollon.

Percentiles	Probabilities	Number Infected	Percent of Infected	Number Uninfected	Percent of Total Sample
> 0.90	> 0.882	33	11.5	3	8.4
0.90 - 0.80	0.882 - 0.859	51	17.8	6	13.2
0.80 - 0.70	0.859 - 0.821	32	11.1	4	8.4
0.70 - 0.60	0.821 - 0.774	30	10.5	5	8.1
0.60 - 0.50	0.774 - 0.737	24	8.4	5	6.7
0.50 - 0.40	0.737 - 0.715	52	18.1	11	14.6
0.40 - 0.30	0.715 - 0.694	34	11.8	14	11.1
0.30 - 0.20	0.694 - 0.559	19	6.6	25	10.2
0.20 - 0.10	0.559 - 0.243	0	0.0	5	1.2
< 0.10	< 0.243	12	4.2	66	18.1

5.5.2c. Foria

The sample from Foria was again divided into two, at random, to generate a model to predict which individuals were infected with hookworm. The model was generated using 215 people and 182 people to compare the predictive power of this model. The model predicted correctly 78.14% of the sample for which it was generated and 77.47% of the testing sample. It performed better in predicting infected individuals correctly (95.86% in the sample with which it was generated and 99.15% for the

comparison sample) than in predicting those that were uninfected (41.43% in the generating sample and 38.46% in the testing sample). Factors shown to be important in the prevalence of hookworm infection in Foria were the logarithm of the age of an individual, the age of an individuals and the square of an individual's age. The equation was Z = -2.450 + 6.4175 (logarithm of an individual's age) - 0.2779 (age) + 0.0027 (age squared). Again $1/(1+e^{-z})$ equals the probability of being infected, this time with hookworm, in Foria. Percentile breakdowns of the predicted probabilities of having hookworm infections for the individuals surveyed are presented in Table 5.18. As age was seen to be a major contribution to the distribution of hookworm prevalence in Foria, a scatter graph of the predicted values versus age of individuals is presented in Figure 5.20. It can be seen that, as found in all three study sites, the probability of infection with hookworm increases with the age of an individual.

Table 5.18.. Percentiles of predicted probabilities of being infected with hookworm in Foria from the generated model.

Percentiles	Probabilities	Number Infected	Percent of Infected	Number Uninfected	Percent of Total Sample
> 0.90	> 0.822	20	7.6	3	5.8
0.90 - 0.80	0.822 - 0.817	29	11.1	8	9.3
0.80 - 0.70	0.817 - 0.799	53	20.2	17	17.6
0.70 - 0.60	0.799 - 0.784	18	6.9	3	5.3
0.60 - 0.50	0.784 - 0.757	35	13.4	16	12.8
0.50 - 0.40	0.757 - 0.737	27	10.3	6	8.3
0.40 - 0.30	0.737 - 0.724	52	19.8	10	15.6
0.30 - 0.20	0.724 - 0.583	21	8.0	18	9.8
0.20 - 0.10	0.583 - 0.301	5	1.9	17	5.5
< 0.10	< 0.301	2	0.8	38	9.8

5.5.3. *Trichuris trichiura* Models

5.5.3a. Kroo Bay

A predictive model for *T. trichiura* infection in Kroo Bay was generated for 121 individuals selected randomly from the 261 individuals from the targeted households. This model was tested on the remaining 140 individuals from the targeted households. It correctly predicted the infection status of 57.78% of those found not to be infected and 86.84% of those found to be infected in the 121 individuals from which it was generated, an overall rate of 76.03%. It's predictive power was 52.17% for the individuals found to be uninfected with *T. trichiura* in the testing groups and 73.40% for those found to be infected with *T. trichiura*, giving an overall success rate of 66.43%. The equation for this

model was Z = -0.7605 - 0.6918 (an individual's age) + 8.0491 (logarithm of an individual's age) + 0.0133 (the square of an individual's age) + 0.4665 if the individual lived in area 1 or - 0.4665 if the person lived in area 2. The probability of being infected with *T. trichiura* was $1/(1+e^{-Z})$. The percentiles of probabilities of being infected are given in Table 5.19 along with the number of individuals found to be both infected and uninfected with *T. trichiura*. Age of individual was the single most predictive factor for infection with *T. trichiura* in Kroo Bay, although the relationship was not a linear one. The relationship between age and predicted probability of being infected with *T. trichiura* is represented in Figure 5.21

Table 5.19. Percentiles of predicted probabilities of being infected with *T. trichiura* in Kroo Bay from the generated model.

Percentiles	Probabilities	Number Infected	Percent of Infected	Number Uninfected	Percent of Total Sample
> 0.90	> 0.894	23	13.5	2	9.6
0.90 - 0.80	0.894 -0.841	22	12.9	4	10.0
0.80 - 0.70	0.841 - 0.789	21	12.4	5	10.0
0.70 - 0.60	0.789 - 0.742	23	13.5	4	10.3
0.60 - 0.50	0.742 - 0.670	21	12.4	6	10.3
0.50 - 0.40	0.670 - 0.610	12	7.1	9	8.0
0.40 - 0.30	0.610 - 0.486	19	11.2	11	11.5
0.30 - 0.20	0.486 - 0.386	17	10.0	8	9.6
0.20 - 0.10	0.386 - 0.144	10	5.9	17	10.3
< 0.10	< 0.144	2	1.1	24	10.0

5.5.3b. Rowollon

A predictive model for *T. trichiura* infection in Rowollon was generated for 230 individuals selected randomly from the 465 individuals in the total sample. This model was tested on the remaining 235 individuals. It correctly predicted the infection status of 61.82% of those found not to be infected and 80.83% of those found to be infected in the 230 individuals from which it was generated, an overall rate of 71.74%. It's predictive power was 55.40% for the individuals found to be uninfected with *T. trichiura* in the testing groups and 83.64% for those found to be infected with *T. trichiura*, giving an overall success rate of 68.09%. The equation for this model was Z = -2.7187 - 0.0871 (an individual's age) + 4.5998 (logarithm of an individual's age) + 0.5969 if the individual was male or - 0.5969 if female and + 0.3546 if an individual lived in area 1 or -0.3546 if an individual lived in area 2. The probability of being infected with *T. trichiura* was $1/(1+e^{-Z})$. The percentiles

of probabilities of being infected are given in Table 5.20 along with the number of individuals found to be both infected and uninfected with *T. trichiura*.

Table 5.20. Percentiles of predicted probabilities generated from the model of being infected with *T. trichiura* in Rowollon.

Percentiles	Probabilities	Number Infected	Percent of Infected	Number Uninfected	Percent of Total Sample
> 0.90	> 0.830	38	16.5	8	9.9
0.90 - 0.80	0.830 - 0.772	29	12.6	16	9.7
0.80 - 0.70	0.772 - 0.727	33	14.3	17	10.8
0.70 - 0.60	0.727 - 0.643	26	11.3	19	9.8
0.60 - 0.50	0.643 - 0.588	31	13.5	15	9.9
0.50 - 0.40	0.588 - 0.524	20	8.7	20	8.6
0.40 - 0.30	0.524 - 0.368	27	11.7	23	10.8
0.30 - 0.20	0.368 - 0.264	10	4.3	29	8.4
0.20 - 0.10	0.264 - 0.146	13	5.7	45	12.5
< 0.10	< 0.146	3	1.3	43	9.9

Age of individual was the single most predictive factor for infection with *T. trichiura* in Rowollon, although the relationship was not a linear one. The relationship between age and predicted probability of being infected with *T. trichiura* is represented in Figure 5.22.

5.5.4. *Schistosoma mansoni* Model

5.5.4a. Foria

A predictive model for *S. mansoni* infection in Foria was generated for 185 individuals selected randomly from the 397 individuals in the sample for which all the information was available. This model was tested on the remaining 212 individuals. It did not predict any of the individuals to be infected (greater than 0.50 probability of being infected). The equation for this model was Z = - 6.8567 + 6.6149 (logarithm of an individual's age) - 0.1336 (an individual's age). The probability of being infected with *S. mansoni* was $1/(1+e^{-Z})$. The percentiles of probabilities of being infected are given in Table 5.21 along with the number of individuals found to be both infected and uninfected with *S. mansoni*.

Table 5.21. Percentiles of predicted probabilities of being infected with *S. mansoni* in Foria from the generated model.

Percentiles	Probabilities	Number Infected	Percent of Infected	Number Uninfected	Percent of Total Sample
> 0.90	> 0.297	7	13.0	30	9.3
0.90 - 0.80	0.279 - 0.263	11	20.4	35	11.6
0.80 - 0.70	0.263 - 0.248	12	22.2	24	9.1
0.70 - 0.60	0.248 - 0.211	2	3.7	20	5.5
0.60 - 0.50	0.211 0.171	13	24.1	48	15.4
0.50 - 0.40	0.171 - 0.124	2	3.7	38	10.1
0.40 - 0.30	0.124 - 0.075	4	7.4	38	10.6
0.30 - 0.20	0.075 - 0.032	3	5.6	45	12.1
0.20 - 0.10	0.032 - 0.008	0	0.0	25	6.3
< 0.10	< 0.008	0	0.0	40	10.1

Age of individual was the single most predictive factor for infection with *S. mansoni* in Foria, although the relationship was not a linear one. The relationship between age and predicted probability of being infected with *S. mansoni* is represented in Figure 5.23.

5.6. Models for Combined Control

5.6.1. Kroo Bay

Logistic regression of the prevalence of being infected with one or more helminth infections was investigated by coding all infections as one and all uninfected individuals as zero. The sample of 261 individuals from targeted households was split randomly into two, giving 127 for generating a logistic regression model for predicting infection with either *A. lumbricoides*, hookworm, *T. trichiura* or any combination of these three helminths. The model was tested by using it to predict the infection status of the remaining 134 individuals from the targeted households. It correctly identified 38.89% of those found to be uninfected in the sample of 127 and 95.60% of those found to be infected, with an overall success rate of 79.53%. In the testing sample, it correctly identified 42.50% of those found to not be infected and 97.87% of those found to be infected with an overall rate of 81.34%. The equation for predicting individuals which had any combination of the major three helminth infection was Z = + 0.0499 + 2.3073(the logarithm of an individual's age) - 0.0573(an individual's age) where $1/(1+e^{-Z})$ equals the probability of being infected.

Table 5.22. Probabilities of being infected with *A. lumbricoides*, hookworm, *T. trichiura* or any combination of these helminths in Kroo Bay from the model generated for combined infections.

Percentiles	Probabilities	Number Infected	Percent of Infected	Number Uninfected	Percent of Total Sample
> 0.90	> 0.864	26	14.1	4	11.5
0.90 - 0.80	0.864 - 0.852	17	9.2	2	8.4
0.80 - 0.70	0.852 - 0.842	24	13.0	4	10.7
0.70 - 0.60	0.842 - 0.818	12	6.5	4	6.1
0.60 - 0.50	0.818 - 0.784	27	14.6	2	12.3
0.50 - 0.40	0.784 - 0.744	25	13.5	3	10.7
0.40 - 0.30	0.744 - 0.676	23	12.4	2	9.6
0.30 - 0.20	0.676 - 0.579	19	10.3	10	11.1
0.20 - 0.10	0.579 - 0.454	10	5.4	16	10.0
< 0.10	< 0.454	2	1.1	23	9.6

The breakdown of the number of each of the infections in the percentiles of predicted probabilities is given in Table 5.23. Figure 5.24 illustrates the relationship between the age of an individual and the predicted probability of being infected with any of the three most common helminth infections in Kroo Bay.

5.6.2. Rowollon

Logistic regression of the prevalence of being infected with one or more helminth infections was investigated by coding all infections as one and all uninfected individuals as zero. The sample of 431 individuals from Rowollon was split randomly into two, giving 225 for generating a logistic regression model for predicting infection with either *A. lumbricoides*, hookworm, *T. trichiura* or any combination of these three helminths. The model was tested by using it to predict the infection status of the remaining 206 individuals. It correctly identified 46.00% of those found to be uninfected in the sample of 225 and 94.44% of those found to be infected, with an overall success rate of 80.89%. In the testing sample, it correctly identified 62.96% of those found to not be infected and 94.08% of those found to be infected with an overall rate of 85.92%. The equation for predicting individuals which had any combination of the major three helminth infections was Z = -2.8909 + 12.7056 (the logarithm of an individual's age) - 0.8819 (an individual's age) + 0.0168 (age squared) where $1/(1+e^{-Z})$ equals the probability of being infected.

Table 5.24. Probabilities of being infected with *A. lumbricoides*, hookworm, *T. trichiura* or any combination of these helminths in Rowollon from the model generated for combined infections.

Percentiles	Probabilities	Number Infected	Percent of Infected	Number Uninfected	Percent of Total Sample
> 0.90	> 0.915	34	10.8	1	8.1
0.90 - 0.80	0.915 - 0.896	28	8.9	3	7.2
0.80 - 0.70	0.896 - 0.879	48	15.3	3	11.8
0.70 - 0.60	0.879 - 0.839	34	10.8	4	8.8
0.60 - 0.50	0.839 - 0.817	40	12.7	5	10.4
0.50 - 0.40	0.817 - 0.809	46	14.6	9	12.8
0.40 - 0.30	0.809 - 0.719	24	7.6	6	7.0
0.30 - 0.20	0.719 - 0.567	25	8.0	20	10.4
0.20 - 0.10	0.567 - 0.235	13	4.1	28	9.5
< 0.10	< 0.235	5	1.6	38	10.0

The breakdown of the number of each of the infections in the percentiles of predicted probabilities is given in Table 5.25. Figure 5.25 illustrates the relationship between the age of an individual and the predicted probability of being infected with any of the three most common helminth infections in Rowollon.

5.6.3. Foria

Logistic regression of the prevalence of being infected with one or more helminth infections was investigated by coding all infections as one and all uninfected individuals as zero. The sample of 397 individuals was split randomly into two, giving 186 for generating a logistic regression model for predicting infection with either *A. lumbricoides*, hookworm or a combination of these two helminths. *Schistosoma mansoni* infection was not included in this model, as the common drugs used to treat *A. lumbricoides* and hookworm infections are not effective against this helminth. The model was tested by using it to predict the infection status of the remaining 211 individuals in the sample. It correctly identified 32.00% of those found to be uninfected in the sample of 186 and 95.59% of those found to be infected, with an overall success rate of 78.49%. In the testing sample, it correctly identified 32.20% of those found to not be infected and 96.05% of those found to be infected with an overall rate of 78.20%. The equation for predicting individuals which had any combination of these two helminth infection was Z = -0.7955 + 2.9071 (the logarithm of an individual's age) - 0.0565 (an individual's age) and - 0.4653 if the individual was female or + 0.4653 if male, where $1/(1+e^{-Z})$ equals the probability of being infected.

Table 5.26. Probabilities of being infected with *A. lumbricoides*, hookworm or a combination of these two helminths in Foria from the model generated for combined infections.

Percentiles	Probabilities	Number Infected	Percent of Infected	Number Uninfected	Percent of Total Sample
> 0.90	> 0.908	27	9.4	5	8.1
0.90 - 0.80	0.908 - 0.890	43	14.9	5	12.1
0.80 - 0.70	0.890 - 0.811	33	11.5	6	9.8
0.70 - 0.60	0.811 - 0.793	31	10.8	12	10.8
0.60 - 0.50	0.793 - 0.779	28	9.7	9	9.3
0.50 - 0.40	0.779 - 0.755	37	12.8	7	11.1
0.40 - 0.30	0.755 - 0.712	30	10.4	11	10.3
0.30 - 0.20	0.712 - 0.633	28	9.7	6	8.6
0.20 - 0.10	0.633 - 0.484	27	9.4	19	11.6
< 0.10	< 0.484	4	1.4	29	8.3

The breakdown of the number of each of the infections in the percentiles of predicted probabilities is given in Table 5.27. Figure 5.26 illustrates the relationship between the age of an individual and the predicted probability of being infected with any of these two common helminth infections in Foria.

5.7. Correlation of Predicted Probabilities and Intensity

The predicted probabilities produced in the above models were tested to determine if there was a correlation between them and the intensity (EPG) of infection in those infected. If there was a significant correlation found this would indicate that treating those with higher predicted probabilities would also result in treating those with the highest intensity. This would have important implications for reducing the number of infective stages released into the environment by infected hosts.

Table 5.28. Results of Spearman rank correlation between predicted probabilities from the models generated for each helminth infection and intensity of helminth infection.

Helminth	Community	r_s	df	*P*
A. lumbricoides	Kroo Bay	0.2088	99	0.038
	Rowollon	0.000	90	1.000
	Foria	0.1365	126	0.127
Hookworm	Kroo Bay	0.0213	84	0.847
	Rowollon	0.1668	287	0.005
	Foria	0.1814	262	0.003
T. trichiura	Kroo Bay	0.2559	170	0.001
	Rowollon	-0.0377	230	0.570
S. mansoni	Foria	0.2405	54	0.080

Correlations were completed both on the predicted probabilities from the models generated for each helminth infection separately (Table 5.28) and also on those generated for the models generated for combined control (Table 5.29).

Table 5.29. Results of Spearman rank correlation between predicted probabilities for all helminth infections from models for combined control and intensity of helminth infection.

Helminth	Community	r_s	df	*P*
A. lumbricoides	Kroo Bay	0.2174	71	0.069
	Rowollon	-0.0188	90	0.860
	Foria	-0.0336	126	0.709
Hookworm	Kroo Bay	-0.1259	61	0.333
	Rowollon	0.1433	287	0.015
	Foria	0.1942	262	0.002
T. trichiura	Kroo Bay	0.0076	170	0.921
	Rowollon	0.2172	212	0.001

5.8 Discussion

5.8.1. Modelling Intensity of Infections

5.8.1a. *Ascaris lumbricoides*

The regression lines explaining intensity of *A. lumbricoides* infections by age and number of individuals in a household were significant in Kroo Bay for the logarithm of age and in Foria for the simple, polynomial and logarithmic lines. The other lines did not fit the data significantly. These lines only accounted for between 3 to 7% of the variation in the data, which is not very impressive. When the regression lines were included in covariance analysis, in the case of Kroo Bay the regression line of the covariate was not significant but the effect of area in which a host lived showed an influence on the intensity of infection with *A. lumbricoides*. In Rowollon, no significant effects were detected in the analysis of the intensity of *A. lumbricoides*. The covariance analysis in Foria on *A. lumbricoides* intensity indicated a significant effect due to the covariate of logarithm of age and number of individuals in a household but no other significant effects. No overall patterns of association between any of the factors from one community to the next were seen in this analysis. From the Kroo Bay data and the Foria data, some effect of the logarithm of age was seen on the intensity of infection, with Figures 5.1 and 5.5 indicating the relationship. From these it can be seen that the relationship is different for the two communities, in Kroo Bay the intensity of infection appears to increase with age and then level out, but in Foria it appears to decrease and then level out. In Foria, the intensity of infection is seen to decrease with increasing numbers of individuals in a household. In Kroo Bay, hosts living in area 1 was seen to have more intense infection of *A. lumbricoides* than those living in area 2, even with differences in age being taken into account. This

would probably relate to the quality and availability of sanitation, combined with the quality of housing.

5.8.1b. Hookworm

In the intensity of hookworm infection in Rowollon and Foria, age was seen to be significantly related to intensity of infection, with the highest significance associated with the logarithm of age. No significant regression line was associated with the logarithm of age Kroo Bay, although this was the line found to be closest to significant and which was used in covariance analysis for this helminth in the analysis of intensity for individuals in this community. The regression line for this in covariance analysis was found to be significant. By using covariance analysis in this manner, an almost significant result was found for the difference between the intensity of males an females infected with hookworm in Kroo Bay. This relationship is illustrated in Figure 5.12, where it can be seen that the number of males found to be infected in the older age groups in Kroo Bay is much lower than the number of females found to be infected. This must be interpreted with the knowledge from Chapter Three, where it was shown that the sample of males in the Kroo Bay survey was made up of fewer older males than would be expected. Of the males that were infected, it appears that there is a tendency for them to have more intense infections than females, regardless of their age. In Rowollon and Foria, the regression line for the logarithm of age was used for the covariate in covariance analysis. A significant difference was seen between males and females in Rowollan in their intensities, regardless of age (Figure 5.13) with males having more intense infections on average than females. In Foria the regression line for the logarithm of age was significant but there were no significant differences found between sex of host and area in which the host lived. From this it appears to be an overall trend that the intensity of infection with hookworm will increase with age and then reach some kind of plateau, with some communities showing males as having more intense infections than females.

5.8.1c. *Trichuris trichiura*

The regression lines for *T. trichiura* intensity were all non-significant. However, the lines closest to significance were used as covariates without any success. The only significant result was that of significant differences in the mean intensity of those people in area 1 versus those in area 2 (Figure 5.14) which was found o be still significant even when the other factors studied were taken

into effect. This points out the problems inherent in studies where these factors are not controlled for or where ages are lumped together in categories. The significant results seen between the different age classes in the intensity of *T. trichiura* in earlier chapters are not confirmed with this analysis. There do not appear to be any significant results from the two communities where *T. trichiura* infections were found in large numbers that would help identify hosts infected with higher intensity of infections of this helminth, excepting the differences seen in the different areas in Rowollon for *T. trichiura* intensity.

5.8.1d. *Schistosoma mansoni*

No significant results were found in the multiple regression analysis or in the covariance analysis in the intensity of *S. mansoni*. It does not appear possible to model the intensity of those infected with this infection in Foria.

5.8.2. Modelling the Prevalence of Infection

5.8.2a. *Ascaris lumbricoides*

The models generated for the prevalence of *A. lumbricoides* in the three different communities were very different from one another. Age was shown to be the most important factor in the probability of being infected with *A. lumbricoides*, but the manner of this was different for all the communities (compare these to those reviewed in Chapter One and illustrated in Figure 1.1). In Kroo Bay, the probability of infection increased quickly with age and then levelled off. In Rowollon, the probability of infection increased with age until about 10 yr of age and the dropped and then increased again, finally dropping when an individual reached about 45 yr of age. In Foria, the probability of infection was high at birth, remained high until about 20 yr of age and then decreased slowly until 60 yr of age. There appear to be little similarities between the three models, although all three predict fairly high prevalences in those individuals aged 5 through 10 yr of age which are often cited as the ages when the prevalence of this helminth will be the highest. The very different models generated by this data indicate that this observation on its own will not be terribly informative about the probability of infection in other age groups and the manner in which that probability of infections will change over an individuals life span. The significant correlation between intensity and probability of infection seen in Kroo Bay indicates that treating those with a higher probability of being infected

would also treat those found to have the highest intensities of infection. The same result was not seen in Rowollon and Foria.

5.8.2b. Hookworm

The models generated for hookworm prevalence in the two rural communities were fairly similar, with an increase in the probability of being infected with this helminth with an increase in age, followed by a decrease in the probability of being infected followed by another increase (compare to those illustrated in Figure 1.1). The probability of being infected with hookworm was seen to differ in the model of hookworm infection in Kroo Bay, the urban site. In Kroo Bay, the probability of being infected increased with age and then dropped again. The significant correlation seen between intensity and probability of being infected with hookworm in Rowollon and Foria indicated that treating those with the highest predicted probabilities of being infected would also treat those with the highest intensities. There was no significant correlation between intensity and predicted probability in the model generated for hookworm infection in Kroo Bay.

5.8.2c. *Trichuris trichiura*

In both Kroo Bay and Rowollon, effects other than age of individual were seen to have and effect of the predicted probability of being infected with *T. trichiura*. Those individuals living in area 1 in Kroo Bay were seen to have higher predicted probabilities of being infected than those in area 2. In Rowollon, males were seen to have higher probabilities of being infected than females, with those males living in area 1 having higher probabilities of being infected than those in area 2. The same was true of the females. In Kroo Bay, two peaks of high predicted probability of being infected with *T. trichiura* were seen, one between 5 and 10 yeas of age and one at about 60 yr of age. In Rowollon, the highest probability of being infected was seen in those individuals about 20 yr of age. Significant correlations were seen between predicted probabilities and intensity in Kroo Bay but not in Rowollon. Treating those with higher predicted probabilities of being infected in Kroo Bay would have succeeded in treating those with the heaviest intensities.

5.8.2d. *Schistosoma mansoni*

The model of prevalence of *S. mansoni* indicated that the highest predicted probabilities of being infected with this parasite were found in those people of about 20 yr of age. There was no

significant correlation between the intensity of infection and the predicted probability of being infected with this helminth.

5.8.2e. Combined Control

The models for combined control of helminth infection were similar between Foria and Kroo Bay, with females in Foria having lower predicted probabilities of being infected with helminths than did males. Both of the models showed the prevalence in infection increasing with age to reach a high for those aged about 15 yr of age and then decreasing. In Rowollon, there were two peaks of high predicted probability of being infected, one occurring between age 5 and 10 and the other at about age 55. Correlation analysis of the predicted probabilities and intensities of infection indicated that none of the combined models resulted in a significant correlation for any of the communities for those infected with *A. lumbricoides*. The predicted probabilities showed a significant relationship between the intensity of hookworm infection in Rowollon and Foria (the rural areas with high prevalence) but not in those infected with hookworm in Kroo Bay. *Trichuris trichiura* intensity of infection showed a significant correlation in those predicted values generated for the combined model in Rowollon but not in Kroo Bay. *Schistosoma mansoni* was not included in the generation of models for combined control.

The models generated for gastrointestinal helminth prevalence compared favourably to what was seen in the results from several surveys reviewed in Chapter One, Figures 1.1 to 1.4. These indicated that age of the individual is highly predictive of the prevalence of infection, provided that other conditions, such as are reviewed in Chapter One (rural vs. urban, climate factors, humidity, sanitation etc.) favour transmission of gastrointestinal helminths. The treatment of a certain age group of the population, based on the relationship of prevalence and helminth prevalence, has been shown to effectively control infections with gastrointestinal helminths (Asaolu, Holland and Crompton, 1991; Bundy, Wong, Lewis and Horton, 1990). It would be interesting to design a study in which a logistic model of probability of infection with a helminth species was generated and to use this model in determining the individuals requiring treatment. It may be that treatment targeted at age groups is only successful in reducing the helminth burden in the non-treated group if the targeted group had the highest predicted probabilities from a logistic regression model of being infected and if

the predicted probabilities were significantly correlated with intensity, thus ensuring that those responsible for the majority of infective stages were being treated.

5.9. Summary

Regression Analysis

Age of Hosts.

1. Significant regression for the logarithm of the age of hosts for *A. lumbricoides* in Kroo Bay.
2. Significant regression for the logarithm of the age of hosts for hookworm in Rowollon and Foria.
3. No significant regression equations for *T. trichiura* infection and age of host.
4. No significant regression equations for *S. mansoni* infection and age of host.

Number of People Living in Host's Household.

1. Significant regression for the number of individuals in hosts' households and *A. lumbricoides* infection in Foria.
2. No significant regression equations for Hookworm infection and number of individuals in hosts' households.
3. No significant regression equations for *T. trichiura* infection and number of individuals in hosts' households.
4. No significant regression equations for *S. mansoni* infection and number of individuals in hosts' households.

Combination of Age of Host and Number of Individuals in Hosts' Households.

1. Significant regression for the combination of the logarithm of the age of hosts and the logarithm of the number of individuals in hosts' households in Foria for *A. lumbricoides* infection.
2. Significant regression for the combination of the logarithm of the age of hosts and the polynomial equation of the number of individuals in hosts' households in Rowollon and for the combination of the logarithm of the age of hosts and the logarithm of the number of individuals in hosts' households in Foria for Hookworm infection.
3. No significant regression equations for the combination of age of hosts and the number of individuals in hosts' households for *T. trichiura* infection.
4. No significant regression equations for the combination of age of hosts and the number of individuals in hosts' households for *S. mansoni* infection.

Covariance Analysis

Ascaris lumbricoides.

1. Controlling for the significant relationship of age of host and intensity of *A. lumbricoides* infections, those people in area 1 had higher intensities than those living in area 2.
2. No significant effects were found for *A. lumbricoides* infections in Rowollon.
3. Significant covariate effects were found the for the logarithm of the age of host and the logarithm of the number of people living in a host's household for *A. lumbricoides* infections in Foria.

Hookworm.

1. Significant covariate effects were found for the logarithm of the age of host for Hookworm infections in Kroo Bay.
2. Controlling for the significant relationship of the logarithm of the age of host and intensity of Hookworm infections in Rowollon, males had heavier intensity of infection than females.
3. Significant covariate effects were found for the logarithm of the age of host for Hookworm infections in Foria.

Trichuris trichiura.

1. No significant effects were found for *T. trichiura* infections in Kroo Bay.
2. A significant effect was found in the intensity of *T. trichiura* infections between the two areas of Rowollon, with area 1 having the heavier intensity.

Schistosoma mansoni.

1. No significant effects were found for S. mansoni infections in Foria.

Logistic Regression

Ascaris lumbricoides.

1. The logarithm of an individual's age was included in a model of the probability of becoming infected with *A. lumbricoides* in Kroo Bay, which failed to predict any infected individuals in this community.
2. A polynomial equation of an individual's age was included in a model of the probability of becoming infected with *A. lumbricoides* in Rowollon, which only correctly predicted 13.33% of those individuals found to be infected with this helminth in the testing sample.

3. The cube of an individual's age was included in a model of the probability of becoming infected with *A. lumbricoides* in Foria, which failed to predict any infected individuals in this community.

Hookworm.

1. An individual's age and the logarithm of an individual's age were included in a model of the probability of becoming infected with hookworm in Kroo Bay, which failed to predict any infected individuals in this community.

2. A polynomial equation of an individual's age combined with the logarithm of an individual's age was included in a model of the probability of becoming infected with hookworm in Rowollon, which successfully predicted 95.54% of those found to be infected with this helminth in the testing sample.

3. The logarithm of an individuals age, the square of the age and the age of an individual were included in a model of the probability of becoming infected with hookworm in Foria, which correctly predicted 99.15% of the infected individuals in the testing sample.

Trichuris trichiura.

1. The logarithm of an individuals age, the square of the age and the age of an individual, along with a factor which contributed more weight if an individual lived in area 1, were included in a model of the probability of becoming infected with *T. trichiura* in Kroo Bay, which correctly predicted 73.40% of the infected individuals in the testing sample.

2. The logarithm of an individuals age and the age of an individual, along with a factor which contributed more weight if an individual were male and a factor that contributed more weight if an individual lived in area 1 were included in a model of the probability of becoming infected with *T. trichiura* in Rowollon, which correctly predicted 83.64% of those found to be infected in the testing group.

Schistosoma mansoni.

1. The logarithm of an individuals age and the age of an individual were included in a model of the probability of becoming infected with *S. mansoni* in Foria, which failed to predict any infected individuals in this community.

Combined Control.

1. The logarithm of an individuals age and the age of an individual were included in a model of the probability of becoming infected with *A. lumbricoides*, hookworm and/or *T. trichiura* in Kroo Bay. This model correctly predicted 95.60% of those found to be infected within the testing sample.

2. The logarithm of an individuals age, the square of an individuals age and the age of an individual were included in a model of the probability of becoming infected with *A. lumbricoides*, hookworm and/or *T. trichiura* in Rowollon. This model correctly predicted 94.08% of those found to be infected within the testing sample.

3. The logarithm of an individuals age and the age of an individual, along with a factor which contributed more if an individual were male, were included in a model of the probability of becoming infected with *A. lumbricoides*, hookworm and/or *S. mansoni* in Foria. This model correctly predicted 96.05% of those found to be infected within the testing sample.

Correlation of Predicted Probability and Intensity of Infection

Individual Helminth Species Models.

1. *A. lumbricoides* intensity significantly correlated with predicted probabilities in Kroo Bay.
2. Hookworm intensity significantly correlated with predicted probabilities in Rowollon and Foria.
3. *T. trichiura* intensity significantly correlated with predicted probabilities in Kroo Bay
4. *S. mansoni* intensity not significantly correlated with predicted probabilities in Foria.

Combined Helminth species Models.

1. *A. lumbricoides* intensity not significantly correlated with predicted probabilities in any community.
2. Hookworm intensity significantly correlated with predicted probabilities in Rowollon and Foria.
3. *T. trichiura* intensity significantly correlated with predicted probabilities in Rowollon.

Table 5.23. Probabilities for predicted infection of *A. lumbricoides*, hookworm, *T. trichiura* and those found to be uninfected from the model generated for combined infections in Kroo Bay.

Percentile	Probabilities	Number Infected with *A. lumbricoides*	% Infected with *A. lumbricoides*	Number Infected with Hookworm	% Infected with Hookworm	Number Infected with *T. trichiura*	% Infected with *T. trichiura*	Number Uninfected	% Uninfected
> 0.90	> 0.864	9	12.7	9	14.8	26	15.3	4	5.7
0.90 - 0.80	0.864 - 0.852	7	9.9	8	13.1	17	10.0	2	2.9
0.80 - 0.70	0.852 - 0.842	13	18.3	10	16.4	23	13.5	4	5.7
0.70 - 0.60	0.842 - 0.818	2	2.8	4	6.6	11	6.5	4	5.7
0.60 - 0.50	0.818 - 0.784	9	12.7	10	16.4	24	14.1	2	2.9
0.50 - 0.40	0.784 - 0.744	7	9.9	8	13.1	24	14.1	3	4.3
0.40 - 0.30	0.744 - 0.676	12	16.9	4	6.6	19	11.2	2	2.9
0.30 - 0.20	0.676 - 0.579	6	8.5	4	6.6	15	8.8	10	14.3
0.20 - 0.10	0.579 - 0.454	5	7.0	4	6.6	9	5.3	16	22.9
< 0.10	< 0.454	1	1.4	0	0.0	2	1.2	23	32.9

Table 5.25. Probabilities for predicted infection of *A. lumbricoides*, hookworm, *T. trichiura* and those found to be uninfected in Rowollon from the models generated for combined control.

Percentile	Probabilities	Number Infected with *A. lumbricoides*	% Infected with *A. lumbricoides*	Number Infected with Hookworm	% Infected with Hookworm	Number Infected with *T. trichiura*	% Infected with *T. trichiura*	Number Uninfected	% Uninfected
> 0.90	> 0.915	20	22.2	48	16.7	39	18.6	1	0.9
0.90 - 0.80	0.915 - 0.896	8	8.9	27	9.4	22	10.5	3	2.6
0.80 - 0.70	0.896 - 0.879	13	14.4	46	16.0	34	16.2	3	2.6
0.70 - 0.60	0.879 - 0.839	6	6.7	32	11.1	26	12.4	4	3.4
0.60 - 0.50	0.839 - 0.817	8	8.9	38	13.2	30	14.3	5	4.3
0.50 - 0.40	0.817 - 0.809	15	16.7	42	14.6	27	12.9	9	7.8
0.40 - 0.30	0.809 - 0.719	7	7.8	22	7.7	14	6.7	6	5.1
0.30 - 0.20	0.719 - 0.567	8	8.9	19	6.6	11	5.2	20	17.1
0.20 - 0.10	0.567 - 0.235	4	4.4	9	3.1	6	2.9	28	23.9
< 0.10	< 0.235	1	1.1	4	1.4	1	0.5	38	32.5

Table 5.27. Probabilities for predicted infection of *A. lumbricoides*, hookworm and those found to be uninfected in Foria from the model for combined control.

Percentile	Probabilities	Number Infected with *A. lumbricoides*	% Infected with *A. lumbricoides*	Number Infected with Hookworm	% Infected with Hookworm	Number Uninfected	% Uninfected
> 0.90	> 0.908	9	7.1	26	9.9	5	4.6
0.90 - 0.80	0.908 - 0.890	12	9.5	42	16.0	5	4.6
0.80 - 0.70	0.890 - 0.811	15	11.9	32	12.2	6	5.5
0.70 - 0.60	0.811 - 0.793	17	13.5	28	10.7	12	13.8
0.60 - 0.50	0.793 - 0.779	13	10.3	27	10.3	9	8.3
0.50 - 0.40	0.779 - 0.755	16	12.7	33	12.6	7	6.4
0.40 - 0.30	0.755 - 0.712	15	11.9	28	10.7	11	10.1
0.30 - 0.20	0.712 - 0.633	9	7.1	28	10.7	6	5.5
0.20 - 0.10	0.633 - 0.484	17	13.5	17	6.5	19	17.4
< 0.10	< 0.484	3	2.4	1	0.4	29	26.6

Figure 5.1. Age of host versus the logarithm of *A. lumbricoides* intensity (EPG) in those individuals found to be infected with this helminth in Kroo Bay. The line represents the regression line of the logarithm of host age. This line only accounts for 3.4% of the variation in the intensity.

Figure 5.2. Age of host versus the logarithm of hookworm intensity (EPG) in people found to be infected with this helminth in Rowollon. The line represents the regression line for the logarithm of age on intensity. It only explains 2.5% of the variation in the intensity data.

Figure 5.3. Age of host versus the logarithm of hookworm intensity (EPG) in individuals found to be infected with this helminth in Foria. The line is the regression line of the logarithm of age of host. It explains 5.9% of the variation in the data.

Figure 5.4. Number of individuals living in hosts households versus the logarithm of *A. lumbricoides* (EPG) in individuals found to be infected with this helminth in Foria. The regression line of logarithm of the number of people in a household explains 7.0% of the variation in the data.

Figure 5.1: Kroo Bay

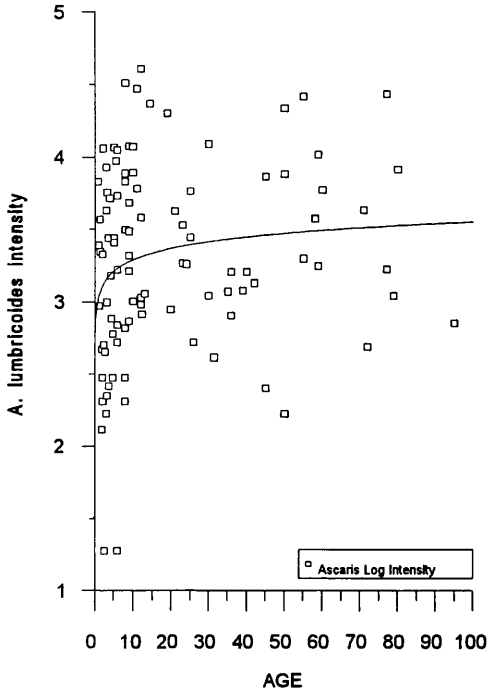


Figure 5.2: Rowollon

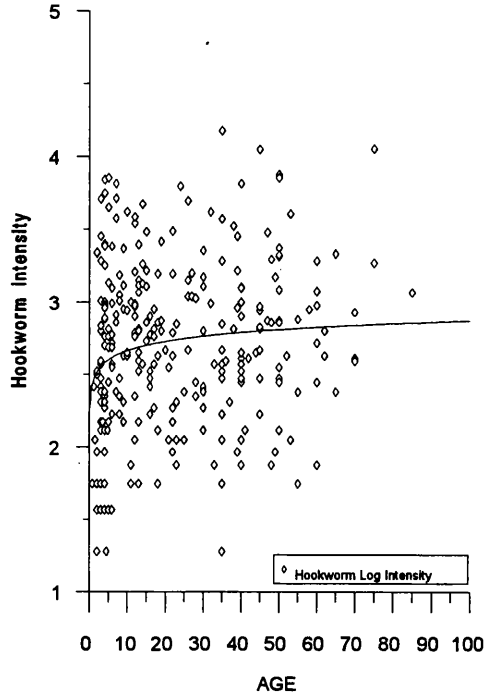


Figure 5.3: Foria

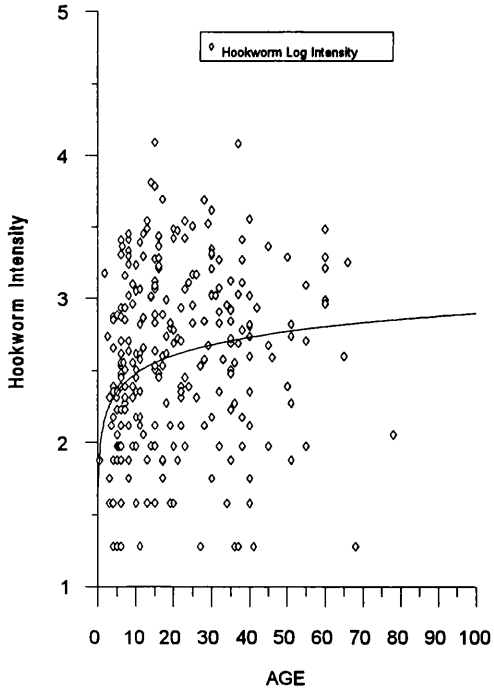


Figure 5.4: Foria

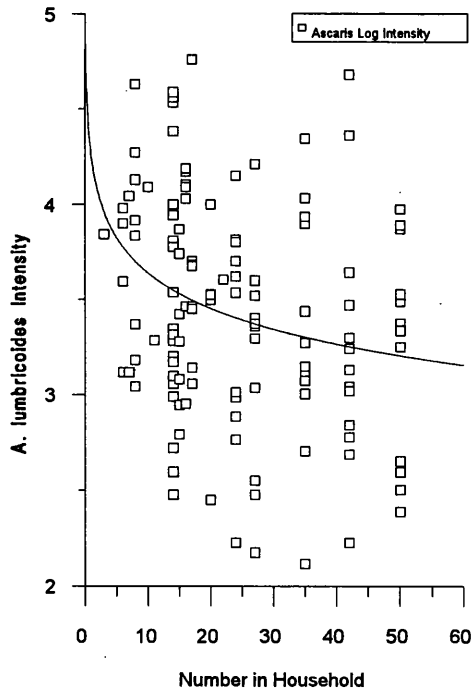


Figure 5.5. Age of host versus the logarithm of the *A. lumbricoides* intensity (EPG) in those individuals found to be infected with this helminth in Foria. The filled in squares are the predicted values based on a regression line including the logarithm of the age of host and the logarithm of the number of people living in the host's household. This regression line explained 8.8% of the variation of the data

Figure 5.6. Number of individuals living in the host's household versus the logarithm of the intensity of *A. lumbricoides* (EPG). The filled in squares represent the predicted values for the regression line of logarithm of age and logarithm of individuals in the hosts household (as in Figure 5.5). the regression line explains 8.85 of the variation in this data.

Figure 5.7. Age of host versus logarithm of hookworm intensity (EPG) in those individuals found to be infected with this helminth in Rowollon. The filled-in squares represent the predicted values from a regression line which includes the logarithm of the age of hosts and a polynomial of the number of children under-five in the host's household. This regression line explains 3.0% of the variation in the data.

Figure 5.8. The number of children under-five in a host's household versus the logarithm of hookworm intensity (EPG). The filled-in squares represent the predicted values from a regression line which includes the logarithm of the age of hosts and a polynomial of the number of children under-five in the host's household (as in Figure 5.7).

Figure 5.5: Foria

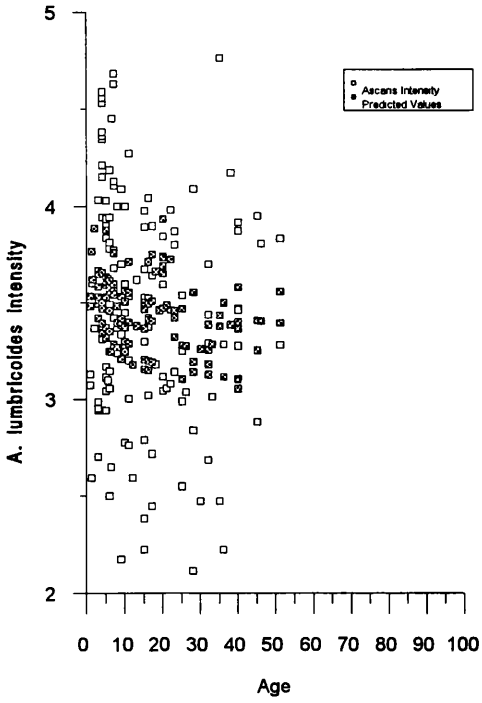


Figure 5.6: Foria

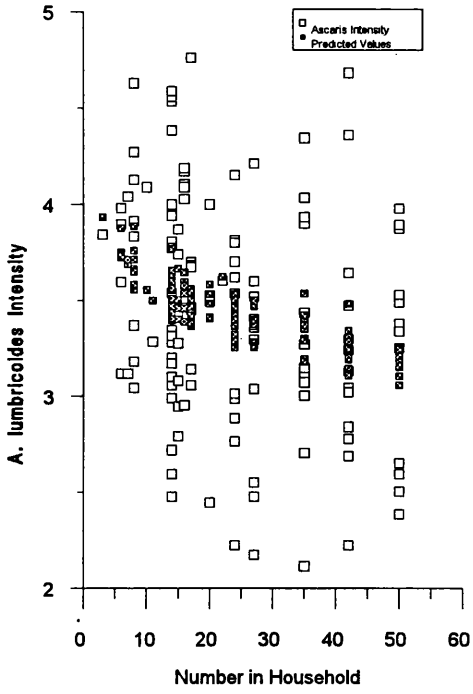


Figure 5.7: Rowollon

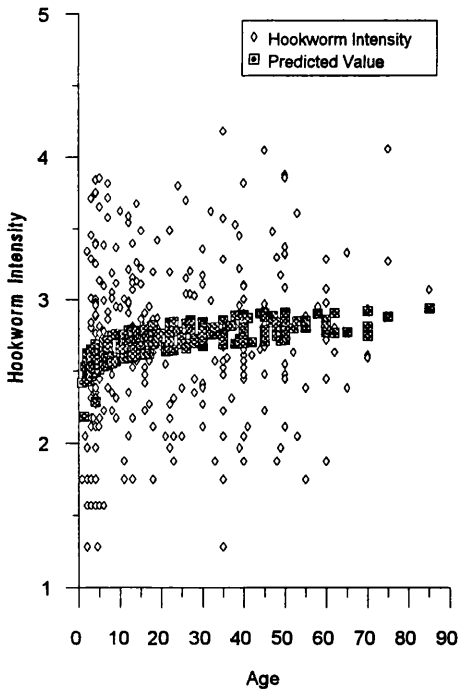


Figure 5.8: Rowollon

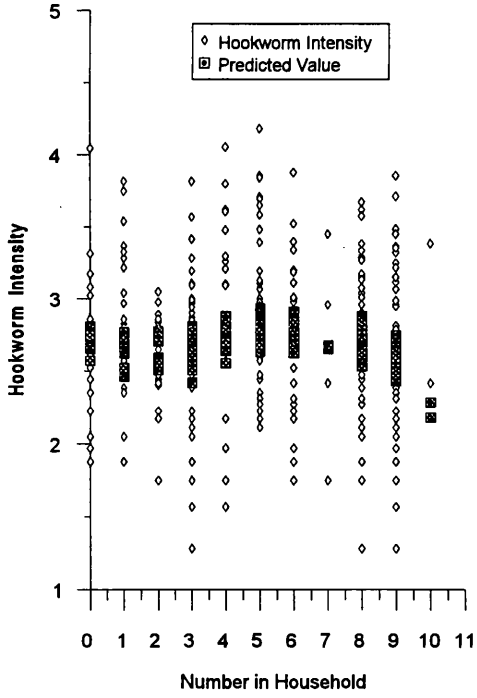


Figure 5.9. Age of host versus the logarithm of hookworm intensity (EPG) in those individuals found to be infected with this helminth in Foria. The filled-in squares represent the predicted values from a regression line which includes the logarithm of the age of the host and the logarithm of the number of individuals living in a host's household. This regression line accounts for 2.7% of the variation in the intensity data.

Figure 5.10. Number of individuals in a host's household versus the logarithm of the intensity of hookworm infection (EPG). The filled-in squares represent the predicted values for the regression line of the logarithm of age of host and number of individuals living in a host's household (as in Figure 5.9).

Figure 5.9: Foria

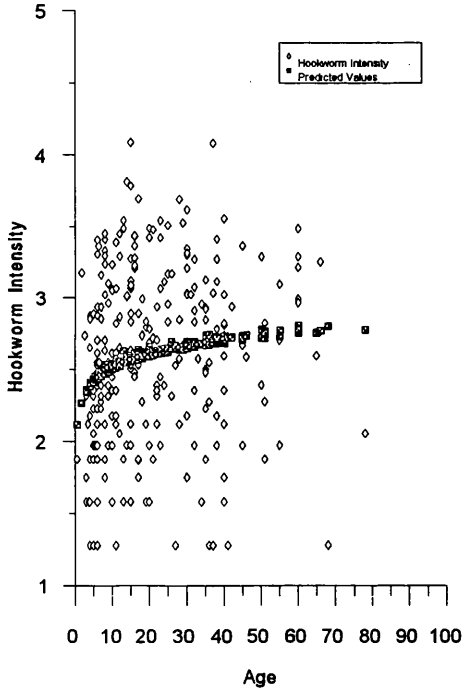


Figure 5.10: Foria

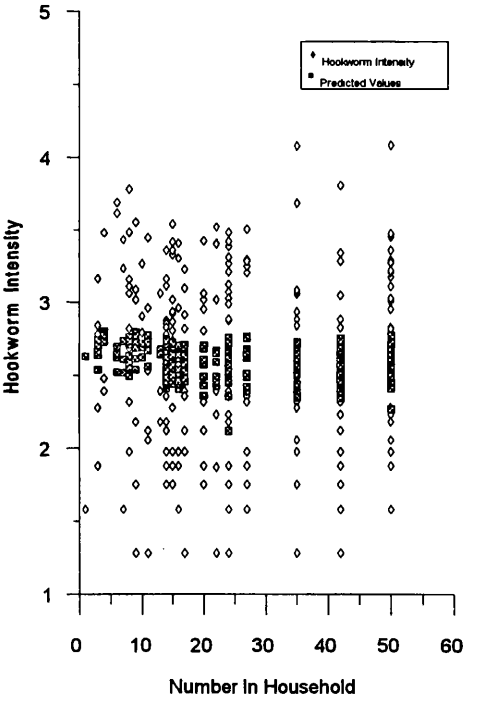


Figure 5.11. The logarithm of the intensity of *A. lumbricoides* intensity in those individuals found to be infected with this helminth in Kroo Bay. The open squares are those individuals who lived in area 1, the filled in squares are those who lived in area 2. The continuous line is the regression line of the logarithm of host's age for those individuals living in area 1, the dashed line is the regression line of those living in area 2 (see Figure 3.1).

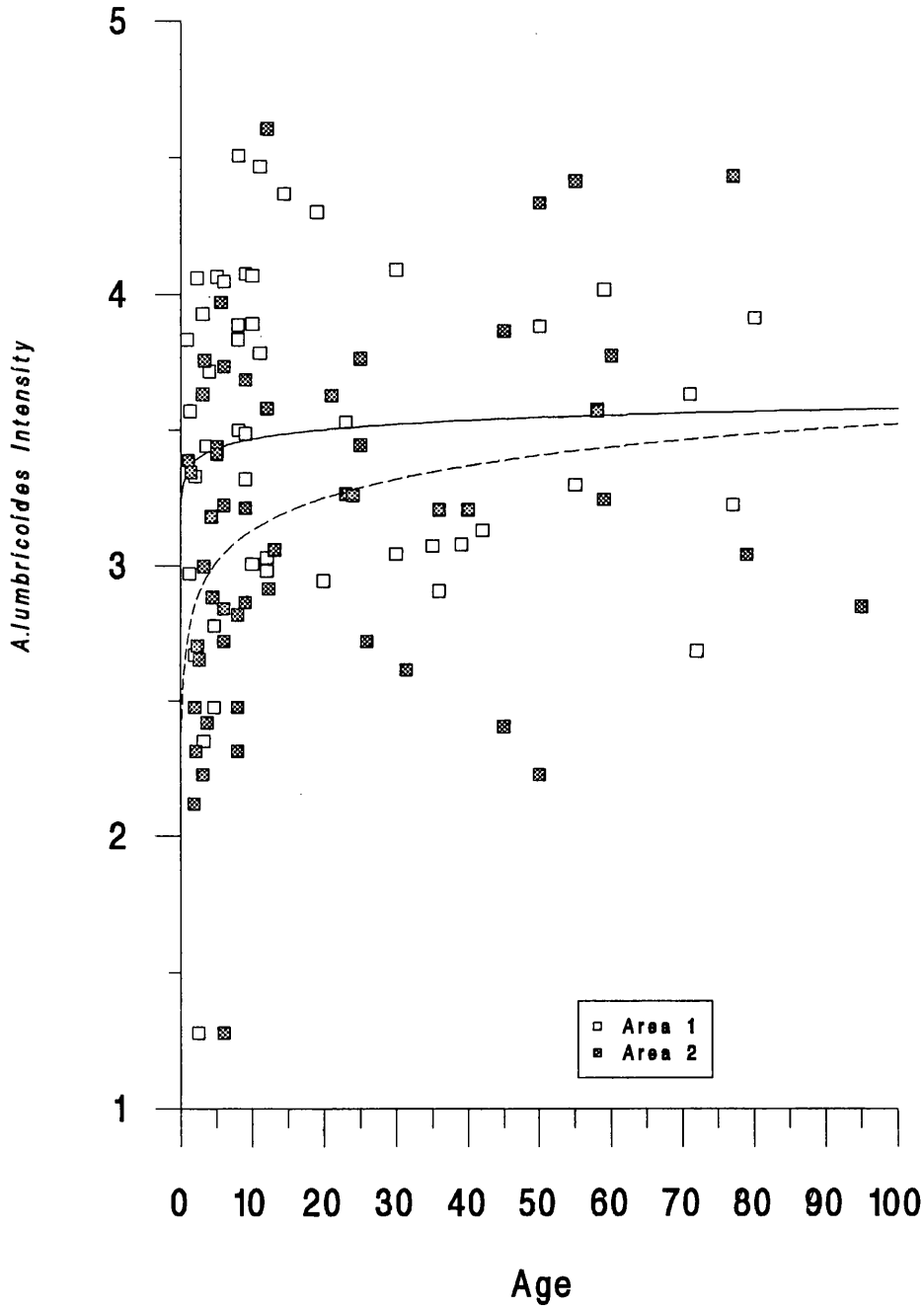

A.lumbricoides Intensity
5
4
3
2
1
0
10
20
30
40
50
60
70
80
90
100
Age
Area 1
Area 2

Figure 5.12. The logarithm of hookworm intensity (EPG) versus the host age in those individuals found to be infected in Kroo Bay. The open diamonds are the intensities for female hosts, the closed ones for males. The dashed line is the line representing the regression of logarithm of host age on hookworm intensity of males found to be infected, the continuous line is that of females.

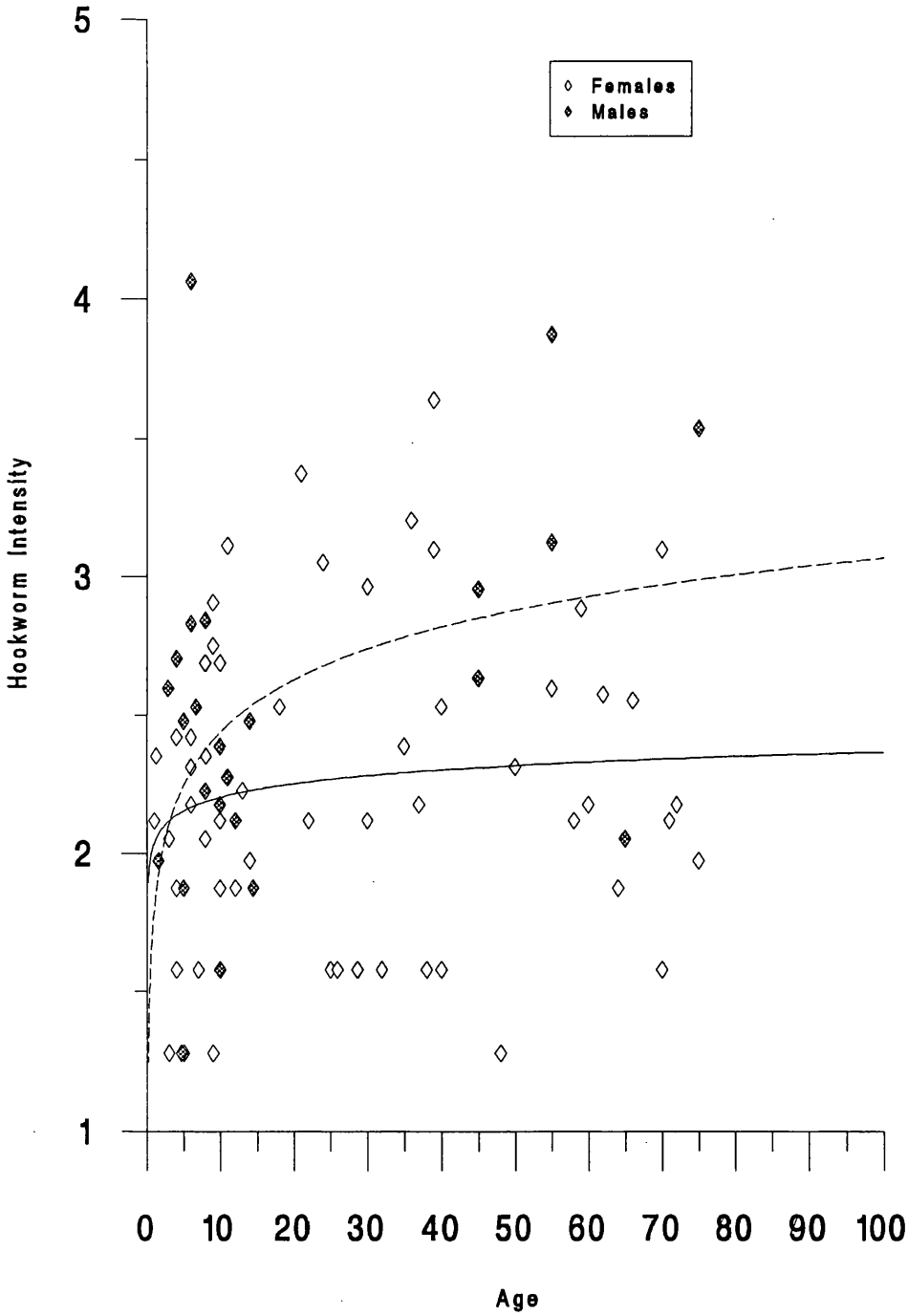

Females
Males
Hookworm Intensity
5
4
3
2
1
0
10
20
30
40
50
60
70
80
90
100
Age

Figure 5.13. The logarithm of hookworm intensity (EPG) versus the age of hosts for those individuals found to be infected with this helminth in Rowollon. The open diamonds are the female hosts, the closed ones are the males. The dashed line is the represents the regression of the logarithm of male host age on the intensity of infection and the continuous one is the regression line for the females found to be infected.

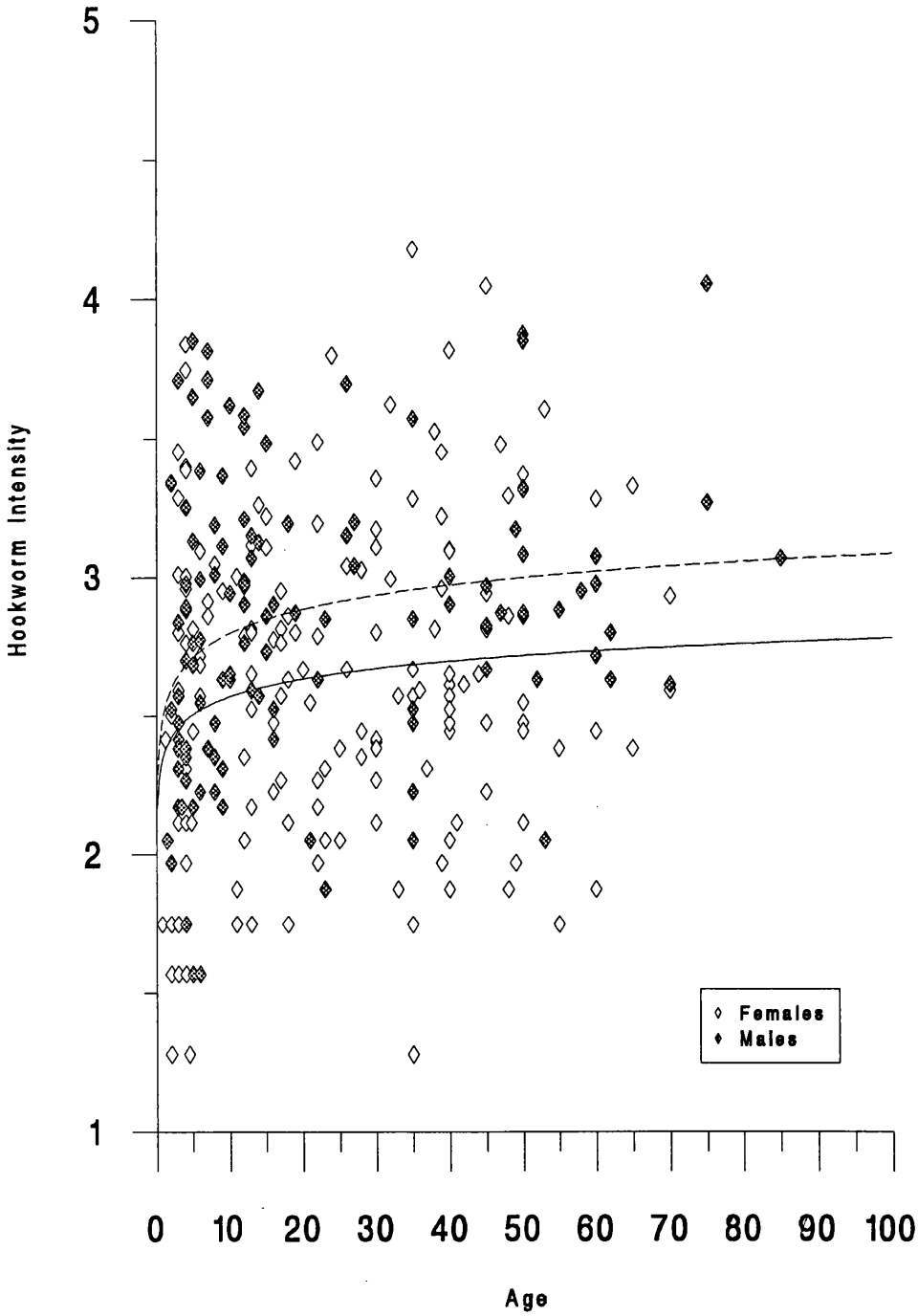

5
4
3
2
1
Hookworm Intensity
0
10
20
30
40
50
60
70
80
90
100
Age
Females
Males

Figure 5.14. Box plot of *T. trichiura* intensity in those individuals found to be infected with this helminth in Rowollon, showing the differences in the central tendency of *T. trichiura* intensity found to be significant between infected individuals living in area 1 versus those found to be infected and living in area 2.

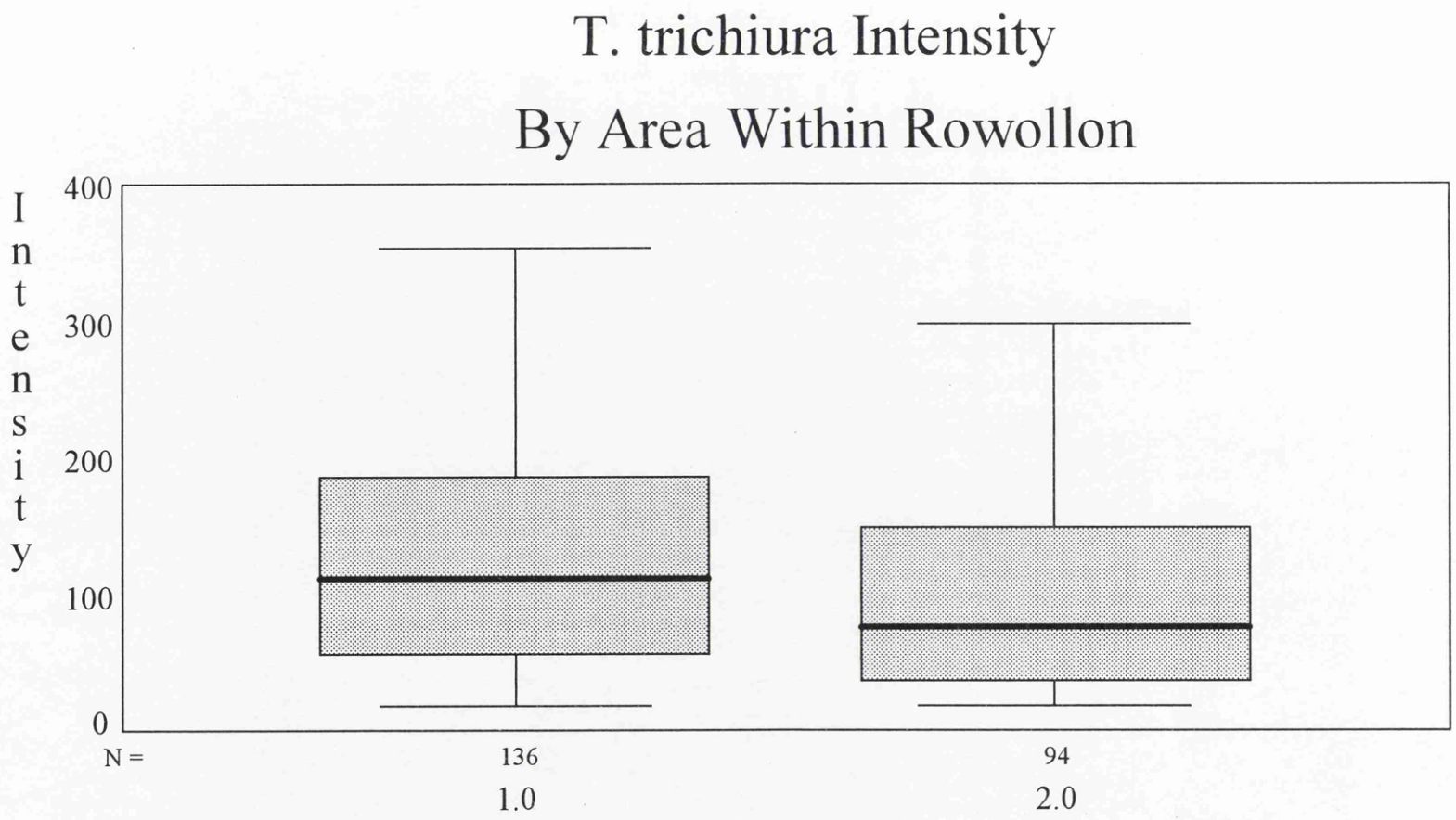

T. trichiura Intensity
By Area Within Rowollon
Intensity
400
300
200
100
0
N =
136
94
1.0
2.0
Area (See Figure 3.2)

Figure 5.15. Predicted probabilities of the model generated to predict *A. lumbricoides* prevalence in Kroo Bay versus age of individuals.

Figure 5.16. Predicted probabilities of the model generated to predict *A. lumbricoides* prevalence in Rowollan versus age of individuals.

Figure 5.17. Predicted probabilities of the model generated to predict *A. lumbricoides* prevalence in Foria versus age of individuals.

Figure 5.15: Kroo Bay

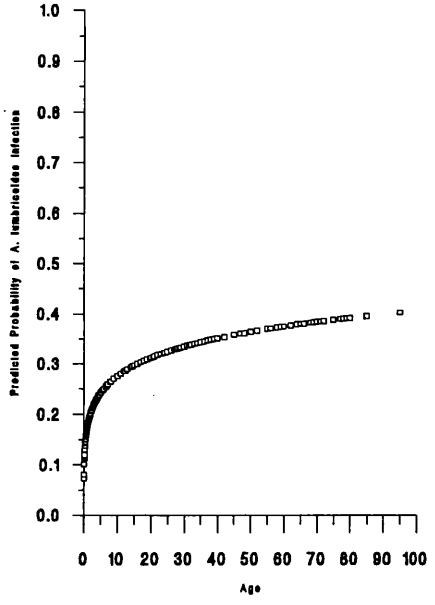


Figure 5.16: Rowollon

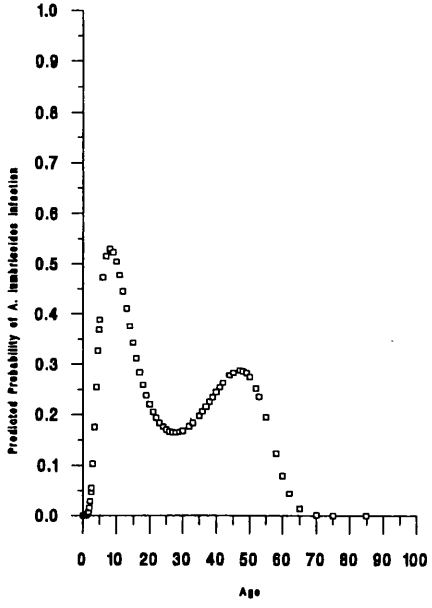


Figure 5.17: Foria

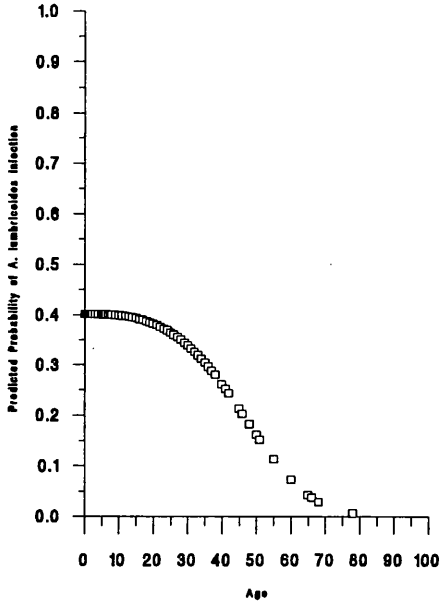


Figure 5.18. Predicted probabilities of the model generated to predict hookworm prevalence in Kroo Bay versus age of individuals.

Figure 5.19. Predicted probabilities of the model generated to predict hookworm prevalence in Rowollan versus age of individuals.

Figure 5.20. Predicted probabilities of the model generated to predict hookworm prevalence in Foria versus age of individuals.

Figure 5.18: Kroo Bay

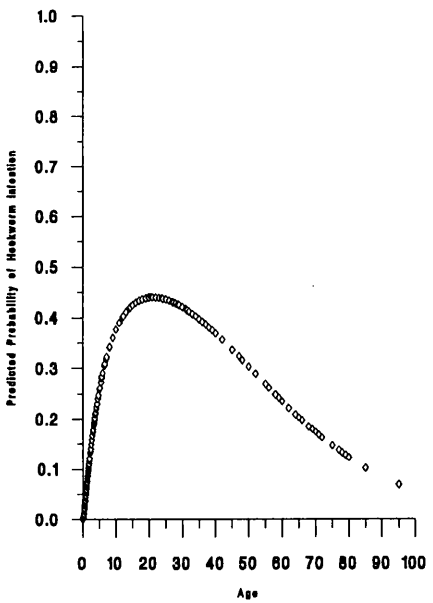


Figure 5.19: Rowollon

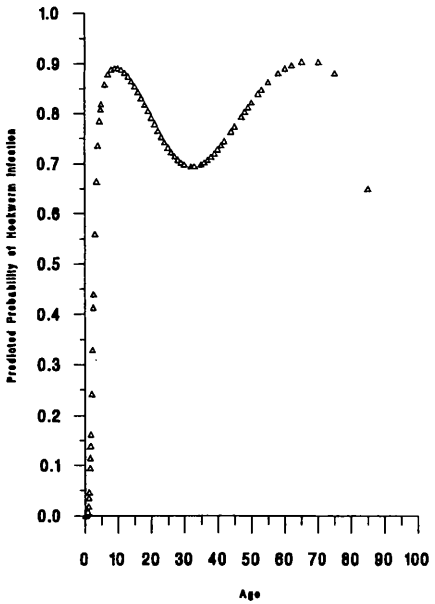


Figure 5.20: Forla

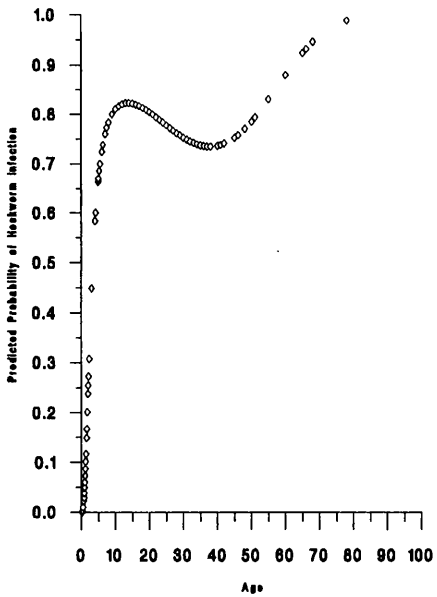


Figure 5.21. Predicted probabilities of the model generated to predict *T. trichiura* prevalence in Kroo Bay versus age of individuals. The open triangles refer to the predicted probability of those living in area 1, the filled-in triangles to those living in area 2.

Figure 5.22. Predicted probabilities of the model generated to predict *T. trichiura* prevalence in Rowollan versus age of individuals. The open squares refer to the predicted probability of the males living in area 1, the filled-in squares to males living in area 2. The open triangles refer to the females living in area 1, the filled-in triangles to females living in area 2

Figure 5.21: Kroo Bay

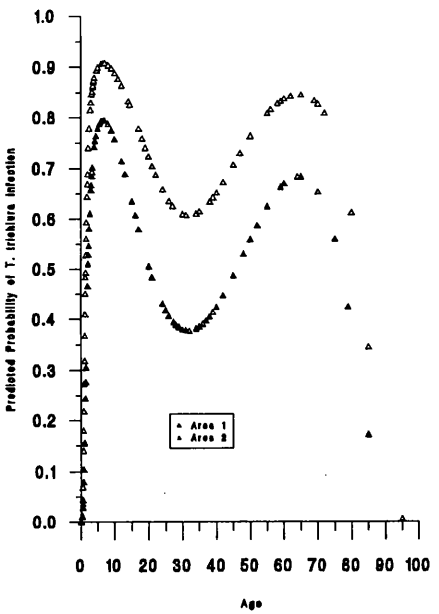


Figure 5.22: Rowollon

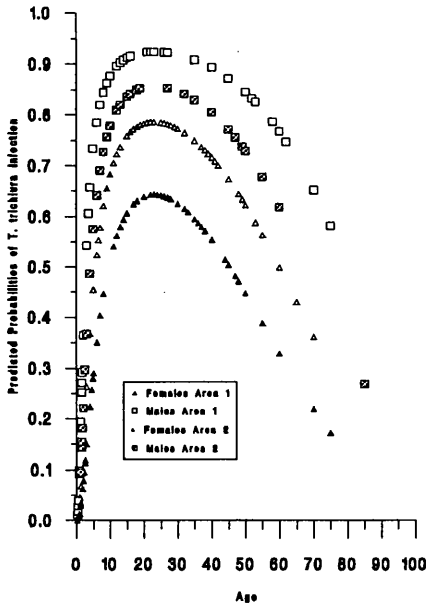


Figure 5.23. Predicted probabilities of the model generated to predict *S. mansoni* prevalence in Foria versus age of individuals.

Figure 5.23: Foria

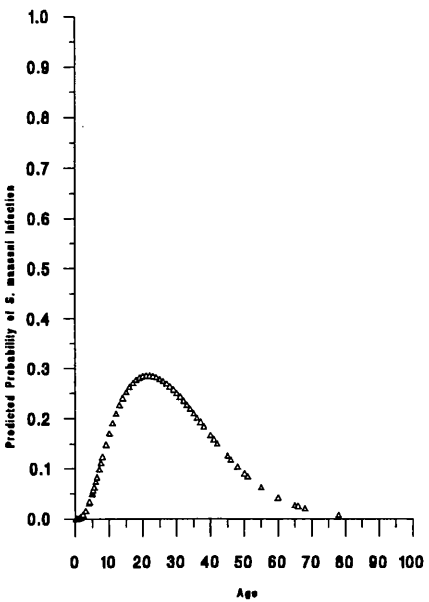


Figure 5.24. Predicted probabilities of the model generated to predict the combined prevalence of *A. lumbricoides*, hookworm and *T. trichiura* prevalence in Kroo Bay versus age of individuals.

Figure 5.25. Predicted probabilities of the model generated to predict the combined prevalence of *A. lumbricoides*, hookworm and *T. trichiura* prevalence in Rowollon versus age of individuals.

Figure 5.26. Predicted probabilities of the model generated to predict the combined prevalence of *A. lumbricoides* and hookworm prevalence in Foria versus age of individuals.

Figure 5.24: Kroo Bay

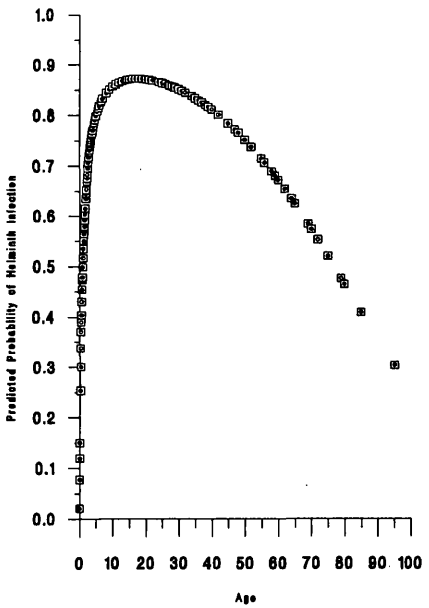


Figure 5.25: Rowollon

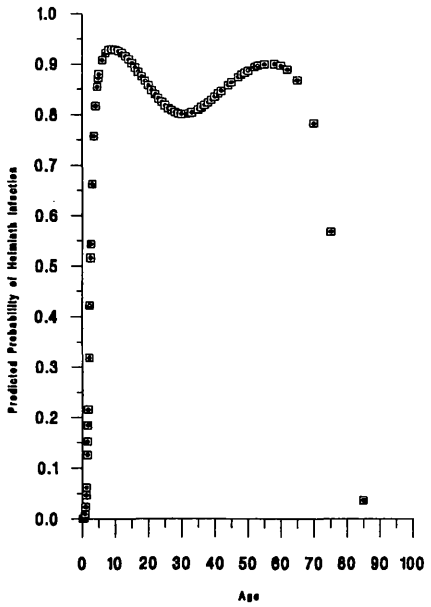
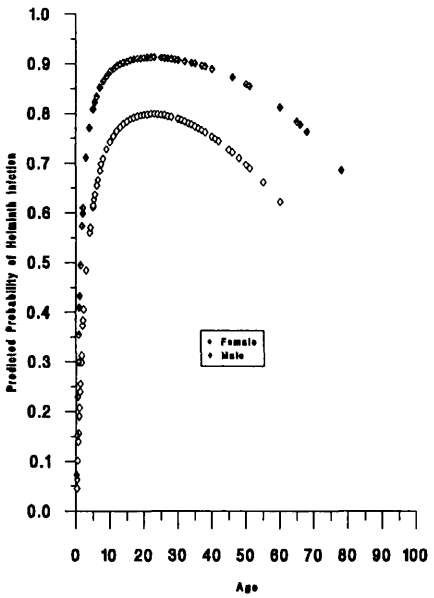


Figure 5.26: Foria



Chapter Six. Anthropometric Measurements of the Children in the Three Communities and Their Relationships to Infection Status and Other Factors.

6.1. Introduction

The effect of intestinal helminths on the health of children has frequently been investigated by other workers (for recent reviews see Bundy and Cooper, 1989; Crompton and Stephenson, 1985; Stephenson, 1993; Thein Hlaing, 1993). The effect can be investigated in two ways: (1) by studying the effect of increasing intensity of helminth infections on measurements of nutritional status and (2) by using a longitudinal study design incorporating administration of anthelmintic drugs to those found to be infected with helminths and monitoring any increase in nutritional status (Crompton and Stephenson, 1985; Stephenson, 1987). The second manner of investigation is more likely to show a difference due to the presence of helminths on nutritional status, especially when the problem of sample size and controlling for factors other than helminth infection is taken into account in the first. Guidelines for the set-up of intervention studies on gastrointestinal helminth have been set out else where (World Health Organization, 1981; Thein Hlaing, 1989a).

The survey reported here was cross-sectional because there was no possibility of return to the study site. It was impossible to compare children who were given anthelmintic treatment with those who were not, in regards to their nutritional status after treatment, as has been used successfully in previous studies (Gupta, Mithal, Arara and Tandon, 1977; Willett, Kilama and Kihamia, 1979; Stephenson, Crompton, Latham, Schulpen, Nesheim and Jansen, 1980; Stephenson, Latham, Kurz, Kinoti and Brigham, 1989; Thein Hlaing, 1989b). Any relationship between intestinal helminth infections and nutritional status detected during the present study could only indicate an association between these variables. For health workers in Sierra Leone, however, it is important to identify the factors associated with malnutrition in children living in various parts of the country. Although information about associational relationships does not indicate the cause of the malnutrition, it can result in recommendations for health care which may improve the life of children in the age groups and area being studied. Similar studies have been used to investigate the relationship between malnutrition and infection with various gastrointestinal helminths (Cole and Parkin, 1977; Gupta, Parsad and Tandon, 1978; Meakins, Harland and Caswell, 1981; Cooper, Bundy, MacDonald and Golden, 1990; Robertson, Crompton, Sanjur and Nesheim, 1992; Corbett, Butterworth, Fulford, Ouma and Sturrock, 1992).

The anthropometric measurements that have been proposed to be of most interest are weight-for-height and height-for-age, which are recommended for use in place of the weight-for-age (Waterlow *et al.*, 1977). All three are discussed in this work to allow comparison between them and to give an overall assessment of nutritional status. This report also suggested that measurements taken on individuals should be related to the reference population by standard deviations scores (z-scores) instead of the percentage of the median of the reference population, which had been used in the past (Stephenson, Latham and Jansen, 1983). The reference population recommended by WHO is that from the U.S. National Center for Health Statistics (Hamill, Drizd, Johnson, Reed and Roche, 1977) and it is also suggested that children should be separated into different age classes, which were reflective of different nutritional problems.

The anthropometric indicators give a measure of two processes involved in malnutrition (W.H.O. Working Group, 1986). These are (1) wasting, which is evidenced by a child having less tissue or fat mass than would be expected by a child of that height (weight-for-height) and (2) stunting, which is a slowing down of skeletal growth (height-for-age). Wasting may have been brought about by the failure of a child to gain weight or from a loss of weight. Stunting is brought about from lack of growth over what is usually a long time. Both of these processes may be affected by age of child, as it will take some time for stunting to appear, it being the result of a more gradual process than that of wasting and wasting may be more apparent in children undergoing some kind of immediate trauma, such as weaning, which is also age dependent. Children are considered to be wasted or stunted when they fall below the cut-off point of -2 SD or have a z-score of -2 or below (W.H.O. Working Group, 1986). Wasting may be the easier of these two to address, as increase in weight often takes less time compared to an increase in height.

6.2. Materials and Methods

Measurements were taken in Kroo Bay, Rowollon and Foria of height and weight on all children who participated in the survey and whose height was 135 cm or below. These measurements were related to the child's age to determine their weight-for-age and height-for-age and to one another to determine their weight-for-height. When a child's age could not be ascertained with any certainty (*i.e.* date of birth was not known), a child was determined to be half way through the year reported as the child's age by the caregiver.

Anthropometric data was collected using a height-for-weight chart that was produced by UNICEF. This allowed the measurement of the height of children up to 135 cm. The limitation of information on children under this height may have biased the sampling of the older age groups of children, with data only being collected on individuals which were lacking in stature for their age and/or weight. The data set for the anthropometric data was compared to the data set for all individuals in the study to determine at what age there was a significant proportion of the total children surveyed that did not have information of their height recorded. From this it was shown that, in children living in Foria there were only half the numbers aged 8 to 9 yr in the anthropometric data set that would be expected by looking at the total data set from this community. It was decided to only use children in the anthropometric data that were under 8 yr of age, using the same cut-off point for all the communities.

For comparisons between communities, only the children selected at random for the survey were included in the analysis. For comparisons of anthropometric measurements between infected and uninfected children for each helminth infection, results from non-randomly selected children were first checked to determine if they differed from the randomly selected children (Tables 1 to 4, Appendix III). Those which did not differ were included in the analysis while those that did were not. This procedure was done to avoid biasing the sample with children who might have been more likely to have attended the clinic due to suspected poor nutritional status. The data investigated the effects of infection using Kruskal-Wallis analysis for testing associations between intensity of infection and anthropometric data. The final analysis of regression and covariance was only carried out on the children randomly selected for the survey.

The anthropometric data on the children was analysed using SPSS for Windows, Version 5.0.2. The values of weight-for-age, height-for-age, and height-for weight were converted to z-scores as recommended by the W.H.O. (1986) using a program provided by the Centers for Disease Control on request (Anthro, Version 1.01, 1990). Results from the three communities were compared to determine if they differed in any of the anthropometric data and in the prevalence and/or intensity (EPG) of the helminth infections of interest, *A. lumbricoides*, hookworm, *T. trichiura* and *S. mansoni*. One-way analysis of variance was used on the anthropometric data, after Kolmogorov-Smirnov tests were done to determine if the distribution of this data differed significantly from a normal

distribution. The intensity data was transformed by taking the base ten logarithm of the data. This allowed the use of parametric one-way analysis of variance to determine if the intensity of infection of children in the study differed between communities.

Differences in anthropometric measurements between those found to be infected and uninfected for each helminth infection in each community were investigated using either a t-test or a median test. The intensity of helminth infection data was divided into classes to allow for effects on the anthropometric measurements due to increasing intensity of infection to be investigated. The infections of *A. lumbricoides* were divided into classes in the following manner: Individuals with egg counts of 1 to 999 (EPG), class 1; egg counts of 1000 to 4999 (EPG), class 2; egg counts of 5000 to 19999 (EPG), class 3: and those with over 20000 (EPG), class 4. Hookworm infections were divided into six classes, not all of which were found in all three communities. These are: class 1, 1 to 99 (EPG); class 2, 100 to 999 (EPG); class 3, 1000 to 1999 (EPG); class 4, 2000 to 2999 (EPG); class 5, 3000 to 4999 (EPG) and class 6, greater than 5000 (EPG). Infections of *T. trichiura* were divided into three classes: those with 1 to 99 (EPG), class 1; those with 100 to 499 (EPG), class 2 and those with over 1000 (EPG), class 3. There were not enough infections of *S. mansoni* in the individuals for which data was collected to form reasonable classes with a reasonable sample size in each and the analysis was not undertaken for infections with this helminth. Due to the small sample sizes in some classes of intensity, Kruskal-Wallis nonparametric analysis of variance was used to test for differences in the anthropometric measurements between different classes of helminth intensity. Regression analysis was used to investigate the importance of age of child and numbers of individuals living in a child's household on the anthropometric measurements. This was then used for analysis of covariance to determine if there were differences in measurements based on sex of child, area of the community in which a child lived and the infection status of a child. For this analysis, all the infections were lumped together and a child was classed as either infected or uninfected. This final analysis was only completed on the children randomly selected for the survey in each community.

6.3 Results

6.3.1. Community Differences in Anthropometric Measurements

Results from the three communities were compared in regards to the mean values for the different anthropometric measurements (Table 6.1, Figures 6.1 - 6.3). The results of Levene's test of homogeneity of variances are displayed in Table 5, Appendix III.

Table 6.1. Values of central tendency for the anthropometric measurements in the different communities.

Community	Weight-for-Age*	Height-for-Age*	Weight-for-Height
Kroo Bay	-1.3701 (-1.6831 to -1.0571)	-1.3900 (-1.5953 to -1.1847)	-0.72 (-1.33 to -0.26)
Rowollon	-1.0472 (-1.3348 to -0.7596)	-1.6256 (-1.8403 to -1.4110)	-1.28 (-1.94 to -0.58)
Foria	-2.2176 (-2.4808 to -1.9544)	-1.5868 (-1.7784 to -1.3952)	-0.20 (-0.89 to 0.38)

* Means and 95% confidence interval.
† Median and inter quartile ranges.

Significant differences were found between communities in the mean weight-for-age z-scores and the central tendencies of the weight-for-height z-scores (Table 6.2). There were no significant differences found between the height-for-age z-scores in the different communities.

Table 6.2. Results from tests for differences between communities in the anthropometric measurements.

Anthropometric Measurement	Test Statistic	df	*P*
Weight-for-Age	F = 19.2534*	2,285	0.0000
Height-for-Age	F = 1.4588	2,367	0.2339
Weight-for-Height	Chi-square = 32.7417*	2	0.0000

* Indicates differences found to be significant at the $P \leq 0.05$ level.

The differences between the three means of the weight-for-age z-scores are compared in Table 6.3. The differences needed between means to indicate significant differences are displayed in Table 6, Appendix III. From Table 6.3 it can be seen that both children living in Kroo Bay and Rowollon differed significantly from those living in Foria in their weight-for-age z-scores. From the data in Table 6.1 it can be seen that children living in Foria had the lowest mean weight-for-age z-scores followed by Kroo Bay and then Rowollon. All the communities had mean values which were negative, indicating a high level of malnutrition in the children.

Table 6.3. Comparisons of differences in weight-for-age between the different communities.

	Community		
Community	Kroo Bay	Rowollon	Foria
Kroo Bay	-	0.3229	0.8475*
Rowollon		-	1.1704*
Foria			-

* Indicates differences which were found to be significant at $P \leq 0.05$.

The results of a median test (Sprent, 1993) for differences in the central tendency of the weight-for-height z-scores indicated that there were significant differences between the three communities (Table 6.4). The median table was collapsed. This indicated that the children living in Rowollon had significantly lower values of weight-for-height than children living in Kroo Bay (Table 6.5).

Table 6.4. Median test for differences between communities in their central tendency for weight-for-height.

Weight-for	Community		
Height	Kroo Bay	Rowollon	Foria
Greater than Median	37	30	74
Less than Median	39	73	34

Table 6.5. Collapse of median test for differences between communities in their central tendency for weight-for-height.

Weight-for	Community	
Height	Kroo Bay	Rowollon
Greater than Median	51	38
Less than Median	25	65

From collapsing the table again (Table 6.6), it can be seen that the children living in Kroo Bay had significantly higher weight-for-height z-scores than those living in Foria. This allowed the ranking of the communities in order of increasing weight-for-height z-scores; Rowollon, Kroo Bay and Foria. This was different from the weight-for-age data.

Table 6.6. Collapse of median test for differences between communities in their central tendency for weight-for-height.

Weight-for	Community	
Height	Kroo Bay	Foria
Greater than Median	25	67
Less than Median	51	41

From these results, it appears that the communities differ as regards degree of wasting, measured by either weight-for-age or weight-for-height z-scores but not in degree of stunting, measured by the height-for-age z-scores. The cut-off values for determining whether a child is wasted

or stunted is a z-score of -2 (W.H.O. Working Group, 1986). The prevalence of those determined to be wasted or stunted using the three indicators are presented in Table 6.7.

Table 6.7. Percentages and 95% Bonferoni confidence intervals of wasting and stunting for the anthropometric measurements in the different communities.

Community	Weight-for-Age	Height-for-Age	Weight-for-Height
Kroo Bay	32.9 (23.6 - 42.2)	33.3 (22.9 - 43.7)	13.2 (3.9 - 22.5)
Rowollon	26.2 (16.1 - 36.3)	33.9 (23.6 - 44.2)	24.3 (14.2 - 34.4)
Foria	52.3 (50.1 - 54.5)	34.1 (24.2 - 44.0)	0.9 (0.0 - 3.1)

The prevalence of wasting and stunting was compared by using Chi-square analysis to determine if there were more wasted or stunted children in certain communities than others. The results of this investigation are presented in Table 6.8, with the Chi-square tables themselves being presented in Tables 7-9, Appendix III. It can be seen that the communities differ in the proportion of children found to be classed as wasted, but not in the proportion of children classed as stunted.

Table 6.8. Results from analyses of differences in prevalence of wasting and stunting between communities.

Anthropometric Measurement	Chi-square	df	*P*
Weight-for-Age	16.39	2	$P \leq 0.05$
Height-for-Age	0.02	2	$P > 0.05$
Weight-for-Height	26.23	2	$P \leq 0.05$

The Chi-square tables were collapsed to determine where the differences in prevalence were located for the weight-for-age and weight-for-height results. The chi-square tables for this are presented in Tables 10-13, Appendix III and the results in Table 6.9. In weight-for-age scores, there were more children seen to be classed as wasted in Foria than in Rowollon and Kroo Bay. In weight-for-height scores the opposite was true, with fewer children in Foria being classed as wasted.

Table 6.9. Results from collapsing Chi-square tables for differences in prevalences of wasting

Anthropometric Measurement	Comparisons	Chi-square	*P*
Weight-for-Age	Rowollon versus Kroo Bay	0.95	$P > 0.05$
	Rowollon & Kroo Bay versus Foria	15.56	$P \leq 0.05$
Weight-for-Height	Foria versus Kroo Bay	11.89	$P > 0.05$
	Kroo Bay versus Rowollon	3.43	$P \leq 0.05$

The z-scores of weight-for-age, height-for-age and weight-for-height were analysed to determine if they were correlated with one another in the three communities. Spearman rank

correlations were calculated to determine if individuals with a low value for one of the measurements also had a low value for the others (Table 6.10). From these results it can be seen that weight-for-age and height-for-age are correlated in all the communities as are weight-for-height and height-for-age. Weight-for-age and weight-for-height are negatively correlated in Kroo Bay, indicating that as one increases the other decreases. The two are not significantly negatively correlated in Rowollon or in Foria, but the same pattern is evident.

Table 6.10. Results of correlation analysis of weight-for-age, height-for-age and weight-for-height z-scores.

Community	Anthropometric Measurement	Spearman	*P*
Kroo Bay	Weight-for-Age with Height-for-Age	0.7559	0.000
	Weight-for-Age with Weight-for-Height	-0.1958	0.042
	Height-for-Age with Weight-for-Height	0.4414	0.000
Rowollon	Weight-for-Age with Height-for-Age	0.7420	0.000
	Weight-for-Age with Weight-for-Height	-0.1428	0.219
	Height-for-Age with Weight-for-Height	0.4803	0.000
Foria	Weight-for-Age with Height-for-Age	0.5905	0.000
	Weight-for-Age with Weight-for-Height	-0.1771	0.074
	Height-for-Age with Weight-for-Height	0.6190	0.000

6.3.2. Community Differences in the Prevalence and Intensity of Helminth Infections

The samples of children (in contrast to the results for individuals of all ages, reported in Chapter Four) were compared to determine if they differed significantly in their prevalence or intensity of helminth infections. Significant differences in the prevalence of *A. lumbricoides*, hookworm and *T. trichiura* infections in the children in the three communities were detected (Table 6.11.). The Chi-square tables for this analysis are presented in Tables 14 - 16, Appendix III and the results of these in Table 6.12. The differences in the prevalence and intensity of *S. mansoni* in the three communities was not tested, as Foria was the only community in which infection with this helminth was found in any number.

Table 6.12. Results from tests of differences in helminth prevalence between communities.

Helminth Infection	Chi-square	df	*P*
A. lumbricoides	17.60	2	$P \leq 0.05$
Hookworm	47.20	2	$P \leq 0.05$
T. trichiura	105.01	2	$P \leq 0.05$

The Chi-square tables testing for differences between prevalences of helminth infections were collapsed to determine where the differences were (Table 6.13). Significant differences were not

found between the prevalence of *A. lumbricoides* in Rowollon and Kroo Bay (Table 17, Appendix III) and their prevalence values were combined and compared to the prevalence values in Foria, where a significant difference was found (Table 18, Appendix III).

Table 6.13. Results from collapsing Chi-square tables for differences in prevalences

Helminth Infection	Comparisons	Chi-square	*P*
A. lumbricoides	Rowollon versus Kroo Bay	0.26	$P > 0.05$
	Rowollon & Kroo Bay versus Foria	17.43	$P \leq 0.05$
Hookworm	Rowollon versus Foria	1.73	$P > 0.05$
	Rowollon & Foria versus Kroo Bay	45.36	$P \leq 0.05$
T. trichiura	Kroo Bay versus Rowollon	13.86	$P \leq 0.05$
	Rowollon versus Foria	62.73	$P \leq 0.05$

No significant differences were found between the prevalence of hookworm infections in Foria and Rowollon (Table 19, Appendix III), but a significant differences was found between the combined prevalence of these two communities and the prevalence of hookworm in Kroo Bay (Table 20, Appendix III), with Kroo Bay having the lowest prevalence of this helminth. The prevalence of *T. trichiura* was found to differ between Kroo Bay and Rowollon (Table 21, Appendix III) and between Rowollon and Foria (Table 22, Appendix), with Kroo Bay having the highest prevalence of this helminth, followed by Rowollon and then by Foria.

Table 6.15. Results from analyses of differences in intensity of helminth infections between communities.

Helminth Infection	Test Statistic	df	*P*
A. lumbricoides	F = 8.2431*	2,119	0.0004
Hookworm	F = 7.8112*	2,175	0.0006
T. trichiura	t = 4.65*	128	0.000

* Indicates differences found to be significant at the $P \leq 0.05$ level.

Differences in the intensity of the helminth infections (Table 6.14) in the children in the different communities were tested, using an analysis of variance for the intensity of *A. lumbricoides* and hookworm and a t-test for the differences between Kroo Bay and Rowollon in the intensity of *T. trichiura* infection. Results of tests for homogeneity of variances are presented in Table 23, Appendix III. All of the comparisons between intensities of infection indicated significant differences in the intensity between the infected children in the communities (Table 6.15).

Table 6.16. Comparisons of differences between means of *A. lumbricoides* intensity between the different communities.

	Community		
Community	Kroo Bay	Rowollon	Foria
Kroo Bay	-	0.2802	0.5843*
Rowollon		-	0.3041*
Foria			-

* Indicates differences which were found to be significant at $P \leq 0.05$.

The differences between means of helminth intensity for each of the communities were investigated using a least significant difference test for unequally replicated means. The values needed for significant differences are presented in Table 24 for *A. lumbricoides* infections and Table 25 for hookworm infection, in Appendix III. Results of the comparison of the means of *A. lumbricoides* intensity are presented in Table 6.16, where it can be seen that hosts in both Kroo Bay and Rowollon differ significantly from those in Foria in their intensity of this helminth infection . Table 6.14 displays the means and 95% confidence intervals for this data, where it can be seen that children infected with *A. lumbricoides* in Foria have a higher mean intensity than those children infected with this helminth in Kroo Bay or Rowollon.

Table 6.17. Comparisons of differences between means of hookworm intensity between the different communities.

	Community		
Community	Kroo Bay	Rowollon	Foria
Kroo Bay	-	0.4189*	0.0772
Rowollon		-	0.3417*
Foria			-

* Indicates differences which were found to be significant at $P \leq 0.05$.

Results of comparisons of the mean intensity of hookworm infection between the three communities are displayed in Table 6.17. From this it can be seen that children infected in both Kroo Bay and Foria differ in their means intensity of infection from those children infected with hookworm in Rowollon. From Table 6.14 it can be seen that individuals infected in Kroo Bay and Foria have lower mean intensities of this helminth than those found to be infected with hookworm in Rowollon.

The intensity of *T. trichiura* infections in Kroo Bay and Rowollon was compared using a t-test, as there were not enough individuals infected with this helminth in Foria to warrant including those individuals infected with it in tests for differences in mean intensity. The t-test revealed significant differences between the mean intensity of those infected with *T. trichiura* in Kroo Bay and

Rowollon. From Table 6.14 it can be seen that infections with this helminth were more intense in Kroo Bay than in Rowollon.

6.3.3. Comparisons of Anthropometric Measurements Between Infected and Uninfected Individuals

Differences between those individuals found to be infected and those found to be uninfected in their anthropometric measurements were investigated using a t-test or a median test, depending on the values of a Levene's test for equality of variances (Table 26, Appendix III). These are presented in Table 6.18. In Kroo Bay and Foria, significant differences were seen in the weight-for-age z-scores of those individuals which varied in their prevalence of hookworm infection. There were no significant differences found in any of the other measurements or for any of the other infections in these two communities. In Rowollon, differences were seen in the weight-for-age z-scores and the height-for-age z-scores in those found to be infected and uninfected with each separate helminth infection. By examining Table 6.19, which displays the means and 95% confidence intervals for those found to be infected and uninfected for each of the helminth infections for all three anthropometric measurements, the direction of the difference can be seen. In Foria and Kroo Bay, those found to be uninfected with hookworm were seen to have mean values of weight-for-age z-scores which were lower than those children found to be infected with hookworm. The same was true of those found to be infected and uninfected in Rowollon, for all helminth infections and for both weight-for-age and height-for-age z-scores.

6.3.4. Comparison of Anthropometric Measurements Between Levels of Intensity of Infection

The intensity of each of the helminth infections in each community was divided into classes as described previously. Kruskal-Wallis analysis of variance was used to test for differences in the anthropometric measurements between the different levels of intensity. The results are reported in Table 6.20 for *A. lumbricoides*, Table 6.21 for hookworm and Table 6.22 for *T. trichiura*. There were not enough infections of *S. mansoni* to permit testing for differences associated with the intensity of this helminth infection.

Table 6.20. Results from Kruskal-Wallis analysis of differences for the different classes of *A. lumbricoides* intensity.

Community	Anthropometric Measurement	Chi-square	df	*P*
Kroo Bay	Weight-for-Age	0.9439	2	0.6238
	Height-for-Age	1.6030	2	0.4487
	Weight-for-Height	0.1942	2	0.9075
Rowollon	Weight-for-Age	2.9488	3	0.3996
	Height-for-Age	2.9263	3	0.4031
	Weight-for-Height	5.1248	3	0.1629
Foria	Weight-for-Age	0.5163	3	0.9153
	Height-for-Age	2.7319	3	0.4348
	Weight-for-Height	1.3852	3	0.7090

Table 6.21. Results from Kruskal-Wallis analysis of differences for the different classes of hookworm intensity.

Community	Anthropometric Measurement	Chi-square	df	*P*
Kroo Bay	Weight-for-Age	3.1284	2	0.2093
	Height-for-Age	0.8321	2	0.6596
	Weight-for-Height	3.0451	2	0.2182
Rowollon	Weight-for-Age	7.8365	5	0.1655
	Height-for-Age	7.5703	5	0.1816
	Weight-for-Height	11.3464*	5	0.0449
Foria	Weight-for-Age	5.7479	3	0.1245
	Height-for-Age	4.3106	3	0.2298
	Weight-for-Height	1.0595	3	0.7868

* Significant differences at $P \leq 0.05$.

Table 6.22. Results from Kruskal-Wallis analysis of differences for the different classes of *T. trichiura* intensity.

Community	Anthropometric Measurement	Chi-square	df	*P*
Kroo Bay	Weight-for-Age	1.4184	2	0.4920
	Height-for-Age	0.0634	2	0.9688
	Weight-for-Height	0.3607	2	0.8350
Rowollon	Weight-for-Age	0.2461	2	0.8842
	Height-for-Age	0.6695	2	0.7155
	Weight-for-Height	2.0281	2	0.3627

The only significant difference found was between those individuals living in Rowollon who were infected with hookworm. A multiple comparison test was used to determine where the differences were. The results are presented in Table 6.23, with differences needed for significant shown in Table 27, Appendix III. No significant differences were found, although the trend indicated was one of lower mean ranks for the classes with the highest intensity.

Table 6.23. Differences between mean ranks of weight-for-height z-scores by classes of hookworm intensity in children infected in Rowollon.

Intensity		Class					
Class	Mean Rank (n)	1-99 EPG	100-999 EPG	1000-1999 EPG	2000-2999 EPG	3000-4999 EPG	> 5000 EPG
1-99 EPG	45.68 (17)	-	1.40	17.10	15.82	19.35	22.85
100-999 EPG	44.28 (46)		-	15.70	17.22	17.95	21.45
1000-1999 EPG	28.58 (6)			-	32.92	2.25	5.75
2000-2999 EPG	61.50 (6)				-	35.17	38.67
3000-4999 EPG	26.33 (3)					-	3.50
> 5000 EPG	22.83 (6)						-

6.3.5. Analysis of Anthropometric Measurements For Age of Individual and Numbers in Household

The combined analysis of the anthropometric measurements for all factors recorded in this survey was undertaken in a manner similar to the analysis of the intensity of infection for all factors recorded in this survey. Equations describing different relationships of age of child to anthropometric measurement were tested to determine which described the relationship best. Equations describing the relationships between the number of individuals in a household versus the anthropometric measurements of a child and having both components of age of child and number of individuals in a household were also calculated. The equations which best fit the data are presented in Table 6.24 for age of individuals, Table 6.25 for number of individuals in a household and Table 6.26 for both age of an individual and number of individuals in a household. The actual equations and their F-values are presented in Tables 28- 35 in Appendix III.

Table 6.24. Types of equations for age of hosts that best describe the anthropometric measurements.

Helminth	Community	Best Type of Equation	F Value	df	*P*	Adjusted r^2
Weight-for-Age	Kroo Bay	Polynomial	4.340	3,72	0.0072	0.11784
	Rowollon	Polynomial	4.562	3,99	0.0049	0.09482
	Foria	Polynomial	7.326	3,105	0.0002	0.14947
Height-for-Age	Kroo Bay	Polynomial	11.356	3,113	0.0000	0.21157
	Rowollon	Polynomial	3.402	3,117	0.0201	0.05665
	Foria	Simple	10.378	1,130	0.0016	0.06680
Weight-for-Height	Kroo Bay	Polynomial	0.429	3,72	0.7328	-0.02337
	Rowollon	Polynomial	1.085	3,99	0.3592	0.00249
	Foria	Simple	2.873	1,106	0.0930	0.01720

From Table 6.24 it can be seen that the polynomial equation of age best describes most of the relationships between age and anthropometric measurements, except for the description of height-for-age and weight-for-height in Foria. In children from Foria, a simple equation of age best describes the relationship. The equations describing weight-for-age and height-for-age were all significant at the $P \leq 0.05$ level, as might be expected. They are illustrated in Figures 6.4 through 6.6 for the weight-for-age data and 6.7 through 6.9 for the height-for-age data. None of the equations for the weight-for-height z-scores were significant, indicating that age does not have much influence over this measurement.

Table 6.25. Types of equations for number of hosts in households that best describe the anthropometric measurements.

Helminth	Community	Type of Equation	F value	df	*P*	Adjusted r2
Weight-for-Age	Kroo Bay	Logarithmic	0.981	1,74	0.3252	-0.00025
	Rowollon	Logarithmic	0.114	1,110	0.7365	-0.00876
	Foria	Logarithmic	0.995	1,107	0.3208	-0.00005
Height-for-Age	Kroo Bay	Logarithmic	0.419	1,114	0.5187	-0.00508
	Rowollon	Logarithmic	1.093	1,119	0.2979	0.00078
	Foria	Polynomial	0.821	3,128	0.4846	-0.00412
Weight-for-Height	Kroo Bay	Simple	1.458	1,74	0.2311	0.00607
	Rowollon	Simple	0.710	1,101	0.4015	-0.00285
	Foria	Polynomial	0.360	3,104	0.7604	-0.01740

From Table 6.25 it can be seen that the best description of the relationship between the z-scores for weight-for-age and height-for-age in most communities is that of a logarithm of the number of individuals in a household, except for the description of height-for-age in Foria. This is best described by a polynomial equation of numbers of individuals in a household, as is the weight-for-height z-scores. The weight-for-height z-scores in Kroo Bay and Rowollon were best described by a simple equation of number of individuals in a household. None of the equations are significant at the

P 0.05 level, indicating that the number of individuals in a household has very little influence on the anthropometric measurements of these children.

Table 6.26. Types of equations for host age and number of hosts in households that best describe the anthropometric measurements.

Helminth	Community	Age Equation	Number Equation	F value	df	P	Adjusted r2
Weight-for-Age	Kroo Bay	Polynomial	Logarithmic	3.425	4,71	0.0128	0.11453
	Rowollon	Polynomial	Logarithmic	3.391	4,98	0.0121	0.08571
	Foria	Polynomial	Simple	5.539	4,104	0.0004	0.14392
Height-for-Age	Kroo Bay	Polynomial	Logarithmic	8.234	4,111	0.0000	0.21003
	Rowollon	Polynomial	Logarithmic	2.801	4,116	0.0291	0.05664
	Foria	Simple	Simple	5.152	2,129	0.0070	0.05960
Weight-for-Height	Kroo Bay	Simple	Simple	0.722	2,73	0.4891	-0.00746
	Rowollon	Polynomial	Logarithmic	0.929	4,98	0.4504	-0.00279
	Foria	Simple	Logarithmic	1.431	2,105	0.2436	0.00800

Again, all the equations for weight-for-age and height-for-age are significant at the P 0.05 level. However, none of the equations for weight-for-height z-scores are significant (Table 6.26).

6.3.6. Analysis of Covariance for all Factors Measured

The most highly significant equation from the previous analysis was then used as a covariant in covariance analysis also included the sex of an individual, the area in which an individual lived and whether an individual was found to be infected or not. All infections were pooled to give a reasonable sample size and only those individuals chosen at random were used in this analysis.

6.3.6a. Weight-for-Age

6.3.6a.*i.* Kroo Bay

The equation that was found to be most significant in the analysis of weight-for-age in individuals living in Kroo Bay was that of a polynomial equation for age. This was included as a covariant, with differences in the slope of the lines for different sexes, areas of Kroo Bay and infections status not being significantly different (Table 6.27).

Table 6.27. Results of analysis of covariance on the weight-for-age measurements in Kroo Bay.

Differences Tested	F Value	df	*P*
Slopes of Weight-for-Age by Polynomial Equation of Age for the Different Sexes	1.54	1,68	0.218
Slopes of Weight-for-Age by Polynomial Equation of Age for the Different Areas	2.77	1,68	0.101
Slopes of Weight-for-Age by Polynomial Equation of Age for those found to be Infected and not Infected with Helminths	0.33	1,68	0.568
Significance of Regression Line for Polynomial Equation of Age	8.25	1,67	0.005
Interaction of Sex of Child, Infection Status and Area	3.41	1,67	0.069
Interaction of Sex of Child and Area	2.98	1,67	0.089
Interaction of Infection Status and Area	0.01	1,67	0.913
Interaction of Sex of Child and Infection Status	2.28	1,67	0.136
Main Effect of Sex of Child	3.91	1,67	0.052
Main Effect of Infection Status	1.68	1,67	0.199
Main Effect of Area	2.06	1,67	0.156

The regression line of the polynomial of the age of individuals (Figure 6.4) was found to be significant, but there were no significant differences found in any of the interactions or main effects between the sex of a child, its infection status and the area in which a child lived.

6.3.6a.*ii.* Rowollon

The equation that best described the relationship between age and weight-for-age z-scores in the children living in Rowollon was that of a polynomial curve for age. This was used as a covariant in covariance analysis (Table 6.28). There were significant differences found in the slopes of the polynomial curve for age for the different sexes (Figure 6.10). This indicates that the curves describing the relationship of weight-for-age z-scores to age for males and females were significantly different.

Table 6.28. Results of analysis of covariance on the weight-for-age measurements in Rowollon.

Differences Tested	F Value	df	*P*
Slopes of Weight-for-Age by Polynomial Equation of Age for the Different Sexes	9.61	1,85	0.003
Slopes of Weight-for-Age by Polynomial Equation of Age for the Different Areas	0.16	1,85	0.692
Slopes of Weight-for-Age by Polynomial Equation Age for those found to be Infected and not Infected with Helminths	1.57	1,85	0.214
Significance of Regression Line for Polynomial Equation of Age	0.03	1,84	0.854
Interaction of Sex of Child, Infection Status and Area	0.00	1,84	0.973
Interaction of Sex of Child and Area	0.06	1,84	0.806
Interaction of Infection Status and Area	0.53	1,84	0.470
Interaction of Sex of Child and Infection Status	0.09	1,84	0.768
Main Effect of Sex of Child	0.25	1,84	0.618
Main Effect of Infection Status	2.38	1,84	0.127
Main Effect of Area	0.71	1,84	0.403

No other significant differences were found, including the overall significance of the regression line of the polynomial equation of age.

6.3.6a.*iii.* Foria

The equation that best described the effect of age and/or numbers of individuals in a household on the weight-for-age z-scores in those children living in Foria was that of the polynomial equation of age. No significant differences were found between the slopes of the curves due to different sex of child, infection status or area in which a child lived (Table 6.29).

Table 6.29. Results of analysis of covariance on the weight-for-age measurements in Foria.

Differences Tested	F Value	df	*P*
Slopes of Weight-for-Age by Polynomial Equation of Age for the Different Sexes	1.71	1,101	0.194
Slopes of Weight-for-Age by Polynomial Equation of Age for the Different Areas	0.59	1,101	0.446
Slopes of Weight-for-Age by Polynomial Equation of Age for those found to be Infected and not Infected with Helminths	0.24	1,101	0.627
Significance of Regression Line for Polynomial Equation of Age	9.16	1,100	0.003
Interaction of Sex of Child, Infection Status and Area	0.15	1,100	0.699
Interaction of Sex of Child and Area	0.01	1,100	0.912
Interaction of Infection Status and Area	0.13	1,100	0.722
Interaction of Sex of Child and Infection Status	0.03	1,100	0.855
Main Effect of Sex of Child	0.32	1,100	0.576
Main Effect of Infection Status	2.51	1,100	0.116
Main Effect of Area	1.33	1,100	0.251

The regression line of the polynomial equation of age was significant (Figure 6.6) but no other factor or interaction of factors was found to be statistically significant.

6.3.6b. Height-for-Age

6.3.6b.*i.* Kroo Bay

The equation of age and/or number of individuals per household that was the most highly significant was that of a polynomial equation of age. No differences were found between the slopes of curves between the different sexes, infection status and areas in which children lived (Table 6.30).

Table 6.30. Results of analysis of covariance on the height-for-age measurements in Kroo Bay.

Differences Tested	F Value	df	*P*
Slopes of Height-for-Age by Polynomial Equation of Age for the Different Sexes	1.19	1,106	0.277
Slopes of Height-for-Age by Polynomial Equation of Age for the Different Areas	0.07	1,106	0.799
Slopes of Height-for-Age by Polynomial Equation of Age for those found to be Infected and not Infected with Helminths	0.03	1,106	0.866
Significance of Regression Line for Polynomial Equation of Age	3.22	1,105	0.076
Interaction of Sex of Child, Infection Status and Area	6.00	1,105	0.016
Interaction of Sex of Child and Area	5.27	1,105	0.024
Interaction of Infection Status and Area	0.51	1,105	0.478
Interaction of Sex of Child and Infection Status	1.09	1,105	0.298
Main Effect of Sex of Child	1.06	1,105	0.306
Main Effect of Infection Status	3.20	1,105	0.076
Main Effect of Area	0.64	1,105	0.426

The regression line was not found to be significant. The three-way interaction between sex of child, infection status and area in which a child lived was found to be significant. This indicated that all three had an effect on the height-for-age z-scores, but that this was not straightforward. This is illustrated in Figure 6.11 for females and Figure 6.12 for males. Uninfected females in Kroo Bay in area 2 had the highest height-for-age z-scores. Males who lived in area 2 showed the lowest height-for-age z-scores, especially the uninfected males.

6.3.6b.*ii.* Rowollon

The equation that best describes the effect of age and/or numbers in a household is that of a polynomial equation of age. The slopes of the equations for the different sexes were found to be different (Figure 6.13) but there were no significant differences found between the slopes of the different areas or infection status (Table 6.31).

Table 6.31. Results of analysis of covariance on the height-for-age measurements in Rowollon.

Differences Tested	F Value	df	*P*
Slopes of Height-for-Age by Polynomial Equation of Age for the Different Sexes	6.85	1,95	0.010
Slopes of Height-for-Age by Polynomial Equation of Age for the Different Areas	0.50	1,95	0.483
Slopes of Height-for-Age by Polynomial Equation of Age for those found to be Infected and not Infected with Helminths	1.43	1,95	0.235
Significance of Regression Line for Polynomial Equation of Age	0.08	1,94	0.780
Interaction of Sex of Child, Infection Status and Area	1.93	1,94	0.168
Interaction of Sex of Child and Area	0.09	1,94	0.770
Interaction of Infection Status and Area	0.95	1,94	0.332
Interaction of Sex of Child and Infection Status	2.75	1,94	0.101
Main Effect of Sex of Child	0.03	1,94	0.863
Main Effect of Infection Status	6.50	1,94	0.012
Main Effect of Area	7.97	1,94	0.006

The regression line was not found to be significant, nor were the interactions between the main effects found to be significant. The main effect of infection status and area of the community in which a child lived were found to be significant. Figure 6.14 displays the differences between areas and sexes. Children living in area 1 have higher z-scores than those in area 2. Infected children have higher z-scores than those found to be uninfected.

6.3.6b.*iii.* Foria

The equation that best described the relationship between age and/or number of individuals in a household was a simple linear equation of age. Age of child was then used as a covariant. The slopes of the curves for age of height-for-age z-scores were not significantly different for the different sexes, the different areas of Foria or for children found to be infected versus those found to be uninfected (Table 6.32). The regression line of the age of the children was found to be significant (Figure 6.9) but none of the interactions of the main effects or the main effects were found to be significant.

Table 6.32. Results of analysis of covariance on the height-for-age measurements in Foria.

Differences Tested	F Value	df	*P*
Slopes of Height-for-Age by Age for the Different Sexes	0.49	1,124	0.486
Slopes of Height-for-Age by Age for the Different Areas	0.20	1,124	0.658
Slopes of Height-for-Age by Age for those found to be Infected and not Infected with Helminths	0.01	1,124	0.928
Significance of Regression Line for Age	4.17	1,123	0.043
Interaction of Sex of Child, Infection Status and Area	1.41	1,123	0.238
Interaction of Sex of Child and Area	0.06	1,123	0.807
Interaction of Infection Status and Area	1.14	1,123	0.288
Interaction of Sex of Child and Infection Status	0.08	1,123	0.778
Main Effect of Sex of Child	0.14	1,123	0.713
Main Effect of Infection Status	1.94	1,123	0.166
Main Effect of Area	2.81	1,123	0.096

6.3.6c. Weight-for-Height

6.3.6c.*i.* Kroo Bay

The equation found to best describe the relationship between age and/or numbers of individuals in a household and the weight-for-height z-scores of a child was a linear equation of the number of individuals living in a household. None of the slopes for the lines for different sex, area in which a child lived or the infection status of a child were found to be significantly different (Table 6.33).

Table 6.33. Results of analysis of covariance on the weight-for-height measurements in Kroo Bay.

Differences Tested	F Value	df	*P*
Slopes of Weight-for-Height by Number in a Household for the Different Sexes	0.03	1,68	0.861
Slopes of Weight-for-Height by Number in a Household for the Different Areas	0.44	1,68	0.507
Slopes of Weight-for-Height by Number in a Household for those found to be Infected and not Infected with Helminths	0.05	1,68	0.822
Significance of Regression Line for Number in a Household	0.79	1,67	0.378
Interaction of Sex of Child, Infection Status and Area	1.79	1,67	0.186
Interaction of Sex of Child and Area	0.74	1,67	0.392
Interaction of Infection Status and Area	0.01	1,67	0.929
Interaction of Sex of Child and Infection Status	2.55	1,67	0.115
Main Effect of Sex of Child	6.22	1,67	0.015
Main Effect of Infection Status	5.05	1,67	0.028
Main Effect of Area	0.00	1,67	0.963

The regression line due to the number of individuals was not found to be significant. None of the interactions between the main effects was found to be significantly different, but the main effects of sex of child and infection status were found to be significant (Figure 6.15). The individuals

found to be infected had higher weight-for-height z-scores than those found to be uninfected. Females were found to have higher weight-for-height z-scores than males.

6.3.6c.*ii.* Rowollon

The equation that best described the relationship of age and/or number of individuals in a household was that of a polynomial equation of age. None of the slopes for equations of weight-for-height z-scores for the different sexes, areas of Rowollon or those found to be infected or uninfected were found to be significantly different (Table 6.34).

Table 6.34. Results of analysis of covariance on the weight-for-height measurements in Rowollon.

Differences Tested	F Value	df	*P*
Slopes of Weight-for-Height by Polynomial Equation of Age for the Different Sexes	0.30	1,85	0.583
Slopes of Weight-for-Height by Polynomial Equation of Age for the Different Areas	1.12	1,85	0.292
Slopes of Weight-for-Height by Polynomial Equation of Age for those found to be Infected and not Infected with Helminths	0.08	1,85	0.771
Significance of Regression Line for Polynomial Equation of Age	0.25	1,84	0.618
Interaction of Sex of Child, Infection Status and Area	1.70	1,84	0.196
Interaction of Sex of Child and Area	0.39	1,84	0.532
Interaction of Infection Status and Area	2.19	1,84	0.143
Interaction of Sex of Child and Infection Status	1.45	1,84	0.233
Main Effect of Sex of Child	0.85	1,84	0.359
Main Effect of Infection Status	1.75	1,84	0.190
Main Effect of Area	4.27	1,84	0.042

The regression line for age was not found to be significantly different. None of the interactions of the main effects were found to be significant. Neither was the main effect of sex of child or infection status. Significant differences were found between the children in different areas in Rowollon, with children living in area 1 having higher weight-for-height z-scores than those living in area 2 (Figure 6.16).

6.3.6c.*iii.* Foria

The equation that was the most significant in the description of age and/or number of individuals in a household was a linear equation of age. There was no significant differences found between the slopes of the equations for weight-for-height z-scores for the different sexes, different areas of Foria or those children found to be infected or uninfected (Table 6.35).

Table 6.35. Results of analysis of covariance on the weight-for-height measurements in Foria.

Differences Tested	F Value	df	*P*
Slopes of Weight-for-Height by Age for the Different Sexes	0.62	1,100	0.434
Slopes of Weight-for-Height by Age for the Different Areas	1.46	1,100	0.231
Slopes of Weight-for-Height by Age for those found to be Infected and not Infected with Helminths	2.57	1,100	0.112
Significance of Regression Line for Age	4.19	1,99	0.043
Interaction of Sex of Child, Infection Status and Area	0.03	1,99	0.869
Interaction of Sex of Child and Area	0.40	1,99	0.529
Interaction of Infection Status and Area	0.53	1,99	0.466
Interaction of Sex of Child and Infection Status	0.35	1,99	0.555
Main Effect of Sex of Child	0.06	1,99	0.806
Main Effect of Infection Status	2.52	1,99	0.116
Main Effect of Area	0.00	1,99	0.997

The regression line for the line of age of child was found to be significant (Figure 6.17). None of the interactions between the main effects or the main effects themselves of sex of child, area of Foria in which a child lived or the infection status of a child were found to be significant.

6.4. Discussion

6.4.1. Anthropometric Measurements Between Communities

The comparisons of anthropometric measurements between the three communities showed a discrepancy between the two indicators of wasting, weight-for-age and weight-for-height, in the comparisons between the three communities. This comparison of the weight-for-age z-scores indicated that children living in Foria had the lowest values of this indicator, indicating that the highest levels of wasting occurred in children in this community. Conversely, using the weight-for-height z-scores as an indicator for wasting, Rowollon was shown to have the highest number of children with lower z-scores, followed by Kroo Bay and then Foria. Weight-for-height is considered to be the best indicator for wasting of the two, as it is not related to age of child or even reported age of child (which may in fact be different) (Waterlow *et al.*, 1977; W.H.O. Working Group, 1986). It is therefore taken as the indicator of wasting in this survey and children in Foria were deemed to show the least wasting out of the three communities studied. Children in Kroo Bay had more wasting than those in Foria but less than those children in Rowollon. A similar result for Foria is borne out by the numbers of children in each village who had z-scores below -2, but there was no significant difference in the numbers who were found to be below -2 in Kroo Bay and Rowollon. From this analysis and the analysis of helminth prevalence and intensity of the children, it appears that the only helminth

infections to reflect an increasing amount, both in prevalence and intensity, with an increasing amount of wasting is that of *T. trichiura*.

6.4.2. Comparisons of Prevalence and Intensity of Helminth Infections in Children

The differences found to be significant between the children surveyed in the different communities reflected the differences that were found when all the age groups surveyed were compared (as in Chapter Four). *Ascaris lumbricoides* infection was more common in the children in Foria, hookworm infection was less common in Kroo Bay and children living in Foria had significantly less *T. trichiura* infections than those in Rowollon, who had significantly less than children in Kroo Bay. Infections of *S. mansoni* were found in small numbers in Foria and the odd one was found in Rowollon. The age groups being studied in this survey of indicators of malnutrition, only comprised part of the age groups which were shown to have the highest prevalence of some of the helminths. In Chapter Four, it was shown that individuals in age class 2, 5 through 9 yr of age, and age class 3, 10 through 19 yr of age had higher prevalences of *A. lumbricoides* in Kroo Bay, as did age class 2 in Rowollon. As far as hookworm infection was concerned, age class 1 had significantly lower prevalences than any of the other age classes in all the communities. *Trichuris trichiura* infection had the lowest prevalence in age class 1 in both Kroo Bay and Rowollon, age class 3 being significantly higher in Rowollon. The prevalence of *S. mansoni* was highest in age class 2 and 3 in Foria. Intensity (EPG) of *T. trichiura* infection was seen to be high in children in age class 2 in Kroo Bay, in age classes 2 and 3 in children in Rowollon. A criticism of this analysis of indicators of malnutrition is that the majority of the age groups for which prevalence and intensity of intestinal helminths were highest in the three communities were not included due to the manner in which the information was obtained. A doctor's scale with a device for measuring height which would have allowed older children to be measured reliably would have improved this survey immeasurably.

6.4.3. Helminth Infections and Anthropometric Measurements

In the analysis of helminth prevalence and anthropometric measurements it was shown that, when only helminth infections was taken into account and significant results were found, those infected with helminths were found to have higher anthropometric measurements than those found to be uninfected. This varied by community. In Kroo Bay and Foria, weight-for-age scores were seen to be higher in those found to be infected with hookworm than in those found to be uninfected. In

Rowollon, the same was true for both weight-for-age and height-for-age z-scores for all the helminth infections analysed. This illustrates the problem encountered when the prevalence of a helminth is the only factor used to attempt to explain the nutritional status of individuals. Other factors, such as age, socio-economic status, housing, sanitation, seasonally of food crops and education level of caregiver may be related to the nutritional status of children. In this case, children who were better off in regards to wasting and stunting may have been more likely to encounter helminth transmission stages and would be more likely to become infected. Any effect of age of child on stunting and wasting has not been taken into account and from in previous chapters it had already been shown that an individuals age will influence the possibility of becoming infected with soil-transmitted helminths, thus adding to the confounding of these two factors.

It has been suggested (Anderson, 1989) that the effect of intensity on anthropometric measurements should be investigated to determine if increasing intensity of infection increases the degree of wasting and stunting seen in children. This was done using Kruskal-Wallis analysis and dividing the intensity of infection into classes. Once again, the age of most of the children included in this analysis was outside of the age for which the highest intensities were seen and this resulted in small numbers of individuals in the higher intensity classes. The only significant result seen was that of weight-for-height (wasting) in individuals infected with hookworm in Rowollon. However the differences that were significant could not be pinpointed. There is therefore little evidence from this survey that increasing intensity of infections is associated with increasing degrees of wasting and stunting. There is no evidence to the contrary either.

The age of the child was seen to have a significant influence on the weight-for-age and height-for-age z-scores. The weight-for-age z-scores were seen to be lower from 1 to 2 yr of age, reaching a minimum at a little over 2 yr of age and then to increase to six or seven yr of age, where in Kroo Bay they decreased again. The initial decrease would probably have been due to weaning, which forces the child to rely on foods other than mother's milk very quickly, with abrupt weaning being the rule in Sierra Leone. The same effect was seen on the height-for-age z-scores.

When all the factors were combined it was seen that in Kroo Bay, the regression line for the age of child was the only significant factor in explaining the z-scores for weight-for-age. Height-for-age z-scores were best explained by a combination of sex of child, area in which a child lived and

infection status of child. This indicated that males (whether infected or uninfected) tended to do better in area one than in area 2, whilst females who were uninfected did better in area 2 and those found to be infected did better in area 1. The weight-for-height z-scores indicated that females had higher scores than males and that infected individuals had higher scores than uninfected. The indication that females were better off than males is interesting. Many of the women in Kroo Bay were traders in local markets and one could often observe their daughters helping them, with baskets of food on their heads. Also daughters may be more likely to be involved in the preparation of food and this may in turn allow them to receive more nourishment than sons. There was some indication in all of this for those found to be infected having higher scores than those found to be uninfected. This runs counter to many of the findings of harmful effects of helminth infections in the past and probably indicates a confounding effect between the possibility of becoming infected and having increased mobility and higher nutritional status.

In Rowollon, the slopes for weight-for-age and height-for-age were found to differ significantly due to the sex of the child. This indicates differences in rates of development of malnutrition in males and females due to age. This may be due to differential treatment of children based on their sex, perhaps again a difference in treatment somehow reflecting a difference in ability to obtain nourishment. Again in height-for-age, stunting, those found to be uninfected had lower scores than those found to be infected and those children living in area 1 were better off in terms of both height-for-age and weight-for-height z-scores. This may be reflective of differences in socio-economics reflected in locations in which individuals live in a community.

In Foria, the only factor found to vary significantly with all the anthropometric measurements was age of child, with a polynomial equation explaining more of the variation in weight-for-age and linear equations for height-for-age and weight-for-height. These indicate the lowest values for weight-for-age occur in those children in ages two through three, for height-for-age the values increase with an increase in age, and for weight-for-height, the values decrease with age. This indicates that the degree of stunting will decrease with age, which is a strange finding, as stunting is an indication of long-term malnutrition, while wasting is often thought of as short-term. It may be that the children in Foria are showing an increase in height at the expense of a decrease in weight.

In all of the communities, it would have been interesting to have taken measurements on individuals from older age classes, where helminth infections were more common and more intense. There would have been a greater chance of finding a detrimental effect of nutritional status of individuals and helminth infection. As it was, in this survey there is some indication that infected individuals often show higher values for anthropometric measurements than those found to be uninfected, although there is nothing in the survey to indicate that this is a result of the infection on its own.

6.4.4. Comparisons with Other Studies

Cross-sectional studies have a difficult time showing that differences in child nutritional status are associated with helminth infection, either in intensity or prevalence (Thein Hlaing, 1989a; Hall, 1993). This is due to the fact that it is difficult to control for differences in previous history of infections, socio-economic conditions and diet. This is only compounded by the fact that these factors (other infections, different socio-economic conditions and diet) are often associated with helminth infections (see Chapter One). Intervention studies are the preferred means of determining the association of nutritional status with helminth infections (Thien Hlaing, 1989a), however this approach was not possible in the surveys reported in this thesis. The importance of prevalence and intensity of helminth infections as well as the prevalence and severity of malnutrition within the study population for the selection of an appropriate area in which to complete an intervention study has been stated in several reviews of intervention study methodology (Crompton and Stephenson, 1985; Hall, 1982; Stephenson, 1987; Thein Hlaing, 1989a).

The cross-sectional study reported here was undertaken to determine if the study areas were ones where an intervention with anthelmintic drugs would be likely to show a significant improvement on the nutritional status of the children in the three communities studied. The results of this study are compared to the intensities and prevalence of infection in other areas to determine if the criteria believed to be needed for a significant relationship between treatment and improvement in nutritional status are meet in this area.

The first criteria is that the helminth species to be studied must be present, with both high prevalence and intensity. From this, it appears that a trial for the control of *A. lumbricoides* infection and the effect of this on the nutritional status of children would be more likely to show a significant

result in Foria than in Kroo Bay or Rowollon. Both the intensity and prevalence of this helminth were highest in the children sampled in this community. *Ascaris lumbricoides* infection has been associated with differences in weight-for-age, height-for-age and weight-for-height between treated and controls in interventions studies (Stephenson *et al.*, 1989; Thein Hlaing, Than Toe, Than Saw, Myat Lay Kyin and Myint Lwin, 1991). These values should therefore be low for children living in Foria. The values reported from all the communities are low, with negative z-scores as means. This indicates that there is a large amount of malnutrition in all of the communities studies. Foria does not fulfil the second criteria of having mainly single infections of *A. lumbricoides* infections present, with the prevalence of hookworm being high and a significant amount of co-occurrence with this helminth (Chapter Four). The prevalence (36.6%) and intensity (4460.7 EPG) of *A. lumbricoides* infection in Foria are low compared to some areas where intervention trials have successfully been undertaken (47.1% prevalence in Burma (Thein Hlaing, 1985)) or comparable to others (38.3% Kenya, (Crompton, 1989b)). In Burma the mean EPG results from children studied varied from approximately 21000 to 67500 EPG (Thein Hlaing, 1985), indicating that the intensity of infection in the children in all three communities studies may be too light to expect a significant association of helminth infections and nutritional status. It is suggested that intervention trials should be confined to areas where the prevalence is 60% or higher in the entire community (Thein Hlaing, 1989a). This is not so in Foria, or indeed in Kroo Bay or Rowollon, in terms of *A. lumbricoides* infection.

Studies of effects of hookworm infection have concentrated on the association with iron-deficiency anaemia (Roche and Layrisse, 1966). From the suggestions on organising an intervention trial (Thein Hlaing, 1989a), Foria and Rowollon both have high degrees of prevalence of infection (61.8 and 66.6% respectively). It is interesting to note that it is for hookworm intensity that the only significant result was seen in regards to helminth infection intensity and nutritional status. The intensity of infection was classed into units which are comparable to those used by Layrisse and Roche (1964) to show an association in the decrease in haemoglobin levels and hookworm intensity and compares to results from a study showing improvement in growth rates after treatment for hookworm infection (combined with *S. haematobium* infection) (Stephenson, Latham, Kurz, Kinoti, Oduori and Crompton, 1985). This suggests that an intervention trial in Rowollon (with significantly higher

mean intensity of hookworm) may be worth trying, including an examination of the levels of anaemia in children and their hookworm intensity.

Trichuris trichiura infection has been studied recently in regards to the influence of Trichuris Dysentery Syndrome and lack of stature (Cooper *et al.*, 1990) and in regards to its influence on the cognitive performance of children (Nokes *et al.*, 1992; Callender *et al.*, 1993). Trichiuriasis is quite common in the area where these studies have been undertaken (57% (Bundy, 1986) and large infections are considered to be children who are found to have infections with intensities of *T. trichiura* greater than 20000 EPG (Cooper and Bundy, 1986). In the three communities studied, there were no individuals found to harbour any where near this type of intensity of infection. Any effects due to *T. trichiura* infection would be most likely be found in children living in Kroo Bay (prevalence 51.7%) but it is unlikely that significant differences would be found following an intervention trial due to the small mean intensity in this community.

Schistosoma mansoni infection was not found in sufficient numbers to test for effects in nutritional status associated with this infection. Again, the intensity and prevalence were much higher in those areas where this infection was seen to have an effect on the nutritional status of children (Corbet *et al.*, 1992).

6.5. Summary

Anthropometric Measurements

1. Significantly lower weight-for-age z-scores were detected in children in Foria, in comparison to those of children in Rowollon and Kroo Bay.
2. No significant differences in the height-for-age z-scores between the three communities.
3. Significantly lower weight-for-height z-scores in those children living in Rowollon, followed by those children living in Kroo Bay who had significantly lower scores than those living in Foria.

Helminth Prevalence and Intensity.

1. Children living in Foria had significantly higher prevalence of *A. lumbricoides* than those living in Kroo Bay or Rowollon, who were indistinguishable in their prevalence of this helminth.
2. Children living in Kroo Bay had significantly lower prevalence of hookworm infection than those living in Rowollon or Foria, who were indistinguishable in their prevalence of this helminth.
3. The significantly lowest prevalence of *T. trichiura* was found in children living in Foria, followed by those children living in Rowollon which had a significantly lower prevalence than those children living in Kroo Bay.
4. There were not enough infections of *S. mansoni* to validly test for differences in prevalence or intensity between children living in the different communities.
5. Children found to be infected with *A. lumbricoides* in Foria had significantly higher mean intensity of this helminth than those children found to be infected with this helminth in Rowollon or Kroo Bay.
6. Children found to be infected with hookworm in Rowollon had significantly higher means intensity of this helminth than those children found to be infected with this helminth in Foria or Kroo Bay.
7. Children living in Kroo Bay and infected with *T. trichiura* had significantly higher mean intensity of this helminth than those found to be infected in Rowollon.

Differences in Z-scores Based on Prevalence of Helminths

1. In Kroo Bay and Foria, those infected with hookworm were seen to have higher weight-for-age z-scores than those uninfected with hookworm.
2. In Rowollon, those infected with *A. lumbricoides*, hookworm and *T. trichiura* were shown to have significantly higher weight-for-age and height-for-age z-scores than those found to be uninfected with each in turn.

Differences in Z-scores Based on Intensity of Helminths

1. Significant difference found in weight-for-height z-scores in those found with hookworm infection in Rowollon.

Anthropometric Measurements and Age of Child and Numbers of Individuals in a Household

1. Age had an influence on weight-for-age and height-for-age z-scores in all three communities.
2. Age of child did not have a significant influence on weight-for-height z-scores
3. Number of individuals in a household did not have a significant effect on any of the anthropometric measurements in any of the communities studied.

Covariance Analysis

Kroo Bay

1. Weight-for-age: Regression line of polynomial equation of age significant.
2. Height-for-age: Three-way interaction of sex of child, area in which child lived and infection status of child significant.
3. Weight-for-height: Main effect of sex of child and infection status of child significant, with females higher than males and infected higher than uninfected.

Rowollon

1. Weight-for-age: Slopes for different sexes found to be significantly different.
2. Height-for-age: Slopes for different sexes found to be significantly different; main effects of infections status and area found to be significantly different, with infected higher than uninfected and those living in area 1 higher than those living in area 2.
3. Weight-for-height: Main effect of area found to be significantly different, with those living in area 1 higher than those in area 2.

Foria

1. Weight-for-age: Regression line of polynomial equation of age significant.
2. Height-for-age: Regression line of linear equation of age significant.
3. Weight-for-height: Regression line of linear equation of age significant.

Table 6.11. Prevalence of helminth infection (95% Bonferoni confidence intervals) for the anthropometric data set in the different communities.

	A. lumbricoides		Hookworm		*T. trichiura*		*S. mansoni*	
Community	Numbers Examined	Prevalence	Numbers Examined	Prevalence	Numbers Examined	Prevalence	Numbers Examined	Prevalence
Kroo Bay	179	20.1 (12.9 - 27.3)	179	12.8 (6.8 - 18.8)	118	51.7 (40.7 - 62.7)	207	-
Rowollon	189	18.0 (11.3 - 24.7)	190	44.7 (36.1 - 53.3)	222	31.1 (23.7 - 38.5)	222	0.5 (0.0 - 1.6)
Foria	142	36.6 (26.9 - 46.3)	184	38.0 (29.4 - 46.6)	184	1.1 (0.0 - 2.9)	184	4.3 (1.0 - 7.6)

Table 6.14. Mean intensity of helminth infection (95% confidence intervals) for the anthropometric data set in the different communities.

	A. lumbricoides		Hookworm		*T. trichiura*		*S. mansoni*	
Community	Numbers Infected	Intensity	Numbers Infected	Intensity	Numbers Infected	Intensity	Numbers Infected	Intensity
Kroo Bay	36	1161.7 (658 - 2050)	23	145.6 (76 - 278)	61	249.6 (187 - 333)	0	-
Rowollon	34	2214.6 (1270 - 3862)	85	382.0 (274 - 532)	69	101.2 (78 - 131)	1	466.0
Foria	52	4460.7 (3023 - 6580)	70	173.9 (130 - 233)	2	26.9 (19 - 38)*	8	122.2 (39 - 382)

* Range of values, not 95% confidence interval.

Table 6.18. Differences in anthropometric measurements between infected and uninfected children living in the three communities.

Community	Helminth	Anthropometric Measurement	Test Statistic	df	*P*
Kroo Bay	*A. lumbricoides*	Weight-for-Age	t = 0.32	109	0.752
		Height-for-Age	Chi-square = 0.14	1	0.705
		Weight-for-Height	t = -1.16	109	0.250
	Hookworm	Weight-for-Age	t = -2.00*	109	0.048
		Height-for-Age	Chi-square = 3.33	1	0.068
		Weight-for-Height	t = -0.62	109	0.538
	T. trichiura	Weight-for-Age	t = -0.13	74	0.900
		Height-for-Age	Chi-square = 0.44	1	0.5056
		Weight-for-Height	t = -1.16	74	0.248
Rowollon	*A. lumbricoides*	Weight-for-Age	t = -3.76*	91	0.000
		Height-for-Age	t = -2.87*	101	0.005
		Weight-for-Height	t = -1.00	166	0.320
	Hookworm	Weight-for-Age	t = -2.00*	109	0.048
		Height-for-Age	t = -4.74*	188	0.000
		Weight-for-Height	t = -1.56	166	0.120
	T. trichiura	Weight-for-Age	t = -3.10*	91	0.003
		Height-for-Age	t = -3.54*	220	0.000
		Weight-for-Height	t = -1.53	198	0.128
Foria	*A. lumbricoides*	Weight-for-Age	t = -1.32	117	0.190
		Height-for-Age	t = -1.05	140	0.294
		Weight-for-Height	t = -0.23	106	0.821
	Hookworm	Weight-for-Age	t = -4.25*	107	0.000
		Height-for-Age	t = -1.85	182	0.066
		Weight-for-Height	t = 1.14	149	0.258
	S. mansoni	Weight-for-Age	t = -1.04	150	0.298
		Height-for-Age	t = 0.15	182	0.885
		Weight-for-Height	t = 1.79	149	0.075

* Indicate significant differences at $P \leq 0.05$.

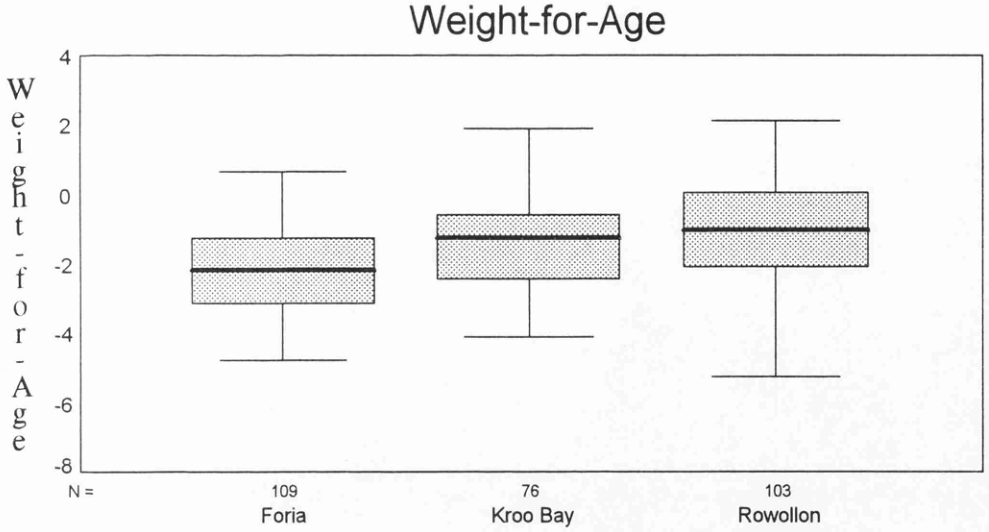
Table 6.19. Means and 95% confidence intervals for anthropometric measurements for infected and uninfected individuals in the three communities.

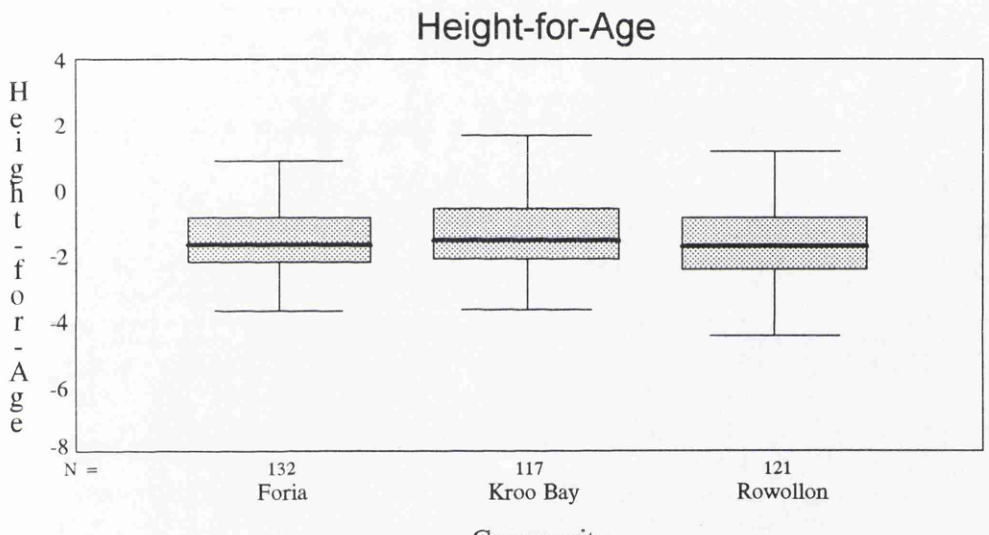
Community	Anthropometric Measurements	*A. lumbricoides* Uninfected	*A. lumbricoides* Infected	Hookworm Uninfected	Hookworm Infected	*T. trichiura* Uninfected	*T. trichiura* Infected	*S. mansoni* Uninfected	*S. mansoni* Infected
Kroo Bay	Weight-for-Age	-1.3675 (-1.66 to -1.07)	-1.4519 (1.86 to -1.04)	-1.5063 (-1.77 to -1.24)	-0.9010 (-1.43 to -0.38)	-1.4014 (-2.03 to -0.77)	-1.3574 (-1.73 to -0.99)	-	-
	Height-for-Age	-1.3504 (-1.54 to -1.16)	-1.4443 (-1.73 to -1.15)	-1.4093 (-1.59 to -1.23)	-1.0923 (-1.42 to -0.77)	-1.3256 (-1.67 to -0.98)	-1.4617 (-1.69 to -1.23)	-	-
	Weight-for-Height	-0.8000 (-1.00 to -0.60	-0.5894 (-0.89 to -0.29)	-0.7640 (-0.95 to -0.58)	-0.6333 (-1.01 to -0.25)	-0.9941 (-1.43 to -0.56)	-0.7467 (-0.96 to -0.53)	-	-
Rowollon	Weight-for-Age	-1.2674 (-1.58 to -0.95)	-0.0552 (-0.66 to 0.55)	-1.8815 (-2.22 to -1.54)	-0.8207 (-1.14 to -0.50)	-1.2867 (-1.63 to -0.94)	-0.3594 (-0.86 to 0.14)	-	-
	Height-for-Age	-1.7994 (-2.08 to -1.52)	-1.0183 (-1.34 to -0.69)	-2.1677 (-2.41 to -1.93)	-1.3400 (-1.58 to -1.10)	-1.9401 (-2.13 to -1.75)	-1.3246 (-1.60 to -1.05)	-	-
	Weight-for-Height	-1.3005 (-1.52 to -1.08)	-1.0603 (-1.44 to -0.69)	-1.4021 (-1.69 to -1.12)	-1.1045 (-1.36 to -0.85)	-1.3358 (-1.55 to -1.12)	-1.0617 (-1.33 to -0.80)	-	-
Foria	Weight-for-Age	-2.3260 (-2.66 to -2.00	-1.9831 (-2.39 to -1.58)	-2.7367 (-3.09 to -2.38)	-1.6889 (-2.03 to -1.35)	2.2462 (-2.47 -2.02)	-2.9350 (-7.83 1.96)	-2.2831 (-2.51 to -2.05)	-1.7550 (-2.74 to -0.77)
	Height-for-Age	-1.6603 (-1.92 -1.40)	-1.4575 (-1.70 -1.22)	-1.6538 (-1.87 -1.44)	-1.3540 (-1.56 -1.15)	-1.5321 (-1.69 -1.37)	-2.2350 (-7.51 3.04)-	-1.5373 (-1.70 to -1.38)	-1.5938 (-2.39 to -0.80)
	Weight-for-Height	-0.2341 (-0.42 to -0.05)	-0.1968 (-0.49 to 0.09)	-0.1430 (-0.32 to 0.04)	-0.2971 (-0.50 to -0.09)	-0.2077 (-0.34 to -0.07)	-0.6450 (-11.76 to 10.47)	-0.1850 (-0.32 to -0.05)	-0.7225 (-1.57 to 0.12)

Figure 6.1. Box plots of weight-for-age z-scores for the different communities.

Figure 6.2. Box plots of height-for-age z-scores for the different communities.

Figure 6.3. Box plots of weight-for-height- z-scores for the different communities


Weight-for-Age
Weight-for-Age
4
2
0
-2
-4
-6
-8
N =
109
Foria
76
Kroo Bay
103
Rowollon
Community


Height-for-Age
Height-for-Age
4
2
0
-2
-4
-6
-8
N =
132
Foria
117
Kroo Bay
121
Rowollon
Community

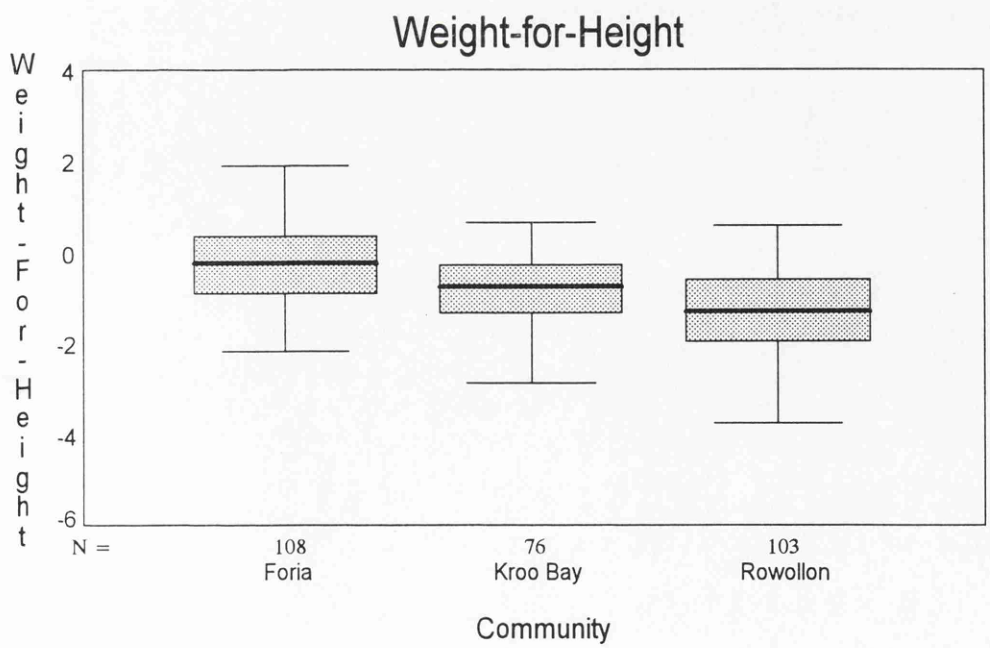

Weight-for-Height
Weight-For-Height
4
2
0
-2
-4
-6
N =
108
Foria
76
Kroo Bay
103
Rowollon
Community

Figure 6.4. Regression line of the polynomial equation of age of child for weight-for-age z-scores in children living in Kroo Bay. The line accounts for 11.8% of the variation in the data.

Figure 6.5. Regression line of the polynomial equation of age of child for weight-for-age z-scores in children living in Rowollon. The line accounts for 9.5% of the variation in the data.

Figure 6.6. Regression line of the polynomial equation of age of child for weight-for-age z-scores in children living in Foria. The line accounts for 14.9% of the variation in the data.

Figure 6.4: Kroo Bay

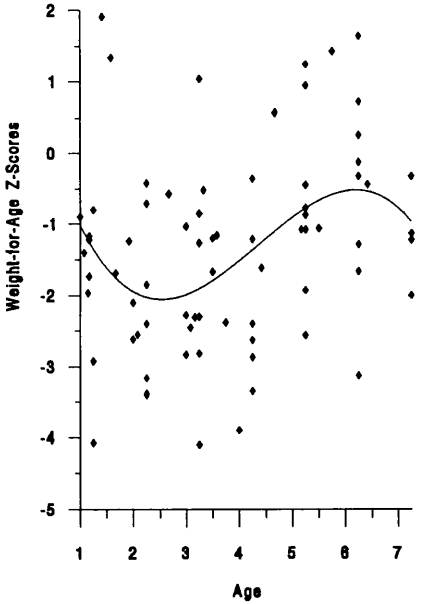


Figure 6.5: Rowollon

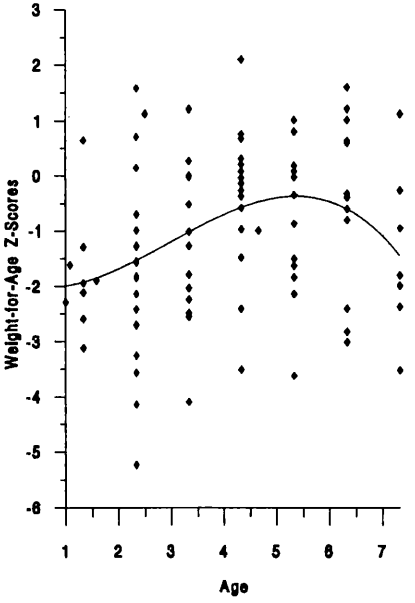


Figure 6.6: Foria

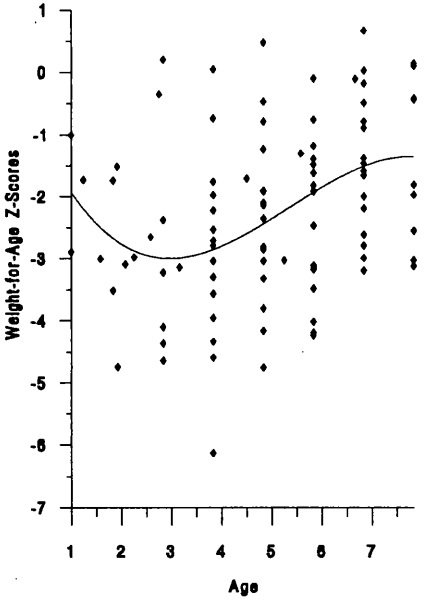


Figure 6.7. Regression line of the polynomial equation of age of child for height-for-age z-scores in children living in Kroo Bay. The line accounts for 21.2% of the variation in the data.

Figure 6.8. Regression line of the polynomial equation of age of child for height-for-age z-scores in children living in Rowollon. The line accounts for 5.7% of the variation in the data.

Figure 6.9. Regression line of the linear equation of age of child for height-for-age z-scores in children living in Foria. The line accounts for 6.7% of the variation in the data.

Figure 6.7: Kroo Bay

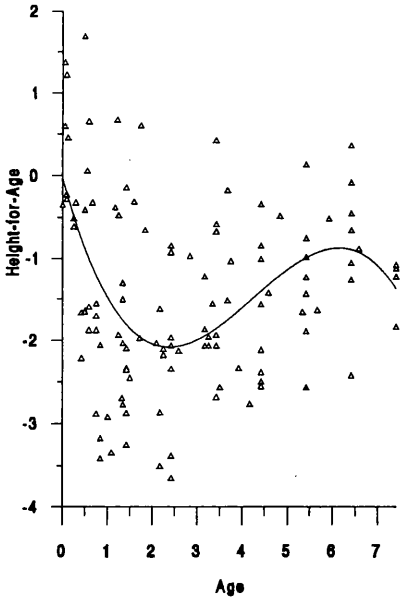


Figure 6.8: Rowollon

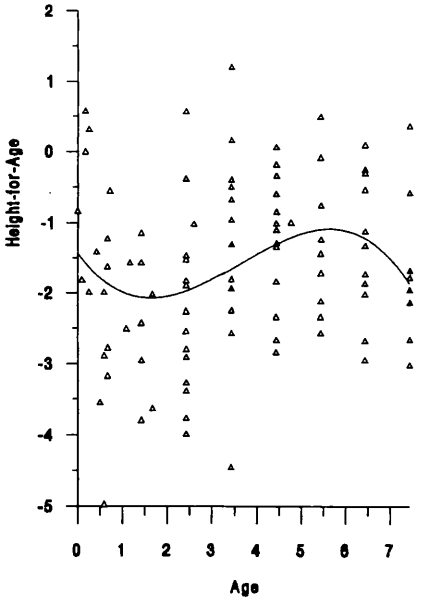


Figure 5.9: Foria

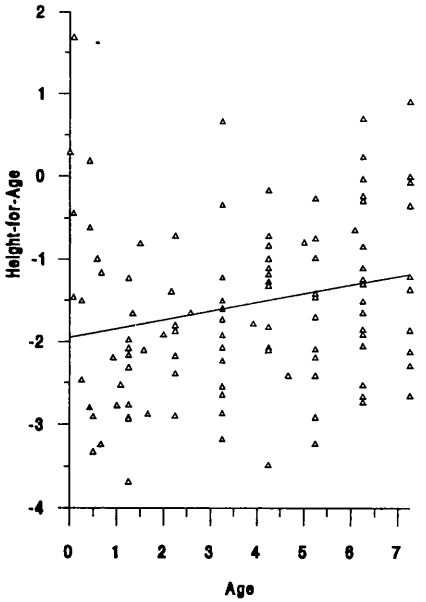


Figure 6.10. Regression lines of the polynomial equation of age of child on weight-for-age z-scores in children living in Rowollon for males and females separately. The thin line is the regression line for male, the thick line is for females.

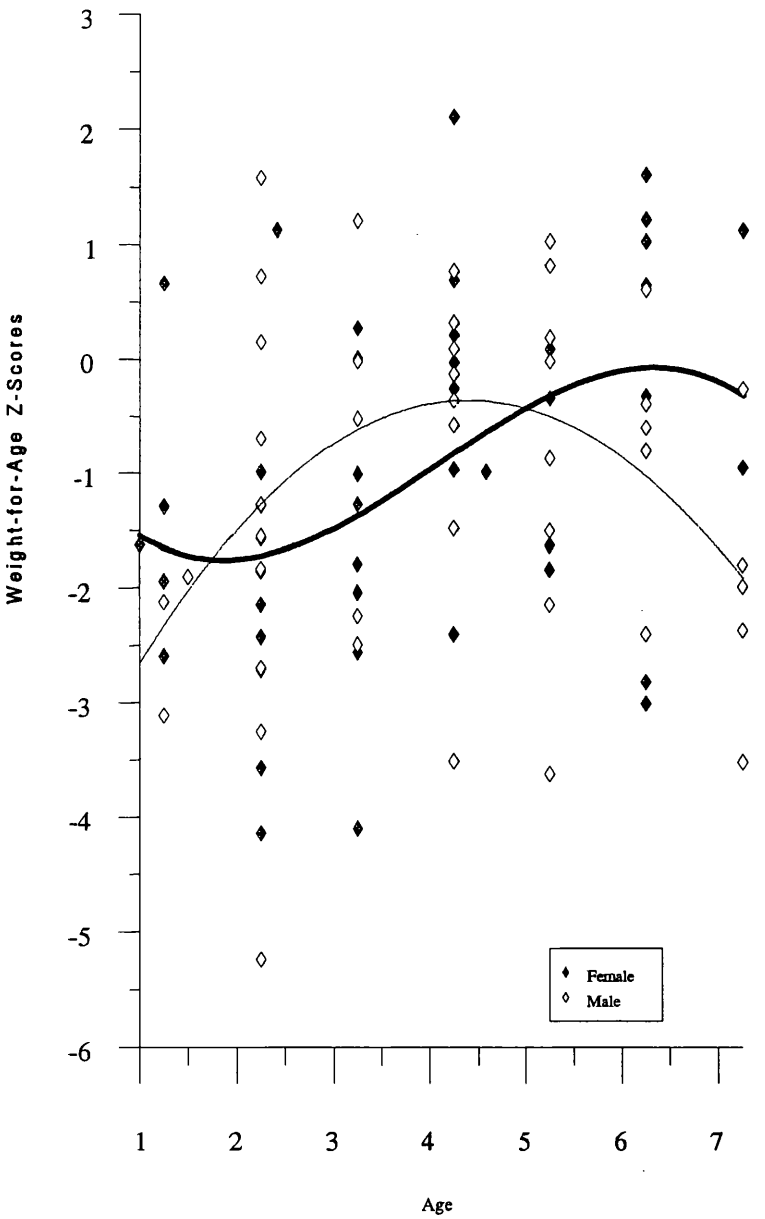
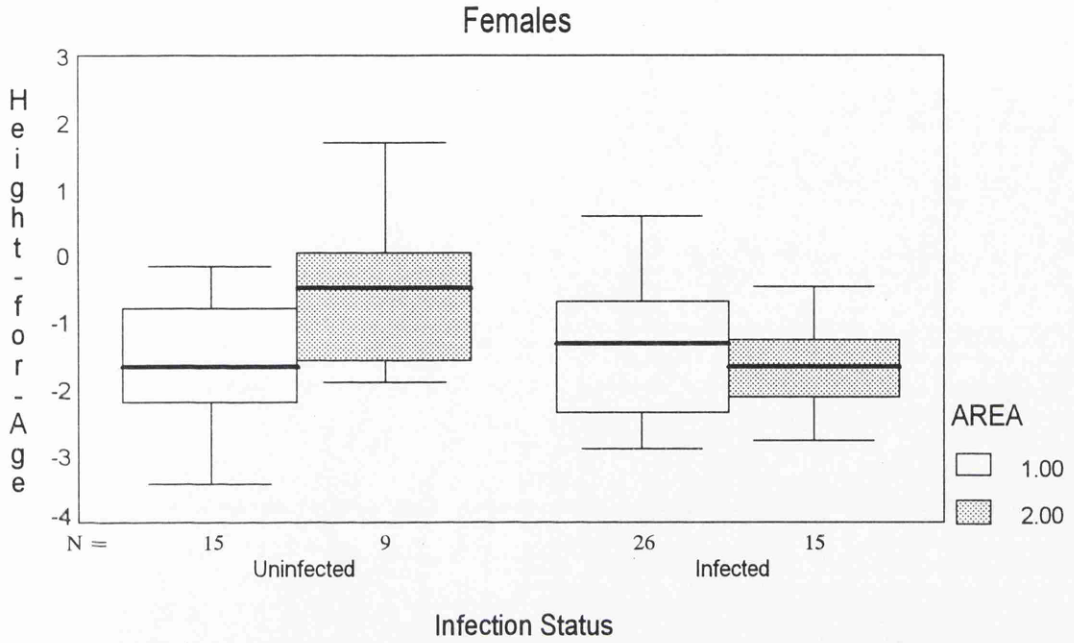

Weight-for-Age Z-Scores
3
2
1
0
-1
-2
-3
-4
-5
-6
1
2
3
4
5
6
7
Age
Female
Male

Figure 6.11. Box plots for height-for-age z-scores in females living in Kroo bay, by area in which the children lived and their infection status.

Figure 6.12. Box plots for height-for-age z-scores in males living in Kroo bay, by area in which the children lived and their infection status.


Females
Height-for-Age
3
2
1
0
-1
-2
-3
-4
N =
15
9
26
15
Uninfected
Infected
Infection Status
AREA
1.00
2.00

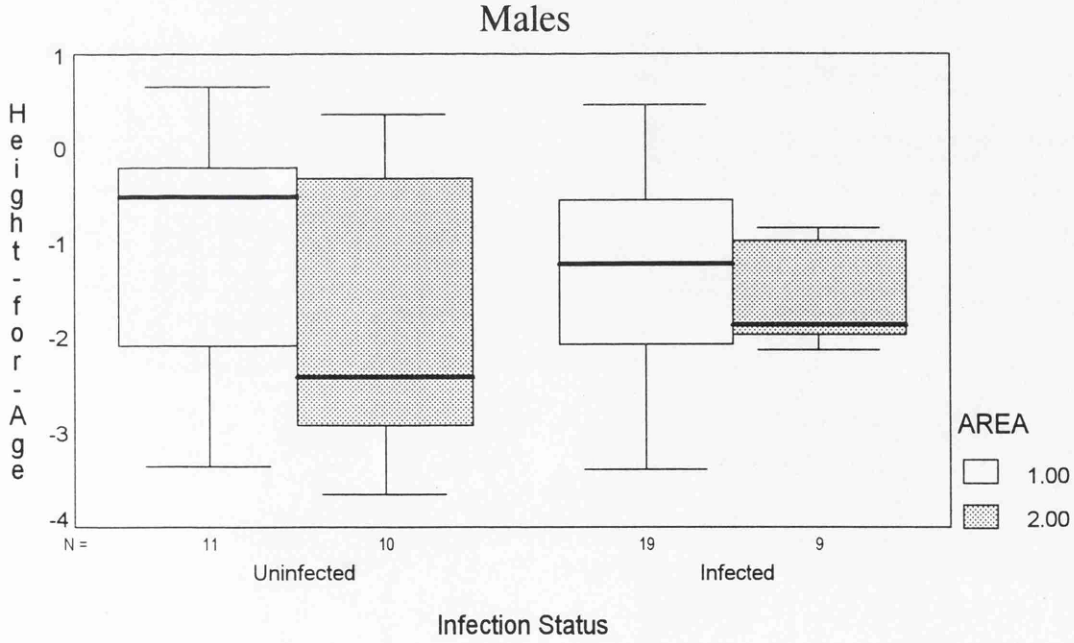

Males
Height-for-Age
1
0
-1
-2
-3
-4
N =
11
10
19
9
Uninfected
Infected
Infection Status
AREA
1.00
2.00

Figure 6.13. Regression lines of the polynomial equation of age of child on height-for-age z-scores in children living in Rowollon for males and females separately. The dotted line is the regression line for male, the continuous line is for females.

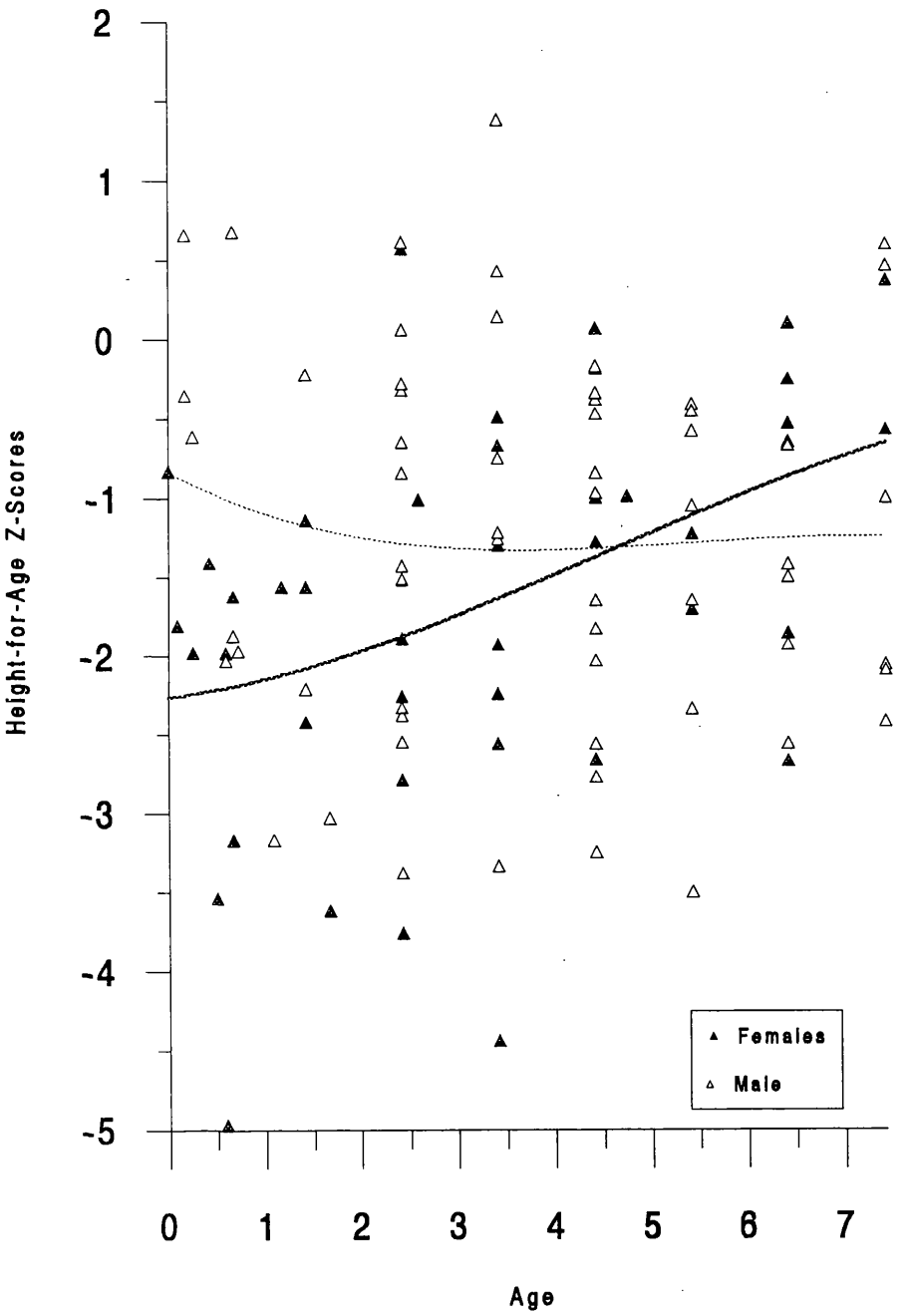
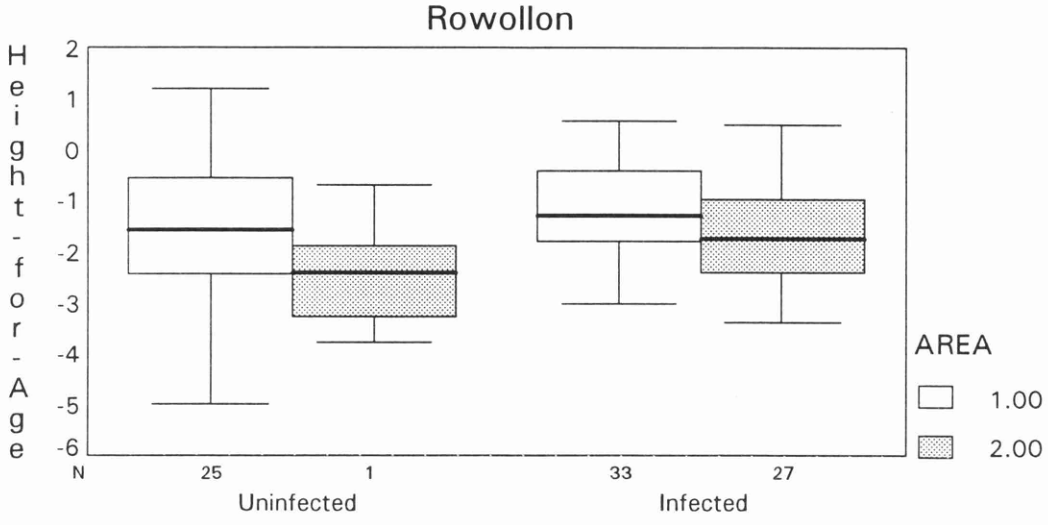
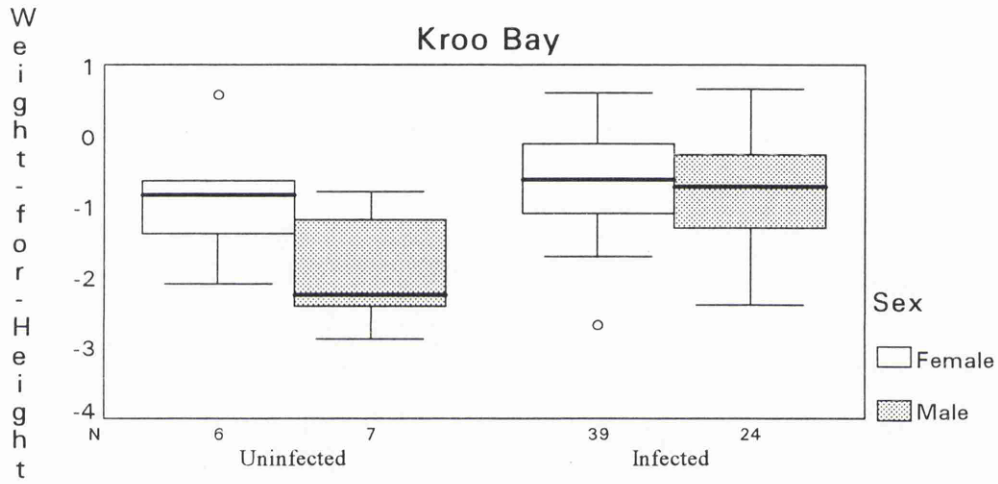

Height-for-Age Z-Scores
2
1
0
-1
-2
-3
-4
-5
0
1
2
3
4
5
6
7
Age
Females
Male

Figure 6.14. Box plot showing height-for-age z-scores for children living in Rowollon based on area in which they lived and their infection status.

Figure 6.15. Box plots of weight-for-height z-scores in children living in Kroo bay, by sex of child and their infection status.

Figure 6.16. Box plots of weight-for-height z-scores in children living in Rowollon, by area in which the children lived.


Rowollon
Height-for-Age
2
1
0
-1
-2
-3
-4
-5
-6
N
25
1
33
27
Uninfected
Infected
Infection Status
AREA
1.00
2.00


Weight-for-Height
Kroo Bay
1
0
-1
-2
-3
-4
N
6
7
39
24
Uninfected
Infected
Infection Status
Sex
Female
Male

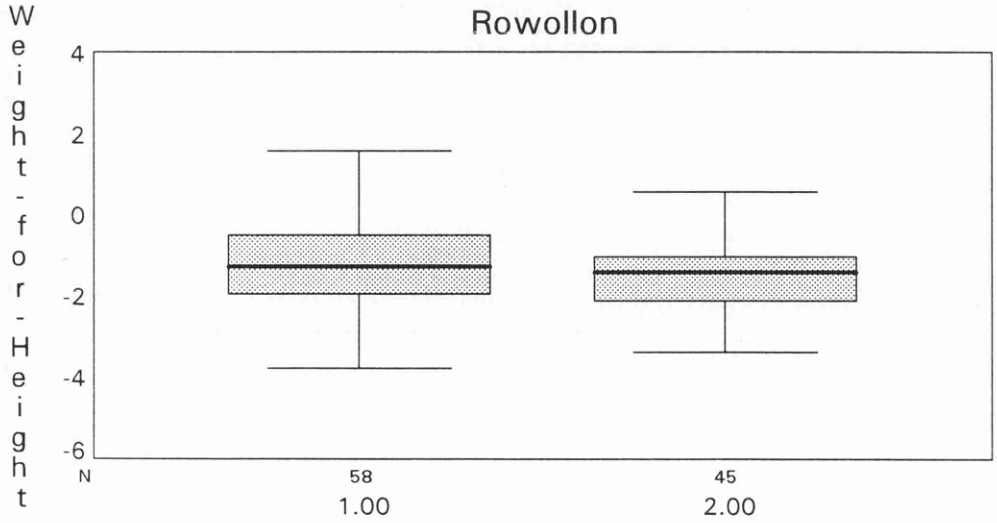
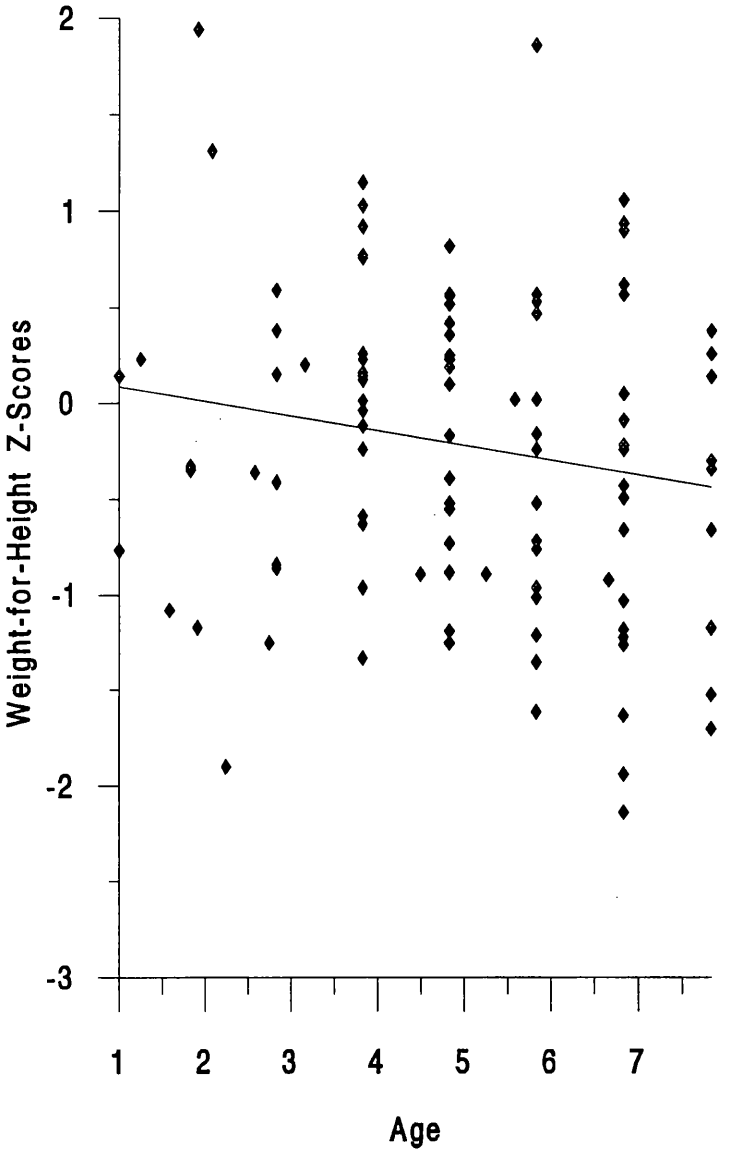

Weight-for-Height
Rowollon
4
2
0
-2
-4
-6
N
58
45
1.00
2.00
Area

Figure 6.17. Regression line of the linear equation of age of child for weight-for-height z-scores in children living in Foria.

Figure 6.17: Foria



Chapter Seven. Transmission Factors Involved in the Distribution of Helminths in Host Populations: Mechanisms, Model Approaches, Laboratory Manipulations and Field Studies.

7.1. Mechanisms of Transmission

The transmission of helminths between their hosts may be classified into five categories (see Table 7.1): 1. Those helminths that are transmitted in predator-prey interactions where an intermediate or paratenic host is preyed upon by the host where development will continue. 2. Those helminths that are transmitted by encounter with the epidermis of the host, resulting either in skin or cuticle penetration or infection of the dermal layer (where physical encounter with an infective stage is necessary for a susceptible host to be infected). 3. Through the bite of an infected intermediate host, i.e. vector transmission. 4. Contamination of food, water or environment of the host leading to ingestion of infective stage. 5. Through the maternal-foetal placental routes (occurring in mammals only). Although species of helminths tend to follow one pattern of transmission as they are transmitted from one host to another, there are instances where more than one type of transmission may be utilised. In those helminth species which have an indirect life cycle, requiring at least one intermediate host, different methods of transmission may occur when going to definitive to intermediate host and back again.

When considering the coexistence of helminths and their hosts, various factors influencing the transmission of these parasites may have evolved, indicating the conflict often seen in helminth/host associations (Toft and Aeschlimann, 1991). Factors increasing transmission appear to be of benefit to the helminths and factors which limit the possibility of transmission are seen to be of benefit to hosts. In predator-prey interactions there is evidence to indicate that in some systems the presence of a parasite in the prey (intermediate host) makes the prey item more susceptible to predation. From the parasite's point of view, this can be due to changes in behaviour such as in *S. solidus* infections in *G. aculeatus* (Tierney, Huntingford and Crompton, 1993) or to changes in morphology of the intermediate host (*Diphyllobothrium mansonoides* in mice (Phares, 1987)) both of which may enhance predation by the appropriate host and so allow further development of the parasite. In those helminths which are transmitted by contact with the skin, the importance of physical contact between host and infective stages of the helminth in time and space is underlined. With human hookworm infection, the tendency of people to use the same areas repeatedly for defecation, will lead to a higher possibility of transmission after a period of time for larval development (Schad, Nawalinski and Kochar, 1983). Infections of humans with *Schistosoma* spp. are reliant on the host's continued use of

water supplies where the development within a suitable snail host has already taken place (Wilkins, 1987). The importance of host finding behaviour by cercariae in the transmission of digenean flukes has been studied to identify its effects on transmission possibilities (Evans and Gordon, 1983). Vector transmission has been studied extensively in the transmission of the filarial nematodes, where different vectors in different areas have differences in biting activity according to the time of day and location (outside or within houses) and may be more likely to feed on certain hosts (World Health Organization, 1987a; recent papers reviewed by Dye, 1990). Some species of helminth that are transmitted by the trans-placental route have been shown to have storage of arrested larvae in somatic tissues and this is related to the infection of the foetus (Schad, 1990; Sprent, 1958), although not all helminths having these stages have been shown to be transmitted in this manner.

Those helminths transmitted through contamination of ingested food have many different means of ensuring that they are transmitted. Cystacanths of *P. paradoxus*, have been shown to engender changes in the behaviour of intermediate hosts so that they are found in the food that the definitive host (mallards etc.) consumes (Bethel and Holmes, 1977). Some, passed in the faecal material of the definitive hosts, appear to make the faecal material more attractive to the intermediate hosts (Evans, Hardy and Singh, 1990). Others may rely on the general contamination of the environment to encounter the appropriate host. Certain behaviours of the suitable host may increase the chances of ingestion of the infective stages, in the case of *A. lumbricoides*, the encounter of parasite with the host in the case of infection of children would be facilitated by playing in a contaminated environment with little thought of hygiene or from geophagus behaviour (Wong, Bundy and Golden, 1991) and in the entire community with the use of contaminated nightsoil on vegetable plots and other foodstuffs (Ghadirian, Croll and Gyrokos, 1979).

Some host related factors have been identified which would curtail the success of the transmission procedure. These could be behavioural differences over the lifetime of the host, for instance the change in behaviour associated with change in age so that children past a certain age spend less time playing in what may be areas contaminated with *A. lumbricoides* and *T. trichiura* infected areas. There may be inherent differences in behaviours which might result in different possibilities of infection. Inherent differences in refractivity may exist between different hosts (for example the differences seen in the possibility of infection in different mouse and rat strains (Behnke

and Robinson, 1985)) which may be due to many factors acting in concert or apart, and might include a behavioural component, differences related to the major histocompatability complex, hormonal differences and actual physical differences between possible host. The immunological responses of the different individuals of the host population may vary as a result of exposure to infection which may influence the ability of helminths to establish and develop within an individual with recent studies on this in *S. haematobium* (Bundy and Blumenthal, 1990; Hagan, Blumenthal, Dunn, Simpson and Wilkins, 1991), *A. lumbricoides* (Haswell-Elkins, Kennedy, Maizels, Elkins and Anderson, 1989) *T. trichiura* (Bundy and Medley, 1992) and hookworm (Pritchard, Quinnell, Slater, McKean, Dale, Raiko and Keymer, 1990), although only that for *S. haematobium* has been shown to have an effect on an individual's intensity of infection. Also the behaviour of individuals may vary according to infection status, with perhaps morbidity from infection either increasing or decreasing the chance of encounter with another infective stage of the helminth.

7.2. Models

The laboratory and mathematical models discussed here are those which have specifically investigated the effect of changing transmission parameters on the distribution of parasite populations when the mode of transmission is that of ingestion of infective stages through oral contamination. A review of this body of work is required as background for discussion of the transmission model which simulated infection taking place as a consequence of contamination of food via the oral route (Chapter Eight). Models, laboratory manipulations and field studies investigating other types of transmission will only be considered when they may be seen to be relevant to this discussion. Consideration of some relevant approaches used in ecological research on the density of members of species and its variability within the environment is included to validate the technique used to investigate the results of the transmission model which was the basis for this research.

7.2.1. Crofton, 1971a, b

The factors responsible for the distribution of helminths within a host population have stimulated much research in the field of parasitology, particularly since the publication of two papers by H. D. Crofton in 1971. In the first of these papers Crofton (1971a) sets out a definition of parasitism that includes the production of an over-dispersed distribution of helminths within the host population and the factors hypothesised to be responsible for creating this distribution. The

mathematical description observed to best fit the distribution of helminths in hosts was found to be the truncated negative binomial, where most members of the host population are either uninfected or lightly infected and truncation occurs at levels which are believed to be approaching the lethal level of helminth infection. Crofton observed that the over-dispersion seen in a helminth's distributions in a host population could be acting as a regulator of the host population, and was related to the densities of both the host and helminth populations. Crofton proposed six ways in which he envisioned over-dispersed distributions arising in parasitic infections.

1. Infection is a consequence of being exposed to waves of infection at random, but the chance of an individual being infected changes from one wave of infection to another.
2. The distribution of infective stages in the environment is not random but clumped; therefore the exposure of individuals to infective stages would not be random.
3. Members of the host population which are already infected are more likely to become infected again.
4. Members of the host population which are already infected are less likely to become infected again.
5. Inherent variation in members of the host population may affect their exposure and susceptibility to infection.
6. There may be variations in exposure and susceptibility of members of the host population over time.

The work to follow, in Chapter Eight and Nine, has investigated two, three, four and five above. This review focuses on investigations relevant to the importance of these factors in generating the patterns of helminth distribution in host populations that have been observed in both natural populations and laboratory settings. Models generated to investigate interactions of the types described in two, three and four above are also included.

The points brought forward by Crofton (1971a) were then used to construct deterministic model of transmission (Crofton, 1971b). This model allowed the manipulation of the initial numbers of parasites infecting a host population, the achievement factor (a combination of the reproductive rate of the parasite with it's ability to establish in a member of the host population), k (a term from the equation for a negative binomial distribution which varies inversely with over-dispersion so that the more over-dispersed a population, the smaller is k) and the lethal level of infection. In addition, the effect of a crude immune response, which required only a small amount of stimulation (i.e. number of parasites) and which removed the parasites within the host expressing this immune response out of the model by either killing them or rendering them sterile, was included in the model formulation.

The initial numbers infecting a host and the achievement factor are components of two, three and four in the previous paper (Crofton, 1971a), and so are of interest to this review. The influence of the parameter k on the host/helminth relationship is also of interest in considerations concerning the influence of two, three and four on this parameter. Crofton's model indicated that the equilibrium levels of host and parasite populations are dependent on the value of k and the value of the achievement factor and the transmission rate, as well as the lethal level of parasites. As two, three and four would influence both the achievement factor and transmission rate, they would be involved in determining the equilibrium levels of host and parasite populations. The degree of over-dispersion of the parasites within the host population appears to be important for determination of the degree of pathogenicity needed for maintaining the host-parasite equilibrium and in the influence of the introduction of an immune response. In general, the higher the over-dispersion, the less important are pathogenic effects in determining the equilibrium of host-parasite populations and the more stable an oscillating system will be when a host immune response is added into the model.

These two papers, published in the early 1970's, have since influenced a large body of work on the distribution of parasites in host populations. This includes the construction of mathematical models to investigate the types of distributions seen in host-parasite systems (Anderson and Gordon, 1982; Anderson and May, 1985; May, 1977) and the use of laboratory experiments (Keymer and Anderson, 1979; Keymer, 1982; McCarthy, 1990; Tanguay and Scott, 1992) and field-based work (Bundy, Cooper, Thompson, Anderson and Didier, 1987a; Bundy, Cooper, Thompson, Didier and Simmons, 1987b; Hominick, Dean and Schad, 1987; Thein Hlaing, Than Saw, Htay Htay, Myint Lwin and Then Maung Myint, 1984; Wong, Bundy and Golden, 1991) to study the influence of the six factors outlined in Crofton's first paper on the distribution of parasites in a host population.

7.2.2. Anderson and Gordon, 1982

The various influences on parasite distributions in host populations were summarised by Anderson and Gordon (1982), in which the factors influencing the distribution of parasites in hosts were divided into those related to under-dispersion and those related to over-dispersion (see Figure 7.1).

Factors concerned with parasite transmission which tend to generate over-dispersed distributions are those that increase the heterogeneity of the host/parasite system. These are, from

Figure 7.1., heterogeneity in susceptibility to infection, either inherently or through changes which occur after infection in comparison to uninfected individuals, or through heterogeneity in the physical environment of the hosts in terms of encounters with parasites. The dynamics of host encounter with parasite infective stages may reflect what is seen in sampling from a patchy environment. Most animal populations are aggregated in nature (Krebs, 1989) and this is likely to be the case with helminth infection stages (Hominick, Dean and Schad, 1987; Wong, Bundy and Golden, 1991). The investigation of the relative contributions of the dynamics of host encounter to over-dispersion of parasites in the host population was reported in Anderson and Gordon (1982). In their Monte Carlo simulations, heterogeneity in immigration rate was seen to lead to over-dispersion and host mortality due to density of parasites was seen to lead to under-dispersion. They concluded that the observed distribution of parasites in host populations was a result of a combination of these sorts of dynamic factors, (demographic stochasticity i.e. the random probability associated with factors such as death rate or infection rates) which may vary for different species of parasites, at different geographical locations and also at different times (environmental stochasticity i.e. the effect of environmental factors which may vary both temporally and spatially). They pointed out the difficulty of investigation of these factors from field-based studies and indicated that laboratory experiments allowing control of different factors and observing their influence on the parasite distribution in the host would be the most profitable way to investigate the relative importance of these factors.

7.2.3. Taylor, 1961

Anderson and Gordon (1982) also drew attention to the applicability of Taylor's Power Law (Taylor, 1961) to parasite/host distributions. This law (model) states that the variance of population counts (S^2) and mean density (m) of populations sampled in Nature are related by the following formula:

$$S^2 = am^b$$

The variables a and b are constants which are characteristic for the species being investigated. This equation leads to the construction of a linear equation for the relationship of the logarithm of the variance plotted against the logarithm of the mean density

$$\log_{10}S^2 = \log_{10}a + b\log_{10}\mathrm{m}.$$

This law has received much attention in the field of ecology in general as well as in parasitology (Anderson, Gordon, Crawley and Hassell, 1982; Hanski, 1987; Perry, 1988; Soberón and Loevinsohn, 1987; Taylor, Woiwod and Perry, 1978). Much of the interest in this law (model) has to do with speculation about the important factors contributing to the relationship seen between variance of population numbers and the mean density of the population. Some authors have placed more importance on the effect of demographic and random factors on the form of this relationship and others have emphasised the importance of behaviour in determining components of this relationship. The influence of the type of sampling undertaken in investigating the variance and mean relationship has been investigated (Soberón and Loevinsohn, 1987). The different sampling procedures, may indicate the importance of different factors, temporal, spatial or behavioural, for the relationships found. The accepted view appears to be that the relationship between the variance and mean abundance of a population is due to a combination of the above factors, which are unique for a certain species, for the locality and time the sample was undertaken. Transmission of infective stages in helminth infections could be included as one of these factors, although it is most likely subject to influences of these factors

7.2.4. Janovy and Kutish, 1988

A model of the transmission of parasites to their hosts was constructed by Janovy and Kutish (1988) to elucidate the temporal heterogeneity of encounters between metazoan hosts and parasite infective stages. They considered hosts and parasites as sums of pairs of random numbers which corresponded to co-ordinates. Infection took place when a parasite was within a certain distance (window) of a host. The infectivity of the parasites can be manipulated by changing the size of the area in which the two populations interact, concentration of hosts and parasites can be concentrated by increasing the numbers of each and the proportion of the parasite population that has the ability to infect the host population can be altered by changing the percentage overlap of the two populations. Two different types of infections were simulated, one with parasites reproducing and the other with no reproduction, and two different types of encounter with infective stage were simulated, multiple waves of small numbers of parasites encountering dispersed hosts and a single wave of parasites encountering concentrated hosts.

The mean density, variance/mean ratios and prevalence were calculated for each population (as defined in Margolis *et al.*, 1982). In the versions of the model where there were parasites continuously supplied to the system, the prevalence increased rapidly as did the parasite/host ratios and increasing infectivity, and the population did not become aggregated. In those versions in which large numbers of fixed parasites were supplied over a restricted time, prevalence and density remained low and the populations were highly aggregated. The results from trials of this model indicate that when infective stages are always present at some low level, the parasite populations are not highly aggregated while when a large number of a parasite's infective stages are encountered by hosts, the first encounters result in infection, leading to a highly aggregated distribution. These simulations indicated that temporal heterogeneity has a large effect on not only the variance/mean but also the mean density and prevalence and that over-dispersion of parasite populations can be generated by transmission factors. It should be noted that these authors were influenced in the manner in which they simulated transmission by the organisms which they are involved in studying, especially monogeneans on fish in a flowing stream, (Janovy and Hardin, 1987; Adams, 1986) but their findings have some relevance to all helminth systems.

7.2.5. McCallum, 1990

The importance of transmission factors in determining patterns of predisposition to infection in field studies of human helminth infections has been studied by McCallum (1990). Where researchers have looked at predisposition to reinfection following chemotherapy, the importance of transmission factors in the reinfection of hosts have underlined the significance of these in the determination of the observed overall distribution of parasites in hosts. Different factors have been postulated to be related to the phenomenon of predisposition by different authors. These have been split into long-term versus short-term factors (McCallum, 1990). Long-term factors are those related to difference in innate resistance to parasitic infection or any difference to exposure to infection which may occur to due other factors which rarely change during an individuals life-time (example occupation or cultural factors). Short-term factors are those related to differences between host in encounter with parasite infective stages which could vary over a short-time, (example encounter with infective stages which are patchily and/or non-randomly distributed in the host's environment).

These factors have also been separated into those involving environmental heterogeneity in exposure and variability in susceptibility to infection (Bundy and Cooper, 1988 for infections with *T. trichiura*). Examples involving environmental heterogeneity which last throughout an individual's lifetime can be imagined (example the increased risk of individuals involved in agricultural to hookworm infection (Schad, Nawalinski, and Kochar, 1983 for hookworm infections) which indicates that the two means of distinguishing factors are not quite identical. Both frameworks were thought to have their place in the analysis of field studies and the construction of effective control programmes. The first, by the construction of a model to determine the effect of over-dispersion generated by both processes indicates, when compared to field data, that long-term factors are less likely to be involved with the over-dispersion seen in parasite populations than short-term factors. This underlies the importance of the host environment, the distribution of infective stages and the likelihood of a successful (from the parasite's point of view) encounter between host and infective stage as the important factors involved in the distribution of parasites within hosts. The same importance was shown by the other approach (Bundy and Cooper), where, predisposition was found to be due to environmental heterogeneity. In some cases (Haswell-Elkins, Elkins, Manjula, Michael and Anderson, 1988 and Haswell-Elkins, Elkins and Anderson, 1989), as analysed by McCallum (1990) both short-term and long-term factors were found to be important in determining the distribution of parasites and predisposition within this community. Within this community, parasitic infection was related to social and behavioural differences which were seen to be different for each sex of host.

7.3. Laboratory Experiments

7.3.1. Keymer and Anderson, 1979 and Keymer, 1982

The influence of different transmission parameters in a system involving ingestion of infective stages via contamination of food was investigated in earlier laboratory experiments. The animal model used to study this interaction was that of *Hymenolepis diminuta* being transmitted to *Tribolium confusum* (Keymer and Anderson, 1979; Keymer, 1982). The transmission in these experiments was considered to be a predator-prey relationship, but according to the types of transmission defined earlier (Chapter Seven, Section 7.1) could equally be considered as oral ingestion of infective stages via contamination of food; the food is not trying to escape from the beetles which are eating it. In the earlier paper (Keymer and Anderson, 1979), the effect of varying the hunger level of the hosts

combined with the density of infective stages was examined, as well as varying the distribution of infective stages within the environment of the host. When hosts were starved, the relationship between infective stage density and the mean parasite density per host was non-linear, with the mean number of parasites rising to a plateau of 15 to 20 *H. diminuta* per beetle as infective stage density increased.

The generation of a plateau mean density was determined to be a consequence of the feeding behaviour of the beetles in their encounter with the food items, not a density-dependent constraint on the number of parasites that could develop within the host. It was modelled and showed that the increase in density of infective stages resulted in lower times of searching and handling food in order to consume it, so that as density of food increased, these would decrease leading to the density-dependence seen in the experiments.

In experiments designed to investigate the distribution of infective stages of *H. diminuta* in the environment of *T. confusum* with the distribution of parasites found in the host population, the authors found that the mean density of parasites remained the same. The frequency distribution within the hosts changed, with the distribution within the beetles becoming more over-dispersed (increasing variance to mean ratio) as the infective stages became more over-dispersed. Although an over-dispersed distribution of *H. diminuta* in *T. confusum* was found when the infective stages were uniform in their distribution, this increased in those arenas where the infective stages were also over-dispersed.

In a further study of laboratory infections of *H. diminuta* in *T. confusum* (Keymer, 1982), the effects of increasing exposure time, host density and age and sex of host were investigated. By increasing the time that the beetles were exposed to infective stages, the number of parasites/host was seen to increase to a plateau, after which there were no differences in the mean number of parasites recovered per host and a model constructed to predict this was found to fit the data well. By increasing host density, the mean number of parasites/host was seen to decrease but the total number of parasites within the whole population of hosts was found to increase. A parameter for the transmission of parasites to hosts was defined on the basis of the time exposed, the density of hosts and the density of infective stages present. Host sex was not found to be related to differences in the mean or variance of the parasite population within the host population, but host age was seen to

influence the mean parasite burden per host, with increasing age related to decreasing burden. The combination of these studies has given much information regarding the types of relationships seen between mean and variance in a host population when factors influencing the transmission of parasites to hosts are allowed to vary.

7.3.2. McCarthy, 1990

The distribution of hosts within the environment on the mean density and prevalence of infection (Margolis *et al.*, 1982) of the digenean *Echinoparyphium recurvatum* has been investigated (McCarthy, 1990). The life cycle of this helminth involves *Lymnaea peregra* as both a first intermediate host and a second intermediate host. McCarthy focused on the infection of the second intermediate host by cercariae released from *L. peregra* and introduced into an environment in which the snails destined to serve as second intermediate hosts were arranged in regular, random or contagious distributions within an arena. The more contagious the distribution of the snails, the higher the prevalence of infection and the mean number of metacercariae found in the snails. The explanation for this was hypothesised to be related to the host-finding behaviour of the cercariae, with chemical secretions from the snails aiding the cercariae in finding their hosts. Clumps of hosts would be more likely to be producing more of this substance and this would lead to the higher densities and prevalence values recorded.

7.3.3. Monks and Nickol, 1989

The possibilities of intensity-dependent regulation in the transmission of *Moniliformis moniliformis* from cockroaches to rats was studied by Monks and Nickol (1989) in a laboratory approach where transmission took place via the definitive host predating on the intermediate host. The effect of high and low density of infective stages within the cockroaches on the distribution of the helminths in the definitive host was investigated. This was found to have a significant effect on the amount of over-dispersion seen in female but not male rats, with greater over-dispersion being associated with higher mean density in the cockroaches. The difference was hypothesised to be either due to differences in the behaviours of the two sexes or perhaps to immunosuppression due to pregnancy in the females, as well as differences due to heterogeneity in susceptibility.

7.3.4. Relevant Research on *Heligomosomoides polygyrus*

The nematode *H. polygyrus* (syn. *Nematospiroides dubius*) has been extensively studied as regards the factors that are involved in transmission, especially the involvement of genetic control in the ability of the helminths is establish and survive and in the immunity to challenge infection using different strains of laboratory mice under laboratory conditions (Enriquez, Zidian and Cypess, 1988; Behnke and Robinson, 1985; Behnke and Wahid, 1991; Keymer, Tarlton, Hiorns, Lawrence and Pritchard, 1990). This parasite is transmitted under natural conditions (Scott, 1988a, b) via contact with infective third-stage larvae in the environment and it is thought that some infection may be due to ingestion of larvae in cleaning behaviour or in ingestion of contaminated soil. Infections with *H. polygyrus* have also been studied in conditions representing more natural means of exposure and the relationship between genetic susceptibility and resistance and the intensity of infection has not been found to be as clear cut (Scott, 1991) although with trickle infections, there is some evidence to support the view that the regulation of the helminth numbers varies according to the strain of mice, indicating some kind of genetic control of infection, although the dose of helminths given is related to the response seen (Trailsford and Behnke, 1992). With this knowledge, the investigation of the generation of the factors responsible for the generation of the aggregation seen in both field (Lewis, 1968) and laboratory infections (Keymer, 1985; Scott, 1987b) was undertaken by Tanguay and Scott (1992). They found that innate variability in resistance to infection did not appear to be responsible for the variable worm burden found after a primary exposure to infection. It may become important when combined with variability in acquired resistance. Variation in behaviour appeared to be responsible for variation in worm burdens, although the relative importance of this may change. Heterogeneity in acquired resistance was seen to be the largest factor contributing to the heterogeneity of the observed worm burdens.

7.4. Field Data

Field studies have been undertaken to investigate factors which lead to aggregation of helminths within hosts other than humans. Investigations of the distribution of *Hymenolepis citelli* among deer mice (*Peromyscus maniculatus*) have indicated that two factors appear to be important in aggregated patterns of distribution. One is the inherent resistance to infection, located on one gene locus, that leads to expulsion of the tapeworm before it matures and the other is the heterogeneity of

infective intermediate hosts in the environment (Wassom, Guss and Grundmann, 1973; Wassom, DeWitt, and Grundmann, 1974; Wassom, Dick, Arnason, Strickland and Grundmann, 1986). Infections with the same species of helminth in a different host species (*Peromyscus leucopus*) were believed to be aggregated by heterogeneity in exposure to the infective intermediate hosts, as inherent immunity was not seen to occur, although some protective immunity was evident (Munger, Karasov and Chang, 1989).

Much interest has been generated in determining the aggregation of human helminth infections, as those individuals with higher intensities of infections are believed to be those most at risk of any morbidity associated with parasitic infections. Studies directed at determining the degree of over-dispersion of parasites within a community have usually been attempts to determine what proportion of infected people must be treated to obtain a decrease in parasite intensity (Anderson and May, 1985; Thein Hlaing, Than Saw, Htay Htay, Myint Lwin and Than Maung Myint, 1984; Bundy *et al.*, 1987a and 1987b). In order to design effective control programmes it is also necessary to determine what are the factors which are responsible for generating an over-dispersed frequency distribution of parasites in a host population (Keymer and Pagel, 1989) thus allowing individuals more at risk of infection to be identified, if there was some method of predicting which individuals are more associated with the factors identified. McCallum (1990) used field data to compare with a model generated to determine what transmission factors are important in determining the amount of predisposition in a community, with indications that varying degrees of long- and short-term factors are involved in transmission for different helminth infections and in different communities.

Some field studies have been carried out to determine the distribution of infective stages in the environment and to determine degree of contact members of a host population have with infective stages. The determination of infective stage distribution in two children's homes in St. Lucia (Wong, Bundy and Golden, 1991) indicated that the distributions of infective stages (eggs) for *T. trichiura* and *A. lumbricoides* were over-dispersed. This study found that the amount of geophagus behaviour evidenced by children in one home explained well their helminth burden, while in another home it did not. They suggested that the result from the home where it did not explain the helminth burden of children was due to the poor sanitary conditions in this home which could have allowed for encounter of hosts with infective stages in a variety of ways, not including geophagous behaviour. The

distribution of infective stages of hookworm in the environment has also been studied. The sites investigated were areas frequently used for defecation (Hominick, Dean and Schad. 1987; Nwosu and Anya, 1980). Infective larvae appear to be over-dispersed and were found to be sensitive to environmental conditions relating to humidity. Some evidence was found to indicate that behavioural differences between individuals were responsible for different levels of infection although this was not true of all individuals.

The most well studied helminth-human system for the importance of exposure to infective stages is that of schistosome infections, with water contact studies. These have been reviewed recently by Bundy and Blumenthal, 1990. The results of studies by Butterworth, Capron, Cordingly, Dayton, Dunne, Kariuki, Koech, Mugambi, Ouma, Prentice, Richardson, Arap Siongok, Sturrock and Taylor (1985) on *S. mansoni* infections in Kenya and Wilkins, Blumenthal, Hagan, Hayes and Tulloch (1987) and Hagan, Blumenthal, Dunn, Simpson and Wilkins (1991) on *S. haematobium* infections in The Gambia indicated that there were two types of encounter with infective stages in this helminth infection. In adults there is evidence of some protective immunity, which protected against reinfection, regardless of exposure and in children, the possibility of infection was influenced by exposure to infective stages via behavioural differences which brought individuals into the micro environment of infective stages in water bodies.

7.5. Summary

The results discussed in this chapter outline the study of the quantitative aspects of transmission of helminth infections. This has been approached in three different ways: models, laboratory studies and collection of data in the field where natural infections are studied. The models used to investigate helminth transmission have often assumed a great deal of homogeneity in both host and helminth encounter and susceptibility to infection, perhaps under-representing the importance that transmission has on determination of patterns of distribution of helminths in their hosts. The laboratory studies undertaken have investigated the effect of both differences in density and pattern of infective stages distribution in the environment and genetic differences in hosts which may affect the establishment of helminths. Finally, field work in humans and other species has demonstrated that there is some evidence to suppose that both resistance to infection and encounter with infective stages differs between individuals of a host population. All of the results of these

researchers have shown that Crofton's (1971a) six means of generating an over-dispersed distribution of helminths are most likely to be operating in some form or another on various helminth life cycles, although the importance of each to each life cycle will vary, due to differences in species of helminths and host and differences in time and place.

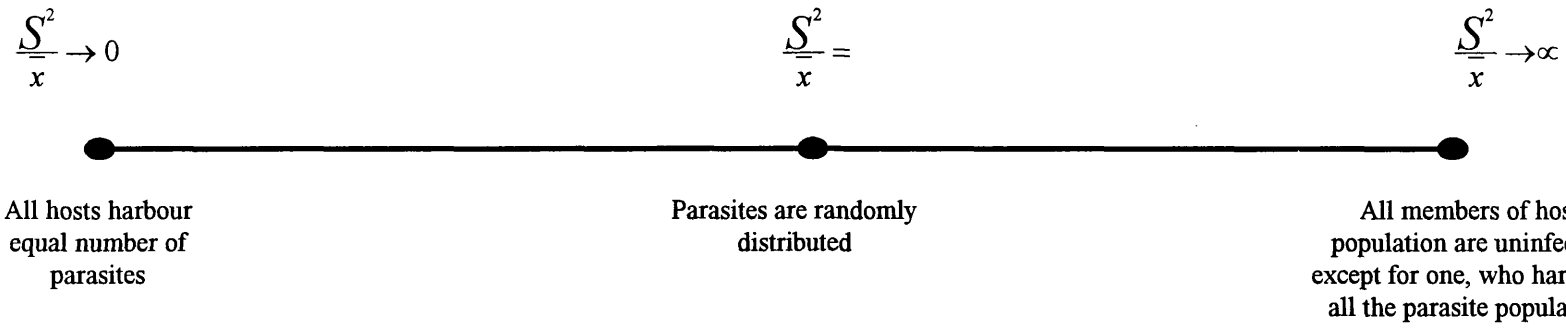
Table 7.1. Examples of different transmission mechanisms.

Transmission Mechanisms				
Predator-prey Interactions	Encounter with the dermal layer of the host	Vector Interaction	Transplacental	Contamination
Centrorhynchus aluconis (*Sorex araneus* to *Strix aluco*)[1] *Schistocephalus solidus* (*Gasterosteus aculeatus* to *Larus canus*)[2] *Moniliformis moniliformis* (*Periplaneta americana* to *Rattus rattus*)[3] *Trichinella spiralis* (*Sus scrofa* to *Homo sapiens sapiens*)[4] *Paragonimus kellicotti* (*Cambarus propinquis* to *Mustela vison*)[3] *Diphylobothrium mansonoides* (*Mus musculus* to *Felis domesticus*)[5]	*Schistosoma mansoni* (Cercariae in water to *Homo sapiens sapiens*)[4] *Ancylostoma duodenale* (Third-stage larvae penetrate skin of *Homo sapiens sapiens*)[4] *Dactylogyrus vastator* (Onchomiracidium in water to *Cyprinus carpio*)[3] *Strongyloides stercoralis* (Third-stage larvae penetrate skin of *Homo sapiens sapiens*)[4]	*Litosomoides carinii* (*Bdellonyssus bacoti* bite , by which third-stage larvae are introduced into *Sigmodon hispidus*)[3] *Onchocerca volvulus* (Bite of *Simulium damnosum* carrying third-stage larvae)[4] *Dirofilaria immitis* (Third stage larvae enter through the puncture hole of *Culex pipiens*)[5]	*Ancylostoma duodenale*[6] *Dirofilaria immitis*[3] *Toxocara canis*[5] *Toxocara vitulorum*[5]	*Polymorphus paradoxus* (*Gammarus lacustris* contaminating food of *Anas platyrhynchos*)[7] *Uncinaria lucasi* (Third-stage larvae in mothers milk of *Callorhinus ursinus*)[3] *Ascaris lumbricoides* (Eggs containing second-stage larvae ingested by *Homo sapiens sapiens*)[4] *Dracunculus medinensis* (Third-stage larvae in *Cyclops leuckarti* in water ingested by *Homo sapiens sapiens*)[4] *Moniliformis moniliformis* (Ingestion by *Periplaneta americana* of *Rattus rattus* faecal material contaminated with acanthors)[3]

1. From Ewald and Crompton, 1993 and Ewald, Crompton, Johnston and Stoddart, 1991.
2. From Hopkins and McCaig, 1963.
3. From Olsen, 1974.
4. From Schmidt and Roberts, 1989.
5. From Noble, Noble, Schad and MacInnes, 1989.
6. Schad, 1990.
7. Holmes and Bethel, 1972.

Figure 7.1. Review of factors responsible for different patterns of parasite distribution in host populations. Re drawn from Anderson and Gordon, 1982.

Dispersion Spectrum



Chapter Eight. The Influence of Infective Stage Distribution on Helminth Populations Parameters: Experimental Infections and Computer Simulations.

8.1. Introduction

In this chapter experimental manipulations of *Moniliformis moniliformis* in cockroaches (*Periplaneta americana*) are described to investigate the effect of distribution of infective stages within the environment on the transmission of helminths. Related studies were carried out previously by Keymer and Anderson (1979) and McCarthy (1990). The results from the experimental manipulations were then used to construct a computer simulation model to describe the infection process. This model was used to investigate the relative influence that changing the 'susceptibility' of hosts to helminths (either inherently or after infection has taken place) has on the parameters describing the distribution of helminths within the host population (results presented in the following chapter). A review of the relevant biology of *M. moniliformis* as regards infections of *P. americana* is first presented, followed by a discussion of the relevant measures of dispersion. The results of the experimental manipulations are then displayed and finally the construction of the model is described. Results of simulations of the model are compared with those of the experimental infections.

8.2. Biology of *Moniliformis moniliformis*

The developmental stages of *M. moniliformis* within the cockroach have been well studied as regards the factors related to the development of this helminth (Moore, 1946). *Periplaneta americana* are found naturally infected with *M. moniliformis*, and the parasite appears to utilise this species of cockroach to a large extent. For example, in a study in Osaka, Japan, of 59 cockroaches caught, 8 were *P. americana* with the majority being *Blatella germanica* and 1 *P. fuliginosa*, with 7 of the 8 *P. americana*, the one *P. fuliginosa* and 2 of the *B. germanica* being found to be infected with *M. moniliformis* (Iseki, Kimata, Izumo and Takada, 1985). Further information on the developmental stages within the cockroach was presented by King and Robinson (1967) who indicated that sex and age of host or the number of larvae infecting a cockroach did not affect the rate of development, but there may be some effect due to season of the year. They were able to obtain infective cystacanths by injecting artificially hatched acanthors into the haemocoel of uninfected cockroaches. The effect of x-irradiation and temperature on the development of *M. moniliformis* has been studied (Robinson and Jones, 1971). Abnormal development was found at temperatures of 32°C and above.

A more quantitative approach on investigations concerning the development of *M. moniliformis* within the intermediate host was undertaken by Lackie (1972a, b). *In vitro* hatching was

studied (Edmonds, 1966) by putting eggs into 0.3M-$NaHCO_3$ at room temperature for 24 hr. This was used both to standardise the dosages given and for 'surgical' infection of cockroach haemocoels. Hatching of acanthors was found to be optimum when they were stored in 60% sucrose at between 24-48 hr after removal from the female *M. moniliformis* body cavity. In feeding experiments with acanthors in sucrose suspension, a large individual variation in recovery of helminths in individuals was found and males were found to harbour less helminths, all else being equal. At high doses of acanthors, Lackie described a 'Law of Diminishing Return', which others might have interpreted to be density-dependent limitations on establishment and development. The variance was found to be much larger at high dosages, and the plateau seen of about 90 helminths/cockroach was interpreted with caution as some individuals were found with many more (400+) *M. moniliformis* in their haemocoel. In artificial infections of the haemocoel, no difference was found from that of oral infection although in these there was no appreciable sex difference. No evidence for resistance due to prior exposure was found in superimposed infections. Development was found to be faster than in the strain described by King and Robinson (1967).

In the second paper in the series, Lackie (1972b) investigated the effect of temperature on the development of *M. moniliformis* within the intermediate host. At low temperatures (11 to 15°C), the acanthors had penetrated the gut of the cockroach but no further development had taken place. At 20°C very slow development took place, at 24°C slightly slower development took place than that at 28°C, the temperature used to maintain infections in the laboratory. At 37°C the acanthors became melanized but if maintained at 28°C and then transferred to 37°C, development did take place. The greatest losses in numbers of an establishing infection are believed to occur at the stage immediately after the acanthors penetrate the midgut (Lackie, 1971a) and not much difference in recovery is noted after this. The effects of temperature, season of the year, photo-period and elevated temperature on the development of *M. moniliformis* in the cockroach intermediate host were investigated by Byram and Byram (1976). They found faster rates of development in summer in comparison to the fall and winter and in those cockroaches exposed to 12 hr light/12 hr dark than in those in total darkness. The development was faster at 26.5°C than at 23°C and faster still at 30°C. The effect of higher temperatures (35°C) was investigated to try and overcome the temperature block in development that had been found by previous workers (Robinson and Jones, 1971; Lackie, 1972b). This was not

successful. Development in cockroaches at 35°C was characterised by larval death and host response to the dead larvae.

The "immune response" of the cockroach to the developing acanthocephalan has been studied in some detail. The parasite, after hatching in the gut and burrowing through the gut wall into the haemocoel is encapsulated by host haemocytes (Rotheram and Crompton, 1972). The helminth goes on to construct an acellular envelope from microvillar extensions of its tegument (Lackie and Rotheram, 1972), which appear to render it safe from attack from host haemocytes (Lackie, 1975; Lackie and Lackie, 1979). Infection with *M. moniliformis* has also been shown to lead to "immunosuppression" of the cockroach, in cockroaches containing surgically transplanted acanthellae (Lackie and Holt, 1988).

Recently, much interest has been generated by the study of the changes in behaviour associated with infection with *M. moniliformis* in cockroaches, reflecting the interest in this phenomenon of acanthocephalan infections in the intermediate host (Moore, 1984). *Moniliformis moniliformis* infected *P. americana* have been shown to differ in behaviour in comparison to uninfected cockroaches in increased amount of activity, a positive reaction to light and an increase usage of white horizontal surfaces (Moore, 1983; Wilson and Edwards, 1986; Carmichael and Moore, 1991; Gotelli and Moore, 1992). Infected cockroaches are believed to make themselves more vulnerable to predation by a visual predator by these changes in behaviour (Silverman and Bell, 1979). These have been seen to differ between different cockroach species believed to be possible natural hosts of *M. moniliformis*, (Lackie, 1975; Freehling and Moore, 1993; Moore and Crompton, 1993) some of which do not appear to have any change in behaviour due to infections with *M. moniliformis* (Allely, Moore and Gotelli, 1992) and some of which appear to have behaviours which would decrease the possibility of predation by a visual predator (Moore and Gotelli, 1992). These differences in behaviour may have implications on the importance of members of a species of possible intermediate hosts in a natural setting (Moore and Gotelli, 1992).

8.3. Which Index of Dispersion to use?

One of the parameters of interest in the analysis of both the experimental results and the model results was the amount of over-dispersion of the parasites in the host population. The question of how to analyse both of these results was settled by reviewing the different methods used in the

literature (both parasitological and ecological) for describing over-dispersed distributions of numbers of parasites per host. Crofton (1971a) used the negative binomial to describe over-dispersed parasitic infections, and this has resulted in most of the subsequent investigators in the field of parasitology using the parameter *k* for descriptions of an over-dispersed distribution. The other parameter which has also been used is the variance-to-mean density ratio. Both are discussed by Anderson and Gordon (1982). The parameter *k* has received much attention and has formed the basis for much theoretical work on the distribution and modelling of parasitic infections, but it may not be the parameter of choice to use for studying over-dispersion (Scott, 1987a).

In comparison of the variance-to-mean ratio with *k*, it has been shown that the two parameters do not measure the same component of over-dispersion (Scott, 1987a; Scott and Anderson, 1984). Both were found to rise with the mean density of parasites, a result which appears to be contradictory, as *k* is believed to vary inversely with over-dispersion and the variance-to-mean ratio to vary directly with over-dispersion (Anderson and Gordon, 1982). In discussing the use of indices of dispersion, Krebs (1989) (quoting Elliott, 1977) indicates that an index should have three properties. These are, as interpreted in a parasitological framework: 1. a smooth change as the distribution changes from uniform to random to aggregated, 2. it should not be affected by changes in the sample size of hosts or population density of helminths, 3. there should be a means of testing to determine if samples are significantly different. Krebs (1989) goes on to recommend either the variance-to-mean ratio as the best indicator of over-dispersion or the standardised Morisita Index of Dispersion (Smith-Gill, 1975) which has 95% confidence limits to allow for testing of distributions to determine whether they are significantly over-dispersed or not.

8.4. Application of Variance-to-Mean Ratio

The variance-to-mean ratio has been used to describe the aggregation of distributions in several laboratory and field-based investigations of helminths in their hosts. As mentioned before, Scott (1987a) found a linear increase in the variance-to-mean ratio with mean density. Both Gordon and Rau (1982) and Lemly and Esch (1984) hypothesised that the decrease in the variance-to-mean ratio at higher densities of helminths in the distribution of metacercariae of *Apotemon gracilis* and of *Uvulifer ambloplitis*, respectively, in brook stickleback and bluegill sunfish, provided evidence for parasite-induced mortality at higher levels of infection. Regression analysis was undertaken on the

variance-to-mean ratio values in one paper (Lemly and Esch, 1984), which allowed for statistical analysis of the distributions seen at different times of the year indicating that over-dispersion changed throughout the year. Scott (1987a) used both the variance-to-mean ratio and the value of k in Spearman rank correlations with prevalence and abundance, to indicate that both were correlated with increasing density. The variance-to-mean ratio was used to investigate heterogeneity in mice infected with *Heligmosomoides polygyrus* (Tanguay and Scott, 1992). The medians, variance and the variance-to-mean ratios were compared between treatments and an index of dispersion (I_D) was calculated to determine where the distributions of parasites between hosts departed from a random distribution. The medians were used to compare the central tendency, the variance to compare variability and the variance-to-mean ratio to compare the amount of aggregation between different treatments. In the following work described below mean density (total number of helminths recovered per arena divided by the total number of cockroaches dissected), variance, variance-to-mean ratio, the total number of helminths recovered in the cockroaches from each replicate and the prevalence of infection were used for comparisons between experimental groups. A similar approach was taken when comparing the results of the experimental infections with the model results.

8.5. Experimental Infections: Procedures

The strain of *M. moniliformis* used in these experiments was brought to Glasgow by Professor D.W.T. Crompton in 1985 from the Molteno Institute in Cambridge. It was provided to the Molteno Institute by Dr. S.J. Edmonds, of the University of Adelaide in 1969, who acquired it in 1956 from Dr. Dorothy Sandars at the Medical Institute in Brisbane (Crompton, Keymer and Arnold, 1984). It has been propagated in the laboratory using as appropriate intermediate hosts *Periplaneta americana* and Wistar rats as definitive hosts. Rats are infected by gavage with cystacanths removed from the body cavity of *P. americana*. Rat faecal pellets collected from rats which had been infected with cystacanths 7 to 9 weeks earlier and are found to contain infective acanthors of *M. moniliformis* are introduced into a cage of cockroaches (kept in an insect room with the temperature set at 28°C and with a regime of 12 hr light, 8 hr dark). The insects have food and water withdrawn from them for 2 days before exposure to the shelled acanthors. The cockroaches consume the faecal material and this results in infective cystacanths in approximately 40 days.

The infections of *M. moniliformis* in cockroaches on which this model are based were carried out in a different manner than that used for maintaining stock cultures of infected cockroaches. For each run of infections six female Wistar rats infected with patent infections of *M. moniliformis* were dissected and the adult worms removed from the rat's intestine. Female worms were rinsed in saline (0.9%) and the contents of the worm's body cavity were collected in 0.9% aqueous NaCl. The contents of the body cavity (shelled acanthors, ovarian balls, developing acanthors) were then rinsed through sieves to separate out mature acanthors (Lackie, 1972a), centrifuged and resuspended in 60% sucrose solution which was stored at 4°C for two days before being used in the experiments. The infectivity of the shelled acanthors collected in such a manner was tested to determine how many of them would hatch using the method of Edmonds (1966).

Adult cockroaches which had been deprived of water and food for 48 hr were introduced into a plastic container, holding a Plexiglas tray containing slots for 61 coverslips(referred to from now an as an arena). The coverslips were arranged so that the resulting distributions of coverslips with acanthors were uniform, random (with locations of acanthors determined by use of a random number table) or clumped. Figure 8.1 shows, in diagram form, the resulting distribution of infective stages. Coverslips holding only 60% sucrose were added to those slots which did not contain coverslips with acanthors. The cockroaches were allowed to feed on the sucrose solutions for 2 days and then the Plexiglas tray was removed and water, cardboard shelters and commercial rat chow pellets were made available to the cockroaches. The coverslips were checked to determine the number of infective stages ingested. Invariably all of the acanthors had been removed from the coverslips, but there was no way of knowing if all had been ingested by the insects.

The number of infective stages introduced into the arena was manipulated to give between 50 and 70 infective stages per spot (i.e. a drop of sucrose/acanthor mixture on a round coverslip) in the even distribution and 110 to 130 for the random and clumped distributions. This resulted in approximately 360 infective stages per arena in all three experimental regimes. Determination of the number of infective stages per food spot was done by counting numbers of mature acanthors in a drop of sucrose and then using the method of Edmonds (1966) to determine how many of them were in fact infective. The number needed to result in the requisite number of infective stages in that food spot was then found and the number at each food spot was counted. Any coverslips not having the

requisite number of infective stages were rejected and more coverslips produced until the required number were collected. Coverslips with sucrose/acanthors on them were kept in a refrigerator at 4°C in petri dishes with moist tissue paper in the bottom until the required number of coverslips was collected.

Cockroaches were dissected 40 days following exposure to the shelled acanthors to determine the number of *M. moniliformis* present in the haemocoel of each insect. The acanthocephalans would not have been infective to the definitive host at this time. From previous studies by Lackie (1972a), where it appeared that the major loss of acanthocephalans from this system occurred immediately after the penetration of the midgut of the cockroach by the acanthor, it was assumed that any *M. moniliformis* present at 40 days post-infection would represent those that would have gone on to become infective to the definitive host. As many infections as possible were carried out with female acanthocephalans from one rat. This resulted in acanthocephalans from three rats producing the acanthors for the 15 successful replications (five for each treatment) of this experiment. Other replications were attempted but failed, with no *M. moniliformis* being recovered from the cockroaches. This happened three times with the problem apparently being solved by the utilisation of freshly made up 0.9% saline instead of the laboratory stock solution. Differences between the infectivity of acanthors from worms from different rats were not tested, due to small sample sizes allowing for the testing of only the effect of changes in the distribution of infective stages. The results of the five replications of the three distribution patterns are presented in Table 8.1, with the replications from groups of rats indicated. Kruskal-Wallis analysis of the mean density, variance, variance-to-mean ratios, prevalence and the total number of *M. moniliformis* recovered from each replication of the experimental set-up are presented in Table 8.2.

Table 8.2. Results of Kruskal-Wallis tests between the three distribution patterns of infective stages in the experimental arenas.

Parameters	Chi-square	df	p
Mean	9.50	2	0.0087
Variance	12.50	2	0.0019
Variance-to-Mean	12.50	2	0.0019
Sum	10.00	2	0.0067
Prevalence	11.31	2	0.0035

Box plots of the distribution parameters are presented in Figure 8.2 and comparisons between the different treatments of these parameters are presented in Table 8.3 As can be seen from the results in Table 8.3 and Figure 8.2, significant differences were found between the three experimental treatments. The even and random distributions experiments did not significantly ($p \leq 0.05$) differ from one another in their mean density, variance, variance-to-mean ratio or in the total numbers of helminths recovered from the roaches in each replicate. Both groups were found to differ significantly from those of a clumped distribution in their mean density. The results from an even distribution of infective stages differed significantly ($p \leq 0.05$) from those of a clumped distribution in their variance and variance-to-mean ratios, while those from a random distribution did not. The results from the random distribution varied significantly from those of a clumped distribution in both the sum of infective stages and prevalence of infection, while the results from an even distribution of infective stages did not. The relationship between the mean density, variance-to-mean ratio and prevalence (Janovy and Kutish, 1988) from these experimental infections is displayed in Figure 8.3.

Table 8.3. Mean ranks of different experimental distribution patterns in infective stages of *M. moniliformis*.

	Acanthor Distributions		
Parameters	Even	Random	Clumped
Mean Density	6.0(a)	5.0(a)	13.0(b)
Variance	3.0(a)	8.0(a,b)	13.0(b)
Variance-to-mean	3.0(a)	8.0(a,b)	13.0(b)
Sum	6.6(a,b)	4.4(a)	13.0(b)
Prevalence	12.8(b)	3.3(a)	7.9(a,b)

* Mean ranks designated by the same letter are not significantly different at $p \leq 0.05$. The difference needed for significantly different ranks is 6.77.

8.6. Introduction of the Model

The model which was generated from this study allows the manipulation of various factors involved in transmission of helminths through an oral route, as reviewed in Chapter Seven. Specifically, the model is based on the infection of cockroaches (*Periplaneta americana*) with *Moniliformis moniliformis* via food spots containing infective stages of the parasite in laboratory infections. Laboratory experiments with infective stages introduced into the infection arena in a random distribution provided the original system to be modelled. The observed effect on population parameters of changing the distribution of the infective stages in the arena during the laboratory experiments was also compared with different versions of the model to determine the best method of

simulating the resulting populations. Variables concerned with differences in behaviour, both inherent and in regards to differences between infected versus uninfected individuals were allowed to vary within the model situation to determine their effect on the distribution patterns of helminths in the hosts (reported in Chapter Nine). In a manner similar to that used by Crofton (1971b) and Anderson and Gordon (1982), the contributions of different factors in transmission, behavioural and environmental, were investigated to determine the effect of varying these different factors on the distribution of parasites within hosts separately and in combination. It is likely that the experimental infections had influences such as host heterogeneity in behavioural and immunological susceptibility to infection. It was hoped that by using cockroaches bred within one colony for many years and by assigning adult cockroaches randomly to treatments that this source of variation would be controlled.

One version of the model, with explanations on how it works is found in Appendix V and a schematic diagram of the model is presented in Figure 8.4. A through description of the model is given in Table 8.4. Comparisons between the experimental and simulations in the model are given. In the 'Model' column, each step of the experimental process involved in the transmission of *M. monilformis* to the cockroaches is outlined. In the 'Life Cycle or Experiments' column, the manipulation that was used in the laboratory experiments is described for each step and in the 'Numerical/Stochastic Step in the Model' column, the mechanism used by the programme to simulate this effect in the model is defined. This explains how the programme reproduces, in the model simulation, the experimental set up of the arenas used to hold the cockroaches and the different patterns of arrangment of the infective stages in the arena. The construction of the cockroaches by the model is described, as well as the manner of initiating changes in their behaviour. The method of simulating the movement of cockroaches is detailed. The encounter of a model cockroach with a model food spot and the subsequent intake of both model food and infective stages is described. Using the language C for programming allowed the construction of objects, called 'roaches', to be achieved and provided for the ability to give them certain behaviours which could be allowed to vary. Various versions of the model were used to simulate differences occurring with changing levels of infective stage density and the physical distribution of infective stages in the environment of the 'roaches'. The behaviour of the 'roaches' was then allowed to vary, both as they became infected and also inherently, *i.e.* with a proportion of the 'roaches' having different behaviours at the beginning of the simulation

which would influence their ability to become infected. In Figure 8.4 the methods of allowing variation in different segments of the model are described. Figure 8.5 gives more detail on the 'decisions' which the objects called roaches make in their encounter with food spots and in their movement.

8.7. Random Distribution of Infective Stages

A similar treatment was followed in the comparison of the results of the simulation models. Different combinations of the encounters of 50 cockroaches (Table 8.5) were modelled to determine which of these most closely resembled the results seen in encounters of cockroaches with infective stages in experimental infections. In each of the simulations the total number of food spots in the simulated arena was 50.

Table 8.5. Combinations, in the model, of numbers of infective stages per food spot, number of food spots and the expected percentage of food spots which were positive for infective stages.

Simulations	Number of Infective Stages per Food Spot	Percentage of Food Spots Positive (approx.)
One	10	25%
Two	10	50%
Three	10	75%
Four	20	25%
Five	20	50%
Six	20	75%
Seven	30	25%
Eight	30	50%
Nine	30	75%

The parameters measured were the mean density, variance, sum of infective stages, prevalence of infection and variance-to-mean ratio. Significant differences were found between the nine simulations runs and the experimental arenas in all of the above parameters. The results of Kruskal-Wallis analyses of variance on several measured parameters of the simulation runs are presented in Table 8.6. To determine where the significant differences were (and more importantly to determine which of the simulations did not differ from the experimental arena results) multiple comparisons were calculated. These are presented in Table 8.7. From this analysis, it could be seen that the simulation run of ten infective stages per food spot and 25% of the food spots positive and that where there were 20 infective stages per spot with 25% of the food spots positive most closely represented the experimental results from random placement of the infective stages in the arena.

Table 8.6. Results of Kruskal-Wallis tests for differences between simulation runs of the model with 50 food spots.

Parameter	Chi-square	df	p
Mean	89.2310	9	0.0000
Variance	87.2798	9	0.0000
Variance-to-Mean	80.1167	9	0.0000
Sum	89.2828	9	0.0000
Prevalence	80.5986	9	0.0000

After consideration of the above results, it was decided to use 15 infective stages per infected spot and to use the setting for 25% of the food spots as positive in an attempt to model more closely the results of the random distribution experiment. Results of a Mann-Whitney test for each of the parameters above between the experimental results and the simulation results from this simulation are presented in Table 8.8. Figures 8.7 to 8.11 present results of comparisons for all simulations used to arrive at the selected simulation and the experimental results. Figure 8.12 displays information regarding the mean, prevalence and the variance-to-mean ratio for all of these groups.

Table 8.8. Results of Mann-Whitney tests between the experimental results and the final model results.

Parameter	z Value	p
Mean	-0.2454	0.8062
Variance	-0.4899	0.6242
Variance-to-Mean	-0.9798	0.3272
Sum	-0.9816	0.3263
Prevalence	-0.6748	0.4998

8.8. Clumped Distribution of Infective Stages

The effect of clumping the distribution of infective stages in the simulation model was then investigated and compared with that of the clumped experimental regime (reported in section 8.6). In the experimental infections, the total number of infective stages introduced into the arena had remained the same, but they were arranged all on one half of the arena. In the model simulations of the clumped distribution infective stages were only placed in one half of the arena initially. Three different model simulations were attempted: 1. 100 food spots were introduced into the arena with infected spots restricted to one half of the arena and with each food spots on the 'positive' half of the arena having a 50% chance of containing 15 infective stages. 2. 50 food spots were used with those on the infected half of the arena having a 99% chance of containing 10 infective stages. 3. 100 food spots were used with those on the infected half of the arena having a 99% chance of containing 5 infective stages per spot. The differences between these three simulations and the parameters from

the experimental distributions were tested using Kruskal-Wallis analysis of variance and the results of this are presented in Table 8.9.

Table 8.9. Results of Kruskal-Wallis analysis of the distributions parameters between the clumped experimental replications and the different clumped simulations of the model.

Parameters	Chi-square	df	p
Mean Density	20.7510	3	0.0001
Variance	30.5919	3	0.0000
Variance-to-Mean	30.8519	3	0.0000
Sum	19.6077	3	0.0002
Prevalence	21.0736	3	0.0001

Figure 8.13 displays the box plots of these data and comparisons between the three models and the experimental results are presented in Table 8.10. As can be seen from these, none of the above simulations closely modelled the results seen from the clumped distribution of infective stages in the experimental set-up, although they do not vary significantly from the experimental results in their mean densities or the total numbers of parasites recovered.

Table 8.10. Differences between first simulations of clumped distributions and experimental infections.

	Simulations		
Parameters	One	Two	Three
Mean Density	3.00	14.65	12.85
Variance	5.10	15.90*	25.90*
Variance-to-Mean	7.50	17.00*	27.30*
Sum	10.30	8.35	5.80
Prevalence	11.65	9.75	24.10*

* Differences in mean ranks greater than 14.81 indicate the medians are significantly different at $p \leq 0.05$.

Using this approach, the most difficult aspect of the experimental infections to model proved to be the combination of the higher variance with a lower prevalence. This appeared to indicate that there were too few model cockroaches infected with large numbers of model helminths and too many with small numbers of helminths. It was decided to curtail the area of the model arena which contained infective stages further and to try different numbers of food spots combined with different numbers of infective stages per spot, using one-quarter of the model arena, with food spots inside this area having a 99% chance of containing infective stages. This resulted in the following combinations of numbers of food spots and infective stages in each food spots: 1. 25 food spots with 40 infective stages in the ones in the infected part of the arena. 2. Fifty food spots with 20 infective stages in the ones in the infected part of the arena. 3. 75 food spots in total with 15 infective stages per food spot

in the infected part of the arena. 4. One hundred food spots in the arena with 10 infective stages per spot in the infected part of the arena. Kruskal-Wallis analysis of the parameters from these simulations and the experimental infections of the clumped distribution are presented in Table 8.11. Comparisons between the three different simulation regimes and the experimental infections are presented in Table 8.12 and box plots are presented in Figure 8.14. Comparisons of mean ranks revealed that the regime that most closely approximated the experimental results was that of 50 food spots with 20 infective stages per positive food spot, in terms of variance and variance-to-mean ratio.

Table 8.11. Results of the Kruskal-Wallis analysis between the highly aggregated simulations from the model and the clumped experimental infections.

Parameters	Chi-square	df	p
Mean Density	13.3134	4	0.0098
Variance	36.4307	4	0.0000
Variance-to-Mean	40.2307	4	0.0000
Sum	10.1751	4	0.0376
Prevalence	37.1217	4	0.0000

There were still some discrepancies between this regime and the experimental infections, with the values for the variance and the variance-to-mean ratio for the distribution of the experimental infections lying between that of model simulations of 25 and 50 food spots. The prevalence in the experimental infections was higher than those for both of these simulations, as was the mean density, although the ranges for the experimental mean density overlapped that of the 25 food spot simulation. The total number of infective stages in the arena was similar to the experimental infections for all of the simulations except for that of the simulation with 50 food spots, however this was not statistically significant. From the multiple mean rank comparisons and the box plots, it was decided to use the simulation of 50 food spots, with 20 infective stages in the food spots in the positive areas. The better fit for the variance-to-mean ratios with the experimental infections was the deciding point. The only significant difference from the experimental infections was the smaller mean density, indicating that more helminths were actually transmitted in the experimental infections than in the model. The relationship between the mean density, variance-to-mean ratio and prevalence is displayed in Figure 8.15.

Table 8.12. Results of comparisons between the second group of model simulations for the clumped experimental distributions of infective stages.

	Simulations			
Parameters	One	Two	Three	Four
Mean Density	13.10	22.05*	4.65	12.40
Variance	6.00	12.30	14.00	27.40*
Variance-to-Mean	10.70	3.00	14.40	23.90*
Sum	1.80	11.55	6.65	0.85
Prevalence	20.00	12.05	2.60	12.35

* Differences in mean ranks greater than 20.19 indicate the medians are significantly different at $p \leq 0.05$.

8.9. Even Distribution of Infective Stages

In the experimental infections with an even placement of infective stages within the arena, the distribution of *M. moniliformis* within the cockroaches was still found to be over-dispersed. An attempt to simulate this result was undertaken with three different model formulation. These were: 1. 25 food spots, of which on average 99% contained 8 infective stages each. 2. 50 food spots as before, with 4 infective stages at each positive food spot and 3. 100 food spots with 2 infective stages at the positive spots. Results of Kruskal-Wallis tests for differences between the five population parameters examined are displayed in Table 8.13.

Table 8.13. Results of Kruskal-Wallis analysis on the differences between the evenly distributed experimental results and the model simulations.

Parameters	Chi-square	df	p
Mean Density	5.3134	3	0.1502
Variance	29.4956	3	0.0000
Variance-to-Mean	29.2117	3	0.0000
Sum	15.0491	3	0.0018
Prevalence	29.4856	3	0.0000

These comparisons indicated that the experimental results and the simulations did not differ significantly in their mean densities. Differences in the mean ranks between the simulations and the experimental results for the remaining parameters were analysed using multiple comparisons and are presented in Table 8.14. Figure 8.16 displays the box plots of these simulation, together with the results of the experimental infection.

Table 8.14. Results of comparisons between the mean ranks of the simulation results and the experimental results for even distribution of infective stages throughout an arena.

	Simulations		
Parameters	One	Two	Three
Variance	1.80	11.50	21.10*
Variance-to-Mean	0.00	12.80	22.20*
Sum	17.75*	18.95*	15.80*
Prevalence	3.00	11.00	20.00*

* Differences in mean ranks greater than 14.81 indicate the medians are significantly different at $p \leq 0.05$.

The results from the first simulation of 25 food spots with 8 infective stages appears to fit the experimental data the best, although all the simulations give total numbers of parasites that are significantly higher than those of the experimental results. Part of this is due to the extreme exact reproducibility of the simulations in the total number of infective stages per arena, with each spot having a 99% chance of having the requisite number of infective stages resulting in less variation between each simulation in the total number of infective stages per arena. The simulations of 25 food spots with 8 infective stages was taken as the simulation that best fits the even distribution of infective stages. Figure 8.17 displays the relationship between the mean density, variance-to-mean ration and prevalence for these simulations and the experimental infections with even distributions of infective stages.

8.10. Discussion

8.10.1. Experimental Results

The results from the experimental infections indicated that the mean density (Margolis et al., 1982) of *M. moniliformis* per *P. americana* was statistically higher in those arenas where the infective stages were presented in a clumped manner. The variance was also higher in the clumped distributions (statistically higher that those from an even distribution), as were the variance-to-mean ratios (statistically different from those in arenas presented with an even distribution of infective stages) and the total number of helminths recovered / arena (statistically higher that those from a random distribution of infective stages). The prevalence of infection was highest in the arenas where infective stages were evenly distributed, being statistically different from those where the infective stages were presented in a random arrangement. This indicates that the arenas with the highest variance-to-mean ratios were also the arenas where the more successful transmission of *M. moniliformis* was taking place, taken as the number of parasites per host.

In earlier work on the infection of *Tribolium confusum* with *Hymenolepis diminuta*, (Keymer and Anderson, 1979) the change from even to random to overdispersed distributions of infective stages was found to alter the variance-to-mean ratio, with greater over-dispersion seen in beetles exposed to over-dispersed infective stages. However, there was no change seen in the mean density in the different regimes of infective stage distribution. Host heterogeneity was hypothesised to account for the over-dispersion seen in uniform distribution of infective stages, with heterogeneity of infective stages accentuating this, but not altering the average rate of parasite acquisition. In other work involving stationary hosts and moving parasites (*Lymnaea peregra* and cercariae of *Echinoparphium recurvatum*), contagious distributions of hosts were found to result in higher mean densities in the hosts than both regular and random distributions of hosts, with a subsequent increase in prevalence in the same manner (McCarthy, 1990). This was considered to be a product of host-finding behaviour of the cercariae, which has been demonstrated for echinostome cercariae (Fried and King, 1989), with clumping of snails resulting in higher concentrations of chemicals, leading to greater transmission efficiency. In two different models of temporal changes in encounter with parasite infective stages, Janovy and Kutish (1988) found that two types of variation in prevalence, mean density and aggregation were seen. In a models where infective stages were supplied more or less continuously this resulted in high prevalence, density and low aggregation of parasites in the host population. In an alternative model, where infective stages were supplied as large numbers of fixed parasites, over a restricted time, this resulted in high aggregation but low prevalence and density of the parasites in the host population. The results of Keymer and Anderson (1979) were taken to reflect a similar effect, in this case with spatial distribution instead of temporal distribution. The results of this study, on a different helminth/host system, do not appear to coincide with this in that the mean density and the prevalence values also change with degrees of aggregation of infective stages, although the over-dispersion results are similar. In the *H. diminuta/T. confusum* system (Keymer and Anderson, 1979), the number of parasites that established in a host was believed to be independent of the density of eggs which will lead to successfully established infections.

In the *M. moniliformis/P. americana* system, this in fact may not be the case, with a 'Law of Diminishing Return' possibly operating (Lackie, 1972a). It would have been expected that any differences in the mean density would have occurred in an opposite fashion to what was observed,

with significant differences between the even and random distributions, but no difference between the random and clumped distributions. In the even distributions of infective stages this would have reflected all cockroaches coming into contact with equal numbers of infective stages. In the random distributions of infective stages, some cockroaches would have a random chance of coming into contact with a higher number of infective stages. In the clumped distributions a few cockroaches may have encountered a large number of infective stages, with those cockroaches ingesting large numbers of acanthors having the number that could have established in their haemocoels curtailed by this plateau in the numbers which can establish. The results from these experiments suggest that there may be some advantage to an acanthor if it is ingested with more of its compatriots, leading to the higher mean densities and higher numbers of helminths recovered from the clumped distributions. Or they may indicate the presence of some individuals who are highly susceptible to infection with *M. moniliformis* having the potential to encounter large numbers of acanthors in the clumped arrangements of infective stages.

The overdispersed distributions seen even in the arenas with even distributions of acanthors may reflect heterogeneity in the encounter of host and infective stage. Cockroaches may not encounter acanthors in a random manner and this may influence the establishment of *M. moniliformis* acanthors. Aggregations of cockroaches could influence transmission and evidence for these have been identified in studies of cockroach behaviour. Studies of the pheromones which are released by sexually receptive female *P. americana* have shown that males are attracted to these over a long distance (Waldow and Sass, 1984). Other chemicals may be implicated in non-homogenous groupings of *P. americana* in caves (see review by Schal, Gautier and Bell, 1984) and these may influence non-random encounter with infective stages in the infection arenas. The other possibility is that interaction with infective stages may be influenced by the infective stages themselves or in the preparation in which the acanthors are kept. Some support for this hypothesis has been found as regards faecal pellets containing eggs of *H. diminuta* and *Tribolium confusum*, where pellets with eggs of *H. diminuta* are more attractive to the beetles than faecal pellets without cestode infective stages (Evans, Hardy and Singh, 1990). In the work of Keymer and Anderson (1979) there was no evidence found for this effect. The other possibility is that there may have been some attractant in the solution containing the acanthors not present in the sucrose solution on its own. This is somewhat doubtful, as

sucrose solutions in each replication were from the same batch of 60% sucrose, but perhaps the addition of acanthors influenced the solution to some degree.

8.10.2. Model Results

The modelling of events in the random and even arenas was relatively straightforward. That of the clumped distribution was not and emphasises the fact that something different and as yet unidentified may be taking place in these arenas. The model which was settled on for simulating the evenly distributed arenas did not exactly reflect the actual situation in the experimental arenas. In the experimental arenas, there were 60 spots containing infective stages while in the model there were 25 food spots, lumping the infective stages into more spots than were used in the experimental infections. The reason that this agreed with the results of the experimental infections more precisely than the model containing 50 food spots most probably relates to heterogeneity of encounter of hosts with acanthors in the experimental arenas and heterogeneity in the cockroaches in susceptibility to establishment of *M. moniliformis*; these process would tend to generate a more over-dispersed exposure to infection than that found in the model with random movement of cockroaches and equal susceptibility to infection. The same was true for the random distribution models, where approximately 25% of 50 food spots contained infective stages (essentially 12-13 spots) in comparison to the 30 which contained acanthors in the experimental arenas. The overall effect in both cases was similar, with approximately 50% of the food spots holding infective stages in the experimental infections being used for the simulation of infection in the model infections.

The clumped distribution was more difficult to model precisely, the final model having an area corresponding to roughly one-quarter of the arena where each spot within it had a 99% chance of being positive with 20 infective stages in those found to be positive and a total of 50 food spots in the arena. On average, between 12-13 of the food spots would fall within this positive area, which reflects similarly with the random distribution. Again, there were 30 food spots with acanthors in the experimental arenas. However, the fit of the clumped model parameters with the experimental parameters is less good than that of the other patterns of distributions, with the mean density of the simulations being significantly lower than that of the clumped distributions.

After the adjustment of the model to fit the observed patterns in experimental conditions, the effect on the distribution of parasites within the cockroaches of changing the inherent behaviour of the

cockroaches was investigated. This simulated what would occur if a proportion of the cockroaches were more refractive to infection, either due to behavioural or immunological factors. Also the effect of changing encounter behaviour after the cockroaches have become infected was investigated. Again, this simulates either changes in behaviour or in the immune system of the host which might make a cockroach less or more likely to be infected after it had once been infected. It is unknown to what degree these factors already were present in the experimental infections on which the model was based. The results of these simulations are presented in the following chapter.

8.11. Summary

Experimental Infections

1. Experimental infections of groups of 50 cockroaches exposed to one of three distributions of infective stages; random, clumped or even.

2. Significant differences found between the three different exposure regimes in the mean density, variance, variance-to-mean ratio, total number of individuals recovered in the arena population of cockroaches and the prevalence of infection via Kruskal-Wallis analysis.

3. Groups of cockroaches exposed to a clumped distribution of infective stages had significantly heavier mean densities than the other groups; their variance and variance-to-mean ratio was significantly higher than those exposed to even distributions of infective stages and they had significantly higher total number of parasites recovered per group than those exposed to a random distribution of infective stages.

4. Groups of cockroaches exposed to an even distribution of infective stages had significantly higher prevalence of infection than those exposed to a random distribution of infective stages.

Model Results

1. The simulation that represented the cockroaches exposed to a random pattern of infective stages best was that of 50 food spots distributed at random, each with a 25% chance of containing 15 infective stages.

2. The simulation that represented the cockroaches exposed to a clumped pattern of infective stages best was that of 50 food spots, where infected food spots were confined to approximately one-fourth of the arena and where those within this area had a 99% chance of containing 20 infective stages each.

3. The simulation that represented the cockroaches exposed to an even pattern of infective stages best was that of 25 food spots distributed throughout the arena, with each of them having a 99% chance of containing 8 infective stages.

4. In the simulations, taken together, the infective stages were found in a more clumped arrangement than what was the case in the experimental regime. This could be taken as evidence of other factors involved in the experimental infections which effectively increased the over-dispersion in the system.

5. The simulations of the clumped distributions gave the least satisfactory results of the three models.

Table 8.1. Results of experimental infections of 50 cockroaches with different patterns of distributed acanthors of *M. moniliformis*.

Rat Group	Infective Stage Distribution	Mean Density	Variance	Variance-to-Mean Ratio	Sum	Prevalence	I_D
1	Even	3.61	12.91	3.58	166	71.7	1.70*
2	Even	4.02	12.49	3.10	177	79.5	1.51*
2	Even	3.66	14.58	3.99	150	75.6	1.80*
3	Even	3.80	13.36	3.57	175	78.3	1.65*
3	Even	3.73	11.14	2.99	179	79.2	1.52*
1	Random	3.44	24.97	7.25	148	55.8	2.78*
2	Random	4.07	33.78	8.30	171	59.5	2.76*
2	Random	4.14	33.43	8.07	207	50.0	2.68*
3	Random	3.24	16.64	5.13	133	63.4	2.25*
3	Random	3.12	20.26	6.49	128	53.7	2.73*
1	Clumped	6.05	62.35	10.31	248	63.4	2.51*
2	Clumped	6.05	80.24	13.27	254	64.3	2.99*
2	Clumped	5.65	62.11	10.99	277	65.3	2.74*
3	Clumped	5.91	37.23	10.14	260	61.4	2.52*
3	Clumped	5.90	50.92	8.62	248	73.8	2.27*

Table 8.4. Table describing the model constructed to simulate the infection of *P. americana* with *M. moniliformis*.

Model	Life Cycle or Experiments	Numerical/Stochastic Step in the Model
Placement of 'Infective Stages' in 'Food Spots'	Experimental Manipulation of *M. moniliformis* Acanthors in Aqueous Sucrose Within the Circular Arena	Use of random number* generator with a certain proportion of food spots positive for infective stages and also those in a certain area of the arena as positive using a system of x, y co-ordinates within the boundaries of the arena.
Introduction of 'Cockroaches'	Placement of Cockroaches into Experimental Arena	Use of the mouse to place roaches into the arena, a certain number may be set to have different characteristics when encountering infective stages.
Heterogeneity in 'Cockroaches'	Cockroaches Vary in Inherent Susceptibility, either through Ease of Infection or through Differences in Behaviour	When those cockroaches that are more susceptible encounter a food spot with infective stages they are 10 times as likely to pick up an infective stage and will stay at any food spot twice as long as the less susceptible cockroaches. They will also stop at a food spot if one is encountered
Movement of 'Cockroaches'	Cockroaches	Redress image of each cockroach at each step through the model one pixel up and one over.
Change in Movement of 'Cockroaches'	Move About	One out of ten moves, at random, each cockroach will change direction by 90 degrees.
'Cockroach' hits a Wall	in Arena	Upon hitting a wall, each cockroach will bounce back at a mirror angle of the angle to which it hit the wall.
Increase in Hunger of 'Cockroach'	Movement Increases Hunger	Cockroaches start out with a 'hunger' rating of zero and pick up one point for every step they make. Depending on their level of susceptibility they will stop at a food spot if one is encountered when this rating hits either 120 or 200.
Encounter of 'Cockroach' with 'Food Spot'	Cockroach stops at a Drop of Sucrose	At each step through the model, the pixel that a cockroach occupies is evaluated to see if the values for food are greater than zero.

Table 8.4. (Cont.)

'Cockroach' Ingests 'Food' &/or 'Infective Stages'	Cockroach Ingests Sucrose (May or May Not Ingest Acanthors)	At each step through the model, while it is at an food spot, a cockroach will loose one of its hunger ratings. It will pick up infective stages in proportion to the amount of food left at the spot (i.e. infective stages/amount of food left). Each food spot starts out with 400 units of food. This is set as an absolute number every step through the model to avoid division by zero. This is multiplied by a constant which is 10 times larger if the cockroach is more susceptible to infections
Change in 'Cockroach'	If the Cockroach becomes Infected this may Change Susceptibility either through Ease of Infection or through Differences in Behaviour	When the cockroach becomes infected, its level of stopping at a food spot and the constant that is used to determine the amount of infective stages picked up at a food spot can be changed to reflect an increase or decrease in susceptibility to infection.
'Cockroach' Leaves 'Food Spot'	Cockroach leaves Spot of Sucrose, either Because it is Satiated or Because there is no Food Left	If the cockroach is less susceptible to infection it will leave the food spot when its hunger rating reaches 160 (from 200); if it is more susceptible if will leave the food spot when its hunger rating reaches 40 (from 120).

* Random number generation uses a command that generates random number from 0 to a certain specified number, for example 1000. A certain proportion of these generated random numbers can then be assigned to one group of objects, say food spots positive for infective stages.

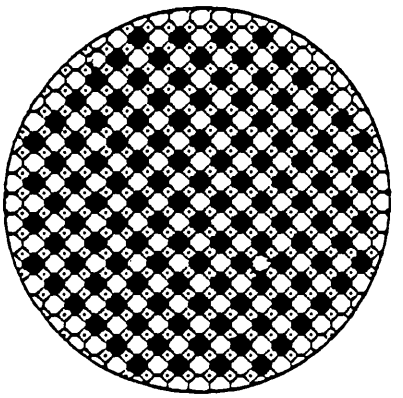
Table 8.7. Results of comparisons of parameters between the experimental group and the model simulations.

Parameter	Groups*								
	One	Two	Three	Four	Five	Six	Seven	Eight	Nine
Mean	6.85	13.75	31.7	10.45	45.65	65.50†	33.35	58.05†	77.10†
Variance	18.40	6.30	0.75	15.35	28.10	37.50	40.70	55.20†	63.70†
Variance-to-Mean	21.60	27.10	34.50	21.50	7.40	5.20	41.50	34.30	19.80
Sum	3.05	16.55	34.4	13.65	48.60	68.30†	36.10	60.85†	79.90†
Prevalence	6.20	29.95	48.55	4.75	29.15	60.90†	2.15	26.45	61.30†

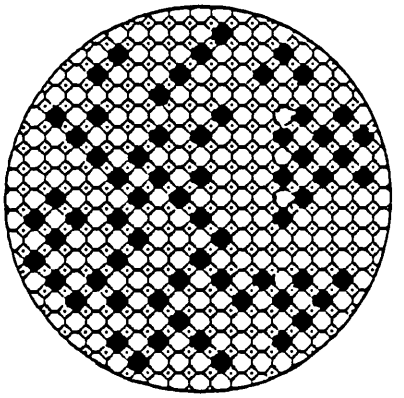
* Group 1: 10 infective stages per spot/ 25% of spots positive.
Group 2: 10 infective stages per spot/ 50% of spots positive.
Group 3: 10 infective stages per spot/ 75% of spots positive.
Group 4: 20 infective stages per spot/ 25% of spots positive.
Group 5: 20 infective stages per spot/ 50% of spots positive.
Group 6: 20 infective stages per spot/ 75% of spots positive.
Group 7: 30 infective stages per spot/ 25% of spots positive.
Group 8: 30 infective stages per spot/ 50% of spots positive.
Group 9: 30 infective stages per spot/ 75% of spots positive.

† Significantly different from the median rank of the experimental group at $p \leq 0.05$, difference needed for significance is 49.83.

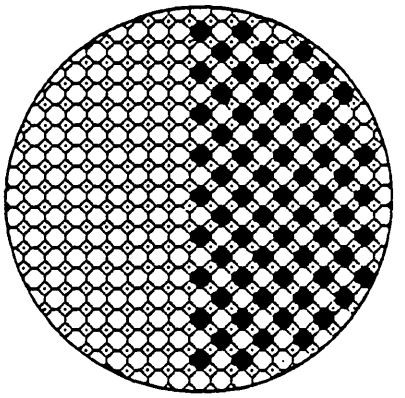
Figure 8.1. Diagram of the Plexiglas trays presented to a groups of 50 cockroaches in an arena. There were 60 coverslips in total (represented by circles) on each tray. The darkened circles represent coverslips containing acanthors in an even, random or clumped spatial pattern.



EVEN

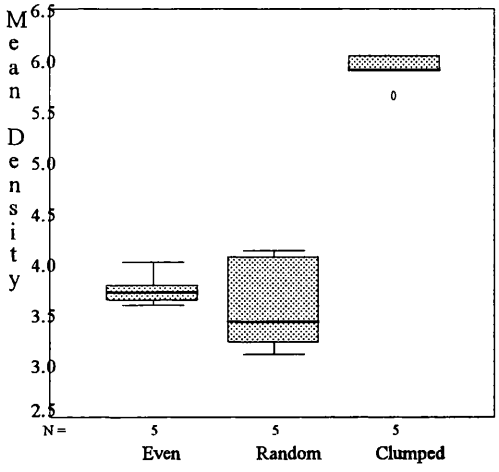


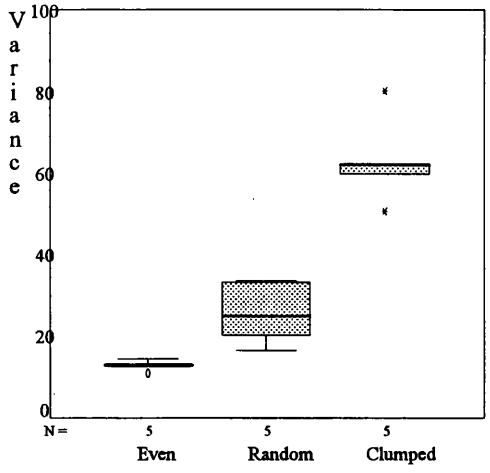
RANDOM

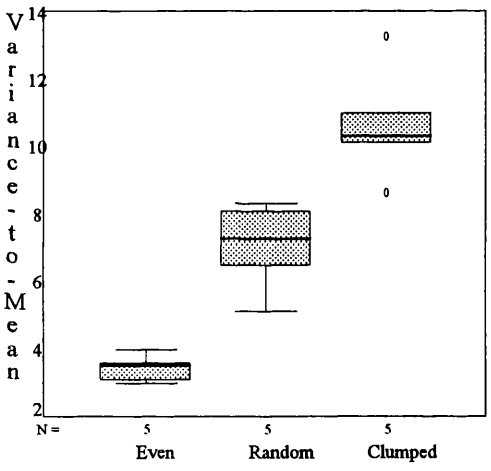


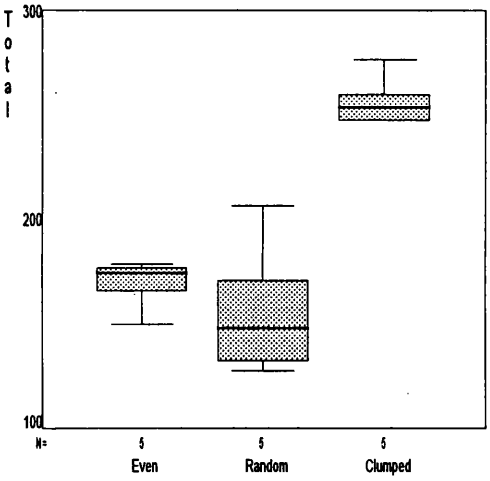
CLUMPED

Figure 8.2. Box plots of the parameters from the experimental infections (a). Mean density of *M. moniliformis* recovered. (b). Variance of *M. moniliformis* recovered. (c). Variance-to-Mean ratios. (d). Total number of *M. moniliformis* recovered in each replication. (e). Prevalence of infection with *M. moniliformis*.


Mean Density
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
N=
5
5
5
Even
Random
Clumped
Distributions


Variance
100
80
60
40
20
0
N=
5
5
5
Even
Random
Clumped
Distributions


Variance-to-Mean
14
12
10
8
6
4
2
N=
5
5
5
Even
Random
Clumped
Distributions


Total
300
200
100
N=
5
5
5
Even
Random
Clumped
Distributions

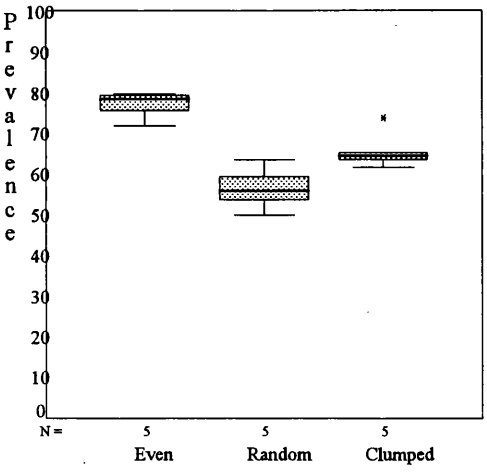

Prevalence
100
90
80
70
60
50
40
30
20
10
0
N=
5
5
5
Even
Random
Clumped
Distributions

Figure 8.3. The relationship between the mean density, variance-to-mean ratio and prevalence in the experimental infections.

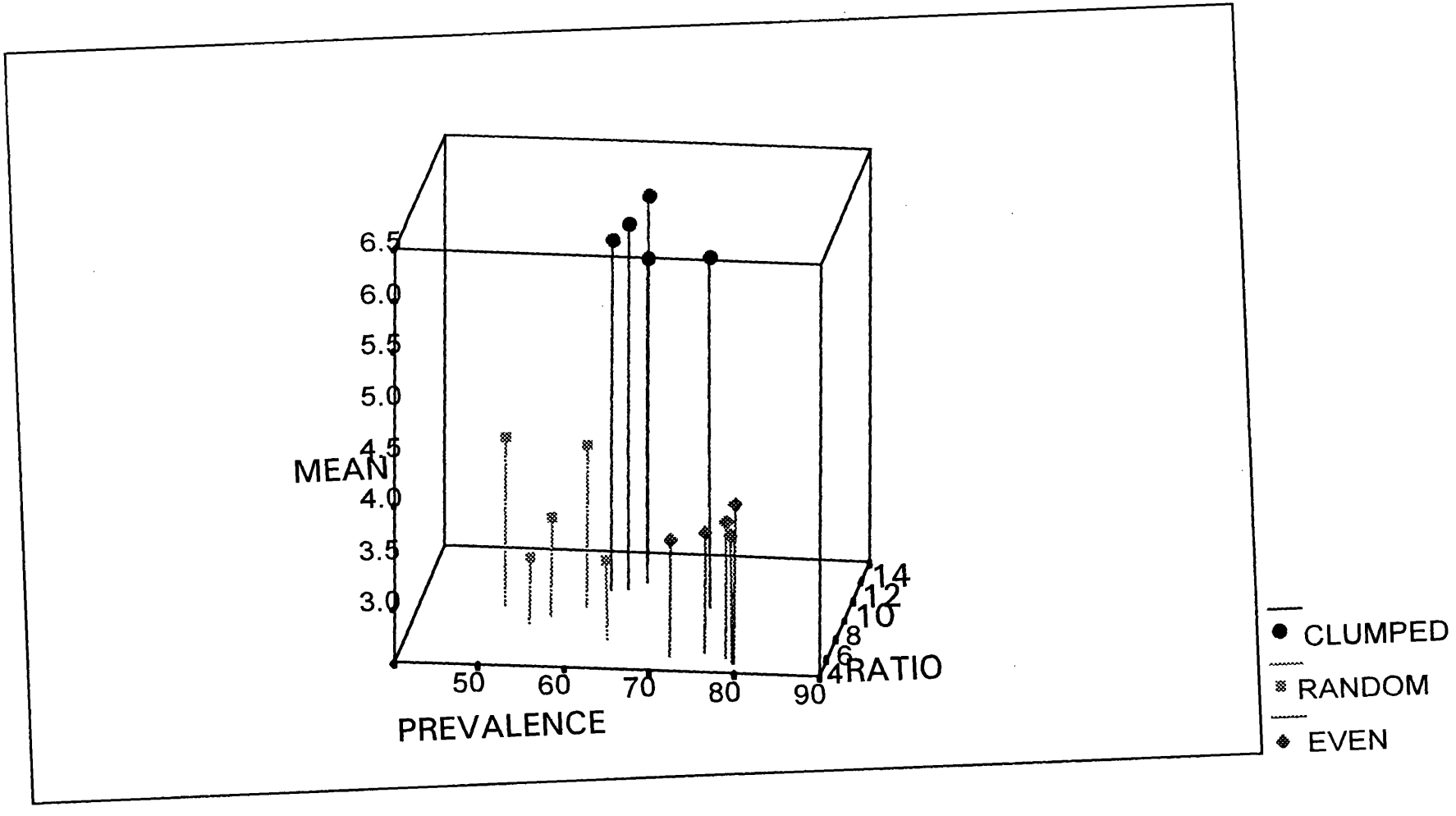
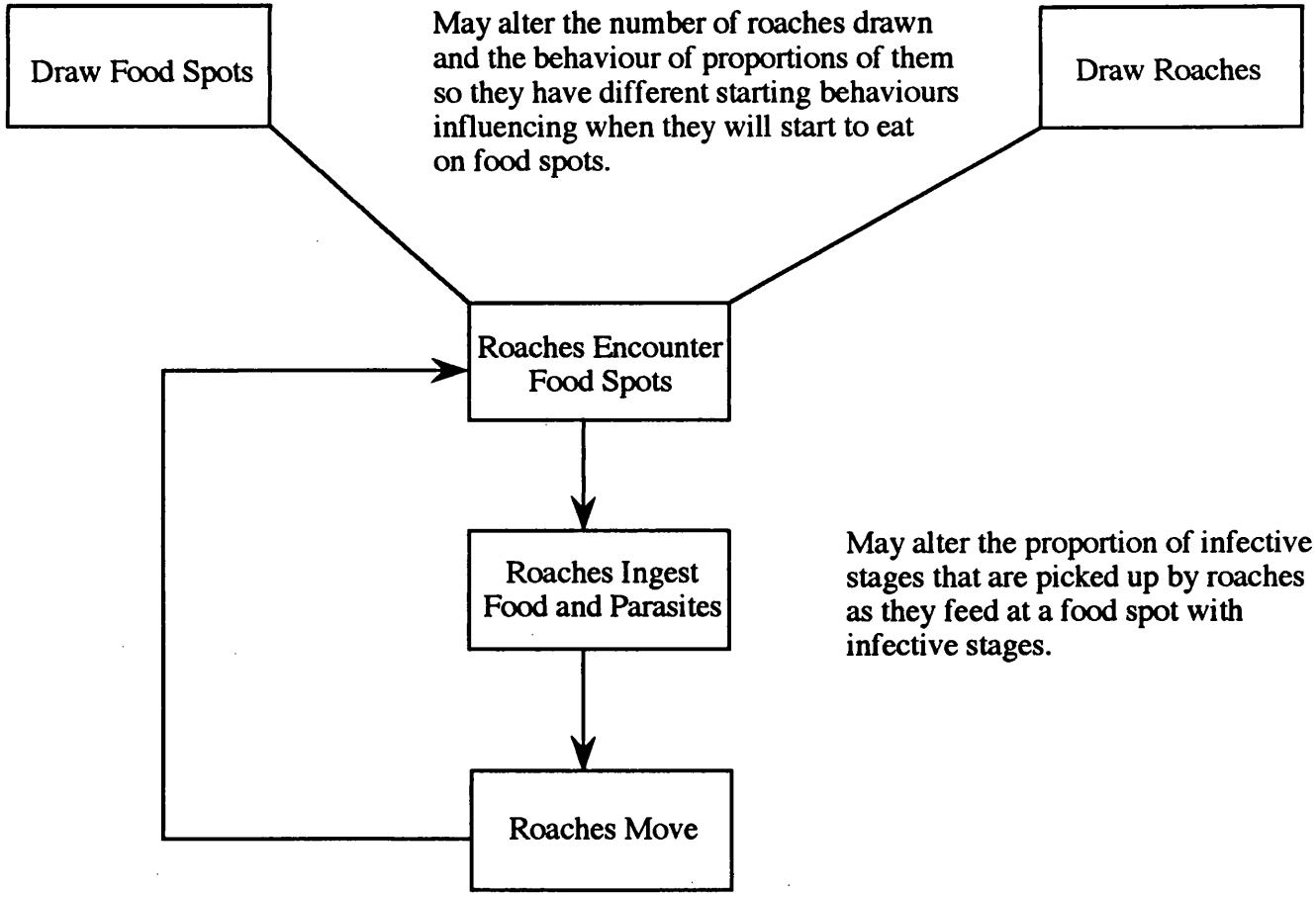

MEAN
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
50
60
70
80
90
PREVALENCE
14
12
10
8
6
4
RATIO
CLUMPED
RANDOM
EVEN

Figure 8.4. Representation of the model with locations of possible alterations noted.

May alter the proportion of food spots that are positive for parasites and the distribution of the food spots positive for parasites.



May alter the number of roaches drawn and the behaviour of proportions of them so they have different starting behaviours influencing when they will start to eat on food spots.

May alter the manner in which roaches ingest food and infective stages after they are infected by altering the levels for uninfected or infected roaches at which they will start and stop eating.

May alter the proportion of infective stages that are picked up by roaches as they feed at a food spot with infective stages.

Figure 8.5. 'Decisions' involved in movement of model cockroaches within the model arenas.

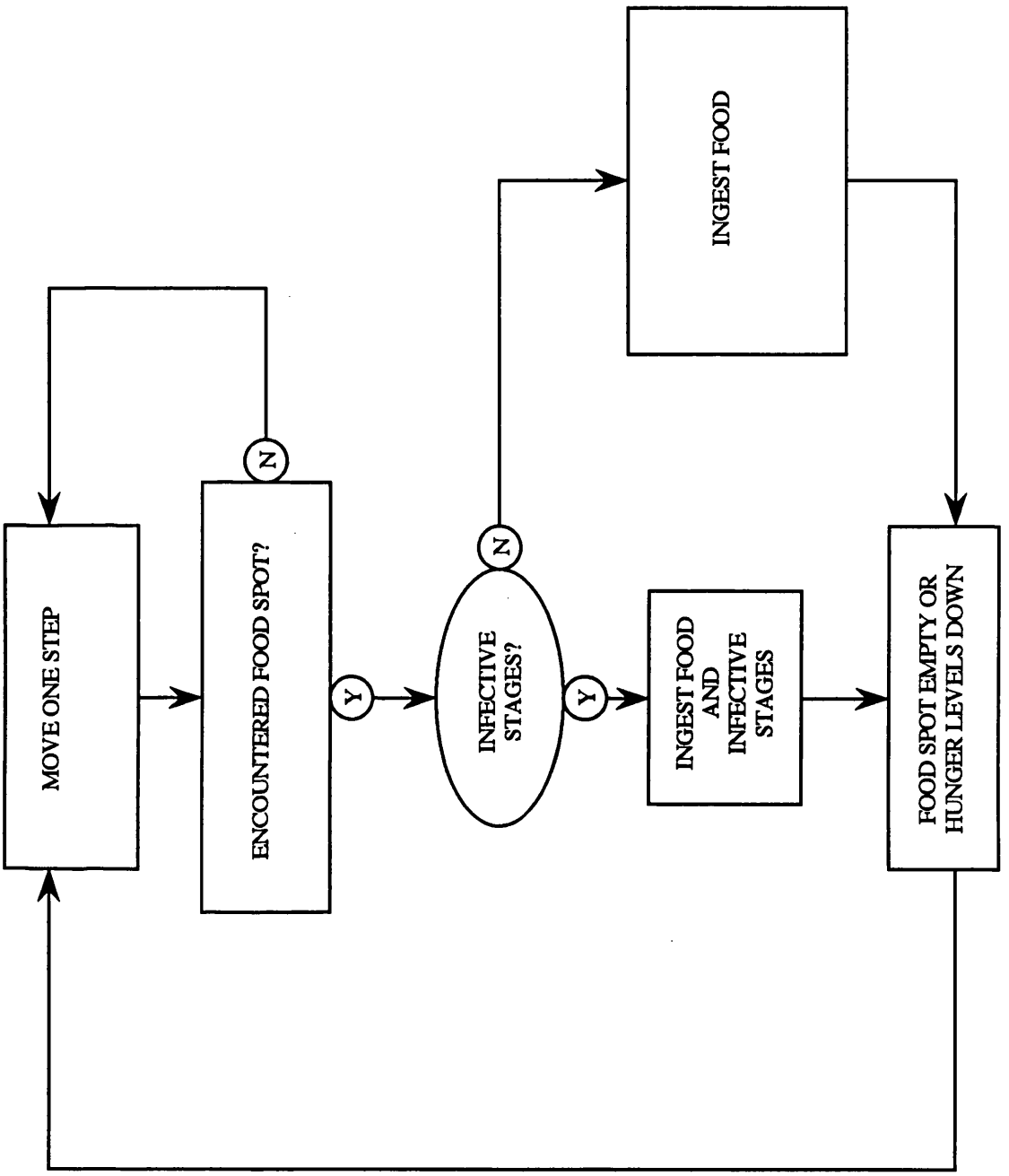

MOVE ONE STEP
ENCOUNTERED FOOD SPOT?
N
Y
INFECTIVE STAGES?
N
Y
INGEST FOOD
INGEST FOOD AND INFECTIVE STAGES
FOOD SPOT EMPTY OR HUNGER LEVELS DOWN

Figure 8.6. Mean density for the nine simulations first undertaken for the model of random distribution of infective stages in the arena. Groups 1 through 3 were those simulations with 10 infective stages per food spot and increasing numbers of food spots positive for infective stages out of 50 food spots (25%, 50% and 75%, respectively). Groups 4 through 6 were groups with 20 infective stages per positive food spot and increasing numbers of food spots positive for infective stages (25%, 50% and 75%, respectively. Groups 7 through 9 were groups with 30 infective stages per positive food spot and increasing numbers of food spots positive for infective stages (25%, 50% and 75%, respectively). The experimental results from the random pattern of infective stages are also presented as are the model results for 25% of the food spots positive with 15 infective stages per spot.

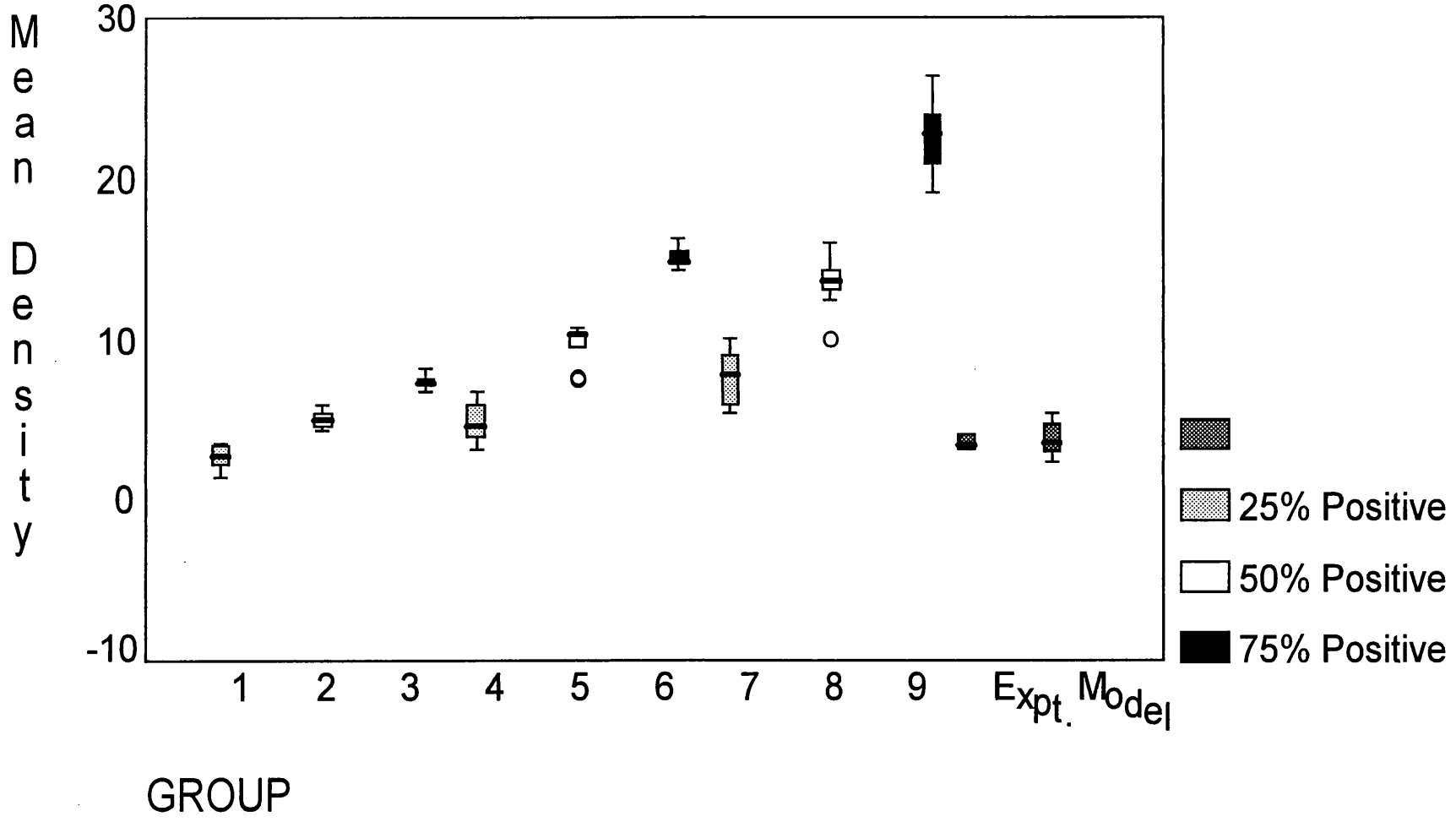

Mean Density
30
20
10
0
-10
1
2
3
4
5
6
7
8
9
Expt. Model
GROUP
25% Positive
50% Positive
75% Positive

Figure 8.7. Variance for the nine simulations first undertaken for the model of random distribution of infective stages in the arena. Groups 1 through 3 were those with 10 infective stages per food spot and increasing numbers of food spots positive for infective stages out of 50 food spots (25%, 50% and 75%, respectively). Groups 4 through 6 were groups with 20 infective stages per positive food spot and increasing numbers of food spots positive for infective stages (25%, 50% and 75%, respectively. Groups 7 through 9 were groups with 30 infective stages per positive food spot and increasing numbers of food spots positive for infective stages (25%, 50% and 75%, respectively). The experimental results from the random pattern of infective stages are also presented as are the model results for 25% of the food spots positive with 15 infective stages per spot.

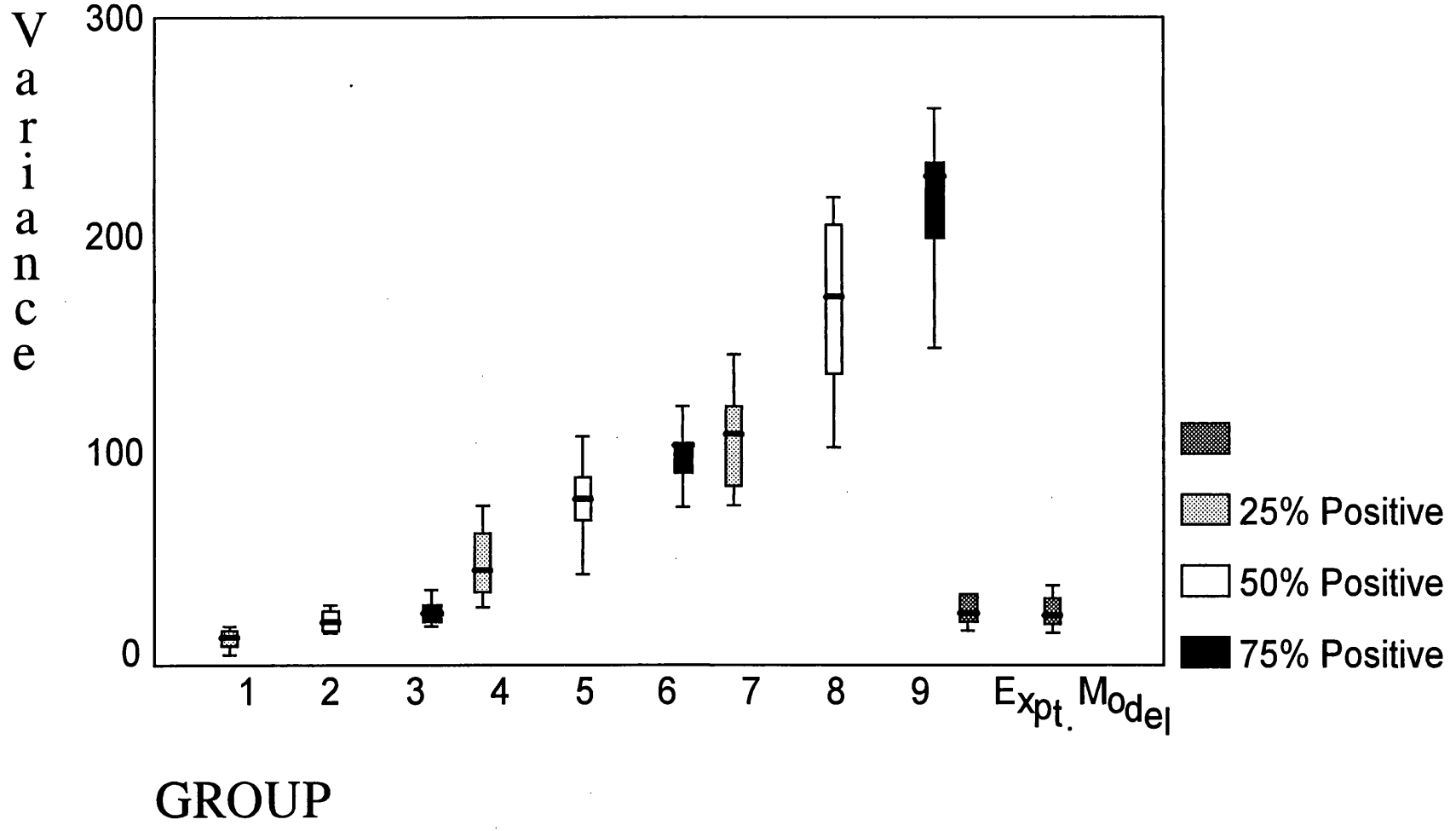

Variance
300
200
100
0
1
2
3
4
5
6
7
8
9
Expt. Model
GROUP
25% Positive
50% Positive
75% Positive

Figure 8.8. Variance-to-Mean ratio for the nine simulations first undertaken for the model of random distribution of infective stages in the arena. Groups 1 through 3 were those with 10 infective stages per food spot and increasing numbers of food spots positive for infective stages out of 50 food spots (25%, 50% and 75%, respectively). Groups 4 through 6 were groups with 20 infective stages per positive food spot and increasing numbers of food spots positive for infective stages (25%, 50% and 75%, respectively. Groups 7 through 9 were groups with 30 infective stages per positive food spot and increasing numbers of food spots positive for infective stages (25%, 50% and 75%, respectively). The experimental results from the random pattern of infective stages are also presented as are the model results for 25% of the food spots positive with 15 infective stages per spot.

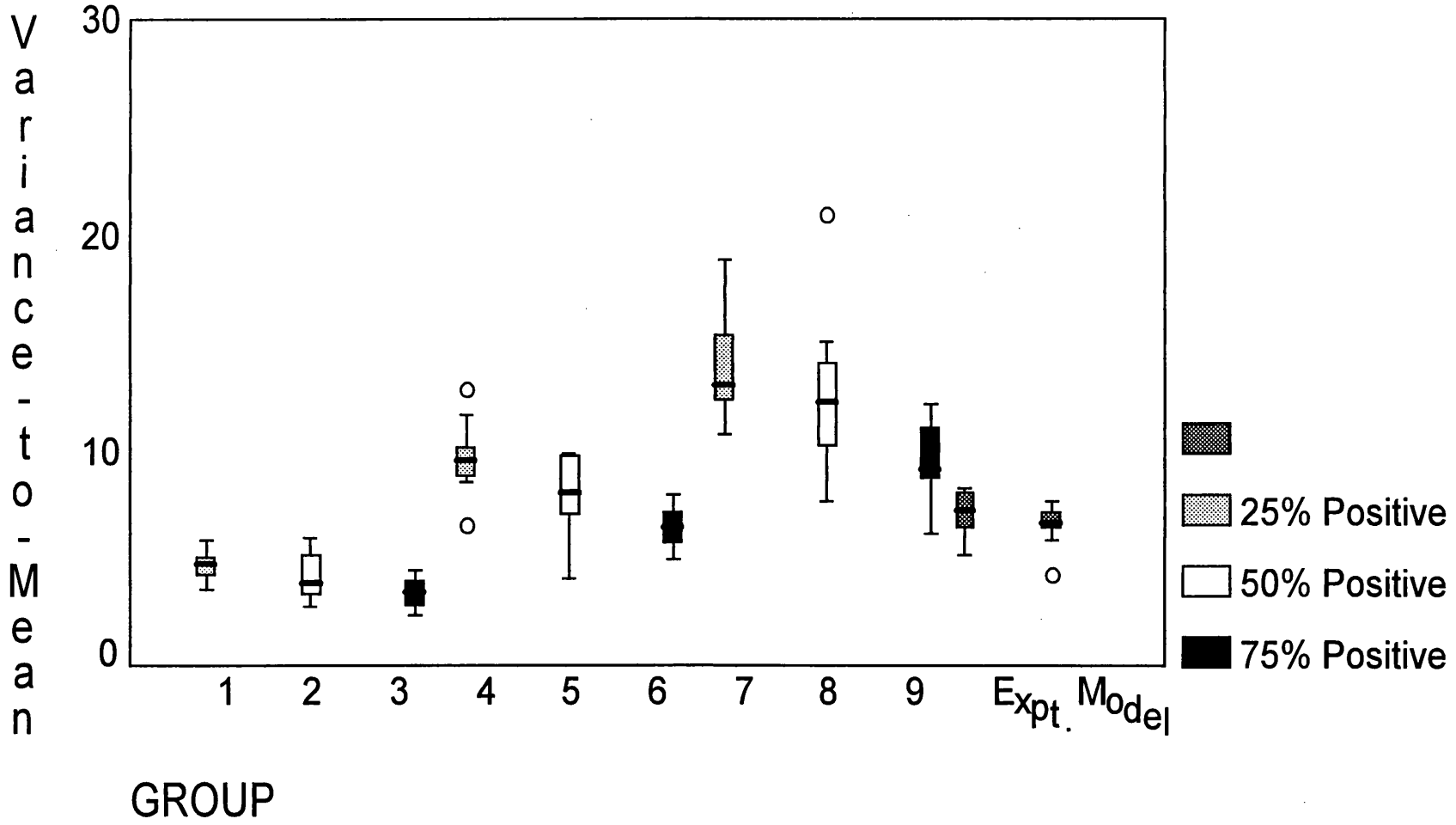

Variance-to-Mean
30
20
10
0
1
2
3
4
5
6
7
8
9
Expt.
Model
GROUP
25% Positive
50% Positive
75% Positive

Figure 8.9. Total number of infective stages recovered for each arena for the nine simulations first undertaken for the model of random distribution of infective stages in the arena. Groups 1 through 3 were those with 10 infective stages per food spot and increasing numbers of food spots positive for infective stages out of 50 food spots (25%, 50% and 75%, respectively). Groups 4 through 6 were groups with 20 infective stages per positive food spot and increasing numbers of food spots positive for infective stages (25%, 50% and 75%, respectively. Groups 7 through 9 were groups with 30 infective stages per positive food spot and increasing numbers of food spots positive for infective stages (25%, 50% and 75%, respectively). The experimental results from the random pattern of infective stages are also presented as are the model results for 25% of the food spots positive with 15 infective stages per spot.

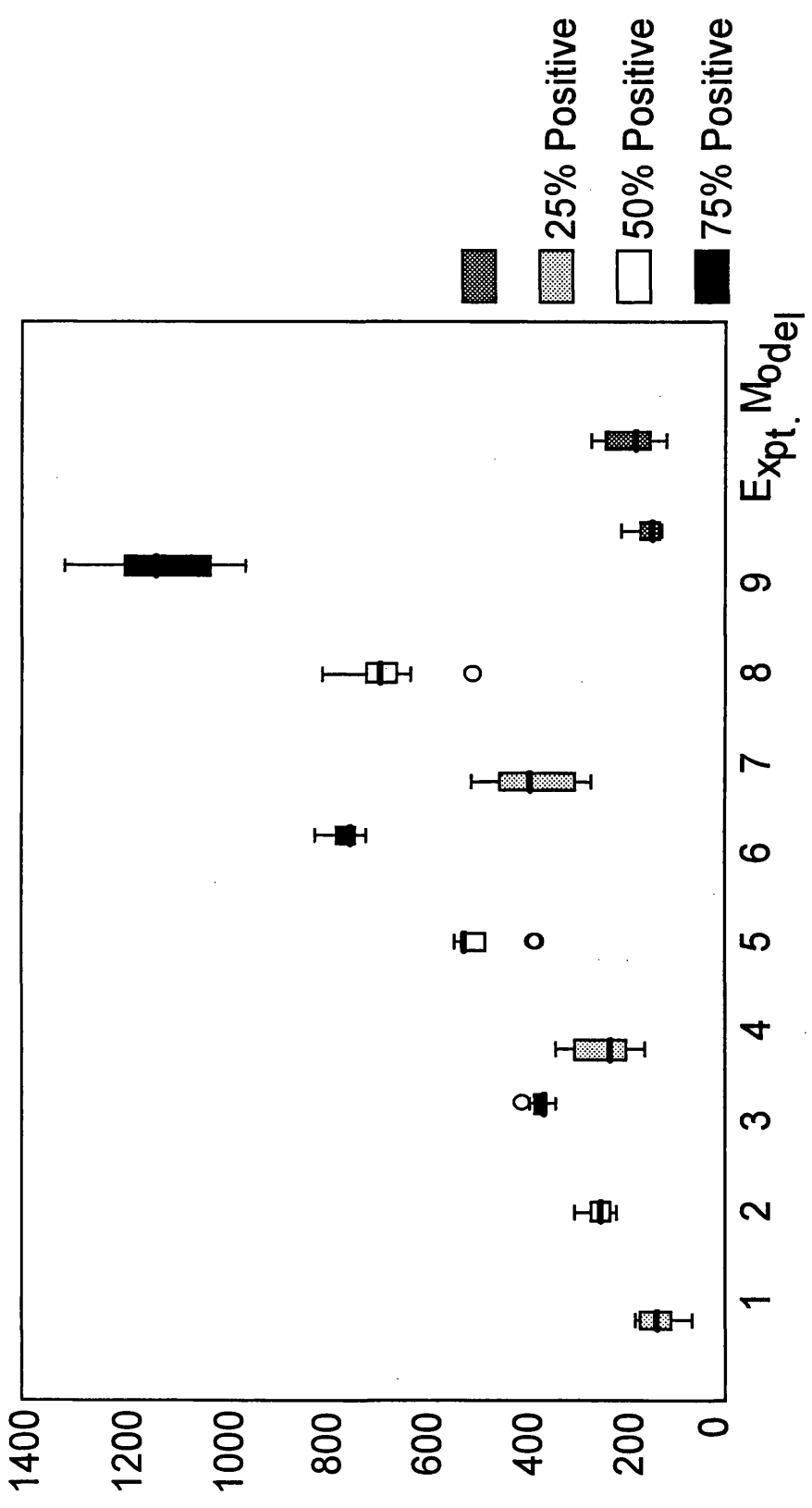

Total
1400
1200
1000
800
600
400
200
0
1
2
3
4
5
6
7
8
9
GROUP
25% Positive
50% Positive
75% Positive
Expt. Model

Figure 8.10. Prevalence of infective stages for the nine simulations first undertaken for the model of random distribution of infective stages in the arena. Groups 1 through 3 were those with 10 infective stages per food spot and increasing numbers of food spots positive for infective stages out of 50 food spots (25%, 50% and 75%, respectively). Groups 4 through 6 were groups with 20 infective stages per positive food spot and increasing numbers of food spots positive for infective stages (25%, 50% and 75%, respectively. Groups 7 through 9 were groups with 30 infective stages per positive food spot and increasing numbers of food spots positive for infective stages (25%, 50% and 75%, respectively). The experimental results from the random pattern of infective stages are also presented as are the model results for 25% of the food spots positive with 15 infective stages per spot.

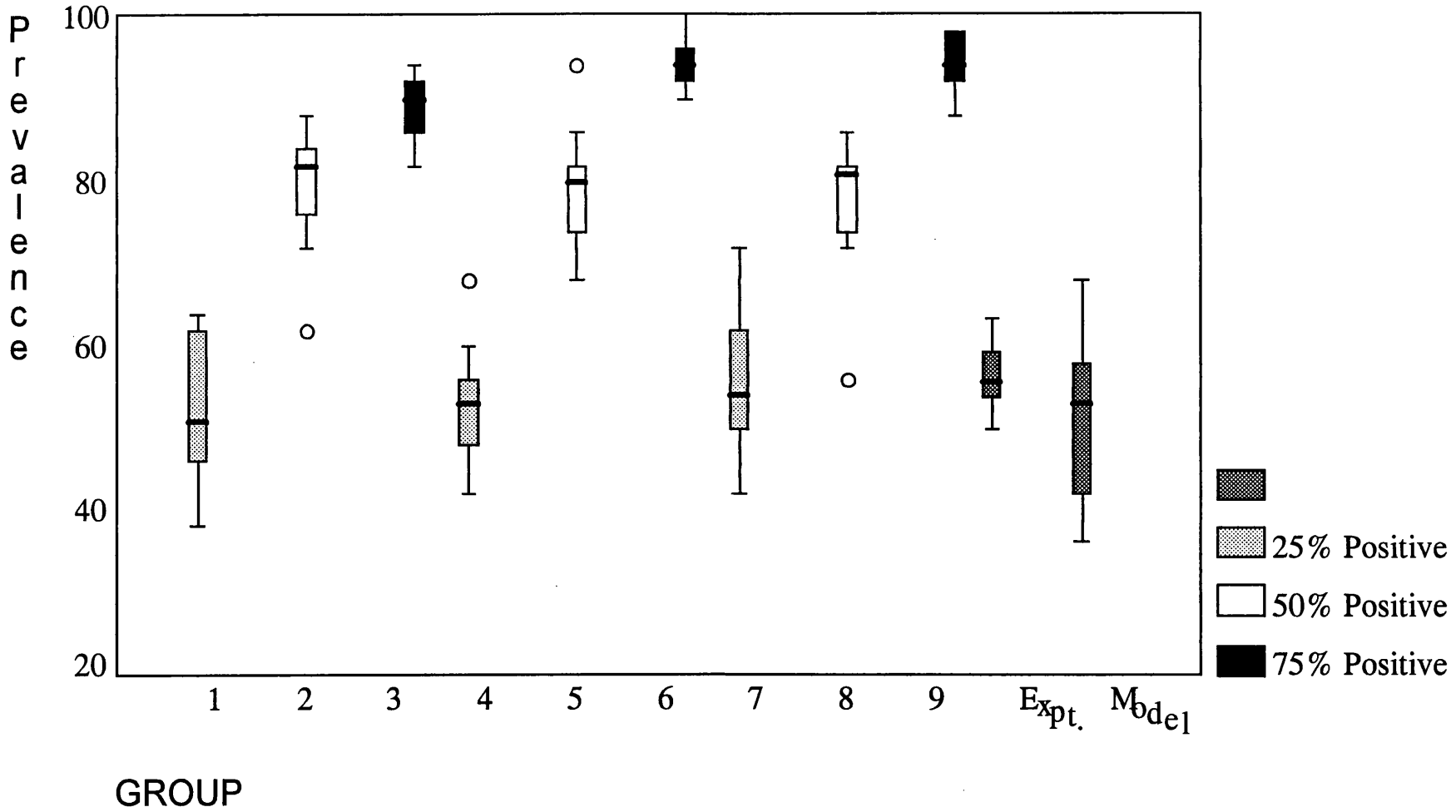

Prevalence
100
80
60
40
20
1
2
3
4
5
6
7
8
9
Expt.
Model
GROUP
25% Positive
50% Positive
75% Positive

Figure 8.11. Results from simulations of randomly distributed infective stages, comparing mean density, prevalence and variance-to-mean ratios. Groups are as before. As can be seen from this representation, the groups from the simulation of 25% of food spots positive with 15 infective stages present in each positive spot most closely approximates that of the experimental infections.

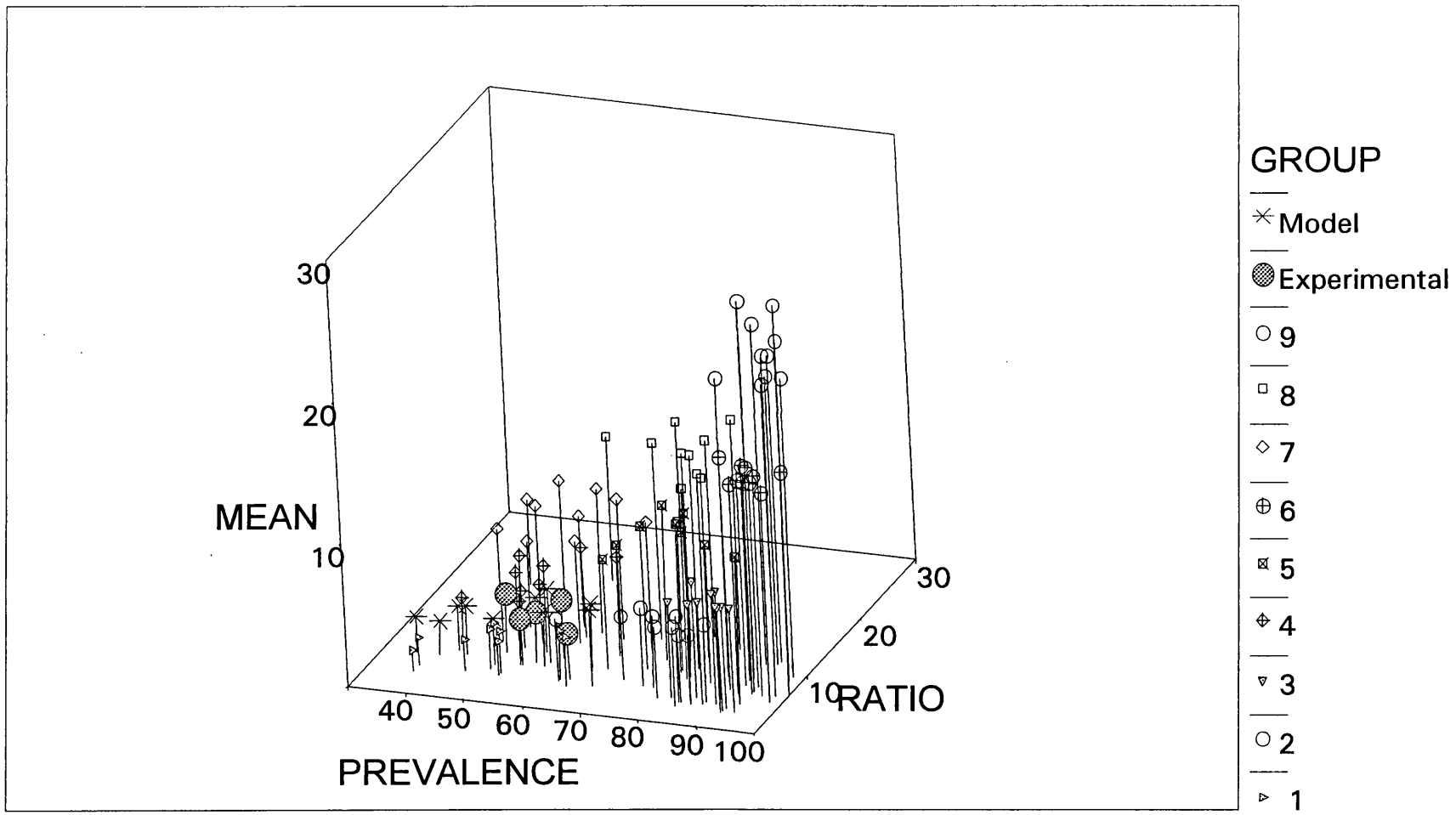
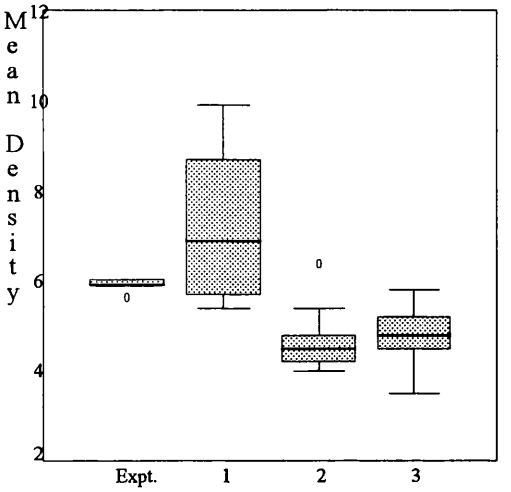
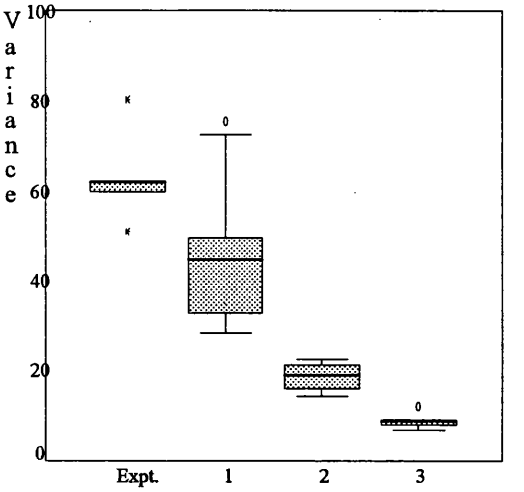

30
20
MEAN
10
40
50
60
70
80
90
100
PREVALENCE
10
20
30
RATIO
GROUP
Model
Experimental
9
8
7
6
5
4
3
2
1

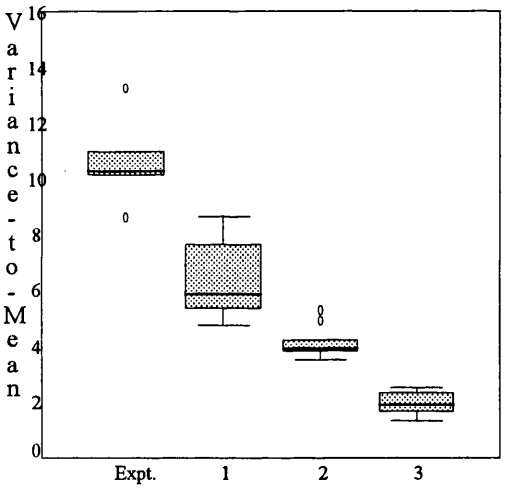
Figure 8.12. Results from first attempt at simulating the clumped experimental infections. The results from the experimental infections are shown. Group 1 refers to 100 food spots introduced into the arena which was divided in half, one half positive for infective stages, the other negative. Each spot on the positive half of the arena had a 50% chance of being infected with 15 infective stages. Group 2 refers to 50 food spots again with the arena divided into halves. Those food spots on the positive side each having a 99% chance of containing 10 infective stages. Group 3 refers to 100 food spots in the arena, where food spots on the positive half each have a 99% chance of containing 5 infective stages. (a). Mean density. (b). Variance. (c). Variance-to-Mean ratio. (d). Total number of infective stages in roaches at end of simulation/replication. (e). Prevalence of infection.



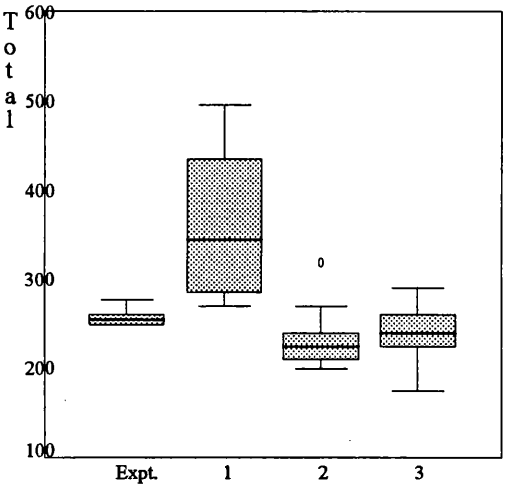
Group



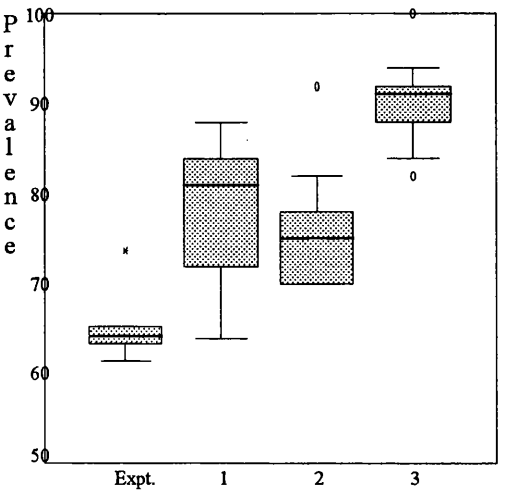
Groups



Groups

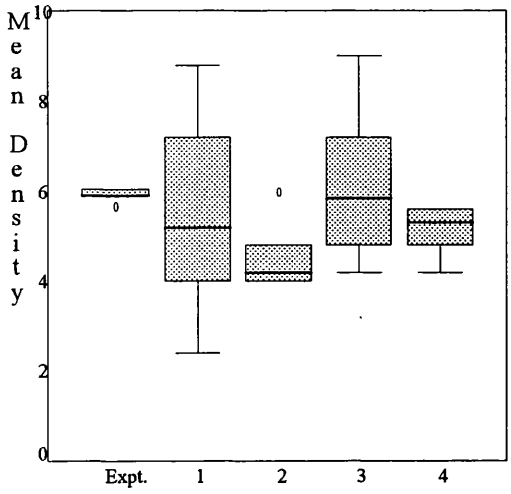


Groups

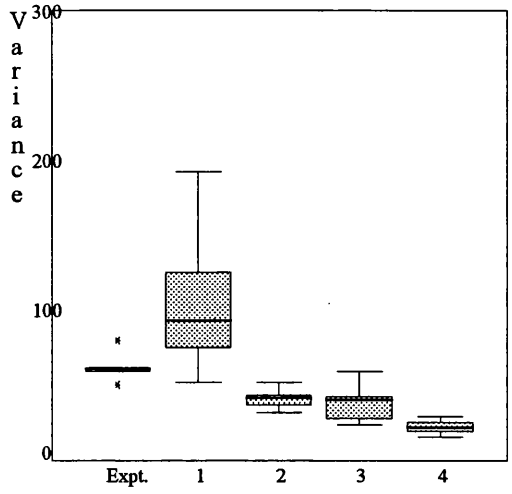


Groups

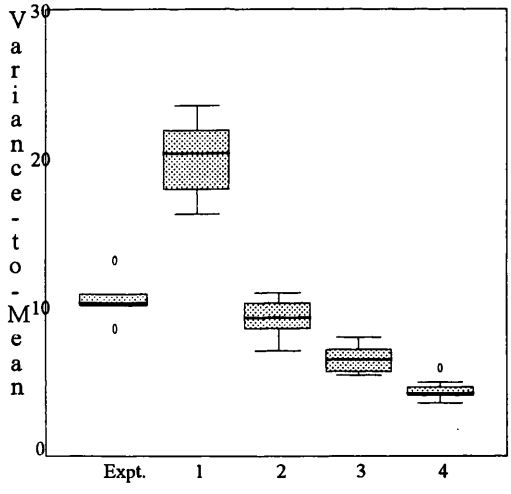
Figure 8.13. Second attempt at simulating the experimental results of the clumped distribution of infective stages. The experimental results are shown. The arena was divided, with one quarter of it having positive food spots present, where any food spot in this area had a 99% chance of being positive for infective stages. Group 1 refers to simulations where 25 food spots were introduced into the arena with 40 infective stages per positive food spot, Group 2 with 50 food spots and 20 infective stages, Group 3 with 75 food spots and 15 infective stages and Group 4 with 100 food spots and 10 infective stages per spot. (a). Mean density. (b). Variance. (c). Variance-to-Mean ratio. (d). Total number of infective stages in roaches at end of simulation/replication. (e). Prevalence of infection.



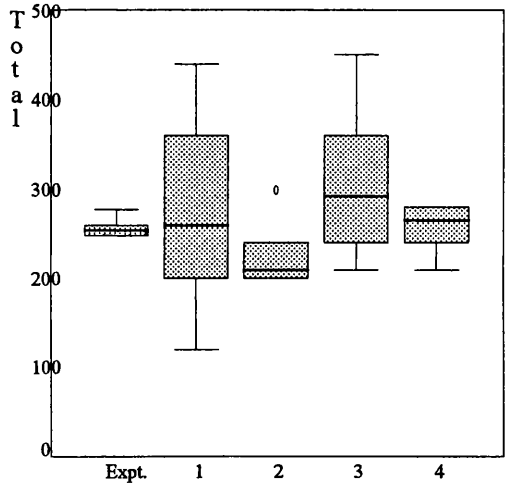
Groups



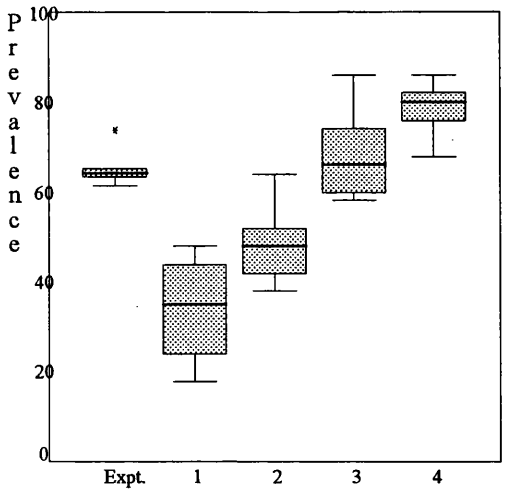
Groups



Groups



Groups

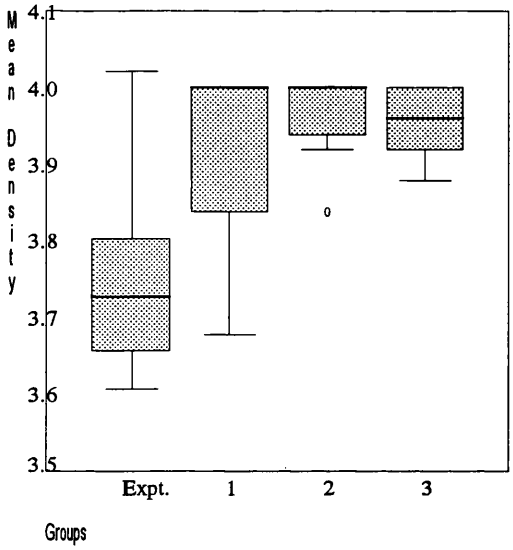


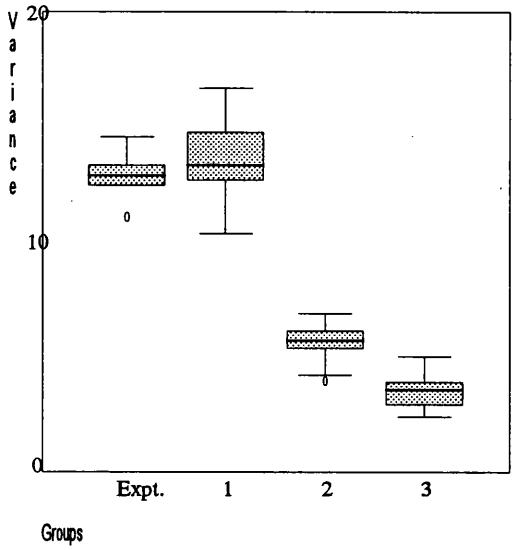
Groups

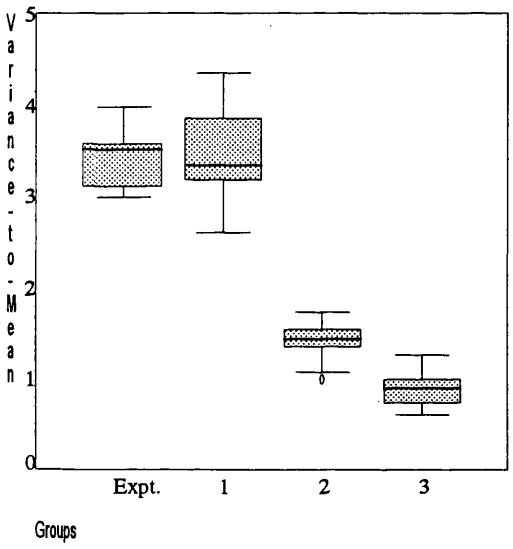
Figure 8.14. Three-dimensional graph displaying the interaction of the mean density, variance-to-mean ratio and prevalence in the clumped patterns of infective stages in the experimental infections and the final four simulations of the model where the arena was divided, with one-quarter of it having positive food spots present, where any food spot in this area had a 99% chance of being positive for infective stages. Group 1 refers to simulations where 25 food spots were introduced into the arena with 40 infective stages per positive food spot, Group 2 with 50 food spots and 20 infective stages, Group 3 with 75 food spots and 15 infective stages and Group 4 with 100 food spots and 10 infective stages per spot.

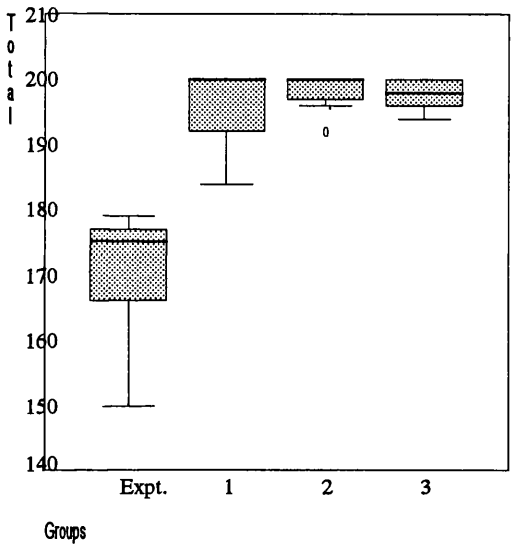
4
3
2
1
Experimental
MEAN
10
8
6
4
RATIO
30
20
PREVALENCE
100
80
60
40
20

Figure 8.15. Results of attempts to simulate the experimental results from the infections where even distributions of infective stages were used. Group 1 refers to that of 25 food spots of which each had 99% chance of being positive with 8 infective stages. Group 2 was 50 food spots with 4 infective stages per spot and Group 3 was 100 food spots and 2 infective stages. (a). Mean Density. (b). Variance. (c). Variance-to-Mean ratio. (d). Total number of infective stages recovered at the end of each replication/simulation. (e). Prevalence of parasites.


Mean Density
4.1
4.0
3.9
3.8
3.7
3.6
3.5
Expt.
1
2
3
Groups


Variance
20
10
0
Expt.
1
2
3
Groups


Variance-to-Mean
5
4
3
2
1
0
Expt.
1
2
3
Groups


Total
210
200
190
180
170
160
150
140
Expt.
1
2
3
Groups

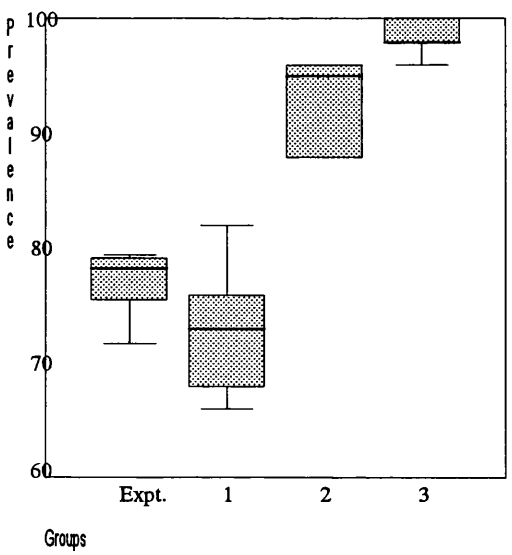

prevalence
100
90
80
70
60
Expt.
1
2
3
Groups

Figure 8.16. Three-dimensional graph of the interaction of mean density, variance-to-mean ratio and prevalence in the experimental and simulation results from the even distribution of infective stages. Group 1 refers the simulation with 25 food spots of which each had 99% chance of being positive with 8 infective stages. Group 2 was 50 food spots with 4 infective stages per spot and Group 3 was 100 food spots and 2 infective stages.

Experimental
1
2
3
MEAN
4.1
4.0
3.9
3.8
3.7
3.6
RATIO2
5
4
3
1
PREVALENCE
100
90
80
70

Chapter Nine. Modelling Helminth Infections: Heterogeneity in Inherent Susceptibility and Acquired Susceptibility.

9.1. Introduction

This chapter presents the results of simulation models (based on the models described in Chapter Eight) in which model cockroaches, confined in an arena with infective stages, vary in factors which are components of their inherent susceptibility to infection or of their susceptibility to subsequent infection after first becoming infected. The effect of an increase in aggregation of infective stages on the over-dispersion of parasites within hosts has been demonstrated in experimental infections and simulation models have been constructed to which appear to mimic the experimental situation well (Chapter Eight). Other influences, besides the distribution of infective stages, which are likely to lead to an over-dispersed distribution of parasites within hosts (Crofton, 1971a) include the effect of both heterogeneity between host individuals in their susceptibility to infection and differences in susceptibility due to previous experience of infection. Anderson and Gordon (1982) considered this to be an example of heterogeneity in environmental factors, in which transmission depended not only on environmental factors involving climate but also host susceptibility and behaviour.

The purpose of the simulations described in this chapter is to determine the effect that differences in inherent and acquired host susceptibility have on the distribution of parasites within their hosts. Differences in inherent susceptibility might be expected to result from differences in the ability of parasites to infect a possible host once an encounter has taken place as has been shown in various systems where host genetics play a large part in the outcome of an encounter between host and parasite. Three examples of this effect are the studies involving different strains of mice and *Heligmosomoides polygyrus* (Behnke and Wahid, 1991; Enriquez, Zidian and Cypess, 1988; Keymer, Tarlton, Hiorns, Lawrence and Pritchard, 1990; Scott, 1988a), the studies on *Hymenolepis citelli* and *Peromyscus maniculatus* (Wassom, Guss and Grundmann, 1973; Wassom, DeWitt, and Grundmann, 1974; Wassom, Dick, Arnason, Strickland and Grundmann, 1986) and studies in humans, where heterogeneity has been shown in immunological responses to *A. lumbricoides* (Haswell-Elkins, Kennedy, Maizels, Elkins and Anderson, 1989). Differences in inherent host susceptibility in hosts may be linked to differences in behaviour which influence whether or not an individual comes into contact with an infective stage of a parasite. This has been suggested to be involved in some of the differences seen in different strains of mice, whose behaviours may differ (Tanguay and Scott, 1992).

Differences in inherent host behaviour has often been the explanation of differences between groups of people in their helminth prevalence and intensity; for example adult females having lower intensities and prevalence of hookworm infection than adult males (Chapter Four; Schad, Nawalinski and Kochar, 1983) and children having higher intensity and prevalence of *A. lumbricoides* and *T. trichiura* (Chapter Four; Crompton, 1989a; Bundy and Cooper, 1989). In a *Moniliformis moniliformis* and cockroach situation, where it has been shown that females are more likely to become infected with higher numbers of infective stages (Lackie, 1972a), this could be related to male cockroach preferring to rest on vertical surfaces, away from acanthors while females may be more likely rest on horizontal surfaces (Schal, Gautier and Bell, 1984).

The possibility that infection subsequently influences the susceptibility of a host has been explored from an immunological point of view. Among helminth infections in humans, this has been most highly studied in *Schistosoma* spp. infections, where the importance of both water contact and immunity to infection have been shown to be important in the commonly observed age-prevalence relationships that are found for these infections (Bundy and Blumenthal, 1990; Hagan, Blumenthal, Dunn, Simpson and Wilkins, 1991). In the *M. moniliformis*/ cockroach system, no decrease in numbers from an acquired immunological response by the cockroach after the helminths have localised in the haemocoel have been found. However it appears that most of the losses to the system occur at the time of hatching of the acanthor in the intestine of the roach and the penetration of the intestine (Lackie, 1972a). Damage to the intestine could either preclude more acanthors having successful penetration or cause damage which may aid the transfer. In previous studies, the proposed ceiling that may exist in some cockroaches was postulated to be associated with the former phenomenon (Lackie, 1972a).

9.2. Modifications to the Model

In the models constructed (Chapter Eight) there were two components to transmission which could be altered. The first was a combination of the number of steps a model cockroach took before it began to search for food spots combined with the amount of food that was picked up, once one had been encountered before the model roach moved again. The second of these was the probability of picking up a parasite while also picking up food from a spot. The first of these options is fairly

straightforward, assign certain cockroaches different behaviours either when they are being constructed by the programme or when they fulfil a certain criteria.

The second is not as straightforward as it might first appear. In the model, the possibility of a model cockroach at a parasite-positive food spot becoming infected is related to the amount of food left at the spot (number of parasites left at food spot/amount of food left at spot). When all cockroaches had equal chances of picking up parasites from a food spot (as in the models described in Chapter Eight, Figures 8.4 and 8.5), this was fairly straightforward. When one half of them had a higher chance of picking up infective stages problems arose, the first of which the food at positive food spots would run out before the parasites, resulting in an error due to dividing by a zero. Setting the amount of food at positive food spots to a constant at each run through the loop of the model and insuring that there was no chance of dividing by zero by using the absolute number of food spots in the denominator and adding one to this number managed to avoid this error. When this version of the model was run, the positive food spots were seen to remain for a longer time than the negative food spots, resulting in many model cockroaches 'feeding' at the positive food spots. Increasing the amount of food at those spots which did not have parasites compensated for the longer running time required to remove all parasites from the food spots and all of the cockroaches did not end up around the positive food spots. Both of these changes are illustrated in Figure 9.1.

In the following analysis, heterogeneity in inherent susceptibility was divided into differences in model cockroach behaviour, thought to vary the probability of picking up an infection, and differences in the possibility of a model cockroach being infected by parasites once a food spot containing infective stages is encountered. The second of these components of inherent susceptibility is referred to as differences in infect-ability in this thesis. The definition of infect-ability is the probability of a model cockroach becoming infected if it encounters a food spot positive for infective stages.

The influence of changes in acquired susceptibility was investigated by altering the susceptibility of model roaches once they had picked up parasites. Both their behaviour and probability of becoming infected were altered if the number of parasites within them was equal or greater than one (Figure 9.2). In addition to this, the effect of altering both the inherent susceptibility and acquired susceptibility was investigated by combining the two alterations. An outline of the

model simulations undertaken for each pattern of distribution of infective stages is presented in Table 9.1.

9.3. Validation of Modifications to the Model

The above change to the model, concerning the rate of parasite ingestion and amounts of food at food spots was first checked to determine if it differed significantly from that of the model designed to simulate a random placement of infective stages in the environment (see Chapter Eight) by completing simulations without changing the susceptibility or behaviour of the two halves of the fifty model cockroaches. Comparisons of the population parameters of mean density, variance, variance-to-mean ratio, sum of the total number of parasites at each simulation and prevalence of infected cockroaches (with Mann-Whitney U-tests) were used to test for differences between the two models. Different placements of infective stages (random, clumped and even) were investigated. The results of these are presented in Table 9.2, where none of the modified models were seen to differ significantly from those arrived at in Chapter Eight for modelling the experimental situations.

Table 9.2. Mann-Whitney U-tests between first model of random, clumped and even placement of food spots and second model with modifications.

Model	Parameters	z Value	p
Random	Mean Density	-0.4169	$p \leq 0.6768$
	Variance	-1.3607	$p \leq 0.1736$
	Variance-to-Mean	-1.3607	$p \leq 0.1736$
	Sum	-0.4169	$p \leq 0.6768$
	Prevalence	-1.2136	$p \leq 0.2249$
Clumped	Mean Density	-0.3839	$p \leq 0.7010$
	Variance	-1.0583	$p \leq 0.2899$
	Variance-to-Mean	-0.9827	$p \leq 0.3258$
	Sum	-0.3839	$p \leq 0.7010$
	Prevalence	-1.6302	$p \leq 0.1031$
Even	Mean Density	-0.1414	$p \leq 0.8875$
	Variance	-0.0756	$p \leq 0.9397$
	Variance-to-Mean	0.0000	$p \leq 1.0000$
	Sum	-0.1414	$p \leq 0.8875$
	Prevalence	-1.4102	$p \leq 0.1585$

As none of the modified models were seen to differ significantly from those used to model the experimental infections, they were used to compare the effect of changing either inherent susceptibility or acquired susceptibility.

9.4. Models of Random Pattern of Distributions of Infective stages: Inherent Susceptibility

9.4.1. Results of Heterogeneity in Inherent Susceptibility via Changed Behaviour

Changing the inherent behaviour of model cockroaches was achieved by dividing the model cockroaches into half when they were being constructed by the model (simulation two, Table 9.1). One half (Group A) was given hunger levels at which they began to 'feed' at a food spot (if encountered) which were half as large as those given the other half of the cockroaches (Group B). Group B were given hunger levels at which they left a food spot that they had been feeding on that were one fifth less than Group A. These manipulations of the model cockroaches resulted in Group A effectively spending twice as long at a food spot (if one was encountered) as Group B. The effect of this on the population parameters of the two groups was tested using a Mann-Whitney U-tests. The results of comparisons between the two groups are presented in Table 9.3. From these it can be seen that there were no significant differences found between the two groups of cockroaches in any of the population parameters.

Table 9.3. Results of Mann-Whitney U-tests for differences between Group A and B model cockroaches in a model of host heterogeneity in inherent susceptibility due to behavioural differences with random placement of infective stages.

Parameters	z Value	p
Mean Density	-1.7778	$p \leq 0.0754$
Variance	-1.6630	$p \leq 0.0963$
Variance-to-Mean	-0.0756	$p \leq 0.9397$
Sum	-1.7778	$p \leq 0.0754$
Prevalence	-0.2656	$p \leq 0.7906$

9.4.2. Results of Heterogeneity in Inherent Susceptibility via Differences in Infect-Ability

The effect of changing the inherent susceptibility of half the cockroaches via differences in infectivity was tested by again dividing the cockroaches into two halves (simulation three, Table 9.1). One half (Group A) was given a 20 times higher chance of becoming infected in each loop of the model in comparison to the other half (Group B), if they were at a food spot positive for infective stages. The effect of this difference in half of the cockroaches was tested by use of Mann-Whitney U-tests (Table 9.4). Significant differences were found in all five population parameters between these two groups and so this manner of changing susceptibility did have an effect on the rate of transmission.

Table 9.4. Results of Mann-Whitney U-tests for differences between Group A and B model cockroaches in a model of host heterogeneity in inherent susceptibility due to infect-ability differences with random placement of infective stages.

Parameters	z Value	p
Mean Density	-3.5164	$p \leq 0.0004$
Variance	-3.7041	$p \leq 0.0002$
Variance-to-Mean	-3.7796	$p \leq 0.0002$
Sum	-3.5164	$p \leq 0.0004$
Prevalence	-2.3567	$p \leq 0.0184$

Box plots of the effect of heterogeneity in infect-ability are presented in Figure 9.3, indicating that those cockroaches with higher levels of infect-ability had higher values for their mean density, variance, variance-to-mean ratio, total number of infective stages picked up in a run of the model and prevalence of infection.

9.4.3. Results of Heterogeneity in Inherent Susceptibility via Changed Behaviour and Infect-Ability

In this simulation (simulation four, Table 9.1), both means of changing inherent susceptibility were applied, with one half of the cockroaches (Group A) having both hunger levels at which they began to 'feed' at a food spot (if encountered) which were half as large as those given the other half of the cockroaches (Group B) and a 20 times higher chance of becoming infected in each loop of the model in comparison to Group B. Group B were given hunger levels at which they left a food spot that they had been feeding on that were one fifth less than Group A. The parameters of the two groups were compared using Mann-Whitney U-tests and a significant difference was found (Table 9.5). Box plots of the populations parameters for these two groups are presented in Figure 9.4., indicating that Group A had higher values of all the tested population parameters.

Table 9.5. Results of Mann-Whitney U-tests for differences between Group A and B model cockroaches in a model of host heterogeneity in inherent susceptibility due to behavioural and infect-ability differences with random placement of infective stages.

Parameters	z value	p
Mean Density	-3.1761	$p \leq 0.0015$
Variance	-3.6285	$p \leq 0.0003$
Variance-to-Mean	-3.7796	$p \leq 0.0002$
Sum	-3.1761	$p \leq 0.0015$
Prevalence	-2.8867	$p \leq 0.0039$

9.5. Models of Random Pattern of Distributions of Infective stages: Acquired Susceptibility

Two differences in acquired susceptibility were investigated. One in which parasite infection made a cockroach easier to infect (simulation five, Table 9.1) and one in which parasite infection made a cockroach harder to infect (simulation six, Table 9.1). Both the behaviour of the cockroaches and infect-ability, as described in the previous section on inherent susceptibility, were changed when a cockroach became infected. Differences in acquired susceptibility were then combined with heterogeneity in the 50 cockroaches in their inherent behaviour and infect-ability, either when the infected individuals were more likely to pick up another infective stages (simulation seven, Table 9.1) or less likely to (simulation eight, Table 9.1). The simulations where the cockroaches were divided into halves are considered first, in terms of differences between the two groups.

9.5.1. Infection Increases Susceptibility and Heterogeneity in Inherent Susceptibility

When heterogeneity in the model cockroaches (behaviour and infect-ability~)was combined with infected cockroaches being easier to infect, there were no significant differences found between the two groups of cockroaches using a Mann-Whitney U-test (Table 9.6) in their mean density, variance or total number of parasites in an arena. They were significantly different in their variance-to-mean ratio and prevalence of infection. Box plots of the variance-to-mean ratio values and prevalences are displayed in Figure 9.5, where it can be seen that the prevalence of infection was higher in the half of the cockroaches which were more easily infected and the variance-to-mean ratio was higher in the half of the cockroaches which were less easily infected.

Table 9.6. Results of Mann-Whitney U-tests for differences between Group A and B model cockroaches in a model of host heterogeneity in inherent susceptibility due to behavioural and infect-ability differences and with infected cockroaches being easier to infect, in a model with random placement of infective stages.

Parameters	Z Value	p
Mean Density	-1.4368	$p \leq 0.1508$
Variance	-1.4363	$p \leq 0.1509$
Variance-to-Mean	-2.8725	$p \leq 0.0041$
Sum	-1.4368	$p \leq 0.1508$
Prevalence	-3.3830	$p \leq 0.0007$

9.5.2. Infection Decreases Susceptibility and Heterogeneity in Inherent Susceptibility

In the model where infected cockroaches were more difficult to infect again and combined with heterogeneity in the inherent susceptibility of the cockroaches (simulation eight, Table 9.1), no

significant differences were found between the two halves of the cockroaches in their mean density, variance, total number of infective stages recovered from an arena and the variance-to-mean ratio (Table 9.7). The prevalence of the two halves was just significantly different, with Group A cockroaches (as defined in section 9.4.5) having the higher prevalence of infection (Figure 9.6).

Table 9.7. Results of Mann-Whitney U-tests for differences between Group A and B model cockroaches in a model of host heterogeneity in inherent susceptibility due to behavioural and infect-ability differences and with infected cockroaches being harder to infect, in a model with random placement of infective stages.

Parameters	Z Value	p
Mean Density	-1.2482	$p \leq 0.2119$
Variance	-0.6047	$p \leq 0.5453$
Variance-to-Mean	-2.7969	$p \leq 0.0052$
Sum	-1.2482	$p \leq 0.2119$
Prevalence	-2.8477	$p \leq 0.0044$

9.6. Models of Random Pattern of Distributions of Infective stages: Comparisons Between Different Simulations

The results for all of the model cockroaches in each of the eight simulations were compared with each other and to the results of the simulation where there were no differences in either inherent or acquired susceptibility (see Table 9.1). This was done in order to investigate the influence that differences in susceptibility had on the population parameters in these simulation models (Table 9.8).

Table 9.8. Results of Kruskal-Wallis analysis of the eight models with random placement of infective stages with heterogeneity in host inherent behaviour and infect-ability to infection and acquired differences in host behaviour and susceptibility.

Parameters	Chi-square	df	p
Mean Density	5.4909	7	$p \leq 0.6003$
Variance	49.3658	7	$p \leq 0.0000$
Variance-to-Mean	5.4909	7	$p \leq 0.0000$
Sum	31.8694	7	$p \leq 0.6003$
Prevalence	62.6948	7	$p \leq 0.0000$

It was shown that the mean density and the total number of parasites did not differ significantly in the eight different models. This would be expected as they are both controlled at the start of a simulation so that on average similar numbers of infective stages would have been added into the model arena. The results for the variance, variance-to-mean ratio and prevalence indicate significant differences among the eight different models. Analysis using multiple comparisons of the mean ranks was considered to determine where the significant differences lay. The results of these are presented in Table 9.9 to Table 9.11 and as box plots in Figure 9.7 to Figure 9.9. It can be seen

that two basic divisions are formed among the eight models, with some overlap, for the values of variance and variance-to-mean ratio (Table 9.9 and 9.10; Figures 9.7 and 9.8). One division comprises of simulations 6 and 8 (where the cockroaches were more difficult to infect again, once they had been infected) combined with simulations one and two (the simulation without any modifications to the susceptibility of the cockroaches and the simulations where only inherent behaviour was changed). The other division consists of simulations three, four, five and seven overlapping with simulations one and two in both divisions. In this division are cockroaches which were easier to infect once they had been infected (simulations six and eight) and those where there was a difference in the infect-ability of half of the cockroaches. In the data for the variance-to-mean ratios, the only group that significantly differs from the random simulation with no differences in susceptibility is that of simulation five (Table 9.10), where those that are infected become easier to be infected, giving rise to higher variance-to-mean ratios. These two divisions are found again in the prevalence data, although here they are reversed with simulations five and seven having the lowest ranking prevalence values and six and eight the highest, reflecting the larger number of infected cockroaches in those simulations which are seen to have less over-dispersion.

9.7. Models of A Clumped Pattern of Distributions of Infective stages: Inherent Susceptibility

A similar approach was carried out for the model with a clumped distribution of infective stages but with similar simulations of inherent and acquired susceptibility (Table 9.1). The effect of heterogeneity in inherent behaviour and infect-ability on the population parameters of the two groups of cockroaches was first tested in each simulation and then the eight different models were compared with one another in terms of the five population parameters studied for each replication of the model.

9.7.1. Results of Heterogeneity in Inherent Susceptibility via Changed Behaviour

First changes in inherent behaviour were applied to the model cockroaches in a manner similar to that for random distribution models (section 9.4.1 and simulation two, Table 9.1). Mann-Whitney U-tests were used to analyse differences which may have occurred between the two groups of cockroaches (Table 9.12). No significant differences were found.

Table 9.12. Results of Mann-Whitney U-tests for differences between Group A and B model cockroaches in a model of host heterogeneity in inherent susceptibility due to behavioural differences with clumped distributions of infective stages.

Parameters	z Value	p
Mean Density	-1.5130	$p \leq 0.1303$
Variance	-1.6630	$p \leq 0.0963$
Variance-to-Mean	-0.5292	$p \leq 0.5967$
Sum	-1.5130	$p \leq 0.1303$
Prevalence	-0.1517	$p \leq 0.8794$

9.7.2. Results of Heterogeneity in Inherent Susceptibility via Differences in Infect-Ability

Simulations (simulation three, Table 9.1), similar to those for random models in section 9.4.2, were completed where half of the cockroaches had higher probabilities of becoming infected with parasites. The differences in the population parameters for each half of the fifty model cockroaches was investigated using Mann-Whitney U-tests (Table 9.13).

Table 9.13. Results of Mann-Whitney U-tests for differences between Group A and B model cockroaches in a model of host heterogeneity in inherent susceptibility due to infect-ability differences with clumped distributions of infective stages.

Parameters	z Value	p
Mean Density	-3.4773	$p \leq 0.0005$
Variance	-3.7796	$p \leq 0.0002$
Variance-to-Mean	-3.7041	$p \leq 0.0002$
Sum	-3.4773	$p \leq 0.0005$
Prevalence	-1.6757	$p \leq 0.0938$

Significant differences were found between the mean density of parasites, the variance of the number of parasites in each roach, the variance-to-mean ratio and the total number of infective stages recovered in each group of cockroaches. The prevalence of infection did not differ significantly between the two groups of 25 cockroaches. Box plots of these results are presented in Figure 9.10, where it can be seen that Group A cockroaches had higher mean density, variance, variance-to-mean ratio and a larger amount of parasites recovered in total. These results indicate that the overall encounter of roaches with food spots which were positive was not significantly different in the two groups, but the outcome once the encounter had taken place depended on the infect-ability of the roach in question. The portion of the fifty cockroaches with high infect-ability had more parasites, but these were found in roughly the same number of cockroaches. This resulted in a few cockroaches being highly infected, leading to the differences seen in over-dispersion.

9.7.3. Results of Heterogeneity in Inherent Susceptibility via Changed Behaviour and Infect-Ability

The two procedures of simulating heterogeneity in host inherent susceptibility were then combined, resulting in alterations in both inherent behaviour and infectivity. This simulation (simulation four, Table 9.1) was similar to those completed in section 9.4.3 for models of random patterns of distribution of infective stages. Again the differences in population parameters between the two halves of cockroaches were tested using Mann-Whitney U-tests (Table 9.14). Here there were significant differences found in all five of the population parameters.

Table 9.14. Results of Mann-Whitney U-tests for differences between Group A and B model cockroaches in a model of host heterogeneity in inherent susceptibility due to behavioural and infect-ability differences with clumped distributions of infective stages.

Parameters	z Value	p
Mean Density	-3.1761	$p \leq 0.0015$
Variance	-3.4017	$p \leq 0.0007$
Variance-to-Mean	-3.4773	$p \leq 0.0005$
Sum	-3.1761	$p \leq 0.0015$
Prevalence	-2.4726	$p \leq 0.0134$

The box plots of these results are presented in Figure 9.11, where it can be seen that Group A cockroaches had higher values for all of the population parameters tested. In this case, the higher density, variance, variance-to-mean ratio and numbers of parasites in total was also combined with a higher prevalence. It appears that the addition of a change in behaviour to the infectivity difference enhances the possibility that Group A cockroaches will encounter a food spot positive for infective stages.

9.8. Models of Clumped Pattern of Distributions of Infective stages: Acquired Susceptibility

The differences in acquired susceptibility were investigated for models using clumped distributions of infective stages as well as those with a random distribution. The influence of changing the acquired susceptibility to make either infected cockroaches easier to infect (simulation five, Table 9.1) or harder to infect (simulation six, Table 9.1) was investigated in the comparisons of the eight different simulations in section 9. Differences in acquired susceptibility were then combined with heterogeneity in the 50 cockroaches in their inherent behaviour and infect-ability, either when the infected individuals were more likely to pick up another infective stages (simulation seven, Table 9.1) or less likely to (simulation eight, Table 9.1). The simulations where the cockroaches were divided into halves are considered first, in terms of differences between the two groups.

9.8.1. Infection Increases Susceptibility and Heterogeneity in Inherent Susceptibility

Heterogeneity in the model cockroaches (simulation seven, Table 9.1) was combined with infected cockroaches being easier to infect and the two groups of cockroaches were compared using Mann-Whitney U-tests (Table 9.15).

Table 9.15. Results of Mann-Whitney U-tests for differences between Group A and B model cockroaches in a model of host heterogeneity in inherent susceptibility due to behavioural and infect-ability differences and with infected cockroaches being easier to infect, with a clumped placement of infective stages.

Parameters	z Value	p
Mean Density	-3.1005	$p \leq 0.0019$
Variance	-1.2851	$p \leq 0.1988$
Variance-to-Mean	-1.6630	$p \leq 0.0963$
Sum	-3.1005	$p \leq 0.0019$
Prevalence	-3.6899	$p \leq 0.0002$

They were found to differ significantly in their mean densities, total number of parasites recovered in each portion of the fifty cockroaches and the prevalence of infection, where the half of the roaches with higher inherent infectivity had higher results for these parameters. Box plots of these results are presented in Figure 9.12 indicating that the amount of over-dispersion in the two sets of cockroaches did not differ significantly.

9.8.2. Infection Decreases Susceptibility and Heterogeneity in Inherent Susceptibility

In the model where heterogeneity in inherent susceptibility was combined with infected cockroaches being more difficult to infect (simulation eight, Table 9.1), no significant differences were found between the two sets of cockroaches in the five population parameters tested (Table 9.16). This seem to indicate that the effect of differences in inherent susceptibility on the distribution of infective stages in a host population may be overwhelmed by some kind of acquired decrease in susceptibility.

Table 9.16. Results of Mann-Whitney U-tests for differences between Group A and B model cockroaches in a model of host heterogeneity in inherent susceptibility due to behavioural and infect-ability differences and with infected cockroaches being harder to infect, with a clumped pattern of distribution of infective stages.

Parameters	z Value	p
Mean Density	-0.9075	$p \leq 0.3642$
Variance	-0.5292	$p \leq 0.5967$
Variance-to-Mean	-1.5875	$p \leq 0.1124$
Sum	-0.9075	$p \leq 0.3642$
Prevalence	-1.6094	$p \leq 0.1075$

9.9. Models of Clumped Pattern of Distributions of Infective stages: Comparisons Between Different Simulations

Differences between the eight different simulations (Table 9.1) in the population parameters from ten replication of each were investigated using Kruskal-Wallis non-parametric analysis of variance (Table 9.17). This indicated that here were no significant differences between the eight different simulations in their mean density or the total number of infective stages in each replication. This was not surprising, as approximately equal numbers of infective stages were used in each replication. This analysis did indicate that there were significant differences in the variances, prevalence and variance-to-mean ratio between the eight simulations. These were investigated by the use of multiple comparisons between the mean ranks which are reported in Table 9.18 for the variances, Table 9.19 for the variance-to-mean ratio, and Table 9.20 for the prevalence values. Box plots for these are presented in Figures 9.13 - 9.15.

Table 9.17. Results of Kruskal-Wallis analysis of the eight models with clumped placement of infective stages with heterogeneity in host inherent behaviour and infect-ability to infection and acquired differences in host behaviour and susceptibility.

Parameters	Chi-square	df	p
Mean Density	5.7123	7	$p \leq 0.5737$
Variance	44.6701	7	$p \leq 0.0000$
Variance-to-Mean	58.9152	7	$p \leq 0.0000$
Sum	5.7123	7	$p \leq 0.5737$
Prevalence	47.3174	7	$p \leq 0.0000$

The highest variances and the highest variance-to-mean ratios were found in simulations where the model cockroaches that became infected were easier to infect, where the cockroaches were split into two groups, with differences in behaviour and infectivity to infection and where these two factors were combined. The lowest variances and variance-to-mean ratios were found in those simulations where those that were infected became harder to infect and where this was combined with heterogeneity in the model cockroaches in their behaviour and infectivity. The prevalence values showed an opposite effect, with the simulations where the cockroaches who were infected became more difficult to infect.

9.10. Models of An Even Pattern of Distributions of Infective stages: Inherent Susceptibility

The importance of heterogeneity in the behaviour of cockroaches when the infective stages were distributed in an even manner was simulated. Differences between the two groups of cockroaches in their mean density, variance, variance-to-mean ratio, total number of infective stages

recovered in each group of roaches and prevalence of infection were tested using Mann-Whitney U-tests.

9.10.1. Results of Heterogeneity in Inherent Susceptibility via Changed Behaviour

The cockroaches were divided into two groups (simulation two, Table 9.1), ones with behaviour that had them stop at food spots sooner and stay there longer (Group A) and roaches that had behaviour where they were less likely to stop and feed (Group B). Significant differences were found in the mean density and the total number of infective stages found (Table 9.21). Results of this are displayed on box plots in Figure 9.16, indicating that Group B roaches had a higher mean density and more parasites were found in them. It appears that in a situation where infective stages are very common and evenly spaced in the environment, those hosts which are more active will pick up more infective stages, but the overall dispersion in this group of hosts will be equal to those who are less mobile.

Table 9.21. Results of Mann-Whitney U-tests for differences between Group A and B model cockroaches in a model of host heterogeneity in inherent susceptibility due to behavioural differences with even distribution of infective stages.

Parameters	z Value	p
Mean Density	-3.4812	$p \leq 0.0005$
Variance	-0.7559	$p \leq 0.4497$
Variance-to-Mean	-1.0583	$p \leq 0.2899$
Sum	-3.4812	$p \leq 0.0005$
Prevalence	-0.9932	$p \leq 0.3206$

9.10.2. Results of Heterogeneity in Inherent Susceptibility via Differences in Infect-Ability

When the cockroaches were given two levels of infect-ability (simulation three, Table 9.1), those with the higher infectivity (Group A) had higher values for their mean density, variance, variance-to-mean ratio, number of parasites recovered in each group and prevalence, using Mann-Whitney U-tests for analysis (Table 9.22). The box plots for this are displayed in Figure 9.17. The higher results indicate that in this situation infectivity relates directly to population parameters.

Table 9.22. Results of Mann-Whitney U-tests for differences between Group A and B model cockroaches in a model of host heterogeneity in inherent susceptibility due to infect-ability differences with even distributions of infective stages.

Parameters	z Value	p
Mean Density	-3.7882	$p \leq 0.0002$
Variance	-3.7796	$p \leq 0.0002$
Variance-to-Mean	-2.6458	$p \leq 0.0082$
Sum	-3.7882	$p \leq 0.0002$
Prevalence	-3.8098	$p \leq 0.0001$

9.10.3. Results of Heterogeneity in Inherent Susceptibility via Changed Behaviour and Infect-Ability

The combination of changes in inherent susceptibility via heterogeneity in behaviour and infectivity was then investigated (simulation four, Table 9.1). Again, Mann-Whitney U-tests were used to determine if the two groups of cockroaches differed significantly from one another. They were found to differ significantly in their mean density, variance, variance-to-mean ratio, the total number of parasites recovered from each group and the prevalence of infection (Table 9.23). The cockroaches which had higher infectivity (Group A) were found to be significantly higher in all of the parameters tested (Figure 9.18). This result indicates that changes in inherent infectivity overruled changes in inherent behaviour.

Table 9.23. Results of Mann-Whitney U-tests for differences between Group A and B model cockroaches in a model of host heterogeneity in inherent susceptibility due to behavioural and infect-ability differences with even distributions of infective stages.

Parameters	z Value	p
Mean Density	-3.7896	$p \leq 0.0002$
Variance	-3.7796	$p \leq 0.0002$
Variance-to-Mean	-3.0237	$p \leq 0.0025$
Sum	-3.7896	$p \leq 0.0002$
Prevalence	-3.7265	$p \leq 0.0002$

9.11. Models of Even Pattern of Distributions of Infective stages: Acquired Susceptibility

Differences in acquired susceptibility were also investigated. Simulations were used to investigate the population parameters resulting when cockroaches became infected of being either easier (simulation seven, Table 9.1) or harder (simulation eight, Table 9.1) to infect. These were then combined with cockroaches which were heterogeneous in their inherent behaviour and infect-ability (simulations seven and eight, Table 9.1). The differences between these cockroaches were investigated by use of Mann-Whitney U-tests to see if this had resulted in statistical differences between the two groups of inherently different cockroaches.

9.11.1. Infection Increases Susceptibility and Heterogeneity in Inherent Susceptibility

When combined with infected cockroaches becoming easier to infect, the two groups of cockroaches (simulation seven, Table 9.1) differed significantly in their mean density, total number of infections in each group and the prevalence of infection (Table 9.24). There were no statistical differences in their variance or variance-to-mean ratio. From Figure 9.19 it can be seen that the group with the higher inherent susceptibility and behaviour that had the roaches spend more time at a food spot had higher mean density, prevalence and total number of parasites, indicating that though there were differences in the number of parasites recovered from each groups the level of over-dispersion did not vary significantly.

Table 9.24. Results of Mann-Whitney U-tests for differences between Group A and B model cockroaches in a model of host heterogeneity in inherent susceptibility due to behavioural and infect-ability differences and with infected cockroaches being easier to infect, with an even placement of infective stages.

Parameters	z Value	p
Mean Density	-3.7796	$p \leq 0.0002$
Variance	-1.5119	$p \leq 0.1306$
Variance-to-Mean	-1.2851	$p \leq 0.1988$
Sum	-3.7796	$p \leq 0.0002$
Prevalence	-3.8026	$p \leq 0.0001$

9.11.2. Infection Decreases Susceptibility and Heterogeneity in Inherent Susceptibility

In the groups that had infected cockroaches being harder to infect, again the levels of dispersion were found not to differ (Table 9.25) and this is illustrated in Figure 9.20.

Table 9.25. Results of Mann-Whitney U-tests for differences between Group A and B model cockroaches in a model of host heterogeneity in inherent susceptibility due to behavioural and infect-ability differences and with infected cockroaches being harder to infect, with an even pattern of distribution of infective stages.

Parameters	z Value	p
Mean Density	-3.7237	$p \leq 0.0002$
Variance	-2.0410	$p \leq 0.0413$
Variance-to-Mean	-0.2268	$p \leq 0.8206$
Sum	-3.7237	$p \leq 0.0002$
Prevalence	-3.4520	$p \leq 0.0006$

9.12. Models of Even Pattern of Distributions of Infective stages: Comparisons Between Different Simulations

The differences between the eight simulation models for even distribution of infective stages within the arena were examined using a Kruskal-Wallis non-parametric analysis of variance (Table 9.26). This revealed significant differences between the variance, variance-to-mean ratio and

prevalence in the eight models. These were examined using multiple comparison tests to determine where the differences lay and the results of these are presented in Table 9.27 for differences in the variance, Table 9.28 for the variance-to-mean and Table 9.29 for the prevalence of infection. The box plots for this are displayed in Figure 9.21 - 9.23 and show again the highest variance and variance-to-mean ratio are in those groups where infected cockroaches are easier to infect again, both with and without heterogeneity in the inherent host susceptibility. The highest prevalence values, on the other hand are found in those models where the infected cockroaches were more difficult to infect.

Table 9.26. Results of Kruskal-Wallis analysis of the eight models with clumped placement of infective stages with heterogeneity in host inherent behaviour and infect-ability to infection and acquired differences in host behaviour and susceptibility

Parameters	Chi-square	df	p
Mean Density	8.5847	7	$p \leq 0.2839$
Variance	61.0716	7	$p \leq 0.0000$
Variance-to-Mean	60.6283	7	$p \leq 0.0000$
Sum	8.5847	7	$p \leq 0.2839$
Prevalence	66.1593	7	$p \leq 0.0000$

9.13. Discussion

The comparisons between the two groups of cockroaches in simulations two, three, four, seven and eight (Table 9.1) allowed the effect on the tested population parameters of heterogeneity in host inherent behaviour or infect-ability, singly, in combination and also in conjunction with post infection changes in behaviour or infect-ability. Simulations were carried out for different patterns of distribution of infective stages (random, clumped and even). The effect of heterogeneity in inherent behaviour of cockroaches (simulation two, Table 9.1) resulted in little significant difference in the population parameters tested, except for the replications where the infective stages were in an even distribution, with nearly all food spots being positive for infective stages. In this model, those roaches that stayed longer at a food spot (Group A) had higher mean densities and total numbers of parasites recovered than the other half of the cockroaches (Group B). The results suggests that host heterogeneity in inherent behaviour, as long as they inhabit the same environment, will not lead to difference in the population parameters tested. If they inhabit an area where infective stages distribution is fairly even and most areas are contaminated with them, however, this will not be the case.

Inherent differences in infect-ability resulted in cockroaches (simulation three, Table 9.1) with higher infect-ability having higher mean densities, variances, variance-to-mean ratios, prevalence and total numbers of parasites. This result held true in all the patterns of infective stage distribution, except for prevalence values in the simulations where the infective stages were arranged in a clumped distribution. Here, although those with higher infect-ability had a higher prevalence, it was not significantly so. Heterogeneity in combined infect-ability and inherent behaviour resulted in significant differences no matter what distribution the infective stages were arranged in, with Group A cockroaches having higher values for all of the parameters studied. This indicated that two groups within a population may vary in their distribution of parasites and the prevalence and density of parasites, regardless of the distribution of infective stages within the environment.

In the simulations with randomly distributed infective stages, the combination of differences in inherent behaviour and infect-ability with infected cockroaches being easier to infect (simulation seven, Table 9.1) resulted in significantly higher variance-to-mean ratio and prevalence in Group A cockroaches. This indicates a difference in the over-dispersion between these two groups. However, in both even and clumped distributions of infective stages, only differences in the mean density, total number of parasites recovered from each group and the prevalence of infection were significantly different, with no differences found in the over-dispersion in the two groups of model cockroaches.

In simulations where there was heterogeneity in the cockroaches inherent behaviour and infect-ability and those which became infected were more difficult to infect again (simulation eight, Table 9.1), the distribution of infective stages had much influence on the population parameters between the two groups of cockroaches. With an even distribution of infective stages, the mean, variance, total number of parasites recovered and the prevalence of infection for the two groups of cockroaches were all significantly different from one another. However, there was no significant difference in the variance-to-mean ratio, the distribution of parasites among the hosts. In randomly distributed infective stages this was not true, with significant differences in the variance-to-mean ratio and the prevalence of infection, indicating a difference in the distribution of parasites among the hosts but not in the mean density or variance. In the simulation with a clumped distribution of infective stages, there were no significant differences, indicating that in clumped distributions of infective

stages, differences in acquired susceptibility mimicking immunity concealed any effect due to heterogeneity in host inherent behaviour or infect-ability.

In the comparisons between the eight replications for each distribution of infective stages, significant differences were seen most frequently in the variances, variance-to-mean ratio and prevalence values between those groups where the infected cockroaches were more likely to be infected with another infective stage (simulation four, Table 9.1) and where infected cockroaches were less likely to be infected with another infective stage (simulation five, Table 9.1). The variances and variance-to-mean ratio were higher in those simulations where cockroaches once infected were easier to infect, leading to an increased over-dispersion of the parasites within the host population. The prevalence values were seen to be highest in those simulations where the cockroaches once infected were harder to infect, with infection spread throughout the population of cockroaches coinciding with a decrease in the over-dispersion of the parasites in the host population. Similar results were found in each of the three different distributions of infective stages, indicating that the general effect stayed the same regardless of the distribution of the infective stages.

There was little significant effect of heterogeneity in host inherent behaviour or infect-ability on variance, variance-to-mean ratio and prevalence. In combination with increase in susceptibility on infection, heterogeneity in inherent susceptibility appeared to have little effect on variance, variance-to-mean ratio or prevalence. A slight lowering of the variance and the variance-to-mean ratio was seen in the models of the clumped distribution of infective stages with a combination of host heterogeneity in inherent susceptibility and infection decreasing the susceptibility to infection. Perhaps this result is an indication that when infective stages are available in a clumped distribution, encounter dynamics and inherent susceptibility have more influence on the over-dispersion seen in the host population than do acquired differences in susceptibility, at least in the circumstance modelled here.

There is further work that would have added to this model and the experimental basis for it. This model only simulates the infection process, also of interest would be a determination of the death rate within a cockroach of acanthors once they had been ingested. This could have been accomplished by doing feeding experiments on cockroaches kept singly to determine the number of acanthors that would be likely to establish once they had become ingested. Investigations into the infectability of the

different sexes or of adult cockroaches of different ages would have answered questions regarding the extent of the heterogeneity in the cockroach population in terms of ease of infection. This could have been accomplished by separating out cockroaches who had just completed their final moult and infecting them at different time intervals post-moulting. Of course the difficulty of obtaining infective acanthors from adult female *M. moniliformis* at the appropriate age would have made this difficult. The behaviour of the cockroaches could have been observed in the experimental arenas to establish movement patterns and determine if the model approximations resembled the patterns observed in the experimental set-up. Specifically the amount of time spent searching for and consuming food would have been of interest. In reality the cockroaches may have been more effective at encountering food than were the model cockroaches. Also experiments to determine if food spots with acanthors are more attractive to cockroaches would be interesting.

The construction of a dynamic model of the life cycle of *M. moniliformis* in both of its hosts, *P. americana* and rats, would have allowed the investigation of the influence of intermediate host heterogeneity in transmission patterns in predicting the parasite population in the definitive host. The results of experiments (Monks and Nickol, 1989) simulating a natural encounter between rats and cockroaches could have been used to model this. It is known that there are changes in the intermediate host behaviour when infected with *M. moniliformis* (Moore, 1983) and this could have been included in a model where the cockroach behaviour could have been allowed to change again, resulting in increased chance of predation by the definitive host.

9.14. Summary

Models of Host Heterogeneity in Inherent Susceptibility

1. Model simulations were used to investigate the influence of heterogeneity in inherent susceptibility (in behaviour and infectivity) of model cockroaches in random, clumped and even distributions of infective stages n the population parameters of mean density, variance, variance-to-mean ratio, prevalence and the total number of parasites recovered.

a. Model cockroaches were divided into two groups and simulations were completed when they:

i. Had different inherent behaviour.

ii. Had different inherent infectivity.

iii. Had differences both in inherent behaviour and infectivity.

Models of Differences in Acquired Susceptibility

1. Model simulation were used to investigate the influence of acquired susceptibility, either infected cockroaches becoming harder or easier to infect, in random, clumped and even distributions of infective stages on the population parameters of mean density, variance, variance-to-mean ratio, prevalence and the total number of parasites recovered.

Models of a Combination of Differences in Acquired Susceptibility and Host Heterogeneity in Inherent Susceptibility

1. The combined effect of heterogeneity in inherent behaviour and differences in acquired susceptibility were then investigated using simulations as above.

The differences in the above population parameters between the two groups of cockroaches in those simulations where there were two groups with different behaviour and/or infectivity were investigated using Mann-Whitney U-tests.

1. Random Distribution.

i. Significant differences were found in simulations with different inherent infect-ability and different inherent combined behaviour and infect-ability in all population parameters.

ii. Where infected cockroaches were easier to infect, there were significant differences in the variance-to-mean ratio and the prevalence.

iii. Where infected cockroaches were harder to infect, there were significant differences in the variance-to-mean ratio and the prevalence.

iv. There were no significant differences between the two groups when just inherent behaviour differed between the two groups.

2. Clumped Distribution.

i. Significant differences were found in simulations with different inherent infect-ability in all but the prevalence of infection and in those simulations with different inherent combined behaviour and infect-ability in all population parameters.

ii. Where infected cockroaches were easier to infect, there were significant differences in the mean density, the total number of parasites recovered in each group of cockroaches and in the prevalence of infection.

iii. There were no significant differences between the two groups when just inherent behaviour differed between the two groups and when those that were infected were harder to infect.

3. Even Distribution.

i. Significant differences were found in simulation with different inherent behaviour in their mean density and the total number of parasites recovered in each group of cockroaches.

ii Significant differences were found in simulations with different inherent infect-ability and different inherent combined behaviour and infect-ability in all population parameters.

iii. Where infected cockroaches were easier to infect, there were significant differences in the mean density, the total number of parasites recovered in each group and in the prevalence of infection.

iv. Where infected cockroaches were harder to infect, there were significant differences in the mean density, the variance, the total number of parasites recovered in each group and in the prevalence of infection.

The differences in the population parameters between the eight different simulations (the one with no differences in either inherent or acquired susceptibility and the seven with various differences) were analysed using a Kruskal-Wallis non-parametric analysis of variance.

1. The largest variances and variance-to-mean ratios were seen in those simulations where infected cockroaches were easier to infect.

2. Those simulations where the infected cockroaches were harder to infect had the highest prevalence of infection.

3. Differences in acquired susceptibility were seen to have a larger effect on the tested population parameters than heterogeneity in inherent susceptibility

Table 9.1. Groups of cockroaches in the model simulations undertaken for each pattern of distribution of infective stages, indicating what were the differences in the model cockroaches.

Simulation Number	Effect Being Simulated	Divided in Half	Half of Cockroaches (Group A)	Half of Cockroaches (Group B)
One	No differences in behaviour or susceptibility	No	Not Applicable	
Two	Difference in inherent behaviour	Yes	Begin to feed quickly and stay longer	Longer to feed and stay less time
Three	Difference in inherent susceptibility	Yes	Higher chance of becoming infected	Lower chance of becoming infected
Four	Difference in inherent behaviour and susceptibility	Yes	Begin to feed quickly and stay longer & higher chance of becoming infected	Longer to feed and stay less time & lower chance of becoming infected
Five	Once infected easier to infect	No	Not Applicable	
Six	Once infected harder to infect	No	Not Applicable	
Seven	Once infected easier to infect and differences in inherent behaviour and susceptibility	Yes	Begin to feed quickly and stay longer & higher chance of becoming infected	Longer to feed and stay less time & lower chance of becoming infected
Eight	Once infected harder to infect and differences in behaviour and susceptibility	Yes	Begin to feed quickly and stay longer & higher chance of becoming infected	Longer to feed and stay less time & lower chance of becoming infected

Table 9.9. Multiple comparisons between ranks for differences in the variance in the replications with random placements of infective stages.

	Replications							
Replications	Simulation 1*	Simulation 2	Simulation 3	Simulation 4	Simulation 5	Simulation 6	Simulation 7	Simulation 8
Simulation 1	-	1.2	12.7	6.8	27.1	25.6	21.1	25.7
Simulation 2		-	11.5	6.6	26.4	26.8	19.9	26.9
Simulation 3			-	5.9	14.4	38.3†	8.4	38.4†
Simulation 4				-	20.3	32.4†	14.3	32.5†
Simulation 5					-	52.7†	6.0	52.8†
Simulation 6						-	46.7†	0.1
Simulation 7							-	46.8†
Simulation 8								-

*Simulation 1: No differences in behaviour or infectivity; Simulation 2: Difference in behaviour; Simulation 3: Difference in infectivity; Simulation 4: Difference in behaviour and infectivity; Simulation 5: Once infected easier to infect; Simulation 6: Once infected harder to infect; Simulation 7: Once infected easier to infect and differences in behaviour and infectivity; Simulation 8: Once infected harder to infect and differences in behaviour and infectivity.

Differences in mean rank are significantly different at $p \leq 0.05$ if larger than 32.07.

Table 9.10. Multiple comparisons between ranks for differences in the variance-to-mean ratio in the replications with random placements of infective stages.

	Replications							
Replications	Simulation 1*	Simulation 2	Simulation 3	Simulation 4	Simulation 5	Simulation 6	Simulation 7	Simulation 8
Simulation 1	-	2.6	21.6	13.8	33.2†	25.0	31.2	20.6
Simulation 2		-	19.0	11.2	30.6	27.6	28.6	23.2
Simulation 3			-	7.8	11.6	46.6†	9.6	42.2†
Simulation 4				-	19.4	38.8†	17.4	34.4†
Simulation 5					-	58.2†	2.0	53.8†
Simulation 6						-	56.2†	4.4
Simulation 7							-	51.8†
Simulation 8								-

*Simulation 1: No differences in behaviour or infectivity; Simulation 2: Difference in behaviour; Simulation 3: Difference in infectivity; Simulation 4: Difference in behaviour and infectivity; Simulation 5: Once infected easier to infect; Simulation 6: Once infected harder to infect; Simulation 7: Once infected easier to infect and differences in behaviour and infectivity; Simulation 8: Once infected harder to infect and differences in behaviour and infectivity.

Differences in mean rank are significantly different at $p \leq 0.05$ if larger than 32.07.

Table 9.11. Multiple comparisons between ranks for differences in prevalence in the replications with random placements of infective stages.

	Replications							
Replications	Simulation 1*	Simulation 2	Simulation 3	Simulation 4	Simulation 5	Simulation 6	Simulation 7	Simulation 8
Simulation 1	-	1.4	17.15	13.35	16.8	24.75	17.9	11.85
Simulation 2		-	15.75	11.95	15.4	26.15	16.5	13.25
Simulation 3			-	3.8	0.35	41.9†	0.75	29.0
Simulation 4				-	3.45	38.1†	4.55	25.2
Simulation 5					-	41.55†	1.1	28.65
Simulation 6						-	42.65†	12.9
Simulation 7							-	29.75
Simulation 8								-

*Simulation 1: No differences in behaviour or infectivity; Simulation 2: Difference in behaviour; Simulation 3: Difference in infectivity; Simulation 4: Difference in behaviour and infectivity; Simulation 5: Once infected easier to infect; Simulation 6: Once infected harder to infect; Simulation 7: Once infected easier to infect and differences in behaviour and infectivity; Simulation 8: Once infected harder to infect and differences in behaviour and infectivity.

Differences in mean rank are significantly different at $p \leq 0.05$ if larger than 32.07.

Table 9.18 Multiple comparisons between ranks for differences in the variance in the replications with clumped placements of infective stages.

	Replications							
Replications	Simulation 1*	Simulation 2	Simulation 3	Simulation 4	Simulation 5	Simulation 6	Simulation 7	Simulation 8
Simulation 1	-	3.20	8.55	14.30	31.45	18.30	14.55	26.15
Simulation 2		-	5.35	11.10	28.25	21.50	11.35	29.35
Simulation 3			-	5.75	22.90	26.85	6.00	34.70†
Simulation 4				-	17.15	32.60†	0.25	40.45†
Simulation 5					-	49.75†	16.90	57.60†
Simulation 6						-	32.85†	7.85
Simulation 7							-	40.70†
Simulation 8								-

*Simulation 1: No differences in behaviour or infectivity; Simulation 2: Difference in behaviour; Simulation 3: Difference in infectivity; Simulation 4: Difference in behaviour and infectivity; Simulation 5: Once infected easier to infect; Simulation 6: Once infected harder to infect; Simulation 7: Once infected easier to infect and differences in behaviour and infectivity; Simulation 8: Once infected harder to infect and differences in behaviour and infectivity.
Differences in mean rank are significantly different at $p \leq 0.05$ if larger than 32.07.

Table 9.19. Multiple comparisons between ranks for differences in the variance-to-mean ratio in the replications with clumped placements of infective stages.

	Replications							
Replications	Simulation 1*	Simulation 2	Simulation 3	Simulation 4	Simulation 5	Simulation 6	Simulation 7	Simulation 8
Simulation 1	-	0.10	6.80	17.20	32.60†	27.60	15.50	28.40
Simulation 2		-	6.90	17.30	32.70†	27.50	15.60	28.30
Simulation 3			-	10.40	25.80	34.40†	8.70	35.20†
Simulation 4				-	15.40	44.80†	1.70	45.60†
Simulation 5					-	60.20†	17.10	61.00†
Simulation 6						-	43.10†	0.80
Simulation 7							-	43.90†
Simulation 8								-

*Simulation 1: No differences in behaviour or infectivity; Simulation 2: Difference in behaviour; Simulation 3: Difference in infectivity; Simulation 4: Difference in behaviour and infectivity; Simulation 5: Once infected easier to infect; Simulation 6: Once infected harder to infect; Simulation 7: Once infected easier to infect and differences in behaviour and infectivity; Simulation 8: Once infected harder to infect and differences in behaviour and infectivity Differences in mean rank are significantly different at $p \leq 0.05$ if larger than 32.07.

Table 9.20. Multiple comparisons between ranks for differences in prevalence in the replications with clumped placements of infective stages.

	Replications							
Replications	Simulation 1*	Simulation 2	Simulation 3	Simulation 4	Simulation 5	Simulation 6	Simulation 7	Simulation 8
Simulation 1	-	0.45	6.25	15.85	21.70	32.00	14.75	23.40
Simulation 2		-	5.80	15.40	21.25	32.45†	14.30	23.85
Simulation 3			-	9.60	15.45	38.25†	8.50	29.65
Simulation 4				-	5.85	47.85†	1.10	39.25†
Simulation 5					-	53.70†	6.95	45.10†
Simulation 6						-	46.75†	8.60
Simulation 7							-	38.15†
Simulation 8								-

*Simulation 1: No differences in behaviour or infectivity; Simulation 2: Difference in behaviour; Simulation 3: Difference in infectivity; Simulation 4: Difference in behaviour and infectivity; Simulation 5: Once infected easier to infect; Simulation 6: Once infected harder to infect; Simulation 7: Once infected easier to infect and differences in behaviour and infectivity; Simulation 8: Once infected harder to infect and differences in behaviour and infectivity.

Differences in mean rank are significantly different at $p \leq 0.05$ if larger than 32.07.

Table 9.27. Multiple comparisons between ranks for differences in the variance in the replications with even placements of infective stages.

	Replications							
Replications	Simulation 1*	Simulation 2	Simulation 3	Simulation 4	Simulation 5	Simulation 6	Simulation 7	Simulation 8
Simulation 1	-	6.10	19.80	17.00	34.10†	24.55	31.30	18.95
Simulation 2		-	13.70	10.90	28.00	30.65	25.20	25.05
Simulation 3			-	2.80	14.30	44.35†	11.50	38.75†
Simulation 4				-	17.10	41.55†	14.30	35.95†
Simulation 5					-	58.65†	2.80	53.05†
Simulation 6						-	55.85†	5.60
Simulation 7							-	50.25†
Simulation 8								-

*Simulation 1: No differences in behaviour or infectivity; Simulation 2: Difference in behaviour; Simulation 3: Difference in infectivity; Simulation 4: Difference in behaviour and infectivity; Simulation 5: Once infected easier to infect; Simulation 6: Once infected harder to infect; Simulation 7: Once infected easier to infect and differences in behaviour and infectivity; Simulation 8: Once infected harder to infect and differences in behaviour and infectivity.

Differences in mean rank are significantly different at $p \leq 0.05$ if larger than 32.07.

Table 9.28. Multiple comparisons between ranks for differences in the variance-to-mean ratio in the replications with even placements of infective stages.

	Replications							
Replications	Simulation 1*	Simulation 2	Simulation 3	Simulation 4	Simulation 5	Simulation 6	Simulation 7	Simulation 8
Simulation 1	-	6.70	19.80	16.90	33.40†	24.85	31.10	19.05
Simulation 2		-	13.10	10.20	26.70	31.55	24.40	25.75
Simulation 3			-	2.90	13.60	44.65†	11.30	38.85†
Simulation 4				-	16.50	41.75†	14.20	35.95†
Simulation 5					-	58.25†	2.30	52.45†
Simulation 6						-	55.95†	5.80
Simulation 7							-	50.15†
Simulation 8								-

*Simulation 1: No differences in behaviour or infectivity; Simulation 2: Difference in behaviour; Simulation 3: Difference in infectivity; Simulation 4: Difference in behaviour and infectivity; Simulation 5: Once infected easier to infect; Simulation 6: Once infected harder to infect; Simulation 7: Once infected easier to infect and differences in behaviour and infectivity; Simulation 8: Once infected harder to infect and differences in behaviour and infectivity.

Differences in mean rank are significantly different at $p \leq 0.05$ if larger than 32.07.

Table 9.29. Multiple comparisons between ranks for differences in prevalence in the replications with even placements of infective stages.

	Replications							
Replications	Simulation 1*	Simulation 2	Simulation 3	Simulation 4	Simulation 5	Simulation 6	Simulation 7	Simulation 8
Simulation 1	-	3.10	5.00	2.20	33.45†	33.60†	26.40	24.15
Simulation 2		-	1.90	5.30	30.35	36.70†	23.30	27.25
Simulation 3			-	7.20	28.45	38.60†	21.40	29.15
Simulation 4				-	35.65†	31.40	28.60	21.95
Simulation 5					-	67.05†	7.05	57.60†
Simulation 6						-	60.00†	9.45
Simulation 7							-	50.55†
Simulation 8								-

*Simulation 1: No differences in behaviour or infectivity; Simulation 2: Difference in behaviour; Simulation 3: Difference in infectivity; Simulation 4: Difference in behaviour and infectivity; Simulation 5: Once infected easier to infect; Simulation 6: Once infected harder to infect; Simulation 7: Once infected easier to infect and differences in behaviour and infectivity; Simulation 8: Once infected harder to infect and differences in behaviour and infectivity.

Differences in mean rank are significantly different at $p \leq 0.05$ if larger than 32.07.

Figure 9.1. Diagram of the model showing the modifications necessary to allow for differences in behaviour and infect-ability between the cockroaches.

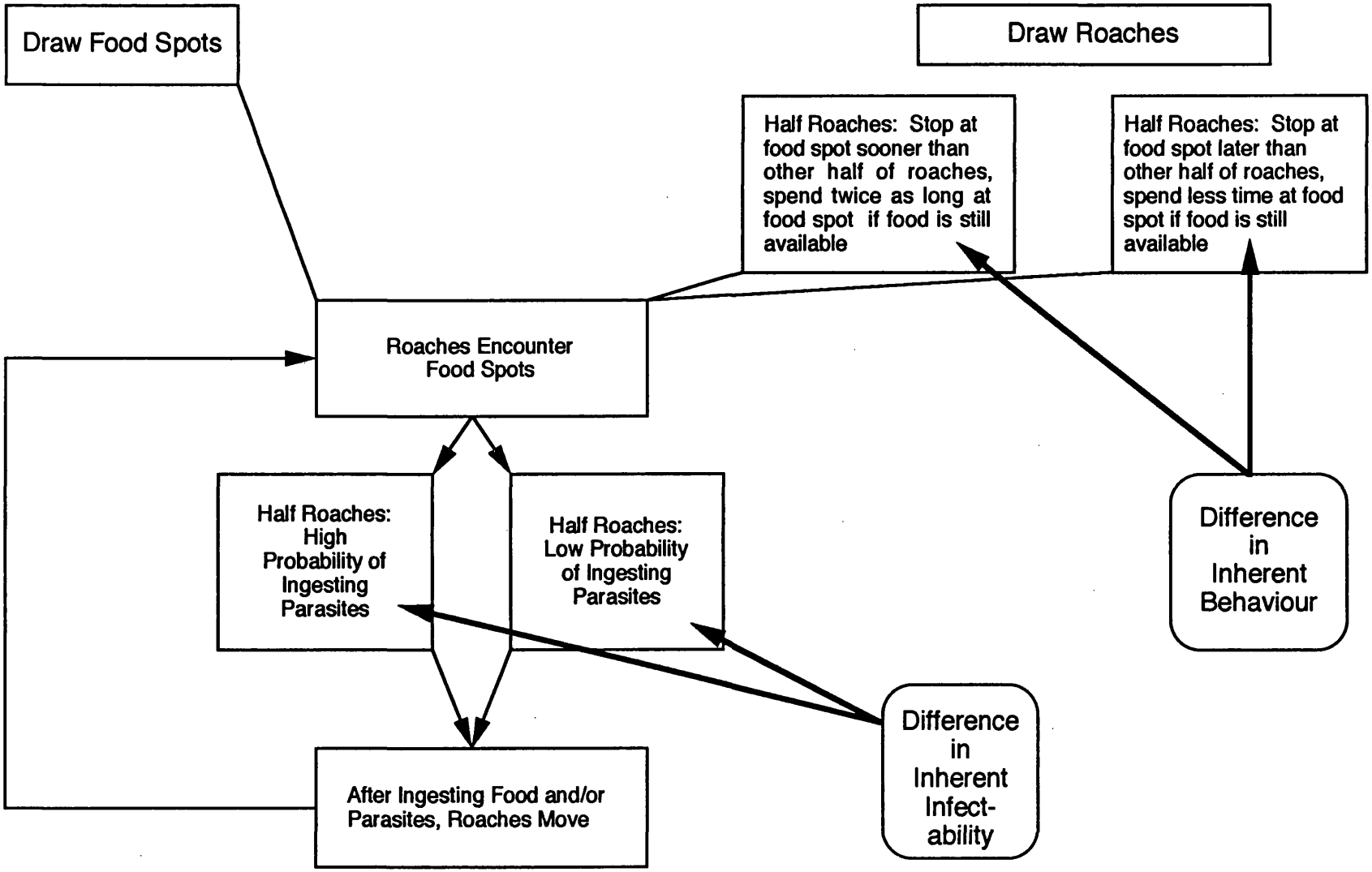

Draw Food Spots
Draw Roaches
Half Roaches: Stop at food spot sooner than other half of roaches, spend twice as long at food spot if food is still available
Half Roaches: Stop at food spot later than other half of roaches, spend less time at food spot if food is still available
Roaches Encounter Food Spots
Half Roaches: High Probability of Ingesting Parasites
Half Roaches: Low Probability of Ingesting Parasites
Difference in Inherent Behaviour
Difference in Inherent Infect-ability
After Ingesting Food and/or Parasites, Roaches Move

Figure 9.2. Diagram of the model indicating modifications which allowed for differences in acquired infectability and behaviour following infection.

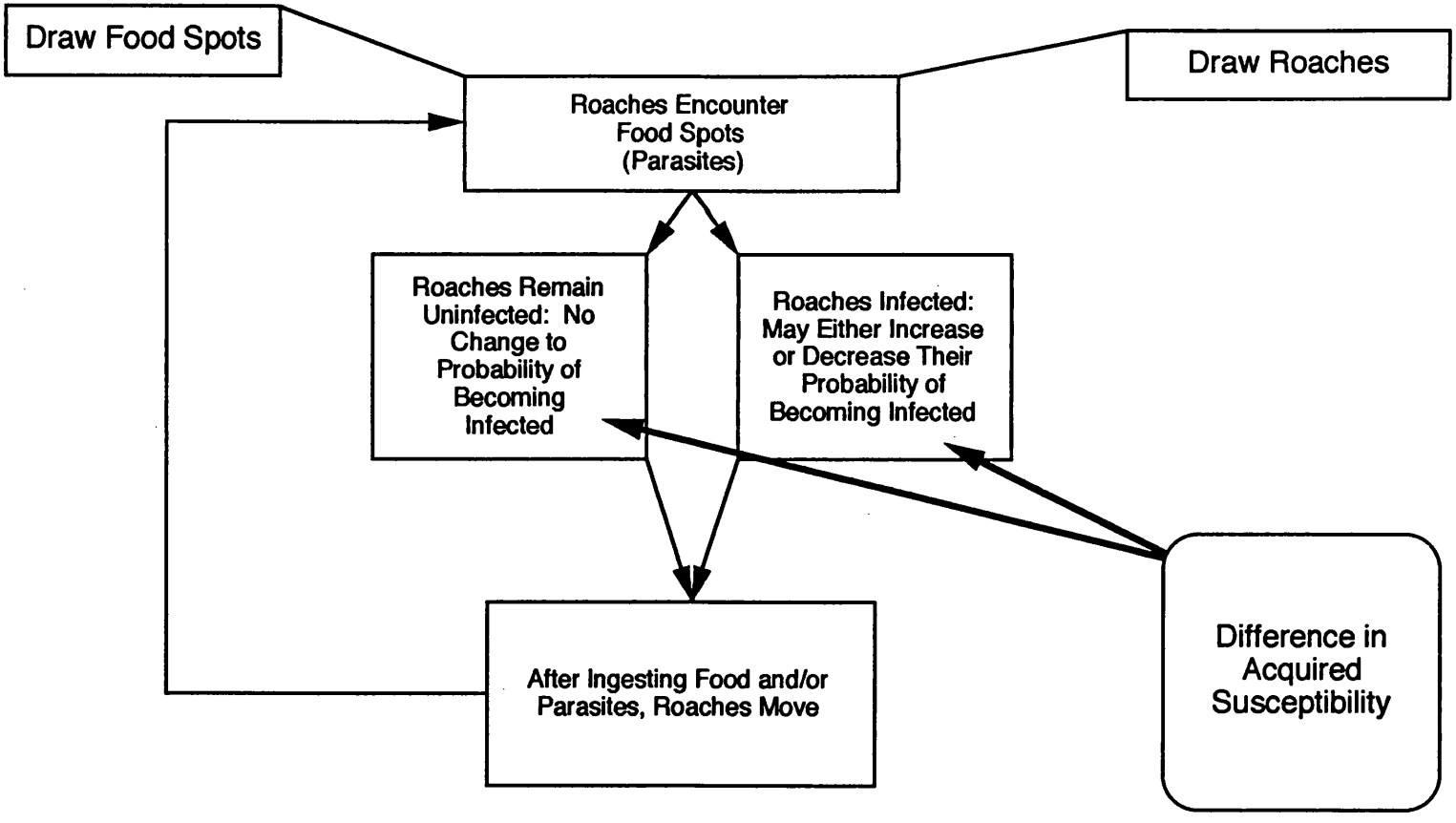
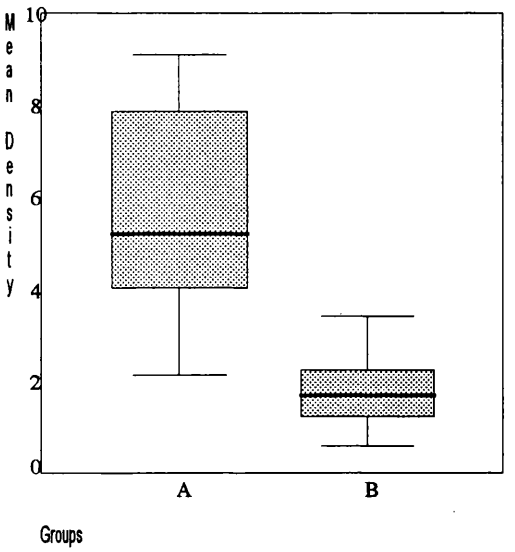
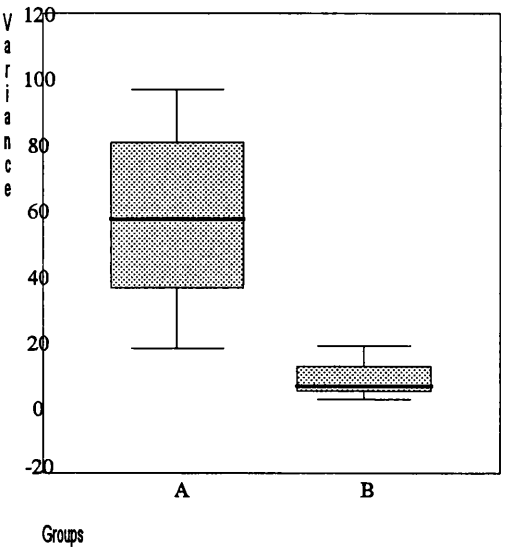
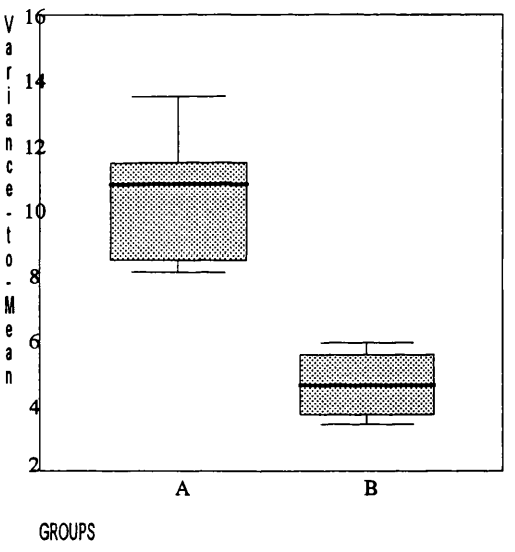
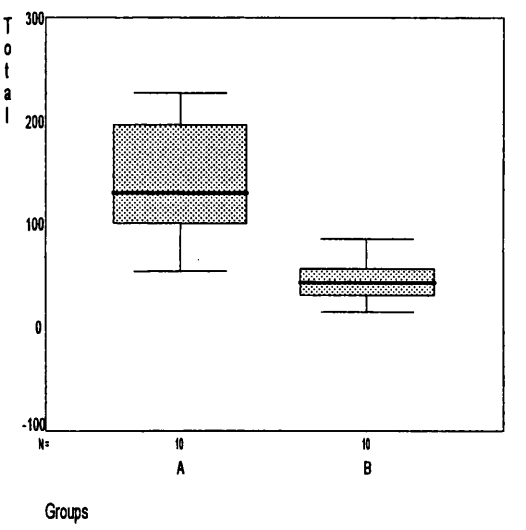

Draw Food Spots
Draw Roaches
Roaches Encounter Food Spots (Parasites)
Roaches Remain Uninfected: No Change to Probability of Becoming Infected
Roaches Infected: May Either Increase or Decrease Their Probability of Becoming Infected
After Ingesting Food and/or Parasites, Roaches Move
Difference in Acquired Susceptibility

Figure 9.3. Box plots of the results from simulations of a model having random distribution of infective stages and where cockroaches are divided into two groups, one of which (Group A) is highly likely to pick up an infective stages if a food spots positive for infective stages is encountered. The mean density, variance, variance-to-mean ratio, total number of parasites recovered from each group and the prevalence of infection are reported in that order.


Mean Density
10
8
6
4
2
0
A
B
Groups


Variance
120
100
80
60
40
20
0
-20
A
B
Groups


Variance-to-Mean
16
14
12
10
8
6
4
2
A
B
GROUPS


Total
300
200
100
0
-100
N=
10
10
A
B
Groups

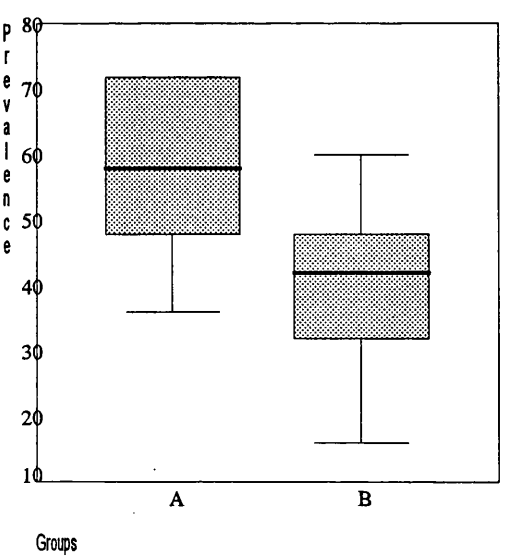
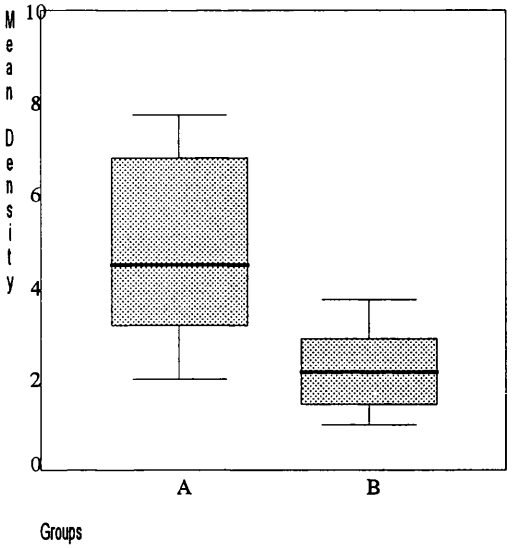
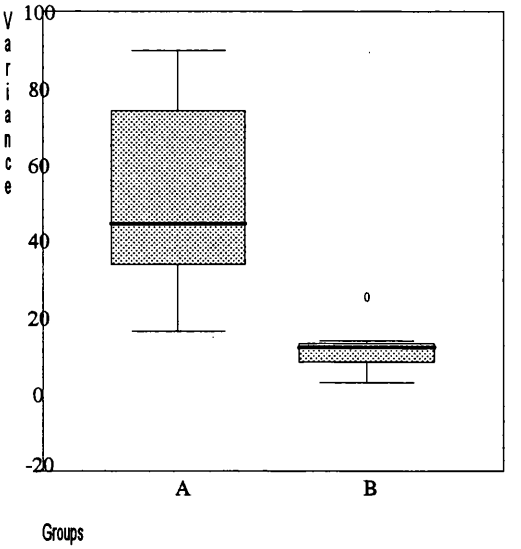
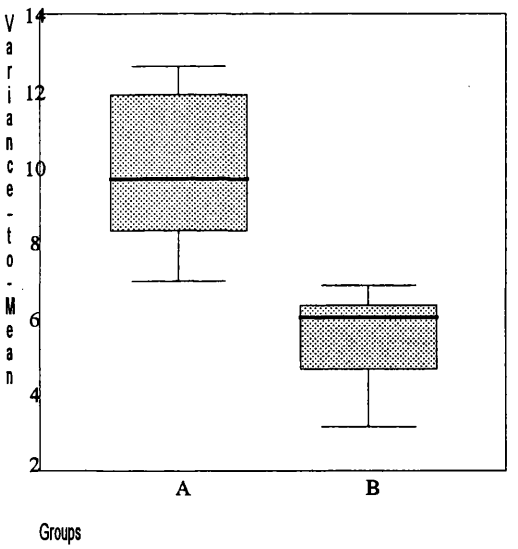
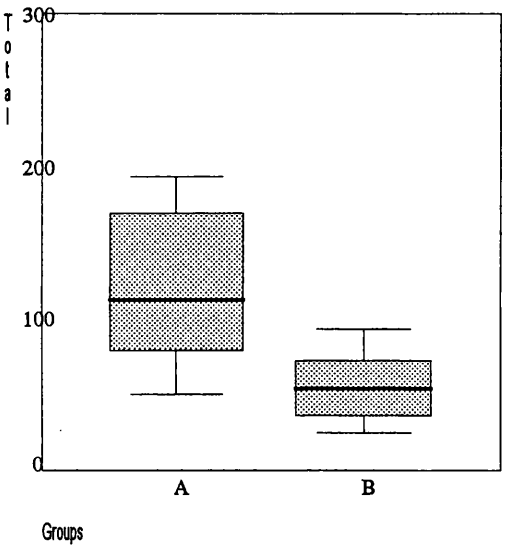

prevalence
80
70
60
50
40
30
20
10
A
B
Groups

Figure 9.4. Box plots of the results from simulations of a model having random distribution of infective stages and where cockroaches are divided into two groups, one of which (Group A) has behaviour that will cause it to stay at a food spot, once encountered, longer than those from the other group and the cockroaches in this group (Group A) are highly likely to pick up an infective stages if a food spots positive for infective stages is encountered. The mean density, variance, variance-to-mean ratio, total number of parasites recovered from each group and the prevalence of infection are reported in that order.


Mean Density
10
8
6
4
2
0
A
B
Groups


Variance
100
80
60
40
20
0
-20
A
B
Groups


Variance-to-Mean
14
12
10
8
6
4
2
A
B
Groups


Total
300
200
100
0
A
B
Groups

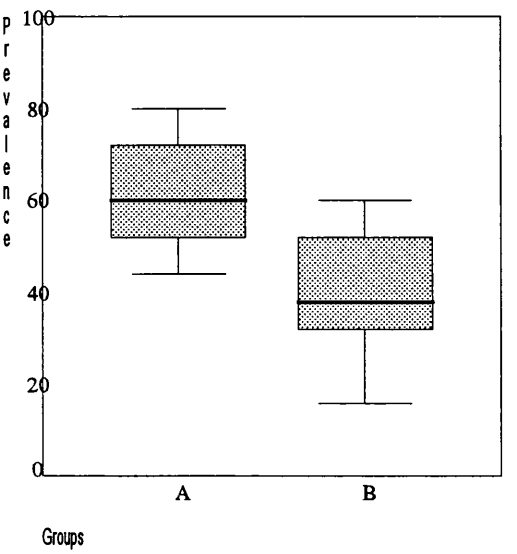
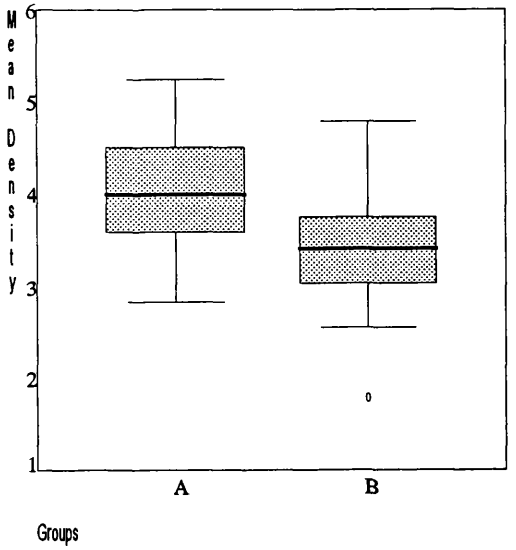
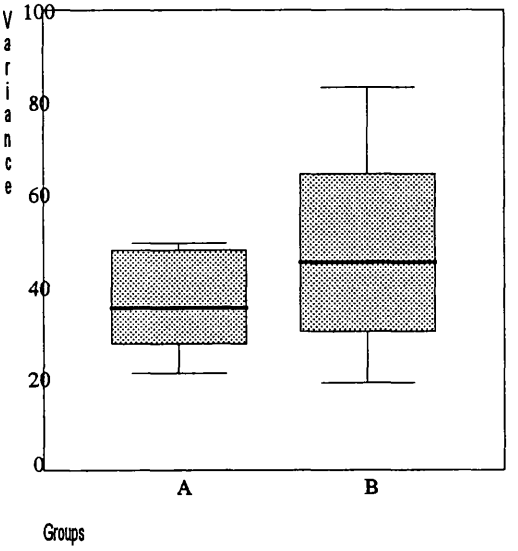
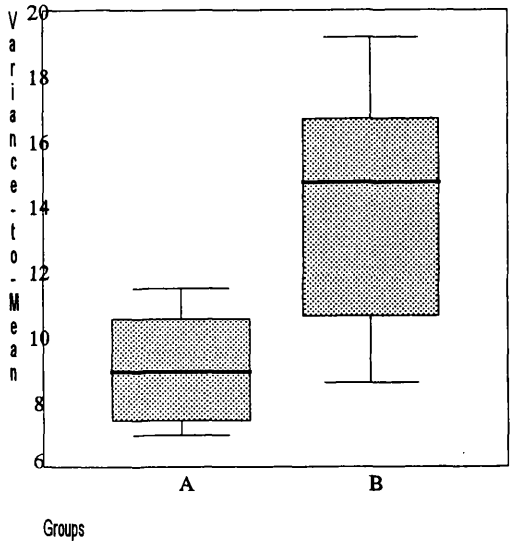
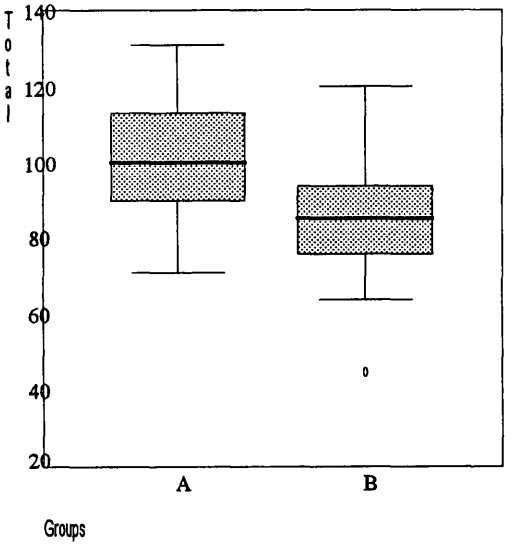

prevalence
100
80
60
40
20
0
A
B
Groups

Figure 9.5. Box plots of the results from simulations of a model having random distribution of infective stages and where cockroaches are divided into two groups, one of which (Group A) has behaviour that will cause it to stay at a food spot, once encountered, longer than those from the other group and the cockroaches in this group (Group A) are highly likely to pick up an infective stages if a food spots positive for infective stages is encountered. The effect of changes in acquired susceptibility, with infected cockroaches being easier to infect was also applied to these simulations. The mean density, variance, variance-to-mean ratio, total number of parasites recovered from each group and the prevalence of infection are reported in that order.


Mean Density
6
5
4
3
2
1
A
B
Groups


Variance
100
80
60
40
20
0
A
B
Groups


Variance-to-Mean
20
18
16
14
12
10
8
6
A
B
Groups


Total
140
120
100
80
60
40
20
A
B
Groups

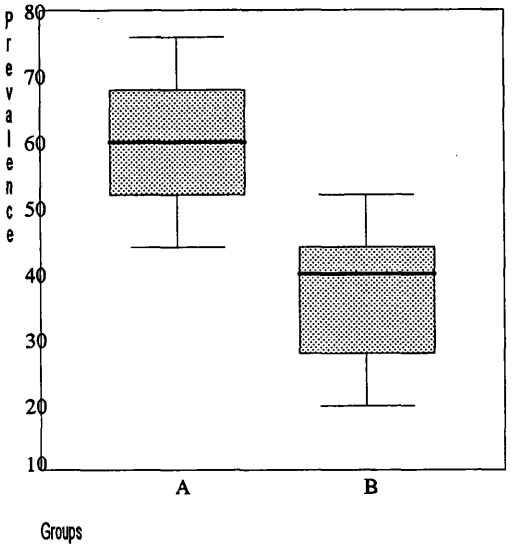
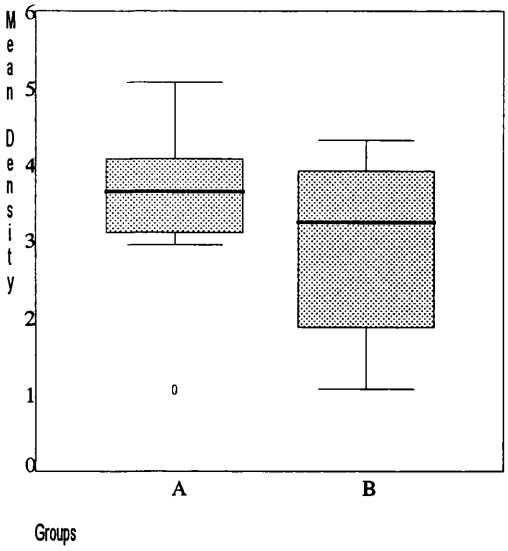
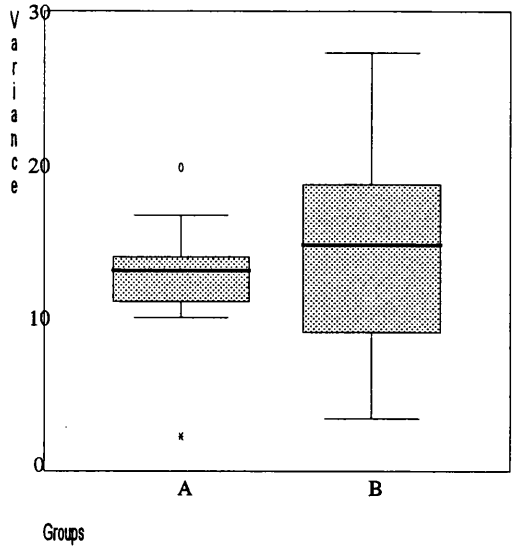
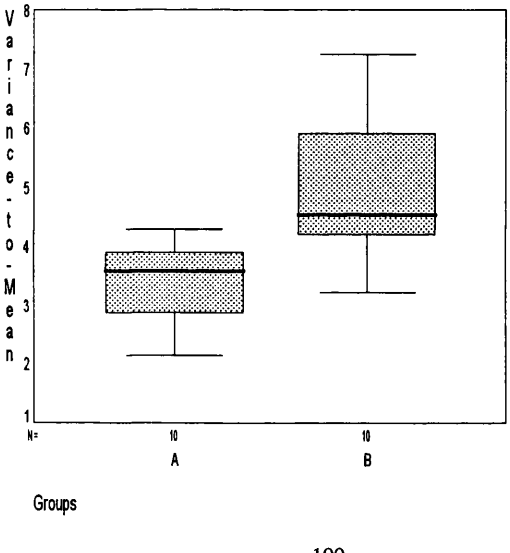
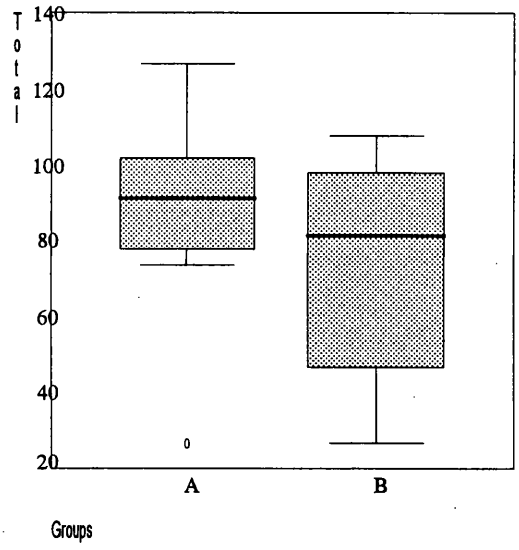

prevalence
80
70
60
50
40
30
20
10
A
B
Groups

Figure 9.6. Box plots of the results from simulations of a model having random distribution of infective stages and where cockroaches are divided into two groups, one of which (Group A) has behaviour that will cause it to stay at a food spot, once encountered, longer than those from the other group and the cockroaches in this group (Group A) are highly likely to pick up an infective stages if a food spots positive for infective stages is encountered. The effect of changes in acquired susceptibility, with infected cockroaches being harder to infect was also applied to these simulations. The mean density, variance, variance-to-mean ratio, total number of parasites recovered from each group and the prevalence of infection are reported in that order.


Mean Density
6
5
4
3
2
1
0
A
B
Groups


Variance
30
20
10
0
A
B
Groups


Variance-to-Mean
8
7
6
5
4
3
2
1
N=
10
10
A
B
Groups


Total
140
120
100
80
60
40
20
A
B
Groups

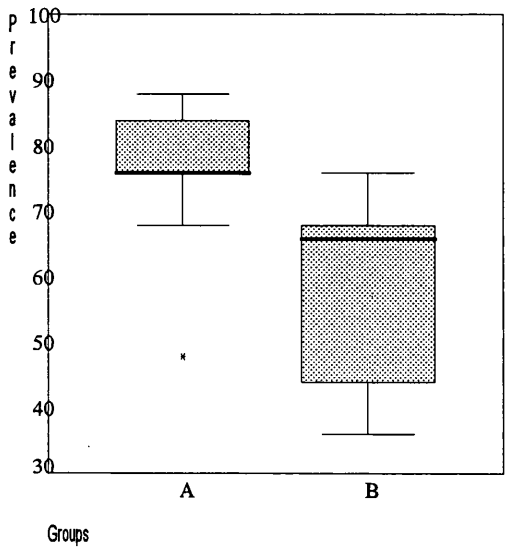

prevalence
100
90
80
70
60
50
40
30
A
B
Groups

Figure 9.7. Box plots of the results for all the cockroaches in the eight simulations of the models where infective stages were placed at random in the arena. These are the results for the variance of the populations.

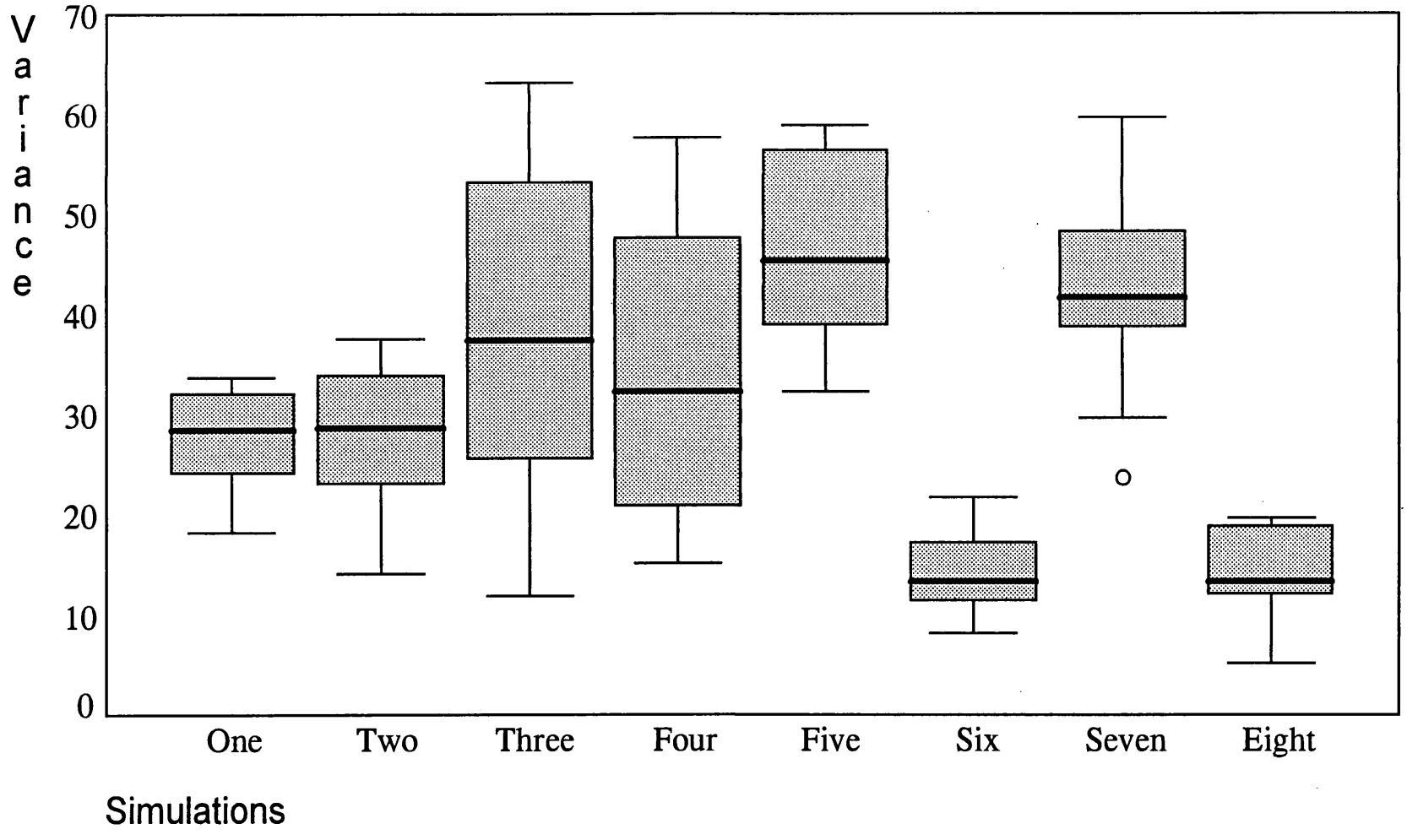

Variance
70
60
50
40
30
20
10
0
One
Two
Three
Four
Five
Six
Seven
Eight
Simulations

Figure 9.8. Box plots of the results for all the cockroaches in the eight simulations of the models where infective stages were placed at random in the arena. These are the results for the variance-to-mean ratios of the populations.

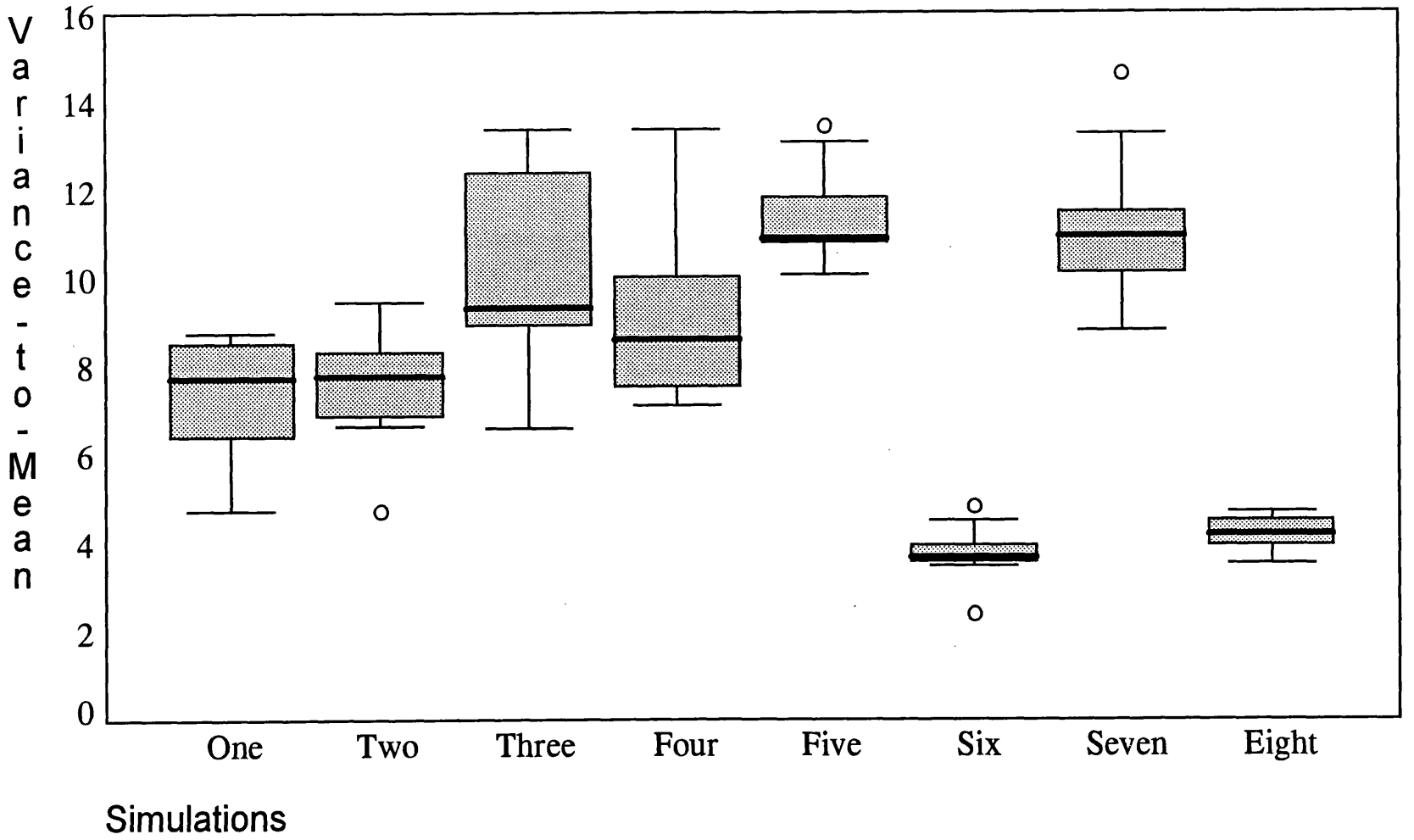

Variance-to-Mean
16
14
12
10
8
6
4
2
0
One
Two
Three
Four
Five
Six
Seven
Eight
Simulations

Figure 9.9. Box plots of the results for all the cockroaches in the eight simulations of the models where infective stages were placed at random in the arena. These are the results for the prevalence of infection of the populations.

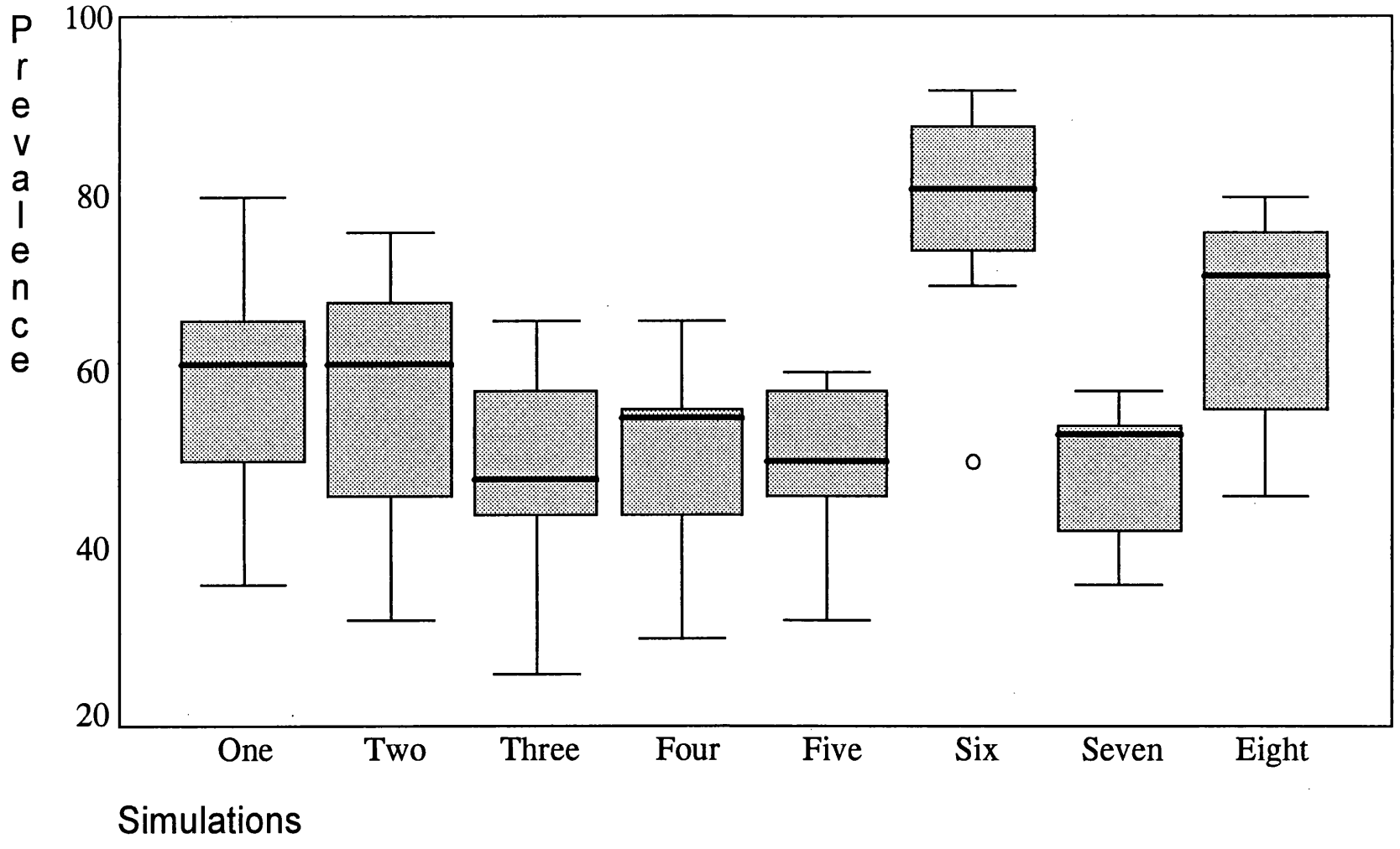
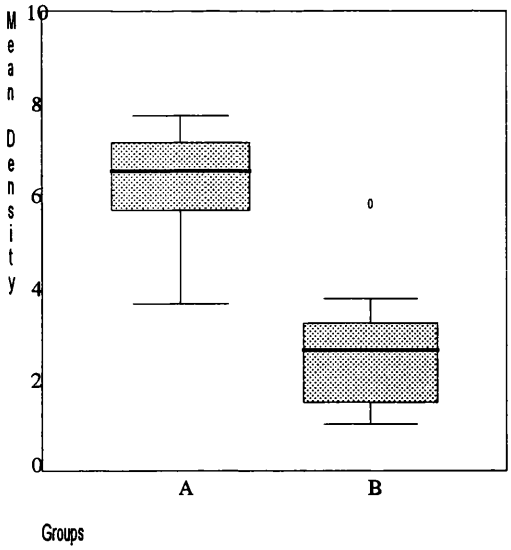
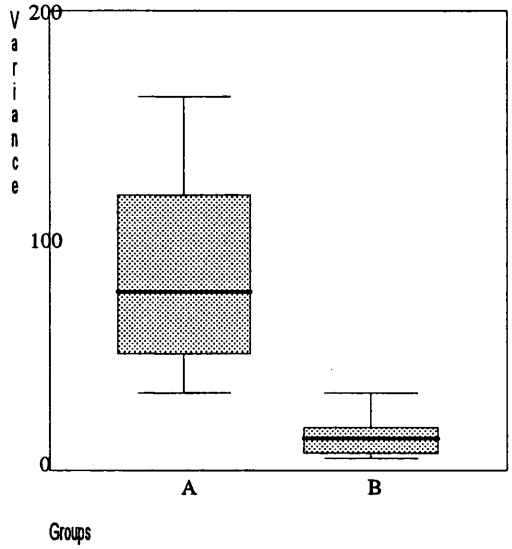
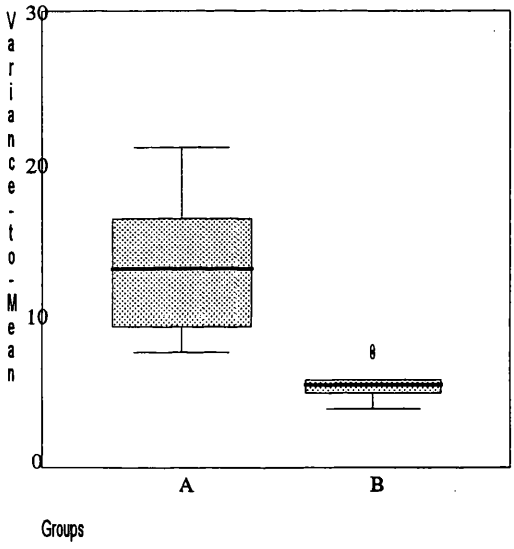
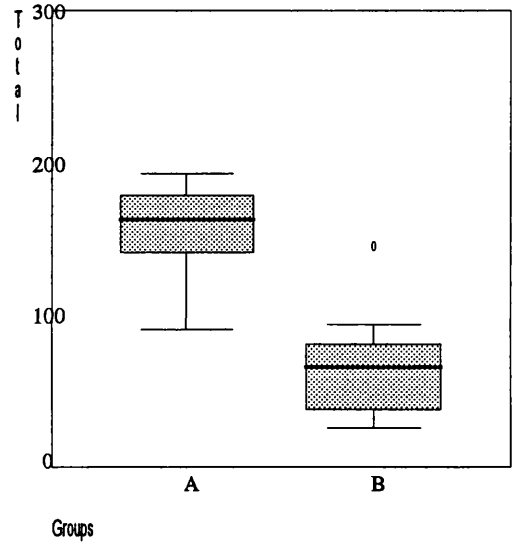

Prevalence
100
80
60
40
20
One
Two
Three
Four
Five
Six
Seven
Eight
Simulations

Figure 9.10. Box plots of the results from simulations of a model having clumped distribution of infective stages and where cockroaches are divided into two groups, one of which (Group A) is highly likely to pick up an infective stages if a food spots positive for infective stages is encountered. The mean density, variance, variance-to-mean ratio, total number of parasites recovered from each group and the prevalence of infection are reported in that order.


Mean Density
10
8
6
4
2
0
A
B
Groups


Variance
200
100
0
A
B
Groups


Variance-to-Mean
30
20
10
0
A
B
Groups


Total
300
200
100
0
A
B
Groups

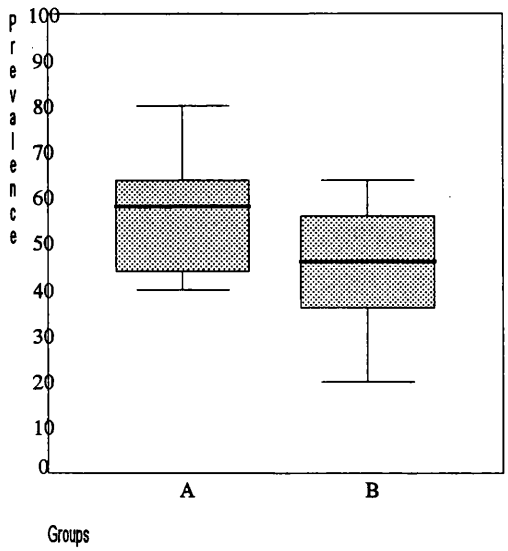
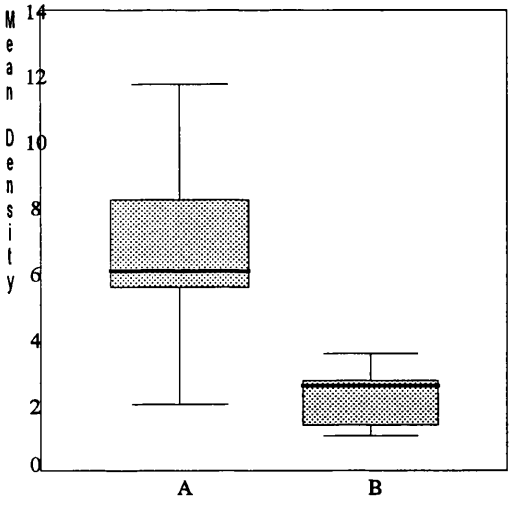
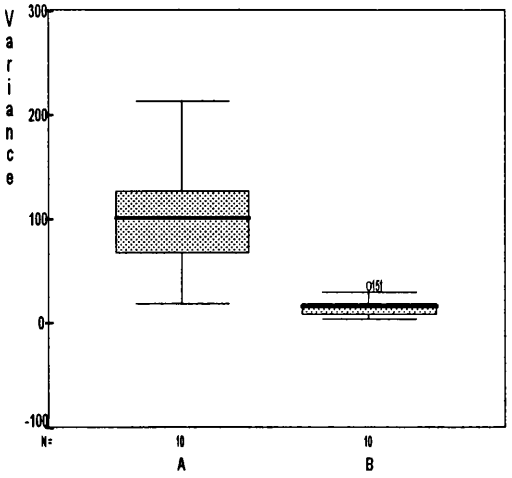
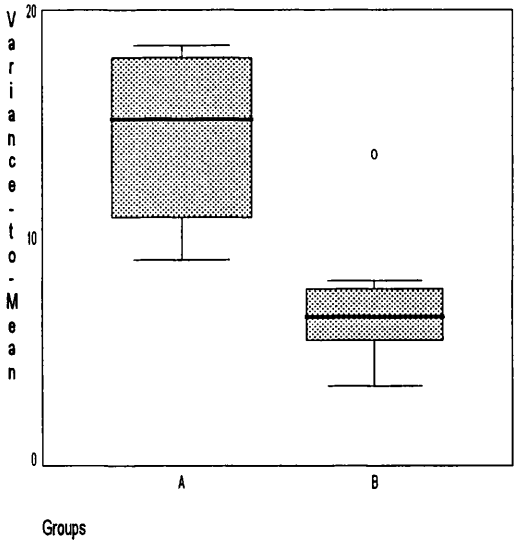
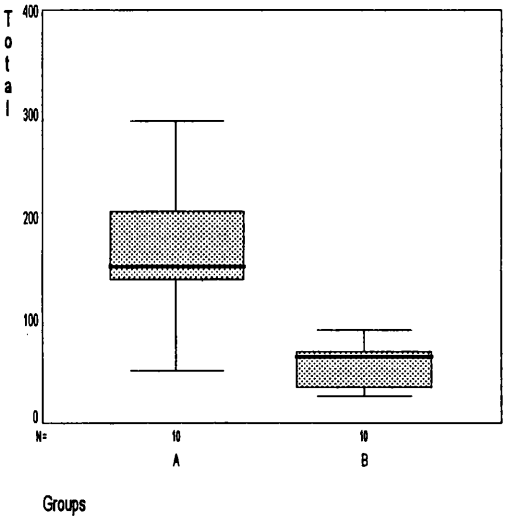

prevalence
100
90
80
70
60
50
40
30
20
10
0
A
B
Groups

Figure 9.11. Box plots of the results from simulations of a model having clumped distribution of infective stages and where cockroaches are divided into two groups, one of which (Group A) has behaviour that will cause it to stay at a food spot, once encountered, longer than those from the other group and the cockroaches in this group (Group A) are highly likely to pick up an infective stages if a food spots positive for infective stages is encountered. The mean density, variance, variance-to-mean ratio, total number of parasites recovered from each group and the prevalence of infection are reported in that order.


Mean Density
14
12
10
8
6
4
2
0
A
B
Groups


Variance
300
200
100
0
-100
N=
10
10
A
B
Groups


Variance-to-Mean
20
10
0
A
B
Groups


Total
400
300
200
100
0
N=
10
10
A
B
Groups

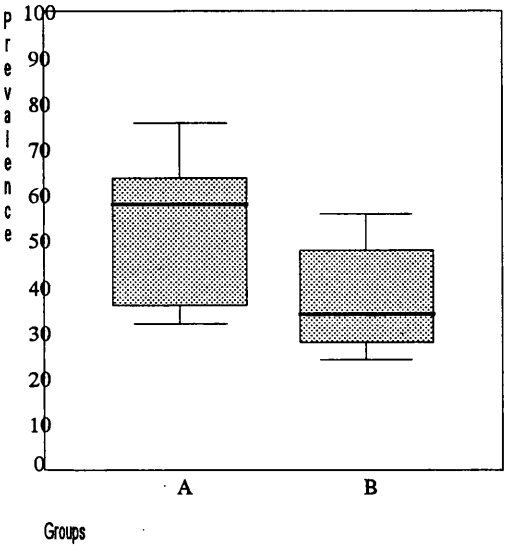
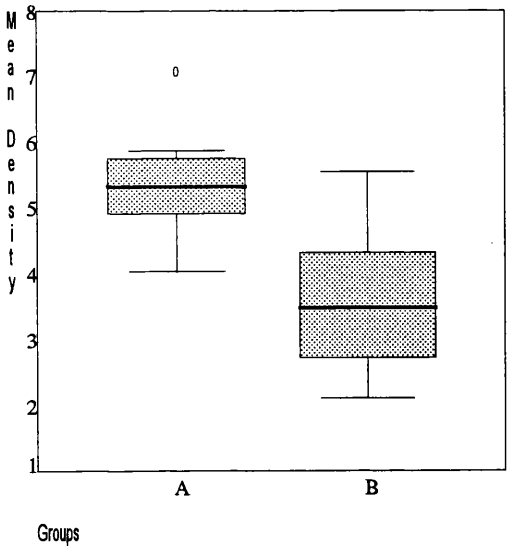
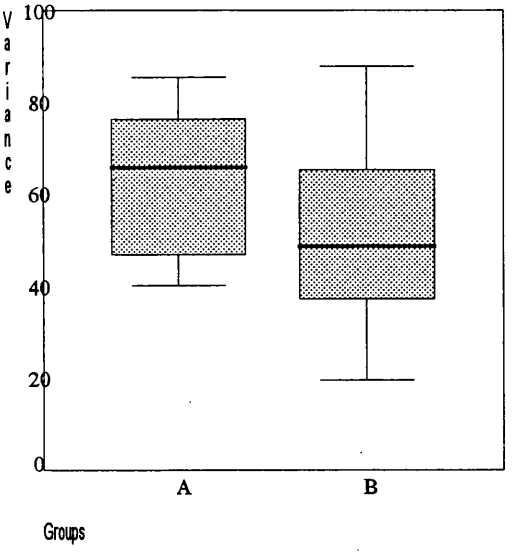
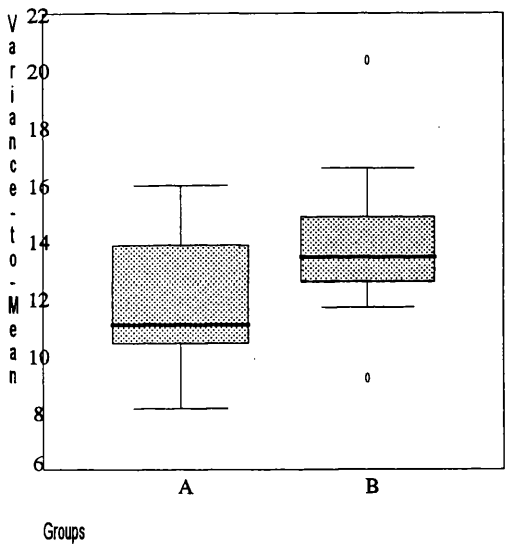
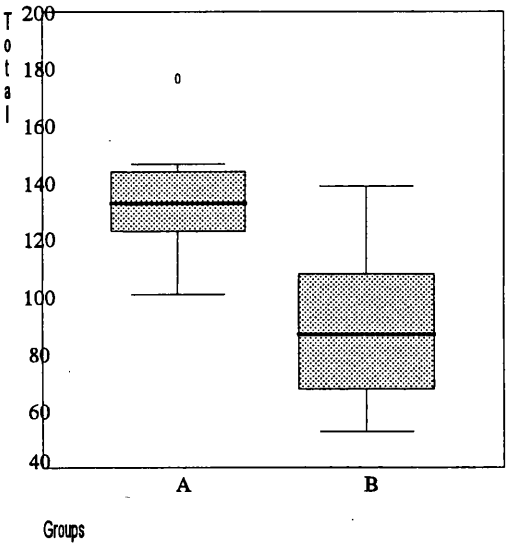

prevalence
100
90
80
70
60
50
40
30
20
10
0
A
B
Groups

Figure 9.12. Box plots of the results from simulations of a model having clumped distribution of infective stages and where cockroaches are divided into two groups, one of which (Group A) has behaviour that will cause it to stay at a food spot, once encountered, longer than those from the other group and the cockroaches in this group (Group A) are highly likely to pick up an infective stages if a food spots positive for infective stages is encountered. The effect of changes in acquired susceptibility, with infected cockroaches being easier to infect was also applied to these simulations. The mean density, variance, variance-to-mean ratio, total number of parasites recovered from each group and the prevalence of infection are reported in that order.


Mean Density
8
7
6
5
4
3
2
1
A
B
Groups


Variance
100
80
60
40
20
0
A
B
Groups


Variance-to-Mean
22
20
18
16
14
12
10
8
6
A
B
Groups


Total
200
180
160
140
120
100
80
60
40
A
B
Groups

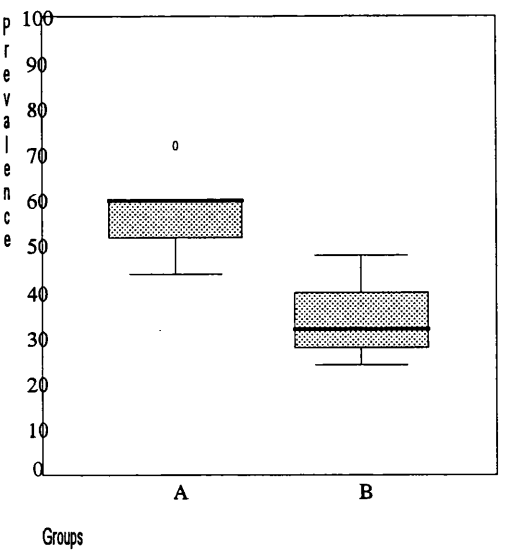

prevalence
100
90
80
70
60
50
40
30
20
10
0
A
B
Groups

Figure 9.13. Box plots of the results for all the cockroaches in the eight simulations of the models where infective stages were placed in a clumped distribution in the arena. These are the results for the variance of the populations.

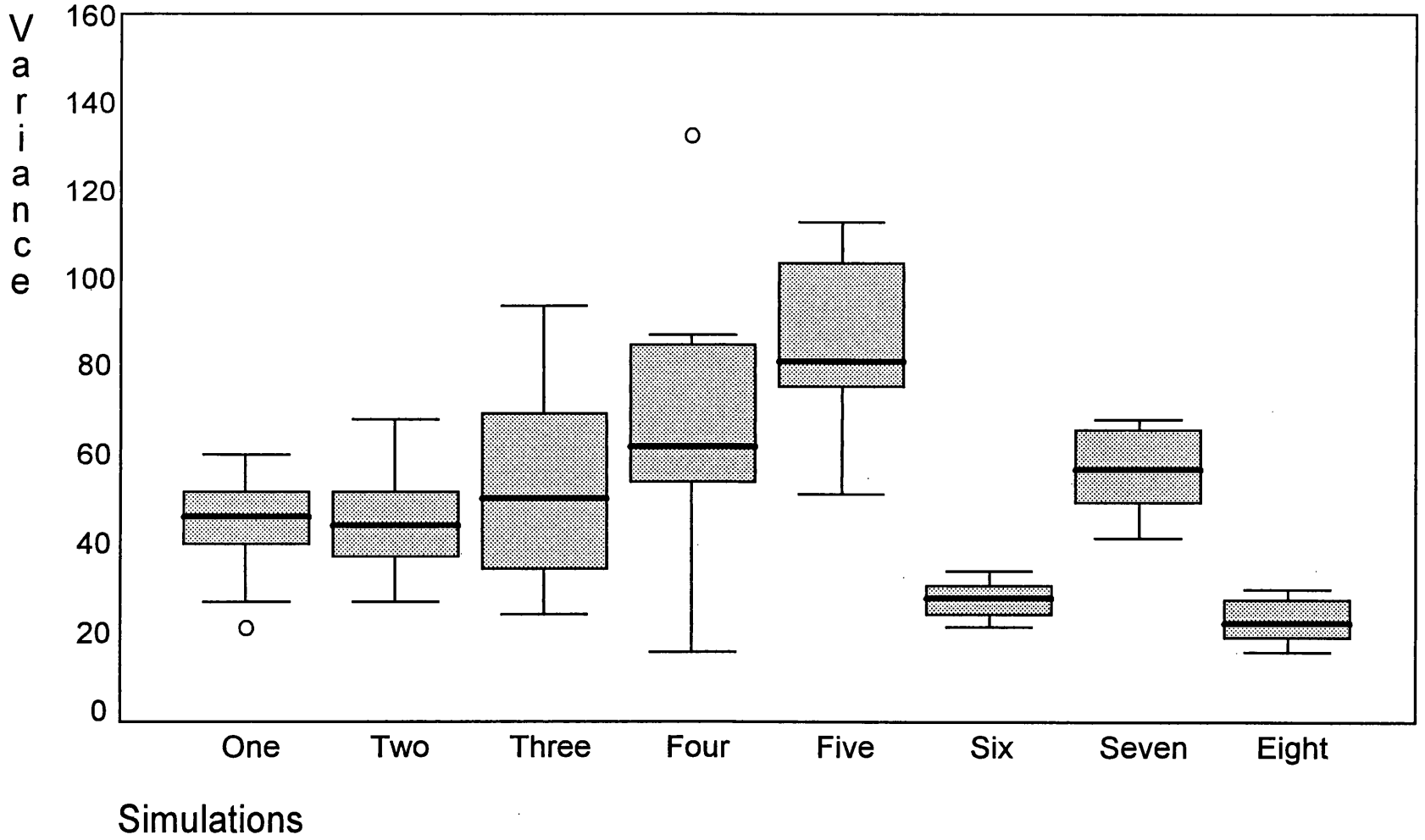

Variance
160
140
120
100
80
60
40
20
0
One
Two
Three
Four
Five
Six
Seven
Eight
Simulations

Figure 9.14. Box plots of the results for all the cockroaches in the eight simulations of the models where infective stages were placed in a clumped distribution in the arena. These are the results for the variance-to-mean ratios of the populations.

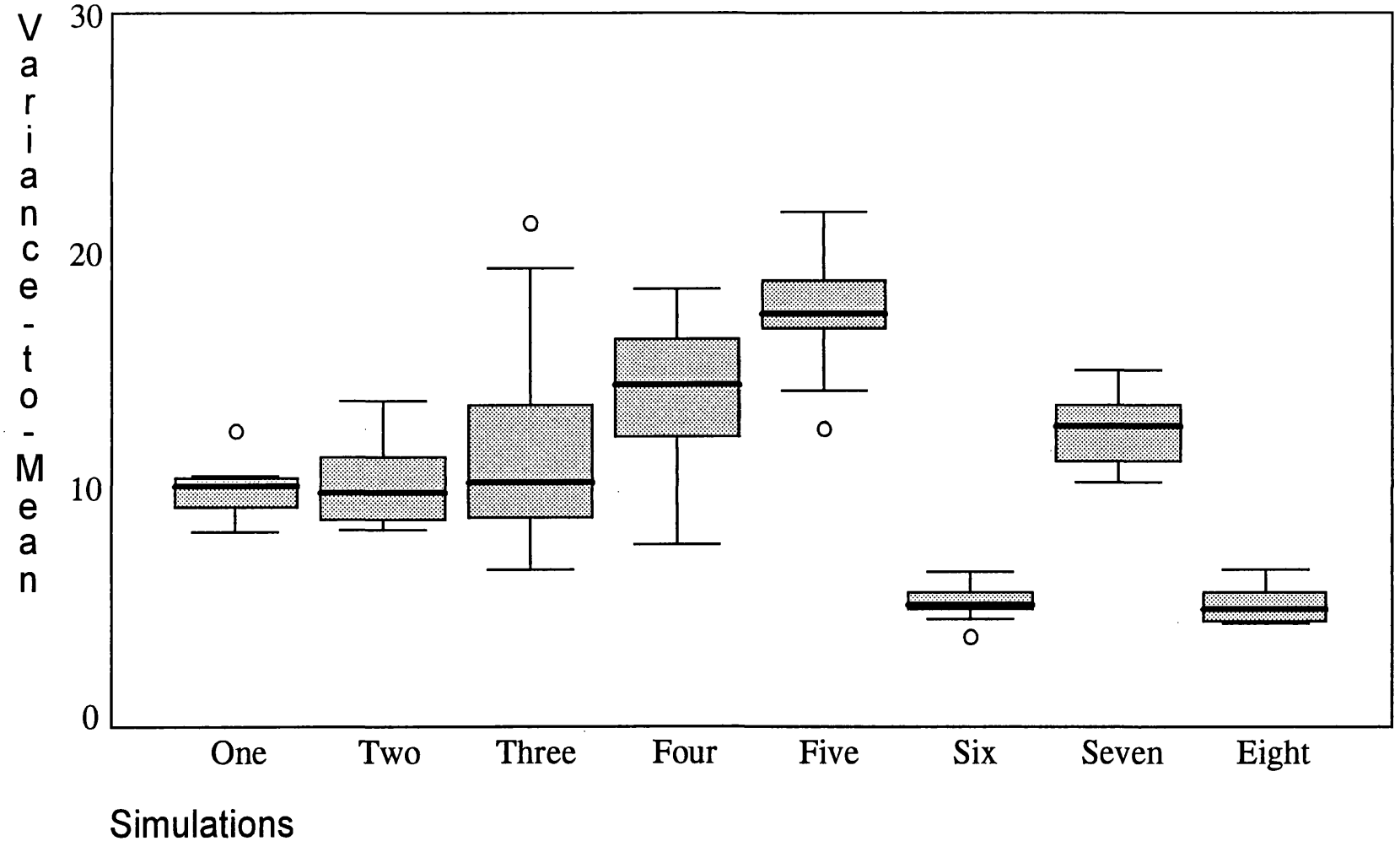

Variance-to-Mean
30
20
10
0
One
Two
Three
Four
Five
Six
Seven
Eight
Simulations

Figure 9.15. Box plots of the results for all the cockroaches in the eight simulations of the models where infective stages were placed in a clumped distribution in the arena. These are the results for the prevalence of infection of the populations.

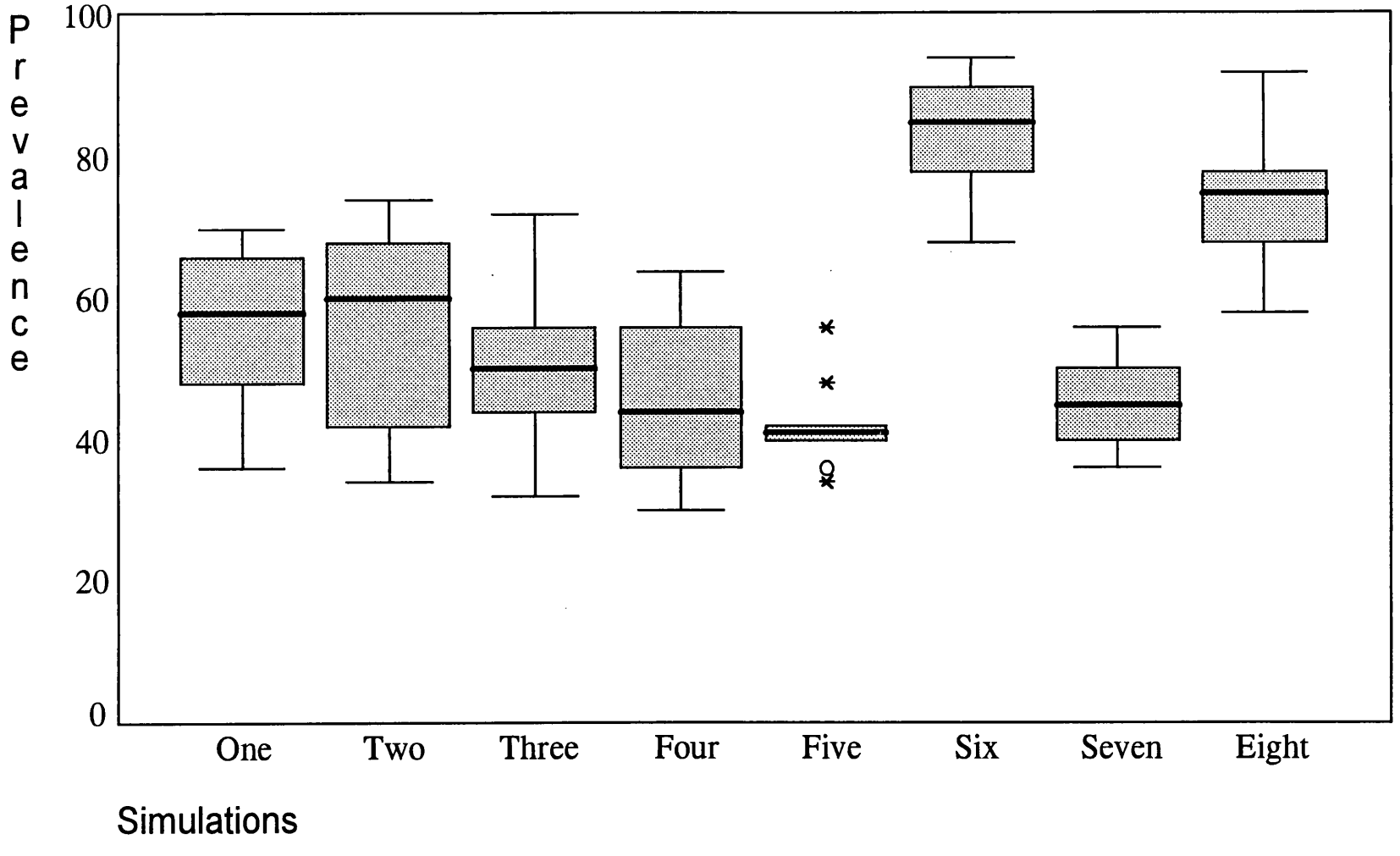
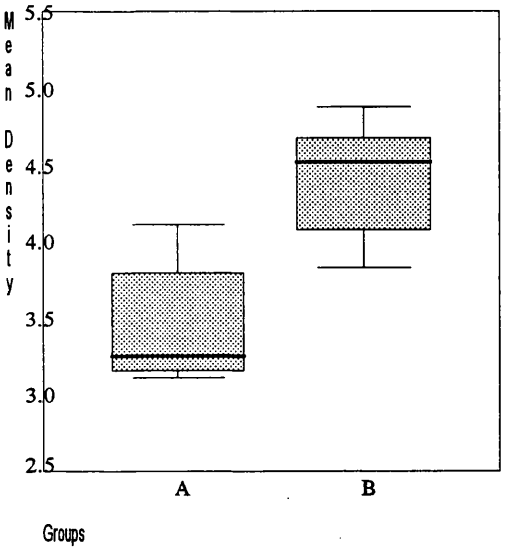
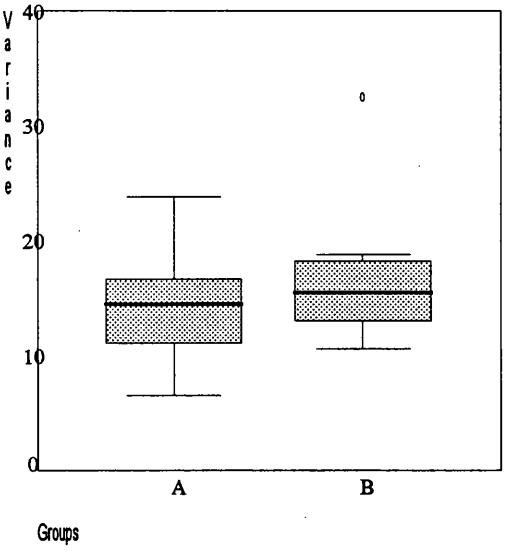
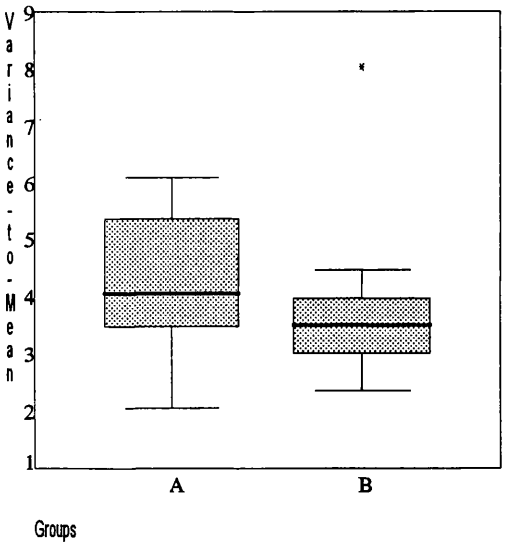
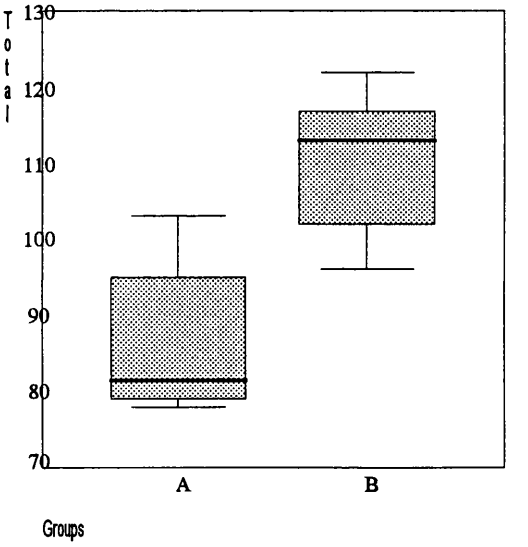

Prevalence
100
80
60
40
20
0
One
Two
Three
Four
Five
Six
Seven
Eight
Simulations

Figure 9.16. Box plots of the results from simulations of a model having even distribution of infective stages and where cockroaches are divided into two groups, one of which (Group A) is more likely to remain at a food spot if one is encountered. The mean density, variance, variance-to-mean ratio, total number of parasites recovered from each group and the prevalence of infection are reported in that order.


Mean Density
5.5
5.0
4.5
4.0
3.5
3.0
2.5
A
B
Groups


Variance
40
30
20
10
0
A
B
Groups


Variance-to-Mean
9
8
7
6
5
4
3
2
1
A
B
Groups


Total
130
120
110
100
90
80
70
A
B
Groups

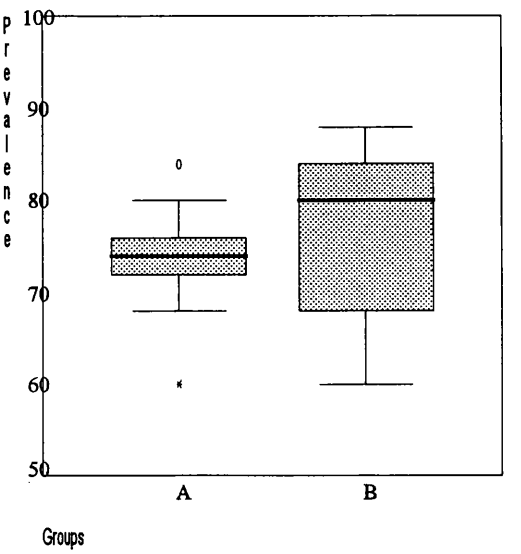
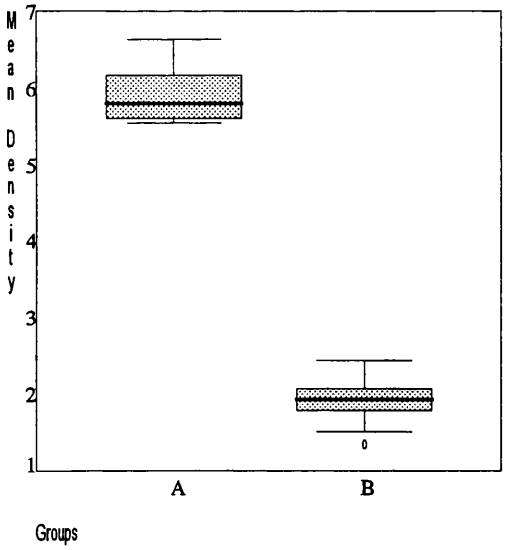
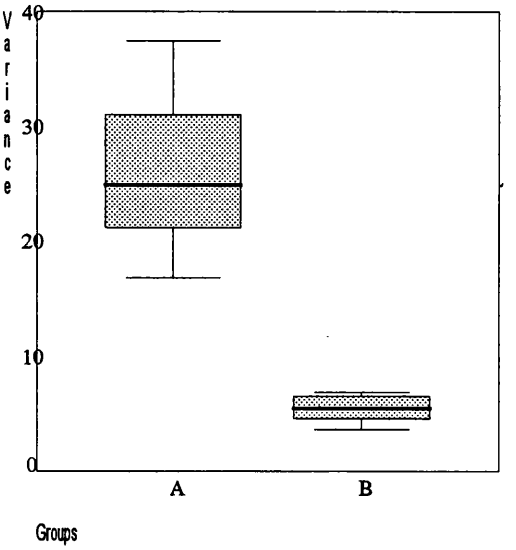
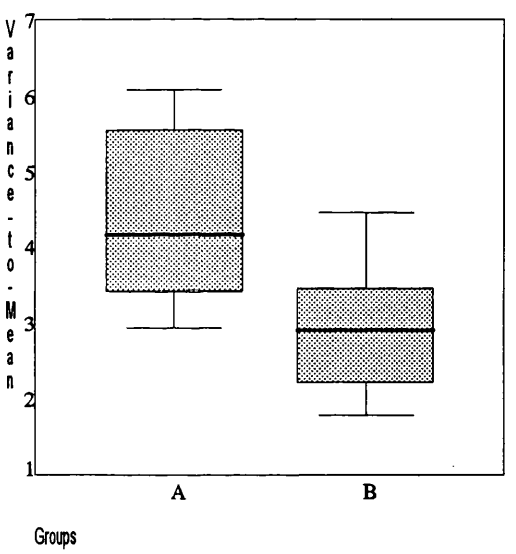
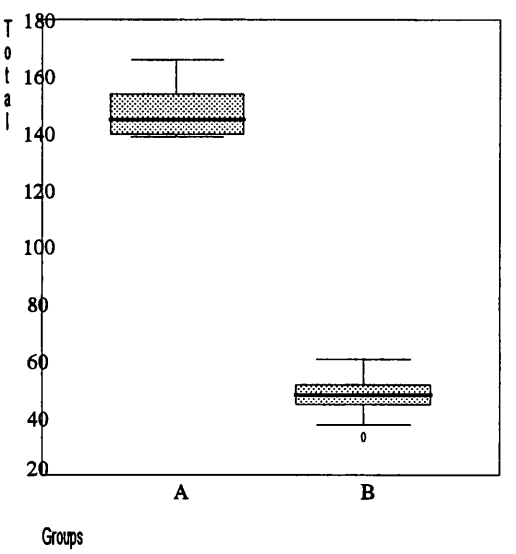

Prevalence
100
90
80
70
60
50
A
B
Groups

Figure 9.17. Box plots of the results from simulations of a model having even distribution of infective stages and where cockroaches are divided into two groups, one of which (Group A) is highly likely to pick up in infective stages if a food spots positive for infective stages is encountered. The mean density, variance, variance-to-mean ratio, total number of parasites recovered from each group and the prevalence of infection are reported in that order.


Mean Density
7
6
5
4
3
2
1
A
B
Groups


Variance
40
30
20
10
0
A
B
Groups


Variance-to-Mean
7
6
5
4
3
2
1
A
B
Groups


Total
180
160
140
120
100
80
60
40
20
A
B
Groups

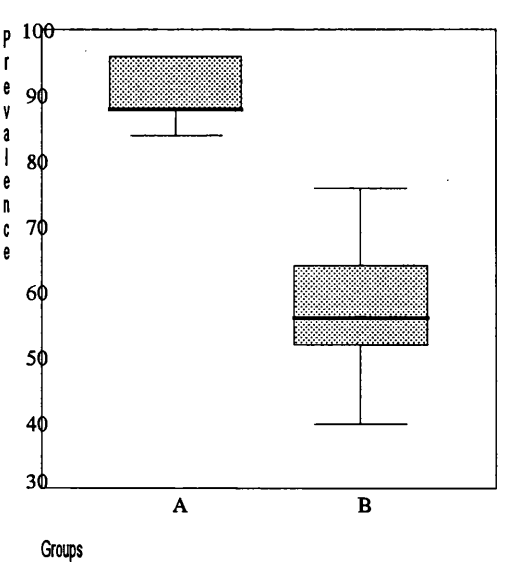
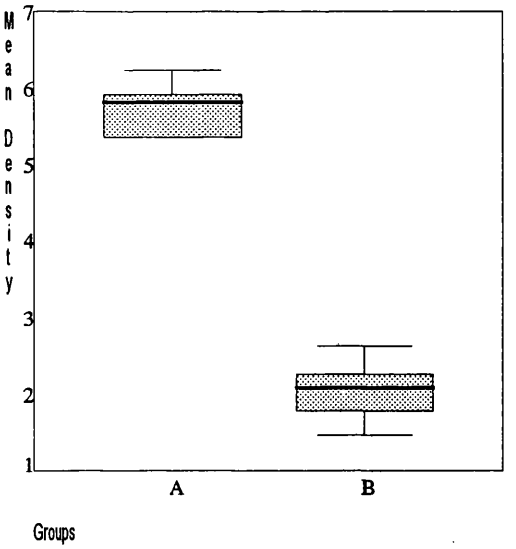
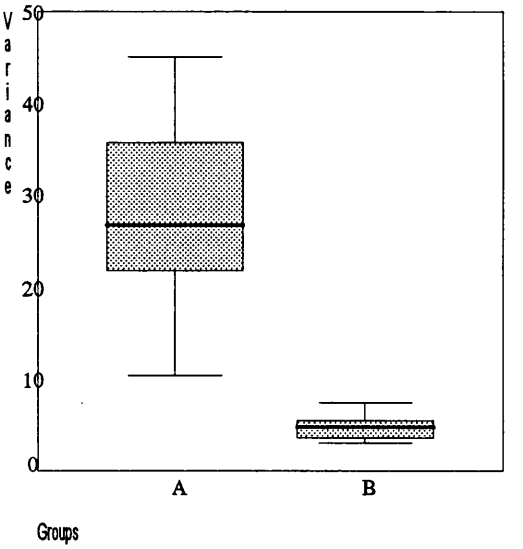
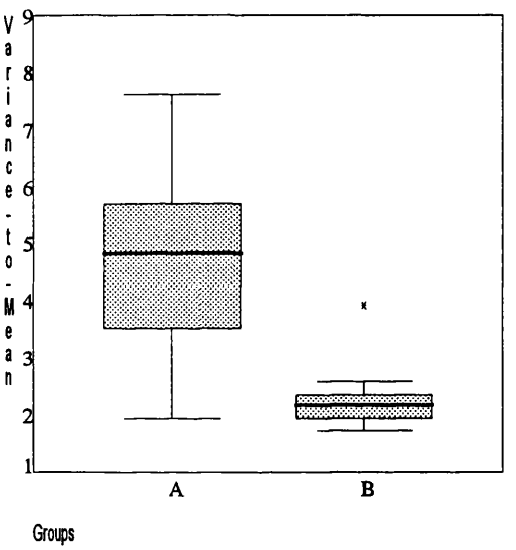
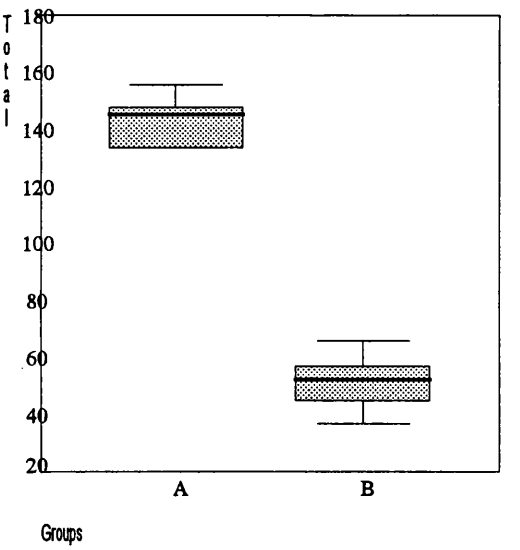

prevalence
100
90
80
70
60
50
40
30
A
B
Groups

Figure 9.18. Box plots of the results from simulations of a model having even distribution of infective stages and where cockroaches are divided into two groups, one of which (Group A) has behaviour that will cause it to stay at a food spot, once encountered, longer than those from the other group and the cockroaches in this group (Group A) are highly likely to pick up an infective stages if a food spots positive for infective stages is encountered. The mean density, variance, variance-to-mean ratio, total number of parasites recovered from each group and the prevalence of infection are reported in that order.


Mean Density
7
6
5
4
3
2
1
A
B
Groups


Variance
50
40
30
20
10
0
A
B
Groups


Variance-to-Mean
9
8
7
6
5
4
3
2
1
A
B
Groups


Total
180
160
140
120
100
80
60
40
20
A
B
Groups

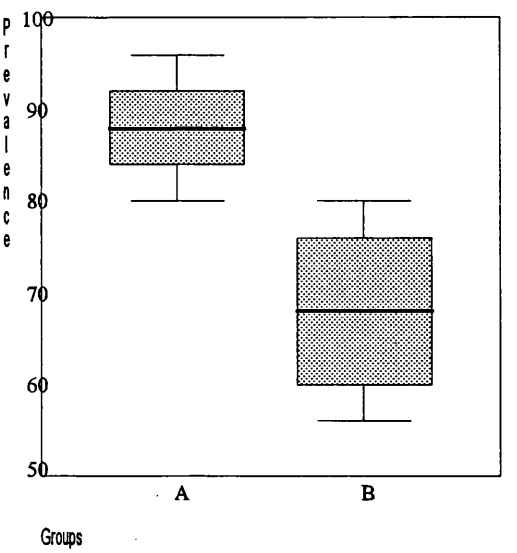
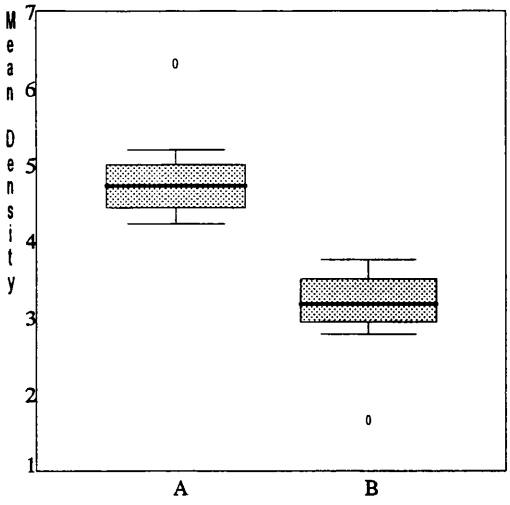
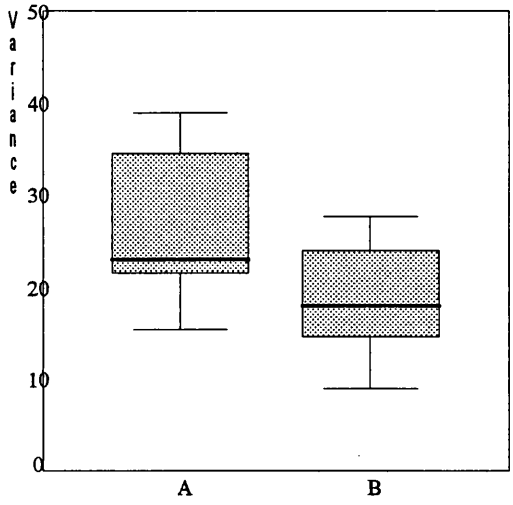
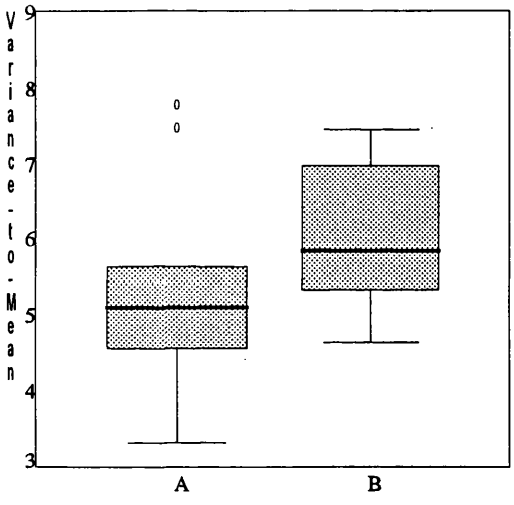
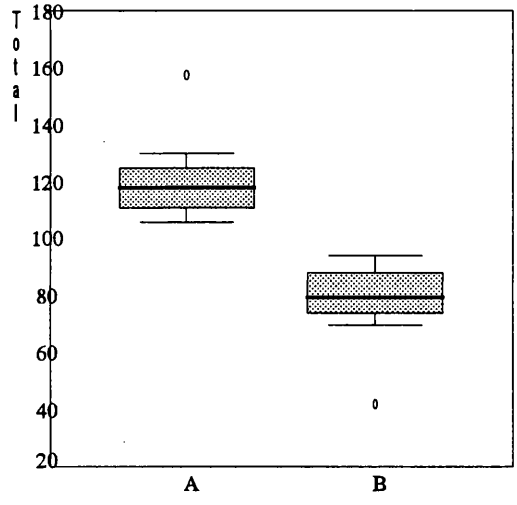

prevalence
100
90
80
70
60
50
A
B
Groups

Figure 9.19. Box plots of the results from simulations of a model having even distribution of infective stages and where cockroaches are divided into two groups, one of which (Group A) has behaviour that will cause it to stay at a food spot, once encountered, longer than those from the other group and the cockroaches in this group (Group A) are highly likely to pick up an infective stages if a food spots positive for infective stages is encountered. The effect of changes in acquired susceptibility, with infected cockroaches being easier to infect was also applied to these simulations. The mean density, variance, variance-to-mean ratio, total number of parasites recovered from each group and the prevalence of infection are reported in that order.


Mean Density
7
6
5
4
3
2
1
A
B
Groups


Variance
50
40
30
20
10
0
A
B
Groups


Variance-to-Mean
9
8
7
6
5
4
3
A
B
Groups


Total
180
160
140
120
100
80
60
40
20
A
B
Groups

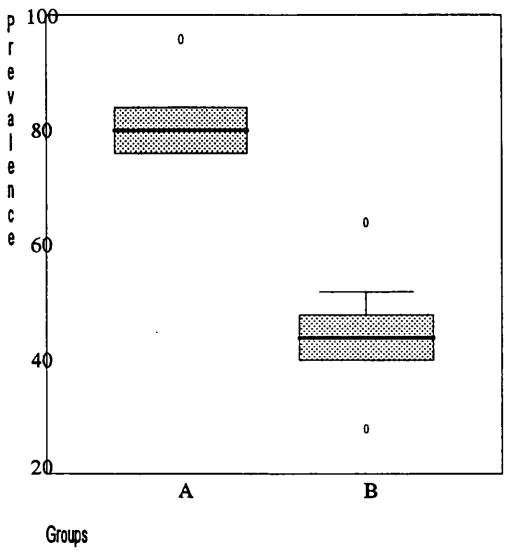
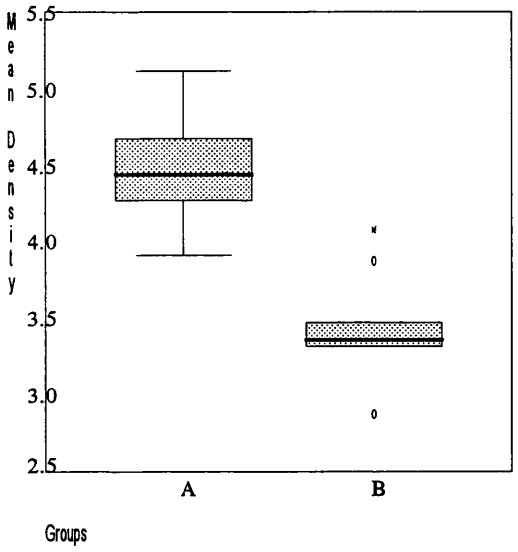
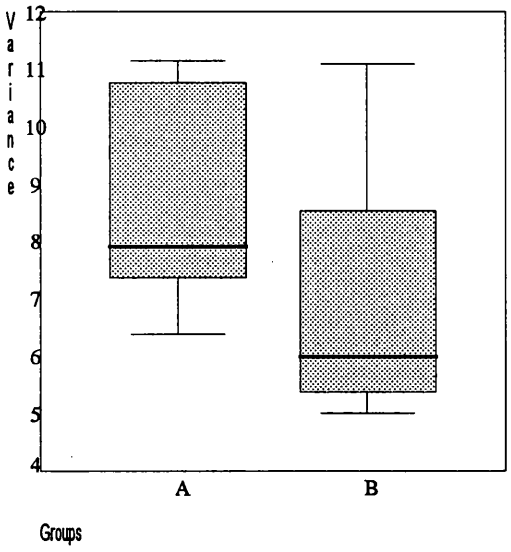
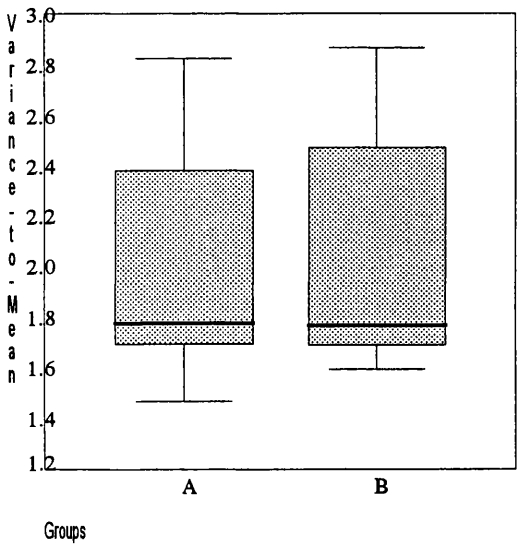
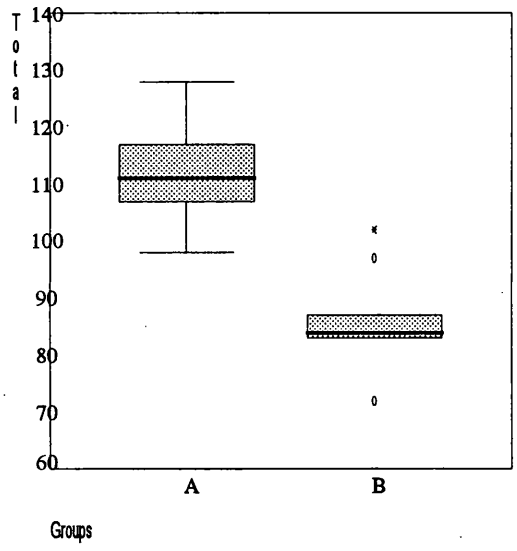

prevalence
100
80
60
40
20
A
B
Groups

Figure 9.20. Box plots of the results from simulations of a model having even distribution of infective stages and where cockroaches are divided into two groups, one of which (Group A) has behaviour that will cause it to stay at a food spot, once encountered, longer than those from the other group and the cockroaches in this group (Group A) are highly likely to pick up an infective stages if a food spots positive for infective stages is encountered. The effect of changes in acquired susceptibility, with infected cockroaches being harder to infect was also applied to these simulations. The mean density, variance, variance-to-mean ratio, total number of parasites recovered from each group and the prevalence of infection are reported in that order.


Mean Density
5.5
5.0
4.5
4.0
3.5
3.0
2.5
A
B
Groups


Variance
12
11
10
9
8
7
6
5
4
A
B
Groups


Variance-to-Mean
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
A
B
Groups


Total
140
130
120
110
100
90
80
70
60
A
B
Groups

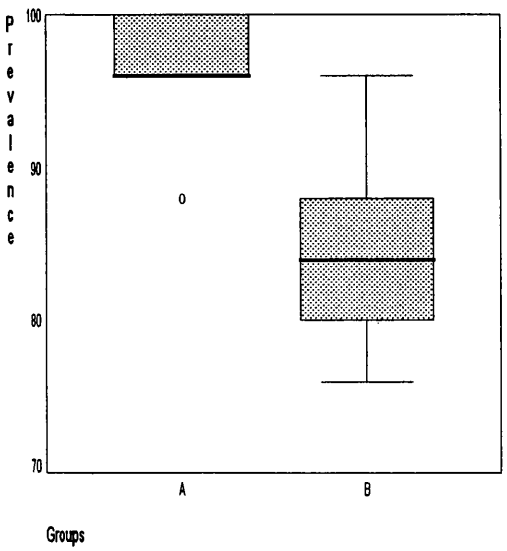

Prevalence
100
90
80
70
A
B
Groups

Figure 9.21. Box plots of the results for all the cockroaches in the eight simulations of the models where infective stages were placed in an even distribution in the arena. These are the results for the variance of the populations.

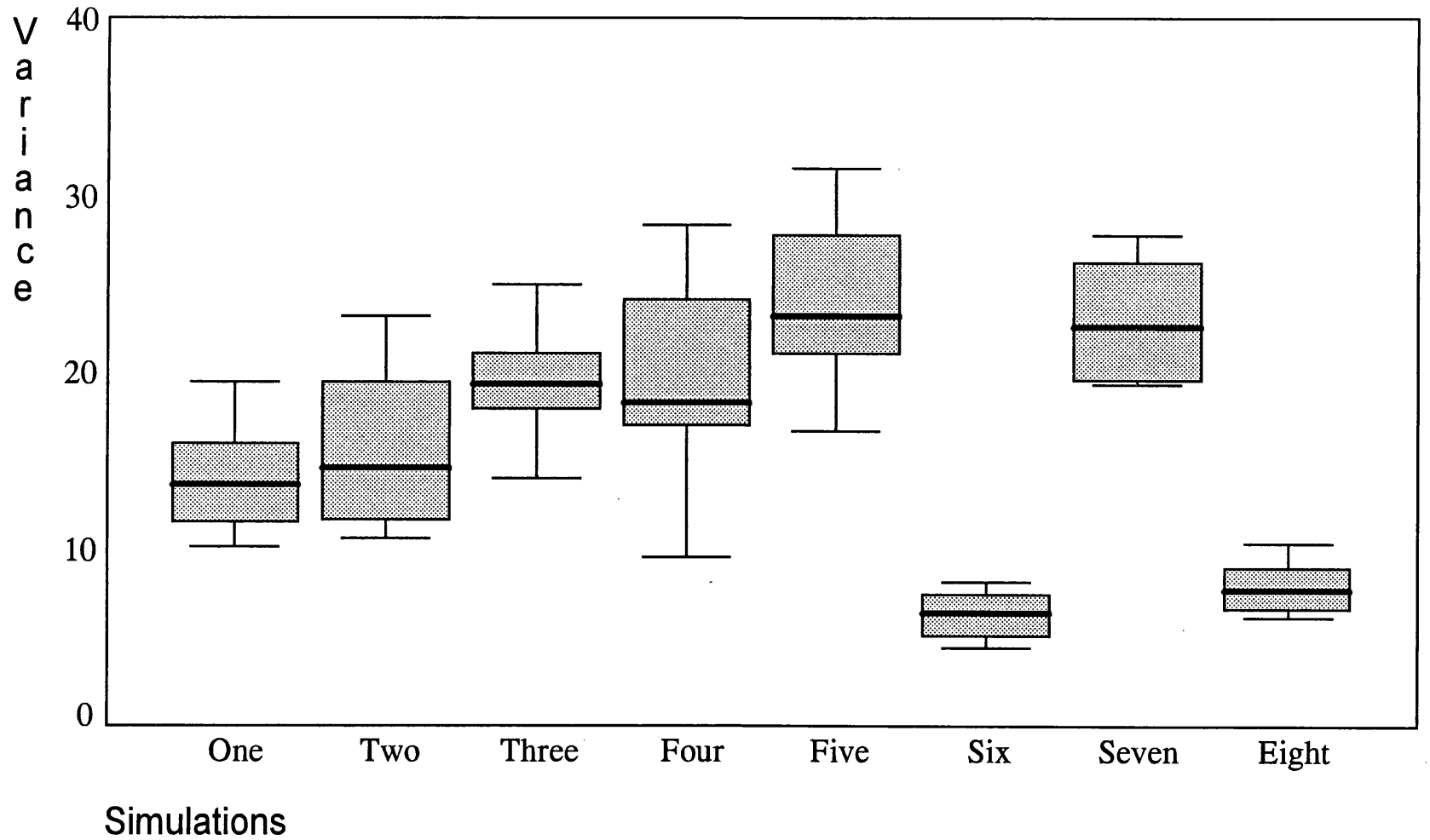

Variance
40
30
20
10
0
One
Two
Three
Four
Five
Six
Seven
Eight
Simulations

Figure 9.22. Box plots of the results for all the cockroaches in the eight simulations of the models where infective stages were placed in an even distribution in the arena. These are the results for the variance-to-mean ratios of the populations.

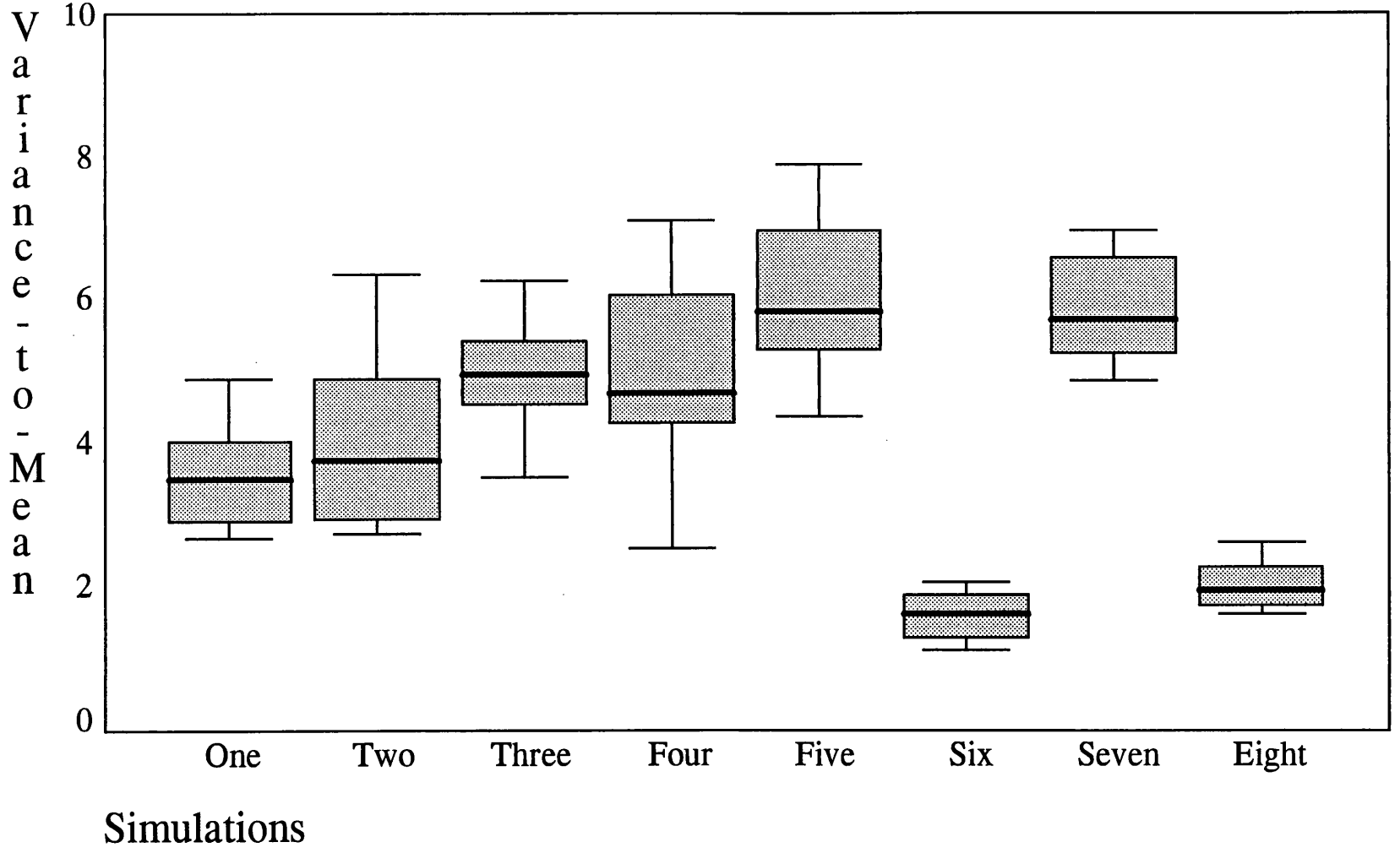
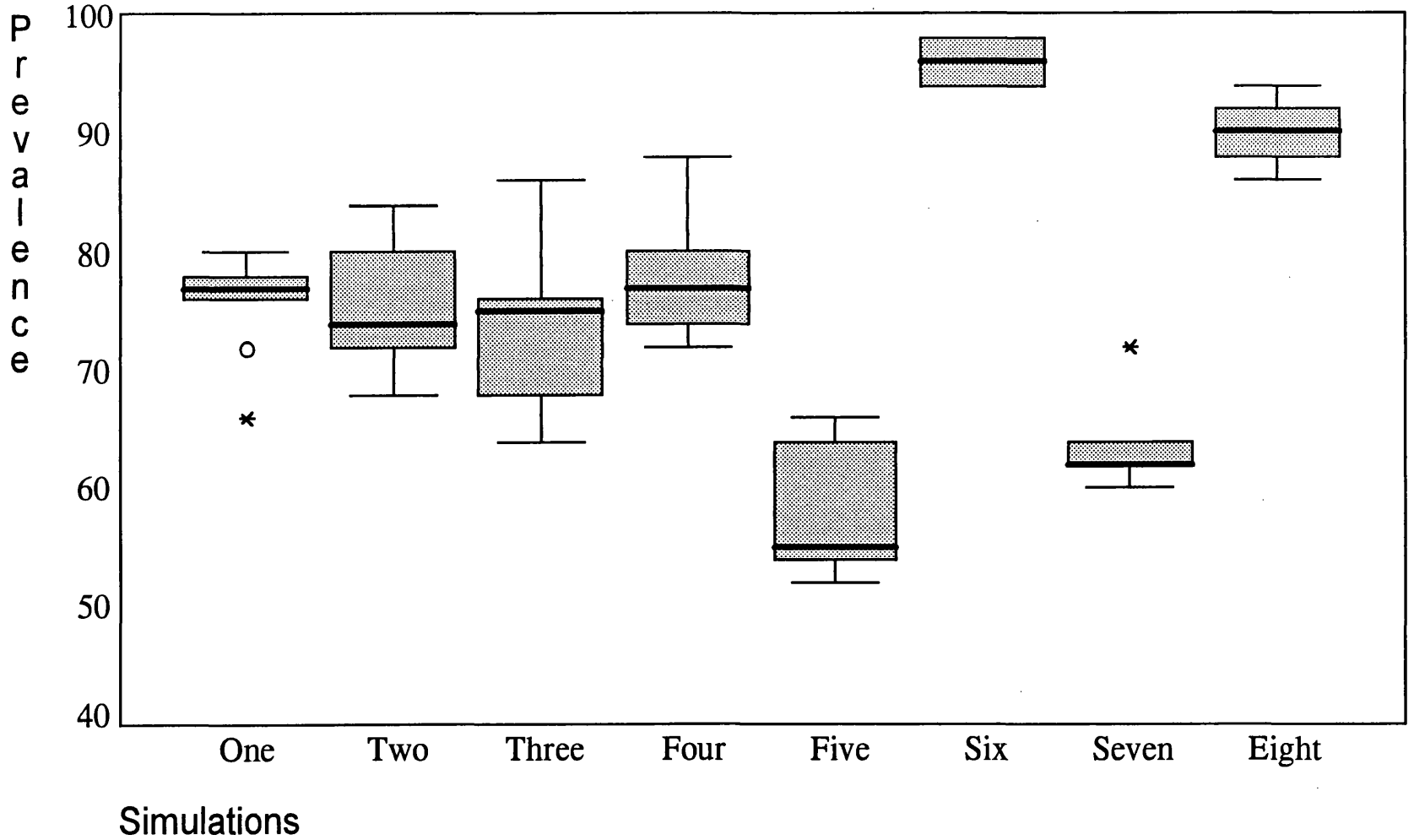

Variance-to-Mean
10
8
6
4
2
0
One
Two
Three
Four
Five
Six
Seven
Eight
Simulations

Figure 9.23. Box plots of the results for all the cockroaches in the eight simulations of the models where infective stages were placed in an even distribution in the arena. These are the results for the prevalence of infection of the populations.


Prevalence
100
90
80
70
60
50
40
One
Two
Three
Four
Five
Six
Seven
Eight
Simulations

Chapter Ten. General Summary

The results of research into factors associated with the transmission and distribution of helminths within host populations are presented in this thesis. Most of the research has been concerned with helminth species which are transmitted via the oral/faecal route, although some attention has been paid to species which are transmitted through skin penetration. The work has approached the subject from two angles. First was an epidemiological survey of human gastrointestinal helminth infections conducted in Sierra Leone. Second was the use of experimental infection to provide the basis of a simulation model to study the effect of changing infection parameters.

The collection of samples for the epidemiological survey was carried out from August to October in 1991. Surveys were carried out in three communities: Kroo Bay, a shanty town in Freetown; Rowollon, a lowland agricultural village in the Northwest of Sierra Leone; Foria, a highland agricultural village in the Northeast of Sierra Leone. The people surveyed were compared with the most recent Sierra Leonean census to determine if they were comparable in their age and sex with what was expected from the census. In Kroo Bay, fewer people of both sexes aged 10 through 40 years of age and especially fewer men than expected were surveyed, indicating that this group has little appreciation for the importance of helminth associated health problems and perhaps very little interest in other health care issues. In Rowollon, there were fewer men than expected in those aged 20 years and older. This may have indicated the same disinterest as was observed in Kroo Bay, but it also may indicate the movement of males out of small communities into the cities in search of jobs. In Foria, there were fewer people over the age of forty than were expected and more aged 10 to 19 years who took part in the study. There were also fewer men in the age group over forty years of age and overall than were expected. Both of the possibilities discussed above could be explanations for this.

Examination of faecal samples, using the modified Kato-Katz technique (Robertson, Crompton, Walters, Nesheim, Sanjur and Walsh, 1989) revealed the most common helminths in Kroo Bay to be *Ascaris lumbricoides* and *Trichuris trichiura*, in Rowollon hookworm (most likely to be *Necator americanus*) and *T. trichiura* were the most common helminth infections and in Foria hookworm (again probably *N. americanus*) was the most common, followed by *A. lumbricoides*. *Schistosoma mansoni* infection was identified in only two of the communities, Rowollon and Foria,

with individuals living in Foria having the higher prevalence of this infection (12.9%) than in Rowollon (0.6%). Rowollon and Kroo Bay did not differ significantly in the prevalence of infection with *A. lumbricoides* (with 20.9% and 26.1% respectively), but they both had significantly lower prevalences than did Foria (32.1%). Hookworm infection was most common in Rowollon (66.6%) and Foria (61.8%) which did not differ significantly in their prevalence but had significantly higher prevalence of hookworm infection than people in Kroo Bay (22.2%). The prevalence of *T. trichiura* infection in Foria was extremely low (1.1%) and significantly less than in Rowollon (49.5%) and in Kroo Bay (65.1%). *Strongyloides stercoralis* infection was identified in all three communities. Rowollon and Kroo Bay did not differ significantly in the prevalence of this helminth (0.4% and 1.1% respectively) but infection with this helminth in Foria were more common (2.9%).

Mean intensity (EPG) of infection with *A. lumbricoides* was found to be highest in Foria, although this was only significantly higher than the intensity in Rowollon, with the intensity in Kroo Bay not differing significantly from either of the other two communities. Mean intensities (EPG) of hookworm infection in the three communities differed significantly from each other. Rowollon had the highest , followed by Foria and then Kroo Bay. *Trichuris trichiura* mean intensity (EPG) was highest in Kroo Bay, followed by Rowollon with the few individuals infected with this helminth in Foria having low intensities of infection. No significant differences in the mean intensities of *S. mansoni* or *S. stercoralis* were found between the communities were these infections were identified.

Various factors which may influence both the prevalence and intensity of infection were investigated. These included the age and sex of an individual, the size of the household in which an individual resided and the location of an individual's house within the village. The sex of host was only found to influence the mean intensity of hookworm infection in Rowollon, where men were seen to have more intense infections than women. Age of a host influenced both prevalence and infection, with the age group of between five to nine years and ten to 19 years of age having the highest prevalence of *A. lumbricoides* in Kroo Bay, with those aged from infancy to 4 years having significantly less intense infections than those aged between ten and 19 and over forty years of age. In Rowollon, those aged five through nine had significantly higher prevalence of infection with *A. lumbricoides*. For hookworm infection, individuals from infancy to five years of age had significantly lower prevalence and intensity of infection than other ages in all of the communities studied.

Trichuris trichiura infection was significantly less prevalent in those individuals from infancy to five year of age in both Kroo Bay and Rowollon, with individuals from ten to 19 years of age having significantly higher prevalence of infection in Rowollon. In Kroo Bay, those aged from five to nine years of age had the highest mean intensity and in Rowollon, those in aged from five to 19 years of age had the most intense infections. *Schistosoma mansoni* infection was significantly more prevalent in people aged ten to 19 years of age.

Size of household was only found to be a factor in prevalence or intensity of helminth infections in Foria, where individuals from smaller households were found to have less intense infections of *A. lumbricoides* and to have a higher prevalence of *S. mansoni*. The location of an individual's house was found to be significant in terms of helminth infections in both Kroo Bay and Rowollon. In Kroo Bay, one area had more intense infections of *A. lumbricoides* and in Rowollon, one area had more intense infections of *T. trichiura*.

In an attempt to predict the most important factors associated with both prevalence and intensity of helminth infections, covariance analysis of the intensity results combined with regression analysis and logistic regression of the prevalence results were performed. In general, the ability of covariance analysis in combination with regression analysis to elucidate general patterns in the intensity values was poor in all the communities for all of the helminth infections studied. For *A. lumbricoides* infections there is some evidence to support a connection of intensity with age, where the intensity decreases with increasing age (Foria) or rises and then levels out (Kroo Bay). In Rowollon and Foria, age was seen to have a significant effect on the intensity of hookworm infection, with intensity increasing with age to a plateau. In Rowollon males were seen to have higher intensities of infection than females at all ages. Covariance analysis of *T. trichiura* infections in Kroo Bay and Rowollon revealed little new information, the only significant factor being the difference between the areas of the village in Rowollon.

Logistic regression was used to construct statistical models based on those factors which were measured in these surveys to produce probability values for infection with different helminth species. For *A. lumbricoides* infection, age was shown to be the most important factor of those measured. This differed between communities, although all of the models predict fairly high probabilities of being infected with this helminth if an individual is aged between five and ten years of age. The prevalence

of hookworm infection in the rural communities lead to the construction of a model in which age was the most important factor . Increasing age was related to increasing probability of being infected with hookworm, until about age ten. From ten until thirty years of age the probability of being infected with hookworm decreased and then rose again until approximately 60 years of age in both models. In Kroo Bay, the urban site, the model of the probability of infection with hookworm rose until about 20 years of age and the decreased again. The logistic regression models for prevalence of *T. trichiura* infection in both Kroo Bay and Rowollon indicated the importance of age and the are in which an individual lived. In Rowollon, the sex of an individual was also important, with females having less of a probability of being infected with *T. trichiura* than males regardless of where they lived.

The effect of the helminth infections on the health of the children in the surveyed population was investigated. The z-score values for weight-for-age, height-for-age and weight-for-height were calculated and used for this analysis (WHO Working Groups, 1986). The children in Foria had significantly lower weight-for-age z-scores than those in the other communities, with those in Rowollon having significantly lower weight-for-height z-scores than those in Kroo Bay, who had significantly lower scores than those in Foria. The only significant differences found between infected and uninfected children indicated that in Kroo Bay and Foria, those found to be infected with hookworm had higher weight-for-age z-scores than those that were uninfected. The same conclusion was arrived at for the those infected with *A. lumbricoides*, hookworm and *T. trichiura* analysed separately in Rowollon as regards their weight-for-age and height-for-age z-scores. The only detrimental effect of infection on the anthropometric measurements was seen in those infected with hookworm in Rowollon, where those with higher intensities appeared to have lower values for weight-for-height z-scores. It is often difficult to find evidence for detrimental effects of helminth infections in children without following the course of both infection and changes in children's health following treatment. It may be that the reason that infected children have higher values for anthropometric measurements is they are the children who are active, with the possibility of encountering infective stages. Children who are perhaps suffering from some other health related problem are unlikely to encounter helminth infective stages if this leads to inactivity.

In comparison to other survey work carried out in Sierra Leone (reviewed in Chapter Two) the results concerning the prevalence of *A. lumbricoides* in Kroo Bay and Rowollon are near those

found in reviews of hospital records from Freetown (Duncan, 1991). The prevalence of *A. lumbricoides* was found to be somewhat higher in Foria. Results reported from mixed age groups in the South of Sierra Leone have indicated that the prevalence of *A. lumbricoides* infection is somewhat higher there (Alghali, Gage, Blockarie, Collier, Terry and Bangura, 1990; Whitworth, Morgan, Maude, McNicholas and Taylor, 1991) than what was found in the surveys reported here. This appears to indicate that this helminth is a more serious public health problem in the South of the country.

The high prevalence of hookworm infection in the two rural sites reported here shows a similar pattern to what has been found in most other surveys of mixed age groups in rural areas (Alghali, Gage, Blockarie, Collier, Terry and Bangura, 1990; Whitworth, Morgan, Maude, McNicholas and Taylor, 1991; Wilson, 1991). The results from the urban site of Kroo Bay are also similar to mixed age group results reported from the mixed age groups reported from hospitals in urban areas (Duncan, 1991).

The prevalence of *T. trichiura* infection in mixed age groups has been shown to have confidence intervals from about 60% to 0% in previous surveys (Alghali, Gage, Blockarie, Collier, Terry and Bangura, 1990; Duncan, 1991; Whitworth, Morgan, Maude, McNicholas and Taylor, 1991). All of the communities reported here were within this range, with Rowollon and Kroo Bay ranging from 49.5% to 46.0% and individuals in Foria having a low of 1.1%. This however does not give enough importance to the fact that in Foria the prevalence of this helminth was exceedingly low, suggesting either some environmental factor which was responsible for this or perhaps a local practice which hindered the transmission of *T. trichiura* at this locality. As the prevalence of both *A. lumbricoides* and hookworm were both high in Foria it seems unlikely that anthelmintic treatment was responsible for the lack of *T. trichiura* infection.

Schistosoma mansoni infection was only found in any number in Foria. It has been suggested that infection with this helminth is increasing in geographical distribution in Sierra Leone (White, Gbakima and Amaara, 1989). Comparing the results of other surveys on infection with this helminth is difficult as little information is usually given as to whether or not this helminth was looked for. If no *S. mansoni* infection is reported it may be because there was none found or it might be because it was not recorded. A couple of mixed-age surveys have reported higher prevalence

values for this helminth, but most that have reported information have appeared to agree in value with that of this survey.

The prevalence of *S. stercoralis* in Foria was high, but it was similar to results reported from a survey in the south (Alghali, Gage, Blockarie, Collier, Terry and Bangura, 1990) and reports from a Northern hospital (Hodges, 1988). The lower values reported from Rowollon and Kroo Bay were similar to those reported from an urban hospital and some rural areas (Alghali, Gage, Blockarie, Collier, Terry and Bangura, 1990; Duncan, 1991).

Intensity values have not been given for a mixed age survey in those reviewed in Chapter Two. The results of differences in ages in prevalence and intensity illustrate the usual pattern reviewed in Chapter One, where infection with *A. lumbricoides* and *T. trichiura* are more common and intense in young individuals (5 to 20 years of age) and hookworm is more common in older individuals (20 plus years). *Schistosoma mansoni* infection usually peaks in prevalence and intensity between 15 and 25 years of age, as was found here in prevalence. The results of the anthropometric data suggest that a study involving observation of behavioural differences between children and helminth prevalence and intensity might be illuminating.

The second part of the work described in this thesis involved the construction of a model to explore the influence of transmission factors on the distribution of helminth parasites within their host populations. These have been listed by Crofton (1971a) and are reviewed in Chapter Seven. The influence of the pattern of distribution of infective stages within a host population's environment was explored using experimental infections of *Moniliformis moniliformis* in *Periplaneta americana*, a helminth transmitted via the oral route. These indicated that over-dispersion of the helminths in the host population was found even when the distribution of infective stages was uniform throughout the environment. Over-dispersion increased as the distribution of infective stages went from random to clumped. This is similar to the results found with infections of *Hymenolepis diminuta* in *Tribolium confusum* (Keymer and Anderson, 1979).

These results were then used to construct simulation models that simulated the experimental results. The simulations were compared to the experimental data and the model that best fit was used for further manipulations, using the population parameters of mean density, variance, variance-to-mean ratio, total number of parasites recovered after infection and the prevalence of infection. The

models which gave the best fit in each situation did not have exactly the same number of food spots with infective stages as the experimental set-up. The models all had fewer infected food spots than the experimental infections, resulting in clumping on a micro-scale in comparison to the experimental infections. This, in association with the over-dispersion seen when infective stages were introduced into the experimental arena in a uniform pattern, indicated that something other than infective stage distribution was affecting the experimental over-dispersion. When similar results had been found in work involving *H. diminuta* in *T. confusum*, feeding behaviour of the beetles had been postulated to account for this. Differences in behaviour or in infect-ability could have been responsible for a portion of the over-dispersion seen and this can be related to differences in feeding behaviour (Keymer and Anderson, 1979). Perhaps individuals vary in the amount of time they may spend at a food spot or differences in the status of the intestine at the time of ingestion may vary and affect the outcome of an encounter with an orally transmitted helminth infective stages.

The effect of this on the distribution of helminths within their hosts was investigated by modifying the model to simulate heterogeneity in inherent behaviour and infect-ability which may lead to differences in inherent susceptibility to infection. Also included with this was the influence of changes in acquired susceptibility, where cockroaches became either easier or harder to infect once they had become infected. The simultaneous effect of these factors was also studied. This was done for models simulating all three of the distribution patterns of infective stages within the environment, dividing the model cockroaches into two different groups to simulate differences in inherent behaviour and infect-ability and changing their behaviour and infect-ability once they had become infected.

The effect of these changes was analysed first to determine if the two groups of cockroaches differed in any of the population parameters which were of interest. These indicated that for random and clumped distributions of infective stages heterogeneity in inherent behaviour had little effect on the population parameters studied. In the models with even distribution of infective stages there was some effect with significant differences in the mean density and the total number of infective stages recovered from each group. Changes in inherent infect-ability had a more noticeable effect, with nearly all of the population parameters in all three distribution patterns differing significantly between

the two groups of cockroaches. The same was true of the combination of behaviour and infect-ability. This indicated that the effect of differences in infect-ability was stronger than changes in behaviour.

The combination of inherent behaviour and infect-ability with differences in acquired susceptibility was simulated both with infected cockroaches being easier to infect and when they were harder to infect. When they were easier to infect, significant differences were found between the two groups of cockroaches in models of random placement of infective stages in the variance-to-mean ratio and the prevalence of infection and in models of clumped and even distributions of infective stages in the mean density in the total number of parasites recovered in each group and the prevalence of infection. When infected cockroaches became harder to infect, in models with random placement of infective stages the variance-to-mean ratio and the prevalence of infection of the two groups of cockroaches differed significantly, no significant differences were found in those models with a clumped distribution of infective stages and significant differences were found in the mean density, the total number of parasites recovered in each group of cockroaches and the prevalence of infection in those models with an even distribution of infective stages.

When comparisons were undertaken between the entire population of cockroaches recovered for each simulation, however, only two simulations differed significantly from the unmodified simulations. These were, in models with a random and clumped distribution of infective stages the variance-to-mean ratio of the simulation with cockroaches that only differed in acquired susceptibility, with infected cockroaches being easier to infect. In models of even placement of infective stages, there were significant differences between the simulations where cockroaches acquired susceptibility changed. In those simulations where cockroaches became easier to infect there was a significant difference from the unmodified simulation in the prevalence of infection. In those simulations where cockroaches became harder to infect there were significant differences from the unmodified simulation in the variance, the variance-to-mean ratio and the prevalence of infection.

In these models it appears that host heterogeneity based on previous experience of infection has a greater effect on the population parameters than heterogeneity based on some inherent quality. This is in spite of the fact that significant differences were seen between the two groups of cockroaches who differed in inherent susceptibility. When cockroaches who became infected were easier to infect again this resulted in larger over-dispersion and conversely, when infected

cockroaches were harder to infect this resulted in smaller over-dispersion. This held true regardless of the distribution pattern of infective stages within the host's environment.

In conclusion, the horizontal epidemiological surveys for gastrointestinal helminths in West Africa indicated that the most important factor in relation to prevalence and intensity of infection was the age of an individual. In the case of hookworm and *T. trichiura* infection there was some evidence for the importance of the sex of the individuals, with females having less probability of being infected with *T. trichiura* in Rowollon and hookworm infection being more intense in males than females in Rowollon and Kroo Bay. The probability of being infected with *T. trichiura* was also found to reflect the area of the village in which an individual lived in Kroo Bay and Rowollon.

These differences in prevalence and intensity may reflect differences in the behaviour which brings the potential host in contact with an infective stage or might reflect differences in the ability of an infective stage to establish within an individual once contact has been made. In the investigations using models of cockroaches, the influence of different inherent behaviour was shown to be minimal at random and clumped distribution patterns of infective stages within the hosts environment. Groups of model cockroaches which varied in behavioural aspects did not vary in either mean density or prevalence of infection. In even distributions of infective stages, there was a significant difference found in the mean density and the total number of parasites recovered in each group of cockroaches. The effect of differences in the ability of infective stages to establish was much larger with significant differences found in the mean density and prevalences as well as other population parameters in models with random, clumped and even distributions of infective stages. This gives an indication that differences in the ability of infective stages to establish is more likely to lead to differences in prevalence and intensity of infection than are differences in the behaviour of potential hosts.

The results from models with an addition of increased or decreased susceptibility due to the presence of an established infection to the effect of heterogeneity in inherent susceptibility showed differences due to the distribution pattern of infective stages. This indicated that distribution of infective stages within the environment of a host, in combination with differences in inherent and acquired susceptibility could lead to differences in prevalence of infection and mean density. The effect all of this may have on the overall distribution of parasites within a host population, with differences in acquired susceptibility having the largest effect in these simulations.

Further research involving an attempt to identify the factors investigated above in models of human gastrointestinal infections would lead to greater understanding of the epidemiology of helminth infections. The research would also aid control programmes, specifically those aimed at educational aspects of public health. If morbidity is associated with higher intensity infections and the variance-to-mean ratio is taken as a useful indicator of this aspect, then a decrease in the variance-to-mean ratio, even without a decrease in the mean density, may result in a decrease in the morbidity seen in helminth infections. From the models, which show no significant difference in mean density but differences in the variance-to-mean ratio, it appears that changing certain aspects of host encounter and establishment of infective stages may accomplish this desirable effect.

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Appendix I

Table 1. Chi-square analysis of the randomly selected survey sample in Kroo Bay in comparison to data from the 1974 census for the urban Western Area.

	Age Classes					
Survey	One (Expected)	Two (Expected)	Three (Expected)	Four (Expected)	Five (Expected)	Totals
1974 Census	47838 (47891.4)	44269 (44276.4)	68232 (68205.6)	99163 (99127.0)	55960 (55961.7)	315462
Kroo Bay	93 (39.6)	44 (36.6)	30 (56.4)	46 (82.0)	48 (46.3)	261
Totals	47931	44313	68262	99209	56008	315723

Table 2. Chi-square analysis of the sex ratio of individuals in age class three in Kroo Bay compared to those of similar age in the 1974 census for the urban Western Area.

	Sex		
Survey	Females (Expected)	Males (Expected)	Totals
1974 Census	33775 (33781.1)	34457 (34450.9)	68232
Kroo Bay	21 (14.9)	9 (15.1)	30
Totals	33796	34466	68262

Table 3. Chi-square analysis of the sex ratio of individuals in age class four in Kroo Bay compared to those of similar age in the 1974 census for the urban Western Area.

	Sex		
Survey	Females (Expected)	Males (Expected)	Totals
1974 Census	43713 (43733.7)	55450 (55429.3)	99163
Kroo Bay	41 (20.3)	5 (25.7)	46
Totals	43754	55455	99209

Table 4. Chi-square analysis of the sex ratio of individuals in age class five in Kroo Bay compared to those of similar age in the 1974 census for the urban Western Area.

	Sex		
Survey	Females (Expected)	Males (Expected)	Totals
1974 Census	24838 (24855.7)	31122 (31104.3)	55960
Kroo Bay	39 (21.3)	9 (26.7)	48
Totals	24877	31131	56008

Table 5. Chi-square analysis of the sex ratio of individuals in all age classes in Kroo Bay compared to those in the 1974 census for the urban Western Area.

	Sex		
Survey	Females (Expected)	Males (Expected)	Totals
1974 Census	149680 (149737.1)	165782 (165724.9)	315462
Kroo Bay	181 (123.9)	80 (137.1)	261
Totals	149861	165862	315723

Table 6. Chi-square analysis of the sex ratio of individuals in age class five in Kroo Bay compared to those of aged 20 to 39 yr old in the 1974 census for the urban Western Area.

	Sex		
Survey	Females (Expected)	Males (Expected)	Totals
1974 Census	43713 (43730.8)	55450 (55432.2)	99163
Kroo Bay	39 (21.2)	9 (26.8)	48
Totals	43752	55459	99211

Table 7. Chi-square analysis of the sex ratio of individuals in age class four in Kroo Bay compared to those of aged 0 to 19 yr old in the 1974 census for the urban Western Area.

	Sex		
Survey	Females (Expected)	Males (Expected)	Totals
1974 Census	81129 (81146.7)	79210 (79192.3)	160339
Kroo Bay	41 (23.3)	5 (22.7)	46
Totals	81170	79215	160385

Table 8. Chi-square analysis of the randomly selected survey sample in Rowollon in comparison to data from the 1974 census for the Northern Province.

	Age Classes					
Survey	One (Expected)	Two (Expected)	Three (Expected)	Four (Expected)	Five (Expected)	Totals
1974 Census	181356 (181368.7)	183288 (183274.1)	189766 (189768.0)	274096 (274087.4)	215934 (215942.4)	1046158
Rowollon	72 (59.3)	46 (59.9)	64 (62.0)	81 (89.6)	79 (70.6)	342
Totals	181428	183334	189830	274177	216013	1046500

Table 9. Chi-square analysis of the sex ratio of individuals in age class four in Rowollon compared to those of similar age in the 1974 census for the Northern Province.

	Sex		
Survey	Females (Expected)	Males (Expected)	Totals
1974 Census	164133 (164149.5)	109963 (109946.5)	274096
Rowollon	65 (48.5)	16 (32.5)	81
Totals	164198	109979	274177

Table 10. Chi-square analysis of the sex ratio of individuals in age class five in Rowollon compared to those of similar age in the 1974 census for the Northern Province.

	Sex		
Survey	Females (Expected)	Males (Expected)	Totals
1974 Census	106637 (106648.0)	109297 (109286.0)	215934
Rowollon	50 (39.0)	29 (40.0)	79
Totals	106687	109326	216013

Table 11. Chi-square analysis of the sex ratio of individuals in all age classes in Rowollon compared to those in the 1974 census for the Northern Province.

	Sex		
Survey	Females (Expected)	Males (Expected)	Totals
1974 Census	547248 (547278.6)	497192 (497161.4)	1046158
Rowollon	209 (178.4)	132 (162.6)	341
Totals	547457	497324	1046499

Table 12. Chi-square analysis of the sex ratio of individuals in age class four in Rowollon compared to those of aged 0 to 19 yr old in the 1974 census for the Northern Province.

	Sex		
Survey	Females (Expected)	Males (Expected)	Totals
1974 Census	342014 (342034.3)	277932 (277911.7)	619946
Rowollon	65 (44.7)	16 (36.3)	81
Totals	342079	277948	620027

Table 13. Chi-square analysis of the randomly selected survey sample in Foria in comparison to data from the 1974 census for the Northern Province.

	Age Classes					
Survey	One (Expected)	Two (Expected)	Three (Expected)	Four (Expected)	Five (Expected)	Totals
1974 Census	181356 (181369.2)	183288 (183286.4)	189766 (189788.0)	274096 (274100.0)	215934 (215897.1)	1046158
Foria	82 (68.8)	68 (69.6)	94 (72.0)	108 (104.0)	45 (81.9)	397
Totals	181438	183356	189860	274204	215979	1046555

Table 14. Chi-square analysis of the sex ratio of individuals in age class five in Foria compared to those of similar age in the 1974 census for the Northern Province.

	Sex		
Survey	Females (Expected)	Males (Expected)	Totals
1974 Census	106637 (106645.8)	109297 (109288.2)	215934
Foria	31 (22.2)	14 (22.8)	45
Totals	106668	109311	215979

Table 15. Chi-square analysis of the sex ratio of individuals in all age classes in Foria compared to those in the 1974 census for the Northern Province.

	Sex		
Survey	Females (Expected)	Males (Expected)	Totals
1974 Census	547248 (547274.0)	497192 (497166.0)	1044440
Foria	234 (208.0)	163 (189.0)	397
Totals	547482	497355	1044837

Table 16. Chi-square analysis of the sex ratio of individuals in age class four in Foria compared to those of aged 0 to 19 yr old in the 1974 census for the Northern Province.

	Sex		
Survey	Females (Expected)	Males (Expected)	Totals
1974 Census	342014 (342023.4)	277932 (277922.6)	619946
Foria	69 (59.6)	39 (48.4)	108
Totals	342083	277971	620054

Table 17. The prevalence of *T. trichiura* infections in targeted and non-targeted households in Kroo Bay.

	Households		
T. trichiura	Targeted (Expected)	Non-targeted (Expected)	Totals
Present	170 (154.95)	55 (70.05)	225
Absent	91 (106.05)	63 (47.95)	154
Totals	261	118	379

Table 18. Levene's tests for equality of variances in differences in intensity between targeted and non-targeted households in Kroo Bay.

Helminth	Levene's F	df	*P*
A. lumbricoides	0.213	1,97	$P \leq 0.645$
Hookworm	7.115*	1,82	$P \leq 0.009$

Significantly different at $P \leq 0.05$.

Table 19. The prevalence of *A. lumbricoides* in the randomly and non-randomly selected children aged 5 to 9 yrs from Rowollon.

	Samples		
A. lumbricoides	Random (Expected)	Non-random (Expected)	Totals
Present	19 (14.95)	7 (11.05)	26
Absent	27 (31.05)	27 (22.95)	54
Totals	46	34	80

Table 20. The prevalence of hookworm in the randomly and non-randomly selected children aged 5 to 9 yrs from Rowollon.

	Samples		
Hookworm	Random (Expected)	Non-random (Expected)	Totals
Present	42 (38.53)	25 (28.48)	67
Absent	4 (7.48)	9 (5.53)	13
Totals	46	34	80

Table 21. Levene's tests for equality of variances in differences in intensity between randomly and non-randomly chosen children in Rowollon.

Helminth	Levene's F	df	*P*
A. lumbricoides Age Class One	4.9178*	1,21	$P \leq 0.038$
Hookworm Age Class One	0.0119	1,55	$P \leq 0.914$
T. trichiura Age Class One	0.0568	1,33	$P \leq 0.813$
T. trichiura Age Class Two	0.3144	1,48	$P \leq 0.578$

Significantly different at $P \leq 0.05$.

Table 22. Levene's tests for equality of variances in differences in intensity between randomly and non-randomly chosen children in Foria.

Helminth	Levene's F	df	*P*
A. lumbricoides Age Class One	1.9931	1,39	$P \leq 0.166$
A. lumbricoides Age Class Two	0.2704	1,33	$P \leq 0.607$
Hookworm Age Class One	0.3225	1,24	$P \leq 0.575$
Hookworm Age Class Two	0.0041	1,58	$P \leq 0.949$
S. mansoni	0.9120	1,3	$P \leq 0.410$

Table 23. Distribution of individuals in the two areas by the classes of number of people in the household in Kroo Bay.

	Household Size			
Area	One (Expected)	Two (Expected)	Three (Expected)	Total
One	45 (69.69)	50 (46.46)	46 (24.85)	141
Two	84 (59.31)	36 (39.54)	0 (21.15)	120
Total	129	86	46	261

Table 24. Number of females and males in each of the age classes in the sample from the targeted households in Kroo Bay.

	Age Classes					
Sex	One (Expected)	Two (Expected)	Three (Expected)	Four (Expected)	Five (Expected)	Total
Females	56 (64.46)	24 (30.51)	21 (20.80)	41 (31.90)	39 (33.29)	181
Males	37 (28.51)	20 (13.49)	9 (9.20)	5 (14.10)	9 (14.71)	80
Totals	93	44	30	46	48	261

Table 25. Distribution of the sexes in the different age classes in Rowollon.

Sex	One (Expected)	Two (Expected)	Three (Expected)	Four (Expected)	Five (Expected)	Totals
Female	88 (96.38)	17 (27.54)	38 (38.31)	65 (48.49)	50 (47.29)	258
Male	73 (64.62)	29 (18.46)	26 (25.69)	16 (32.51)	29 (31.71)	173
Totals	161	46	64	81	79	431

Table 26. Categories of under-fives per household by area in Rowollon.

	Categories of Household Size			
Area	One (Expected)	Two (Expected)	Three (Expected)	Totals
One	51 (76.11)	84 (80.06)	108 (86.83)	243
Two	84 (58.87)	58 (61.94)	46 (67.17)	188
Totals	135	142	154	431

Table 27. Size of household by area in Foria.

	Size of Household			
Area	One (Expected)	Two (Expected)	Three (Expected)	Totals
One	80 (82.98)	91 (100.87)	113 (100.15)	284
Two	36 (33.02)	50 (40.13)	27 (39.85)	113
Totals	116	141	140	397

Appendix II.

Table 1. The prevalence of *A. lumbricoides* in the three communities.

	Community			
A. lumbricoides	Kroo Bay (Expected)	Rowollon (Expected)	Foria (Expected)	Totals
Infected	99 (99.57)	90 (113.23)	131 (107.19)	320
Uninfected	280 (279.43)	341 (317.77)	277 (300.81)	898
Totals	379	431	408	1218

Table 2. The prevalence of hookworm in the three communities.

	Community			
Hookworm	Kroo Bay (Expected)	Rowollon (Expected)	Foria (Expected)	Totals
Infected	84 (195.22)	287 (222.00)	278 (231.79)	649
Uninfected	295 (183.78)	144 (209.00)	172 (218.21)	611
Totals	379	431	450	1260

Table 3. The prevalence of *T. trichiura* in the three communities.

	Community			
T. trichiura	Kroo Bay (Expected)	Rowollon (Expected)	Foria (Expected)	Totals
Infected	170 (89.89)	230 (160.14)	5 (154.97)	405
Uninfected	91 (171.11)	235 (304.86)	445 (295.03)	771
Totals	261	465	450	1176

Table 4. The prevalence of *S. mansoni* in two communities.

	Community		
S. mansoni	Rowollon (Expected)	Foria (Expected)	Totals
Infected	3 (31)	58 (30)	61
Uninfected	462 (434)	392 (420)	854
Totals	465	450	915

Table 5. The prevalence of *S. stercoralis* in the three communities.

	Community			
S. stercoralis	Kroo Bay (Expected)	Rowollon (Expected)	Foria (Expected)	Totals
Infected	4 (5.56)	2 (6.83)	13 (6.61)	19
Uninfected	375 (373.44)	463 (458.17)	437 (443.39)	1275
Totals	379	465	450	1294

Table 6. Levene's Tests for differences in variances between intensity of helminth infections between the communities.

Helminth	F Value	df	p
A. lumbricoides	1.455	2,317	$p \leq 0.235$
Hookworm	1.890	2,646	$p \leq 0.152$
T. trichiura	6.820*	df = 1, 398	$p \leq 0.009$
S. mansoni	1.003	1,59	$p \leq 0.321$
S. stercoralis	0.217	2,16	$p \leq 0.807$

* Indicates where variances were significantly different ($p \leq 0.05$).

Table 7. Values needed for significant differences between means of *A. lumbricoides* in the three communities.

	Communities		
Communities	Kroo Bay	Rowollon	Foria
Kroo Bay	-	0.1820	0.1665
Rowollon		-	0.1711
Foria			-

Table 8. Values needed for significant differences between means of hookworm in the three communities.

	Communities		
Communities	Kroo Bay	Rowollon	Foria
Kroo Bay	-	0.1453	0.1459
Rowollon		-	0.0986
Foria			-

Chi-square tables for helminth prevalence by age class in each of the three communities.

Table 9. *Ascaris lumbricoides* prevalence by age class in Kroo Bay.

	Age Class					
A lumbricoides	One (Expected)	Two (Expected)	Three (Expected)	Four (Expected)	Five (Expected)	Total
Infected	27 (36.83)	23 (15.93)	14 (10.71)	14 (20.64)	21 (21.94)	99
Uninfected	114 (104.17)	38 (45.07)	22 (30.29)	50 (58.36)	56 (62.06)	280
Totals	141	61	36	64	77	379

Table 10. *Ascaris lumbricoides* prevalence by age class in Rowollon.

	Age Class					
A. lumbricoides	One (Expected)	Two (Expected)	Three (Expected)	Four (Expected)	Five (Expected)	Totals
Infected	23 (33.62)	19 (9.61)	16 (13.36)	19 (16.91)	13 (16.50)	90
Uninfected	138 (127.38)	27 (36.39)	48 (50.64)	62 (64.09)	66 (62.50)	341
Totals	161	46	64	81	79	431

Table 11. *Ascaris lumbricoides* prevalence by age class in Foria.

	Age Classes					
A. lumbricoides	One (Expected)	Two (Expected)	Three (Expected)	Four (Expected)	Five (Expected)	Totals
Infected	41 (40.78)	35 (25.98)	32 (30.92)	30 (35.52)	10 (14.80)	148
Uninfected	83 (83.22)	44 (53.02)	62 (63.08)	78 (72.48)	35 (30.2)	302
Totals	124	79	94	108	45	450

Table 12. Hookworm prevalence by age class in Kroo Bay.

	Age Class					
Hookworm	One (Expected)	Two (Expected)	Three (Expected)	Four (Expected)	Five (Expected)	Totals
Infected	13 (31.25)	19 (13.52)	15 (7.98)	15 (14.18)	22 (17.07)	84
Uninfected	128 (109.75)	42 (47.48)	25 (28.02)	49 (49.82)	55 (59.93)	295
Totals	141	61	36	64	77	379

Table 13. Hookworm prevalence by age class in Rowollon.

	Age Class					
Hookworm	One (Expected)	Two (Expected)	Three (Expected)	Four (Expected)	Five (Expected)	Totals
Infected	57 (107.21)	42 (30.63)	58 (42.62)	60 (53.94)	70 (52.61)	287
Uninfected	104 (53.79)	4 (15.37)	6 (21.38)	21 (27.06)	9 (26.39)	144
Totals	161	46	64	81	79	431

Table 14. Hookworm prevalence by age class in Foria.

	Age Classes					
Hookworm	One (Expected)	Two (Expected)	Three (Expected)	Four (Expected)	Five (Expected)	Totals
Infected	26 (76.60)	60 (48.80)	75 (58.07)	81 (66.72)	36 (27.80)	278
Uninfected	98 (47.40)	19 (30.20)	19 (35.93)	27 (41.28)	9 (17.20)	172
Totals	124	79	94	108	45	450

Table 15. *Trichuris trichiura* prevalence by age class in Kroo Bay.

	Age Class					
T. trichiura	One (Expected)	Two (Expected)	Three (Expected)	Four (Expected)	Five (Expected)	Totals
Infected	42 (60.57)	37 (28.66)	26 (19.54)	33 (29.96)	32 (31.26)	170
Uninfected	51 (32.43)	7 (15.34)	4 (10.46)	13 (16.04)	16 (16.74)	91
Totals	93	44	30	46	48	261

Table 16. *Trichuris trichiura* prevalence by age class in Rowollon.

	Age Class					
T. Trichiura	One (Expected)	Two (Expected)	Three (Expected)	Four (Expected)	Five (Expected)	Totals
Infected	35 (79.63)	50 (39.57)	51 (31.66)	46 (40.06)	48 (39.08)	230
Uninfected	126 (81.37)	30 (40.43)	13 (32.34)	35 (40.94)	31 (39.92)	235
Totals	161	80	64	81	79	465

Table 17. *Schistosoma mansoni* prevalence by age class in Foria.

	Age Classes					
S. mansoni	One (Expected)	Two (Expected)	Three (Expected)	Four (Expected)	Five (Expected)	Totals
Infected	3 (15.98)	5 (10.18)	18 (12.12)	27 (13.92)	5 (5.80)	58
Uninfected	121 (108.02)	74 (68.82)	76 (81.88)	81 (94.08)	40 (39.20)	392
Totals	124	79	94	108	45	450

Table 18. *Schistosoma mansoni* prevalence by household size in Foria.

	Household Size			
S. mansoni	1 - 14 (Expected)	15 - 24 (Expected)	25 + (Expected)	Totals
Infected	24 (15.79)	13 (19.18)	17 (19.04)	54
Uninfected	92 (100.22)	128 (121.82)	123 (120.96)	343
Totals	116	141	140	397

Table 19. Association of *A. lumbricoides* infections with hookworm infections in Kroo Bay.

	A. lumbricoides		
Hookworm	Present (Expected)	Absent (Expected)	Totals
Present	35 (21.94)	49 (62.06)	84
Absent	64 (77.06)	231 (217.94)	295
Totals	99	280	379

Table 20. Association of *A. lumbricoides* infections with hookworm infections in Rowollon.

	A. lumbricoides		
Hookworm	Present (Expected)	Absent (Expected)	Totals
Present	77 (59.93)	210 (227.07)	287
Absent	13 (30.07)	131 (113.93)	144
Totals	90	341	431

Table 21. Association of *A. lumbricoides* infections with hookworm infections in Foria.

	A lumbricoides		
Hookworm	Present (Expected)	Absent (Expected)	Totals
Present	109 (91.43)	169 (186.57)	278
Absent	39 (56.57)	133 (115.43)	172
Totals	148	302	450

Table 22. Association of *A. lumbricoides* infections with *T. trichiura* infections in Kroo Bay.

	A. lumbricoides		
T. trichiura	Present (Expected)	Absent (Expected)	Totals
Present	59 (46.25)	111 (123.75)	170
Absent	12 (24.75)	79 (66.25)	91
Totals	71	190	261

Table 23. Association of *A. lumbricoides* infections with *T. trichiura* infections in Rowollon.

	A. lumbricoides		
T. trichiura	Present (Expected)	Absent (Expected)	Totals
Present	68 (44.27)	144 (167.73)	212
Absent	22 (45.73)	197 (173.27)	219
Totals	90	341	431

Table 24. Association of *A. lumbricoides* infections with hookworm infections in Foria.

	A. lumbricoides		
Hookworm	Present (Expected)	Absent (Expected)	Totals
Present	109 (91.43)	169 (186.57)	278
Absent	39 (56.57)	133 (115.43)	172
Totals	148	302	450

Table 25. Association of Hookworm infections with *T. trichiura* infections in Kroo Bay.

	Hookworm		
T. trichiura	Present (Expected)	Absent (Expected)	Totals
Present	55 (39.73)	115 (130.27)	170
Absent	6 (21.27)	85 (69.73)	91
Totals	61	200	261

Table 26. Association of hookworm infections with *T. trichiura* infections in Rowollon.

	Hookworm		
T. trichiura	Present (Expected)	Absent (Expected)	Totals
Present	194 (141.17)	18 (70.83)	212
Absent	93 (145.83)	126 (73.17)	219
Totals	287	144	431

Table 27. Association of *A. lumbricoides* infections with *S. mansoni* infections in Foria.

	A. lumbricoides		
S. mansoni	Present (Expected)	Absent (Expected)	Totals
Present	10 (19.08)	48 (38.92)	58
Absent	138 (128.92)	254 (263.08)	392
Totals	148	302	450

Table 28. Association of hookworm infections with *S. mansoni* infections in Foria.

	Hookworm		
S. mansoni	Present (Expected)	Absent (Expected)	Totals
Present	43 (35.83)	15 (22.17)	58
Absent	235 (242.17)	157 (149.83)	392
Totals	278	172	450

Table 29. Levene's Tests for differences in variances between groups of concurrent infections in an analysis of variance.

Community	Helminth	F Value	df	p
Kroo Bay	*A. lumbricoides*	0.1895	2,96	0.828
	Hookworm	0.3875	2,81	0.680
	T. trichiura	0.5893	2,167	0.556
Rowollon	*A. lumbricoides*	2.7891	2,87	0.067
	Hookworm	1.4522	2,284	0.236
	T. trichiura	0.7392	2,206	0.479
Foria	*A. lumbricoides*	0.0937	2,128	0.911
	Hookworm	1.4459	2,266	0.237
	S. mansoni	0.2931	2,53	0.747

Table 30. Values needed for significant differences between means of *A. lumbricoides* intensity in single, double and triple infections in Kroo Bay.

	Infections		
Infections	Single	Double	Triple
Single	-	0.3794	0.4065
Double		-	0.2763
Triple			-

Table 31. Values needed for significant differences between means of *A. lumbricoides* intensity in single, double and triple infections in Rowollon.

	Infections		
Infections	Single	Double	Triple
Single	-	0.5409	0.4671
Double		-	0.3580
Triple			-

Table 32. Values needed for significant differences between means of Hookworm intensity in single, double and triple infections in Rowollon.

	Infections		
Infections	Single	Double	Triple
Single	-	0.1485	0.1784
Double		-	0.1612
Triple			-

Table 33. Values needed for significant differences between means of *T. trichiura* intensity in single, double and triple infections in Kroo Bay.

	Infections		
Infections	Single	Double	Triple
Single	-	0.1703	0.2210
Double		-	0.2232
Triple			-

Table 34. Values needed for significant differences between means of *T. trichiura* intensity in single, double and triple infections in Rowollon.

	Infections		
Infections	Single	Double	Triple
Single	-	0.2376	0.2493
Double		-	0.1289
Triple			-

Table 35. Levene's Tests for differences in variances between sex of infected people.

Community	Helminth	F Value	df	p
Kroo Bay	*A. lumbricoides*	1.8239	1,97	0.180
	Hookworm	0.4128	1,82	0.522
	T. trichiura	1.250	1,168	0.265
Rowollon	*A. lumbricoides*	0.0262	1,88	0.872
	Hookworm	1.5058	1,285	0.221
	T. trichiura	2.6992	1,228	0.102
Foria	*A. lumbricoides*	4.4399*	1,129	0.037
	Hookworm	3.8527	1,276	0.051
	S. mansoni	0.0611	1,56	0.806

* Indicates where variances were significantly different ($p \leq 0.05$).

Table 36. Levene's Tests for differences in variances between age classes of infected individuals.

Community	Helminth	F Value	df	p
Kroo Bay	*A. lumbricoides*	1.3436	4,94	0.260
	Hookworm	2.1629	4,79	0.081
	T. trichiura	0.8654	4,165	0.486
Rowollon	*A. lumbricoides*	0.8933	4,85	0.472
	Hookworm	2.1841	4,282	0.071
	T. trichiura	0.9871	4,225	0.415
Foria	*A. lumbricoides*	1.4108	4,126	0.234
	Hookworm	0.6650	4,273	0.617
	S. mansoni	0.4527	4,53	0.770

Table 37. Values needed for significant differences between means of *A. lumbricoides* intensity in the different age classes in Kroo Bay.

	Age Classes				
Age Class	One	Two	Three	Four	Five
One	-	0.3601	0.4179	0.4179	0.3692
Two		-	0.4301	0.4301	0.3830
Three			-	0.4796	0.4378
Four				-	0.4378
Five					-

Table 38. Values needed for significant differences between means of Hookworm intensity in the different age classes in Rowollon.

	Age Classes				
Age Class	One	Two	Three	Four	Five
One	-	0.2371	0.2174	0.2157	0.2080
Two		-	0.2362	0.2345	0.2275
Three			-	0.2147	0.2070
Four				-	0.2051
Five					-

Table 39. Values needed for significant differences between means of Hookworm intensity in the different age classes in Foria.

	Age Classes				
Age Class	One	Two	Three	Four	Five
One	-	0.2751	0.2666	0.2641	0.3015
Two		-	0.2029	0.1996	0.2470
Three			-	0.1877	0.2375
Four				-	0.2347
Five					-

Table 40. Values needed for significant differences between means of *T. trichiura* intensity in the different age classes in Kroo Bay.

	Age Classes				
Age Class	One	Two	Three	Four	Five
One	-	0.2358	0.2610	0.2433	0.2454
Two		-	0.2679	0.2504	0.2525
Three			-	0.2742	0.2761
Four				-	0.2595
Five					-

Table 41. Cochran's' C tests for differences in variances between ages and sex of infected individuals in two-way analysis of variance.

Community	Helminth	C	df	p
Kroo Bay	*A. lumbricoides*	0.234	10,9	0.119
	Hookworm	0.191	8,9	0.693
	T. trichiura	0.160	16,10	0.502
Rowollon	*A. lumbricoides*	0.195	8,10	0.388
	Hookworm	0.188*	28,10	0.016
	T. trichiura	0.165	22,10	0.207
Foria	*A. lumbricoides*	0.169	12,10	0.511
	Hookworm	0.139	27,10	0.757

* Indicates where variances were significantly different ($p \leq 0.05$).

Table 42. Bartlett's Box F tests for differences in variances between ages and sex of infected individuals in two-way analysis of variance.

Community	Helminth	F	df	p
Kroo Bay	*A. lumbricoides*	-†	-	-
	Hookworm	0.996	8,3571	0.437
	T. trichiura	1.197	9,6321	0.292
Rowollon	*A. lumbricoides*	1.053	9,1753	0.395
	Hookworm	2.534*	9,44909	0.007
	T. trichiura	1.161	9,29341	0.315
Foria	*A. lumbricoides*	0.855	9,2516	0.565
	Hookworm	0.737	9,34695	0.675

* Indicates where variances were significantly different ($p \leq 0.05$).

† The variance could not be calculated for one of the cells and a Bartlett's test could not be done.

Table 43. Levene's tests for differences in the variances by age class of males and females infected with hookworm in Rowollon.

Sex	F Value	df	p
Female	4.1881*	4,167	0.003
Male	3.5619*	4,110	0.009

* Indicates where variances were significantly different ($p \leq 0.05$).

Table 44. Levene's Tests for differences in variances between groups of household size of infected individuals.

Community	Helminth	F Value	df	p
Kroo Bay	*A. lumbricoides*	0.4856	2,68	0.617
	Hookworm	2.5759	2,58	0.085
	T. trichiura	1.4166	2,167	0.245
Rowollon	*A. lumbricoides*	0.3867	2,87	0.680
	Hookworm	0.0773	2,284	0.926
	T. trichiura	0.6385	2,227	0.529
Foria	*A. lumbricoides*	0.5767	2,123	0.563
	Hookworm	0.5613	2,259	0.571
	S. mansoni	0.3722	2,51	0.691

Table 45. Levene's Tests for differences in variances between groups of infected people separated by area.

Community	Helminth	F Value	df	p
Kroo Bay	*A. lumbricoides*	0.0466	1,97	0.830
	Hookworm	0.0000	1,82	0.998
	T. trichiura	4.807*	1,168	0.030
Rowollon	*A. lumbricoides*	0.0065	1,88	0.936
	Hookworm	1.0260	1,285	0.312
	T. trichiura	1.2048	1,228	0.274
Foria	*A. lumbricoides*	1.3160	1,124	0.254
	Hookworm	0.0297	1,260	0.863
	S. mansoni	0.0551	1,52	0.815

* Indicates where variances were significantly different ($p \leq 0.05$).

Table 46. Values needed for significant differences between means of *A. lumbricoides* intensity in categories of households in Foria.

	Households		
Households	One	Two	Three
One	-	0.2521	0.2399
Two		-	0.2399
Three			-

Table 47. Values needed for significant differences between means of hookworm intensity in categories of households in Rowollon.

	Households		
Households	One	Two	Three
One	-	0.1611	0.1575
Two		-	0.1614
Three			-

Appendix III

Table 1. Equations for curves for age and intensity (EPG) data, with F values, df, p values and adjusted r square values.

Helminth	Community	Type of Equation	Equation	F Value	df	p	Adjusted r^2
A. lumbricoides	Kroo Bay	Simple	$y = 3.209439 + 0.004213(age)$	2.17631	1,97	0.1434	0.01186
		Polynomial	$y = 3.0796 + 0.02464(age) - 0.00045(age^2) + 0.000002(age^3)$	1.28117	3,95	0.2853	0.00853
		Logarithmic	$y = 3.025722 + 0.26218(\log(age))$	4.42885	1,97	0.0379	0.03381
	Rowollon	Simple	$y = 3.240907 - 0.003199(age)$	0.5483	1,88	0.4628	-0.00515
		Polynomial	$y = 3.479136 - 0.046051(age) + 0.001317(age^2) - 0.00001(age^3)$	1.00594	3,86	0.3942	0.00020
		Logarithmic	$y = 3.386692 - 0.193438(\log(age))$	1.43508	1,88	0.2342	0.00486
	Foria	Simple	$y = 3.543689 - 0.005783(age)$	1.99318	1,129	0.1604	0.00758
		Polynomial	$y = 3.64394 - 0.013499(age) - 0.000464(age^2) + 0.000016(age^3)$	2.25129	3,127	0.0856	0.02807
		Logarithmic	$y = 3.657952 - 0.197065(\log(age))$	2.28330	1,129	0.1332	0.00978
Hookworm	Kroo Bay	Simple	$y = 2.193731 + 0.004587(age)$	2.52665	1,82	0.1158	0.01806
		Polynomial	$y = 2.143084 + 0.009786(age) - 0.003042(age^2) + 0.000001(age^3)$	0.96267	3,80	0.4146	-0.00135
		Logarithmic	$y = 2.026864 + 0.239560(\log(age))$	2.97775	1,82	0.0882	0.02327
	Rowollon	Simple	$y = 2.607143 + 0.00398(age)$	5.11516	1,285	0.0245	0.01418
		Polynomial	$y = 2.478404 + 0.029049(age) - 0.000899(age^2) + 0.000008(age^3)$	3.14500	3,283	0.0256	0.02200
		Logarithmic	$y = 2.453745 + 0.209913(\log(age))$	8.19880	1,285	0.0045	0.02455
	Foria	Simple	$y = 2.408544 + 0.006857(age)$	8.30001	1,276	0.0043	0.02568
		Polynomial	$y = 2.040972 + 0.059827(age) - 0.001584(age^2) + 0.000012(age^3)$	7.32554	3,274	0.0001	0.06412
		Logarithmic	$y = 2.058031 + 0.418377(\log(age))$	18.43051	1,276	0.00001	0.05920
T. trichuris	Kroo Bay	Simple	$y = 2.376719 - 0.002011(age)$	1.0351	1,168	0.3104	0.00021
		Polynomial	$y = 2.487377 -0.018875(age) + 0.000393(age^2) + 0.000002(age^3)$	1.27868	3,166	0.2834	0.00492
		Logarithmic	$y = 2.40926 - 0.070179(\log(age))$	0.805487	1,168	0.3707	-0.00115
	Rowollon	Simple	$y = 2.013015 - 0.00217(age)$	1.76233	1,228	0.1857	0.00332
		Polynomial	$y = 2.055783 - 0.004409(age) -0.000136(age^2) +0.000003(age^3)$	1.93853	3,226	0.1242	0.01215
		Logarithmic	$y = 2.077952-0.096861(\log(age))$	1.97614	1,228	0.1612	0.00424
S. mansoni	Foria	Simple	$y = 2.047335 - 0.00151(age)$	0.06575	1,56	0.7986	-0.01666
		Polynomial	$y = 1.660375 + 0.060121(age) - 0.002391(age^2) + 0.000025(age^3)$	0.44196	3,54	0.7239	-0.03026
		Logarithmic	$y = 2.049649 - 0.028537(\log(age))$	0.01258	1,56	0.9111	-0.01763

Table 2. Multiple regression analysis of *A. lumbricoides* intensity (EPG) for age of individual and number of individuals in a household.

Community	Age Equation	Number Equation	F value	df	p	r^2
Kroo Bay	Simple	Simple	0.5314	2,68	0.5902	-0.01357
		Polynomial	0.58759	4,66	0.6728	-0.02414
		Logarithmic	0.55665	2,68	0.5757	-0.01283
	Polynomial	Simple	1.09891	4,66	0.3645	0.00562
		Polynomial	0.79135	6,64	0.5808	-0.01830
		Logarithmic	1.11845	4,64	0.3554	0.00672
	Logarithmic	Simple	1.78290	2,68	0.1759	0.02188
		Polynomial	1.02398	4,66	0.4015	0.00137
		Logarithmic	1.80155	2,68	0.1728	0.02239
Rowollon	Simple	Simple	0.64844	2,87	0.5254	-0.00796
		Polynomial	0.72316	4,85	0.5785	-0.01260
		Logarithmic	0.37710	2,87	0.6870	-0.01420
	Polynomial	Simple	0.90371	4,85	0.4656	-0.00435
		Polynomial	0.84952	6,83	0.5356	-0.01025
		Logarithmic	0.79270	4,85	0.5331	-0.00940
	Logarithmic	Simple	0.98738	2,87	0.3767	-0.00028
		Polynomial	0.89440	4,85	0.4710	-0.00477
		Logarithmic	0.76854	2,87	0.4668	-0.00523
Foria	Simple	Simple	6.04094	2,123	0.0031	0.07464
		Polynomial	3.56408	4,121	0.0087	0.07583
		Logarithmic	6.81390	2,123	0.0016	0.08511
	Polynomial	Simple	4.03155	4,121	0.0042	0.08843
		Polynomial	3.18264	6,119	0.0062	0.09483
		Logarithmic	4.58733	4,121	0.0017	0.10297
	Logarithmic	Simple	6.10613	2,123	0.0030	0.07553
		Polynomial	3.69819	4,121	0.0071	0.07948
		Logarithmic	7.00647	2,123	0.0013	0.08768

Table 3. Equations for curves for numbers in households and intensity (EPG) data, with F values, df, p values and adjusted r square values.

Helminth	Community	Type of Equation	Equation	F value	df	p	r^2
A. lumbricoides	Kroo Bay	Simple	$y = 3.309744 + 0.003988(num)$	0.29146	1,69	0.5910	-0.01023
		Polynomial	$y = 3.519864 - 0.048961(num) + 0.00317(num^2) + 0.000048(num^3)$	0.58921	3,67	0.6242	-0.01792
		Logarithmic	$y = 3.180959 + 0.171569(\log(num))$	0.35703	1,69	0.5521	-0.00927
	Rowollon	Simple	$y = 3.036301 + 0.02546(num)$	1.05799	1,88	0.3065	0.00065
		Polynomial	$y = 3.334528 - 0.22454(num) + 0.04768(num^2) - 0.002562(num^3)$	0.86025	3,86	0.4650	-0.00473
		Logarithmic	$y = 3.045773 - 0.178277(\log(num))$	0.41125	1,88	0.5230	-0.00666
	Foria	Simple	$y = 3.723896 - 0.011526(num)$	9.21682	1,124	0.0029	0.06168
		Polynomial	$y = 3.95732 - 0.032979(num) + 0.000353(num^2) + 0.0000006(num^3)$	3.59211	3,122	0.0157	0.05857
		Logarithmic	$y = 4.260138 - 0.62134(\log(num))$	10.37754	1,124	0.0016	0.06979
Hookworm	Kroo Bay	Simple	$y = 2.257606 + 0.003063(num)$	0.23287	1,59	0.6312	-0.01295
		Polynomial	$y = 2.444135 - 0.051644(num) - 0.003497(num^2) - 0.000054(num^3)$	0.87152	3,57	0.4613	-0.00647
		Logarithmic	$y = 2.153692 + 0.138414(\log(num))$	0.34409	1,59	0.5597	-0.01105
	Rowollon	Simple	$y = 2.737052 - 0.007442(num)$	0.41712	1,285	0.5189	-0.00204
		Polynomial	$y = 2.739189 - 0.109985(num) - 0.039864(num^2) - 0.003277(num^3)$	1.73892	3,283	0.1592	0.00769
		Logarithmic	$y = 2.732177 - 0.046579(\log(num))$	0.14863	1,285	0.7001	-0.00299
	Foria	Simple	$y = 2.632118 - 0.001915(num)$	0.51329	1,260	0.4744	-0.00187
		Polynomial	$y = 2.588319 + 0.021033(num) - 0.001533(num^2) + 0.000023(num^3)$	1.70895	3,258	0.1656	0.00808
		Logarithmic	$y = 2.725504 - 0.107564(\log(num))$	0.71941	1,260	0.3971	-0.00108
T. trichuris	Kroo Bay	Simple	$y = 2.410906 - 0.004665(num)$	1.66335	1,168	0.1989	0.00391
		Polynomial	$y = 2.443524 -0.021899(num) + 0.00135(num^2) - 0.000022(num^3)$	1.18840	3,166	0.3159	0.00333
		Logarithmic	$y = 2.469986 - 0.121622(\log(num))$	0.78216	1,168	0.3777	-0.00129
	Rowollon	Simple	$y = 1.989047 - 0.004268(num)$	0.17655	1,228	0.6748	-0.00361
		Polynomial	$y = 1.918391 + 0.03104(num)- 0.001625(num^2) - 0.000207(num^3)$	0.57230	3,226	0.6338	-0.00563
		Logarithmic	$y = 1.965397 + 0.001803(\log(num))$	0.00029	1,228	0.9865	-0.00438
S. mansoni	Foria	Simple	$y = 2.131909 - 0.006434(num)$	1.53871	1,52	0.2204	0.01006
		Polynomial	$y = 1.892437 + 0.043321(num) - 0.002293(num^2) + 0.000028(num^3)$	0.81001	3,50	0.4943	-0.01087
		Logarithmic	$y = 2.208236 - 0.180408(\log(num))$	0.79797	1,52	0.3758	-0.00383

Table 4. Multiple regression analysis for hookworm intensity (EPG) for age of individual and number of individuals per household.

Community	Age Equation	Number Equation	F value	df	p	r^2
Kroo Bay	Simple	Simple	0.44696	2,58	0.6418	-0.01878
		Polynomial	0.94638	4,56	0.4441	-0.00359
		Logarithmic	0.50918	2,58	0.6037	-0.01663
	Polynomial	Simple	0.43895	4,56	0.7799	-0.03886
		Polynomial	0.74134	6,54	0.6187	-0.02655
		Logarithmic	0.45334	4,56	0.7695	-0.03782
	Logarithmic	Simple	0.41222	2,58	0.6641	-0.01998
		Polynomial	0.92997	4,56	0.4532	-0.00469
		Logarithmic	0.47230	2,58	0.6259	-0.01790
Rowollon	Simple	Simple	2.59027	2,284	0.0768	0.01100
		Polynomial	2.48792	4,282	0.0437	0.02039
		Logarithmic	2.55061	2,284	0.0798	0.01073
	Polynomial	Simple	2.37327	4,282	0.0525	0.01884
		Polynomial	2.25498	6,280	0.0384	0.02565
		Logarithmic	2.35047	4,282	0.0544	0.01854
	Logarithmic	Simple	4.10072	2,284	0.0176	0.02122
		Polynomial	3.20266	4,282	0.0136	0.02989
		Logarithmic	4.10291	2,284	0.0175	0.02124
Foria	Simple	Simple	2.02947	2,259	0.1335	0.00783
		Polynomial	2.14685	4,257	0.0755	0.01727
		Logarithmic	2.08598	2,259	0.1263	0.00825
	Polynomial	Simple	2.79093	4,257	0.0269	0.02671
		Polynomial	2.34946	6,255	0.0316	0.03009
		Logarithmic	2.79143	4,257	0.0269	0.02672
	Logarithmic	Simple	4.65141	2,259	0.0104	0.02722
		Polynomial	3.27668	4,257	0.0121	0.03372
		Logarithmic	4.66887	2,259	0.0102	0.02735

Table 5. Equations for curves for age and number in households for *A. lumbricodes* intensity (EPG) data.

Community	Age Equation	Number Equation	Equation
Kroo Bay	Simple	Simple	3.226263 + 0.003094(age) + 0.005124(num)
		Polynomial	3.44392 + 0.002738(age) - 0.046545(num) + 0.3003054(num^2) - 0.000046(num^3)
		Logarithmic	3.07499 + 0.00305(age) + 0.208754(lognum)
	Polynomial	Simple	3.017478 + 0.033244(age) + 0.000462(age^2) - 0.000024(age^3) + 0.005486(num)
		Polynomial	3.130654 + 0.027113(age) + 0.000462(age^2) - 0.000024(age^3) - 0.017492(num) + 0.001524(num^2) - 0.000024(num^3)
		Logarithmic	2.85254 + 0.032959(age) - 0.00061(age^2) + 0.000003(age^3) + 0.226772(lognum)
	Logarithmic	Simple	2.985208 + 0.275232(logage) - 0.006219(num)
		Polynomial	3.152874 + 0.242028(logage) - 0.02729(num) + 0.00202(num^2) - 0.000031(num^3)
		Logarithmic	2.810162 + 0.272969(logage) + 0.246964(lognum)
Rowollon	Simple	Simple	3.094911 - 0.002233(age) + 0.002291(num)
		Polynomial	3.40823 - 0.002606(age) - 0.226466(num) + 0.046206(num^2) - 0.002423(num^3)
		Logarithmic	3.127787 - 0.002654(age) + 0.134063(lognum)
	Polynomial	Simple	3.342906 - 0.044608(age) + 0.001312(age^2) - 0.00001(age^3) + 0.020087(num)
		Polynomial	3.650266 - 0.040942(age) + 0.001122(age^2) - 0.000008(age^3) - 0.275481(num) + 0.062207(num^2) - 0.003659(num^3)
		Logarithmic	3.375444 - 0.046015(age) + 0.001346(age^2) - 0.00001(age^3) + 0.123929(lognum)
	Logarithmic	Simple	3.242818 - 0.160763(logage) - 0.018986(num)
		Polynomial	3.558364 - 0.168028(logage) - 0.237616(num) + 0.048813(num^2) - 0.002619(num^3)
		Logarithmic	3.295191 - 0.178395(logage) + 0.098219(lognum)
Foria	Simple	Simple	3.843096 - 0.006666(age) - 0.012148(num)
		Polynomial	4.116029 - 0.00734(age) - 0.035539(num) + 0.000343(num^2) + 0.000001(num^3)
		Logarithmic	4.423592 - 0.007045(age) - 0.662046(lognum)
	Polynomial	Simple	3.933397 - 0.016627(age) - 0.000253(age^2) - 0.000012(age^3) - 0.011593(num)
		Polynomial	4.341342 - 0.031288(age) + 0.000396(age^2) + 0.000004(age^3) - 0.042972(num) + 0.000569(num^2) - 0.0000003(num^3)
		Logarithmic	4.549068 - 0.024634(age) + 0.000088(age^2) + 0.000008(age^3) - 0.651251(lognum)
	Logarithmic	Simple	3.958864 - 0.216009(logage) - 0.011971(num)
		Polynomial	4.270196 - 0.251518(logage) - 0.035695(num) + 0.0003(num^2) + 0.000002(num^3)
		Logarithmic	4.556594 - 0.236035(logage) - 0.660611(lognum)

Table 6. Equations for curves for age and numbers in households for hookworm intensity (EPG) data.

Community	Age Equation	Number Equation	Equation
Kroo Bay	Simple	Simple	2.196888 + 0.002766(age) + 0.002913(num)
		Polynomial	2.381865 + 0.003685(age) - 0.057575(num) + 0.003872(num^2) -0.00006(num^3)
		Logarithmic	2.092236 + 0.002791(age) - 0.136398(lognum)
	Polynomial	Simple	2.299392 - 0.022356(age) + 0.000973(age^2) - 0.000009(age^3) + 0.004142(num)
		Polynomial	2.492376 - 0.016382(age) + 0.00082(age^2) - 0.000006(age^3) - 0.062173(num) + 0.004079(num^2) - 0.000062(num^3)
		Logarithmic	2.182045 - 0.021553(age) + 0.000936(age^2) - 0.000009(age^3) + 0.163075(lognum)
	Logarithmic	Simple	2.121299 + 0.122526(logage) + 0.002759(num)
		Polynomial	2.276913 + 0.16802(logage) - 0.05805(num) + 0.003887(num^2) - 0.00006(num^3)
		Logarithmic	2.019826 + 0.123256(logage) + 0.131031(lognum)
Rowollon	Simple	Simple	2.626143 + 0.003897(age) - 0.00332(num)
		Polynomial	2.594685 + 0.003896(age) - 0.068944(num) + 0.031384(num^2) - 0.002748(num^3)
		Logarithmic	2.601115 + 0.004002(age) + 0.00768(lognum)
	Polynomial	Simple	2.498582 + 0.028912(age) - 0.000898(age^2) + 0.000008(age^3) - 0.00344(num)
		Polynomial	2.484313 + 0.026798(age) - 0.000819(age^2) + 0.000008(age^3) - 0.06829(num) + 0.029879(num^2) - 0.00259(num^3)
		Logarithmic	2.477056 + 0.029054(age) - 0.000899(age^2) + 0.000008(age^3) + 0.001699(lognum)
	Logarithmic	Simple	2.466689 + 0.207722(logage) - 0.002018(num)
		Polynomial	2.431488 + 0.205517(logage) - 0.057952(num) + 0.028735(num^2) - 0.002562(num^3)
		Logarithmic	2.434174 + 0.212715(logage) + 0.022718(lognum)
Foria	Simple	Simple	2.521286 + 0.00461(age) - 0.001435(num)
		Polynomial	2.443094 + 0.004526(age) + 0.026353(num) - 0.001701(num^2) + 0.000025(num^3)
		Logarithmic	2.592091 + 0.004556(age) - 0.080368(lognum)
	Polynomial	Simple	2.22355 + 0.04464(age) - 0.001163(age^2) + 0.000009(age^3) - 0.001351(num)
		Polynomial	2.193934 + 0.037128(age) - 0.000904(age^2) + 0.000006(age^3) + 0.023011(num) - 0.001449(num^2) + 0.000021(num^3)
		Logarithmic	2.277897 + 0.044102(age) - 0.001145(age^2) + 0.000008(age^3) - 0.064261(lognum)
	Logarithmic	Simple	2.237248 + 0.310598(logage) - 0.001094(num)
		Polynomial	2.160379 + 0.295309(logage) + 0.027354(num) - 0.001662(num^2) + 0.000024(num^3)
		Logarithmic	2.287193 + 0.308633(logage) - 0.05704(lognum)

Table 7. Equations for curves to fit age and numbers in households for intensity (EPG) data.

Helminth	Community	Age Equation	Number Equation	Equation
T. trichuris	Kroo Bay	Simple	Simple	2.459211 - 0.002156(age) - 0.00488(num)
			Polynomial	2.464789 - 0.002051(age) - 0.017109(num) + 0.0011(num^2) - 0.000019(num^3)
			Logarithmic	2.515234 - 0.002043(age) - 0.12414(lognum)
		Polynomial	Simple	2.571343 - 0.01891(age) + 0.000386(age^2) - 0.000002(age^3) - 0.004967(num)
			Polynomial	2.608427 - 0.021322(age) + 0.000462(age^2) - 0.000003(age^3) - 0.022063(num) + 0.001397(num^2) - 0.000026(num^3)
			Logarithmic	2.627206 - 0.018634(age) + 0.000382(age^2) - 0.000002(age^3) - 0.126173(lognum)
		Logarithmic	Simple	2.504854 - 0.082242(logage) - 0.005084(num)
			Polynomial	2.523108 - 0.089177(logage) - 0.018713(num) + 0.001208(num^2) - 0.000021(num^3)
			Logarithmic	2.556263 - 0.074109(logage) - 0.128626(lognum)
	Rowollon	Simple	Simple	2.049404 - 0.002318(age) - 0.006346(num)
			Polynomial	1.9893 - 0.002231(age) + 0.014449(num) + 0.001763(num^2) - 0.000419(num^3)
			Logarithmic	2.029824 - 0.002223(age) - 0.021563(lognum)
		Polynomial	Simple	2.098222 - 0.004221(age) - 0.000154(age^2) + 0.000003(age^3) - 0.007634(num)
			Polynomial	2.054279 - 0.005432(age) - 0.000109(age^2) + 0.000003(age^3) + 0.001428(num) + 0.004768(num^2) - 0.0000621(num^3)
			Logarithmic	2.08417 - 0.004351(age) - 0.000144(age^2) + 0.000003(age^3) - 0.037004(lognum)
		Logarithmic	Simple	2.12001 - 0.103588(logage) - 0.006558(num)
			Polynomial	2.064733 - 0.103356(logage) + 0.008105(num) + 0.003584(num^2) - 0.000553(num^3)
			Logarithmic	2.097999 - 0.099392(logage) - 0.023589(lognum)
S. mansoni	Foria	Simple	Simple	2.118358 + 0.000556(age) - 0.006424(num)
			Polynomial	1.855897 + 0.001274(age) + 0.044522(num) - 0.002348(num^2) + 0.000029(num^3)
			Logarithmic	2.194378 + 0.000549(age) - 0.179816(lognum)
		Polynomial	Simple	1.087337 + 0.141814(age) - 0.005089(age^2) + 0.000051(age^3) - 0.00627(num)
			Polynomial	0.8748 + 0.140024(age) - 0.004981(age^2) + 0.00005(age^3) + 0.032507(num) - 0.001577(num^2) + 0.000018(num^3)
			Logarithmic	1.154815 + 0.140944(age) - 0.005073(age^2) + 0.000051(age^3) - 0.162023(lognum)
		Logarithmic	Simple	1.913357 + 0.16549(logage) - 0.006377(num)
			Polynomial	1.61409 + 0.196618(logage) + 0.046647(num) - 0.002418(num^2) + 0.00003(num^3)
			Logarithmic	1.9924 + 0.159562(logage) - 0.175107(lognum)

Table 8. Multiple regression analysis for *T. trichuris* and *S. mansoni* intensity (EPG) for age of individual and number of individuals per household.

Helminth	Community	Age Equation	Number Equation	F value	df	p	r^2
T. trichuris	Kroo Bay	Simple	Simple	1.42850	2,167	0.2426	0.00505
			Polynomial	1.15612	4,165	0.3322	0.00368
			Logarithmic	0.92445	2,167	0.3988	-0.00089
		Polynomial	Simple	1.43688	4,165	0.2240	0.01023
			Polynomial	1.33542	6,163	0.2442	0.01177
			Logarithmic	1.16924	4,165	0.3263	0.00399
		Logarithmic	Simple	1.38167	2,167	0.2540	0.00450
			Polynomial	1.21098	4,165	0.3081	0.00497
			Logarithmic	0.83832	2,167	0.4342	-0.00192
	Rowollon	Simple	Simple	1.07072	2,227	0.3445	0.00062
			Polynomial	0.87772	4,225	0.4780	-0.00214
			Logarithmic	0.89739	2,227	0.4091	-0.00090
		Polynomial	Simple	1.59050	4,225	0.1777	0.01021
			Polynomial	1.28910	6,223	0.2632	0.00752
			Logarithmic	1.47765	4,225	0.2098	0.00827
		Logarithmic	Simple	1.19034	2,227	0.3060	0.00166
			Polynomial	0.96618	4,225	0.4268	-0.00059
			Logarithmic	1.00779	2,227	0.3667	0.00007
S. mansoni	Foria	Simple	Simple	0.75849	2,51	0.4736	-0.00920
			Polynomial	0.60549	4,49	0.6605	-0.03069
			Logarithmic	0.39504	2,51	0.6757	-0.02336
		Polynomial	Simple	1.54497	4,49	0.2039	0.03950
			Polynomial	1.11213	6,47	0.3697	0.01254
			Logarithmic	1.31404	4,49	0.2779	0.02315
		Logarithmic	Simple	0.90084	2,51	0.4126	-0.00376
			Polynomial	0.69707	4,49	0.5977	-0.02340
			Logarithmic	0.52321	2,51	0.5958	-0.01832

Table 9. Results of Cochran's C tests for homogeneity of variances for covariance analysis.

Helminth	Community	Cochran'c C	df	p
A. lumbricoides	Kroo Bay	0.28993	24,4	1.000
	Rowollon	0.33018	22,4	0.453
	Foria	0.36212	31,4	0.107
Hookworm	Kroo Bay	0.40830	20,4	0.064
	Rowollon	0.33219	71,4	0.062
	Foria	0.28163	65,4	0.798
T. trichiura	Kroo Bay	0.29987	42,4	0.584
	Rowollon	0.31439	57,4	0.245
S. mansoni	Foria	0.33650	13,4	0.613

Table 10. Results of Bartlett-Box tests for homogeneity of variances for covariance analysis.

Helminth	Community	Bartlett-Box F	df	p
A. lumbricoides	Kroo Bay	0.18071	3,8394	0.910
	Rowollon	0.55834	3,10220	0.643
	Foria	1.64074	3,9538	0.178
Hookworm	Kroo Bay	1.26799	3,6649	0.284
	Rowollon	1.67820	3,128772	0.170
	Foria	0.34459	3,75760	0.793
T. trichiura	Kroo Bay	1.34565	3,32734	0.258
	Rowollon	0.71496	3,82718	0.543
S. mansoni	Foria	0.28950	3,2912	0.833

Appendix IV

Table 1. Differences between morphometric values for randomly and non randomly chosen children for the *A. lumbricoides* analysis.

Community	Morphometric Measurement	Levene's F	df	p	t-value	df	p
	Weight-for-Age	2.810	1,110	0.097	-0.12	110	0.902
Kroo Bay	Height-for-Age	0.190	1,176	0.663	0.65	176	0.514
	Height-for-Weight	0.666	1,110	0.416	1.64	110	0.103
	Weight-for-Age	1.529	1,183	0.218	-3.25*	183	0.001
Rowollon	Height-for-Age	0.471	1,219	0.493	-2.06*	219	0.041
	Height-for-Weight	0.125	1,183	0.724	0.01	183	0.995
	Weight-for-Age	1.916	1,117	0.169	0.84	117	0.401
Foria	Height-for-Age	0.018	1,140	0.892	0.03	140	0.976
	Height-for-Weight	0.279	1,116	0.598	-1.45	116	0.150

* Indicates differences found to be significant at the $p \leq 0.05$ level.

Table 2. Differences between morphometric values for randomly and non randomly chosen children for the hookworm analysis.

Community	Morphometric Measurement	Levene's F	df	p	t-value	df	p
	Weight-for-Age	0.401	1,19	0.534	0.48	19	0.635
Kroo Bay	Height-for-Age	0.029	1,20	0.868	-0.16	20	0.873
	Height-for-Weight	0.308	1,19	0.586	-1.08	19	0.292
	Weight-for-Age	0.001	1,82	0.972	-1.25	82	0.216
Rowollon	Height-for-Age	1.319	1,83	0.254	-0.33	83	0.743
	Height-for-Weight	0.677	1,82	0.413	1.06	82	0.292
	Weight-for-Age	0.222	1,67	0.639	-2.09*	67	0.040
Foria	Height-for-Age	1.865	1,68	0.177	-1.68	68	0.097
	Height-for-Weight	2.046	1,67	0.157	0.24	67	0.815

* Indicates differences found to be significant at the $p \leq 0.05$ level.

Table 3. Differences between morphometric values for randomly and non randomly chosen children for the *T. trichiura* analysis.

Community	Morphometric Measurement	Levene's F	df	p	t-value	df	p
	Weight-for-Age	0.575	217	0.449	-2.68*	217	0.008
Rowollon	Height-for-Age	0.113	253	0.737	-1.46	253	0.145
	Height-for-Weight	0.012	217	0.914	0.16	217	0.876

* Indicates differences found to be significant at the $p \leq 0.05$ level.

Table 4. Differences between morphometric values for randomly and non randomly chosen children for the *S. mansoni* analysis.

Community	Morphometric Measurement	Levene's F	df	p	t-value	df	p
	Weight-for-Age	0.000	150	0.996	-0.53	150	0.597
Foria	Height-for-Age	0.500	182	0.481	0.95	182	0.344
	Height-for-Weight	0.241	149	0.624	0.13	149	0.899

Table 5. Results of Levene's tests of homogeneity of variances for the analyses of variances of the mean morphometric measurements between the three communities.

Morphometric Measurement	F Value	df	p
Weight-for-Age	0.5997	2,285	0.550
Height-for-Age	0.8760	2,367	0.417
Weight-for-Height	3.5922*	2,284	0.029

* Indicates differences found to be significant at the $p \leq 0.05$ level.

Table 6. Differences needed between means for significant differences in weight-for-age between the three communities.

	Community		
Community	Kroo Bay	Rowollon	Foria
Kroo Bay	-	0.4201	0.4151
Rowollon		-	0.3817
Foria			-

Table 7. Chi-square table of differences in prevalence of wasting measured by number of children with z-scores of weight-for-age under -2 between the three communities.

	Community			
Wasting	Kroo Bay (Expected)	Rowollon (Expected)	Foria (Expected)	Totals
Present	25 (28.8)	27 (39.0)	57 (41.3)	109
Absent	51 (47.2)	76 (64.0)	52 (67.7)	179
Totals	76	103	109	288

Table 8. Chi-square table of differences in prevalence of stunting measured by number of children with z-scores of height-for-age under -2 between the three communities.

	Community			
Stunting	Kroo Bay (Expected)	Rowollon (Expected)	Foria (Expected)	Totals
Present	39 (39.5)	41 (40.9)	45 (44.6)	125
Absent	78 (77.5)	80 (80.1)	87 (87.4)	245
Totals	117	121	132	370

Table 9. Chi-square table of differences in prevalence of wasting measured by number of children with z-scores of weight-for-height under -2 between the three communities.

	Community			
Wasting	Kroo Bay (Expected)	Rowollon (Expected)	Foria (Expected)	Totals
Present	10 (9.5)	25 (12.9)	1 (13.5)	36
Absent	66 (66.5)	78 (90.1)	107 (94.5)	251
Totals	76	103	108	287

Table 10. Collapse of Chi-square table for prevalence of wasting measured by number of children with z-scores of weight-for-age under -2 between Kroo Bay and Rowollon combined versus Foria.

	Community		
Wasting	Kroo Bay & Rowollon (Expected)	Foria (Expected)	Totals
Present	52 (67.8)	57 (41.2)	109
Absent	127 (111.2)	52 (67.8)	179
Totals	179	109	288

Table 11. Collapse of Chi-square table for prevalence of wasting measured by number of children with z-scores of weight-for-age under -2 between Kroo Bay and Rowollon.

	Community		
Wasting	Kroo Bay (Expected)	Rowollon (Expected)	Totals
Present	25 (22.1)	27 (29.9)	52
Absent	51 (53.9)	76 (73.1)	127
Totals	76	103	179

Table 12. Collapse of Chi-square table for prevalence of wasting measured by number of children with z-scores of weight-for-height under -2 between Kroo Bay and Foria.

	Community		
Wasting	Kroo Bay (Expected)	Foria (Expected)	Totals
Present	10 (4.5)	1 (6.5)	11
Absent	66 (71.5)	107 (101.5)	173
Totals	76	108	184

Table 13. Collapse of Chi-square table for prevalence of wasting measured by number of children with z-scores of weight-for-height under -2 between Kroo Bay and Rowollon.

	Community		
Wasting	Kroo Bay (Expected)	Rowollon (Expected)	Totals
Present	10 (14.9)	25 (20.1)	35
Absent	66 (61.1)	78 (82.9)	144
Totals	76	103	179

Table 14. Chi-square table of differences in prevalence of *A. lumbricoides* infection between the three communities.

	Community			
A. lumbricoides	Kroo Bay (Expected)	Rowollon (Expected)	Foria (Expected)	Totals
Present	36 (42.8)	34 (45.2)	52 (34.0)	122
Absent	143 (136.2)	155 (143.8)	90 (108.0)	388
Totals	179	189	142	510

Table 15. Chi-square table of differences in prevalence of hookworm infection between the three communities.

	Community			
Hookworm	Kroo Bay (Expected)	Rowollon (Expected)	Foria (Expected)	Totals
Present	23 (57.6)	85 (61.2)	70 (59.2)	178
Absent	156 (121.4)	105 (128.8)	114 (124.8)	375
Totals	179	190	184	553

Table 16. Chi-square table of differences in prevalence of *T. trichiura* infection between the three communities.

	Community			
T. trichiura	Kroo Bay (Expected)	Rowollon (Expected)	Foria (Expected)	Totals
Present	61 (29.7)	69 (55.9)	2 (46.4)	132
Absent	57 (88.3)	153 (166.1)	182 (137.6)	392
Totals	118	222	184	524

Table 17. Collapse of Chi-square table for prevalence of *A. lumbricoides* infection between Kroo Bay and Rowollon.

	Community		
A. lumbricoides	Kroo Bay (Expected)	Rowollon (Expected)	Totals
Present	36 (34.0)	34 (36.0)	70
Absent	143 (145.0)	155 (153.0)	298
Totals	179	189	368

Table 18. Collapse of Chi-square table for prevalence of *A. lumbricoides* infection between Kroo Bay and Rowollon combined versus Foria.

	Community		
A. lumbricoides	Kroo Bay & Rowollon (Expected)	Foria (Expected)	Totals
Present	70 (88.0)	52 (34.0)	122
Absent	298 (280.0)	90 (108.0)	388
Totals	368	142	510

Table 19. Collapse of Chi-square table for prevalence of hookworm infection between Foria and Rowollon.

	Community		
Hookworm	Foria (Expected)	Rowollon (Expected)	Totals
Present	85 (78.7)	70 (76.3)	155
Absent	105 (111.3)	114 (107.7)	219
Totals	190	184	374

Table 20. Collapse of Chi-square table for prevalence of hookworm infection between Foria and Rowollon combined versus Kroo Bay.

	Community		
Hookworm	Foria & Rowollon (Expected)	Kroo Bay (Expected)	Totals
Present	155 (120.4)	23 (57.6)	178
Absent	219 (253.6)	156 (121.4)	375
Totals	374	179	553

Table 21. Collapse of Chi-square table for prevalence of *T. trichiura* infection between Kroo Bay and Rowollon.

	Community		
T. trichiura	Kroo Bay (Expected)	Rowollon (Expected)	Totals
Present	61 (45.1)	69 (84.9)	130
Absent	57 (72.9)	153 (137.1)	210
Totals	118	189	340

Table 22. Collapse of Chi-square table for prevalence of *T. trichiura* infection between Rowollon and Foria.

	Community		
T. trichiura	Rowollon (Expected)	Foria (Expected)	Totals
Present	69 (38.8)	2 (32.2)	71
Absent	153 (183.2)	182 (151.8)	335
Totals	222	184	406

Table 23. Results of Levene's tests of homogeneity of variances for the analyses of variances of the intensity of helminth infections between communities.

Helminth Infection	F Value	df	p
A. lumbricoides	0.5044	2,119	0.605
Hookworm	2.1434	2,175	0.120
T. trichiura	0.072	1,128	0.789

Table 24. Differences needed between means for significant differences in the intensity of *A. lumbricoides* infections between the three communities.

	Community		
Community	Kroo Bay	Rowollon	Foria
Kroo Bay	-	0.3165	0.2869
Rowollon		-	0.2919
Foria			-

Table 25. Differences needed between means for significant differences in the intensity of hookworm infections between the three communities.

	Community		
Community	Kroo Bay	Rowollon	Foria
Kroo Bay	-	0.2845	0.2910
Rowollon		-	0.1954
Foria			-

Table 26. Results of Levene's tests of homogeneity of variances for differences in morphometric measurements between infected and uninfected children in the three communities.

Community	Helminth	Morphometric measurement	Levene's F	df	p
Kroo Bay	*A. lumbricoides*	Weight-for-Age	0.207	1,109	0.650
		Height-for-Age	4.1918*	1,172	0.042
		Weight-for-Height	1.873	1,109	0.174
	Hookworm	Weight-for-Age	0.199	1,109	0.656
		Height-for-Age	4.641*	1,172	0.033
		Weight-for-Height	0.006	1,109	0.937
	T. trichiura	Weight-for-Age	0.059	1,74	0.809
		Height-for-Age	8.741*	1,113	0.004
		Weight-for-Height	1.628	1,74	0.206
Rowollon	*A. lumbricoides*	Weight-for-Age	0.070	1,91	0.792
		Height-for-Age	3.912	1,101	0.051
		Weight-for-Height	1.844	1,166	0.176
	Hookworm	Weight-for-Age	0.096	1,166	0.757
		Height-for-Age	0.471	1,188	0.494
		Weight-for-Height	2.672	1,166	0.104
	T. trichiura	Weight-for-Age	0.135	1,91	0.714
		Height-for-Age	0.332	1,220	0.565
		Weight-for-Height	2.786	1,198	0.097
Foria	*A. lumbricoides*	Weight-for-Age	0.016	1,117	0.900
		Height-for-Age	2.991	1,140	0.086
		Weight-for-Height	1.808	1,106	0.182
	Hookworm	Weight-for-Age	0.004	1,107	0.951
		Height-for-Age	1.571	1,182	0.212
		Weight-for-Height	0.123	1,149	0.726
	S. mansoni	Weight-for-Age	0.446	1,150	0.505
		Height-for-Age	0.047	1,182	0.828
		Weight-for-Height	1.056	1,149	0.306

* Indicates differences found to be significant at the $p \leq 0.05$ level.

Table 27. Differences needed between mean ranks for significant differences at $p \leq 0.05$ for mean comparisons of classes of hookworm intensity and weight-for-height z-scores in children from Rowollon.

Intensity	1-99 EPG	100-999 EPG	1000-1999 EPG	2000-2999 EPG	3000-4999 EPG	> 5000 EPG
1-99 EPG	-	20.32	34.00	34.00	44.83	34.00
100-999 EPG		-	31.08	31.08	42.66	31.08
1000-1999 EPG			-	41.33	50.62	41.33
2000-2999 EPG				-	50.62	41.33
3000-4999 EPG					-	50.62
> 5000 EPG						-

Table 28. Equations for curves for age and morphmetric measurements, with F values, *df*, *p values and adjusted r square values.*

Morphometric Measurement	Community	Type of Equation	Equation	F Value	df	p	Adjusted r^2
Weight-for-Age	Kroo Bay	Simple	-2.209120 + 0.207697(age)	6.010	1,74	0.0166	0.06262
		Polynomial	1.98056 - 3.384579(age) + 0.869101(age^2) - 0.062714(age^3)	4.340	3,72	0.0072	0.11784
		Logarithmic	-2.139821 + 1.383431(logage)	3.85	1,74	0.0535	0.3661
	Rowollon	Simple	-1.793956 + 0.178186(age)	4.963	1,101	0.0281	0.0374
		Polynomial	-1.874953 - 0.406941(age) + 0.294467(age^2) - 0.031042(age^3)	4.562	3,99	0.0049	0.09482
		Logarithmic	-2.116923 + 1.849163 (logage)	7.107	1,101	0.0089	0.05649
	Foria	Simple	-3.496246 + 0.274618(age)	15.167	1,107	0.0002	0.11596
		Polynomial	-0.92544 - 1.786482(age) + 0.4596(age^2) - 0.03056(age^3)	7.326	3,105	0.0002	0.14947
		Logarithmic	-3.283694 + 1.708186(logage)	8.453	1,107	0.0044	0.06455
Height-for-Age	Kroo Bay	Simple	-1.367802 - 0.007565(age)	0.024	0.024	0.8778	-0.00849
		Polynomial	0.132344 - 2.071558(age) + 0.587287(age^2) - 0.045055(age^3)	11.356	3,113	0.0000	0.21157
		Logarithmic	-1.213735 - 0.592447(logage)	6.978	1,115	0.0094	0.04901
	Rowollon	Simple	-1.974296 + 0.095189(age)	3.391	1.119	0.0680	0.01954
		Polynomial	-1.364981 - 0.918873(age) + 0.347961(age^2) - 0.031269(age^3)	3.402	3,117	0.0201	0.05665
		Logarithmic	-1.751679 + 0.280828(logage)	0.982	1,119	0.3237	-0.00015
	Foria	Simple	-2.156712 + 0.140305(age)	10.378	1,130	0.0016	0.06680
		Polynomial	-1.754913 - 0.335529(age) + 0.128396(age^2) - 0.009689(age^3)	3.786	3,128	0.0121	0.05997
		Logarithmic	-1.945404 + 0.710400(logage)	7.258	1,130	0.0080	0.04559
Weight-for-Height	Kroo Bay	Simple	-0.808558 - 0.002409(age)	0.002	1,74	0.9647	-0.01349
		Polynomial	-2.027044 + 1.071882(age) - 0.267462(age^2) + 0.01982(age^3)	0.429	3,72	0.7328	-0.02337
		Logarithmic	-0.837834 + 0.035129(logage)	0.006	1,74	0.9373	-0.01343
	Rowollon	Simple	-1.221118 - 0.006822(age)	0.010	1,101	0.9195	-0.00980
		Polynomial	-3.929655 + 2.19151(age) - 0.51745(age^2) + 0.036699(age^3)	1.085	3,99	0.3592	0.00249
		Logarithmic	-1.304141 + 0.094092(logage)	0.025	1,101	0.8735	-0.00965
	Foria	Simple	0.135706 - 0.075983(age)	2.873	1,106	0.0930	0.01720
		Polynomial	-0.706259 + 0.511069(age) - 0.110682(age^2) + 0.005974(age^3)	1.766	3,104	0.1583	0.02101
		Logarithmic	0.04651 - 0.424745(logage)	1.353	1,106	0.2474	0.00329

Table 29. Equations for curves for numbers in households and morphmetric measurements, with F values, df, p values and adjusted r square values.

Helminth	Community	Type of Equation	Equation	F value	df	p	r^2
Weight-for-Age	Kroo Bay	Simple	-1.596274 + 0.014553(num)	0.966	1,74	0.3290	-0.00046
		Polynomial	-1.8438 + 0.058912(num) - 0.001996($numb^2$) + 0.00002421($numb^3$)	0.353	3,72	0.7870	-0.02656
		Logarithmic	-2.054919 + 0.600134(lognum)	0.981	1,74	0.3252	-0.00025
	Rowollon	Simple	-1.077062 + 0.005078(num)	0.009	1,110	0.9239	-0.00981
		Polynomial	-1.843837 + 0.539747(num) - 0.0965464(num^2) + 0.005109(num^3)	0.363	3,99	0.7800	-0.0191
		Logarithmic	-1.222096 + 0.22118(lognum)	0.114	1,110	0.7365	-0.00876
	Foria	Simple	-2.437654 + 0.009691(num)	0.891	1,107	0.3472	-0.00101
		Polynomial	-1.956996 - 0.095518(num) + 0.005656(num^2) - 0.0000796(num^3)	1.115	3,105	0.3463	0.0032
		Logarithmic	-2.900614 + 0.522925(lognum)	0.995	1,107	0.3208	-0.00005
Height-for-Age	Kroo Bay	Simple	-1.472553 + 0.005112(num)	0.323	1,114	0.5709	-0.00592
		Polynomial	-1.452051 - 0.015501(num) + 0.001719(num^2) - 0.000029(num^3)	0.305	3,112	0.8214	-0.01845
		Logarithmic	-1.679278 + 0.249858(lognum)	0.419	1,114	0.5187	-0.00508
	Rowollon	Simple	-1.845439 + 0.0372(num)	0.865	1,119	0.3543	-0.00113
		Polynomial	-2.622523 + 7.38507(num) - 0.161553(num^2) + 0.010441(num^3)	0.961	3,117	0.4136	-0.00097
		Logarithmic	-2.043615 + 0.52582(lognum)	1.093	1.119	0.2979	0.00078
	Foria	Simple	-1.643239 + 0.002487(num)	0.106	1,130	0.7454	-0.00687
		Polynomial	-1.218449 - 0.084055(num) + 0.004477(num^2) - 0.0000618(num^3)	0.821	3,128	0.4846	-0.00412
		Logarithmic	-1.731037 + 0.110186(lognum)	0.078	1,130	0.7800	-0.00709
Weight-for-Height	Kroo Bay	Simple	- 0.647986 - 0.010959(num)	1.458	1,74	0.2311	0.00607
		Polynomial	-1.007608 + 0.063687(num) - 0.003884(num^2) + 0.000052(num^3)	0.696	3,72	0.5573	-0.01230
		Logarithmic	-0.412769 - 0.35539(lognum)	0.090	1,74	0.3435	-0.00122
	Rowollon	Simple	-1.465044 + 0.0366(num)	0.710	1,101	0.4015	-0.00285
		Polynomial	-1.741841 + 0.289104(num) - 0.057892(num^2) + 0.00372(num^3)	0.309	3,99	0.8189	-0.02075
		Logarithmic	-1.606553 + 0.451111(lognum)	0.706	1,101	0.4027	-0.00289
	Foria	Simple	-0.179241 - 0.001741(num)	0.079	1,106	0.7796	-0.00869
		Polynomial	-0.551069 + 0.040331(num) - 0.001107(num^2) + 0.000007(num^3)	0.390	3,104	0.7604	-0.01740
		Logarithmic	-0.179808 - 0.29906(lognum)	0.009	1,106	0.9350	-0.00935

Table 30. Equations for curves for age and number in households of weight-for-age z-scores.

Community	Age Equation	Number Equation	Equation
Kroo Bay	Simple	Simple	-2.462677 + 0.210429(age) + 0.015607(num)
		Polynomial	-3.008139 + 0.224646(age) + 0.124214(num) - 0.005998(num^2) + 0.0000838(num^3)
		Logarithmic	-2.934122 + 0.209504(age) + 0.628982(lognum)
	Polynomial	Simple	1.635996 -3.250231(age) + 0.83681(age^2) - 0.060364(age^3) + 0.011793(num)
		Polynomial	1.04054 - 3.16876(age) + 0.811432(age^2) - 0.057914(age^3) + 0.121631(num) - 0.005969(num^2) + 0.000083(num^3)
		Logarithmic	1.270763 - 3.248761(age) + 0.833846(age^2) - 0.059981(age^2) + 0.490623(lognum)
	Logarithmic	Simple	-2.407157 + 1.417406(logage) + 0.015916(num)
		Polynomial	-2.84049 + 1.491562(logage) + 0.101682(num) - 0.00465(num^2) + 0.00006464(num^3)
		Logarithmic	-2.874744 + 1.404715(logage) + 0.633694(lognum)
Rowollon	Simple	Simple	-1.801687 + 0.178118(age) + 0.001362(num)
		Polynomial	-2.286601 + 0.171312(age) + 0.308752(num) - 0.045125(num^2) + 0.001834(num^3)
		Logarithmic	-1.898942 + 0.177176(age) + 0.138072(lognum)
	Polynomial	Simple	-1.870899 - 0.401503(age) + 0.293258(age^2) - 0.03096(age^3) - 0.001918(num)
		Polynomial	-2.212329 - 0.374384(age) + 0.283471(age^2) -0.030105(age^3) + 0.174558(num) - 0.020486(num^2) + 0.000476(num^3)
		Logarithmic	-1.912443 - 0.421494(age) + 0.297529(age2) - 0.031244(age3) + 0.073609(lognum)
	Logarithmic	Simple	-2.110003 + 1.849947(logage) - 0.001253(num)
		Polynomial	-2.536389 + 1.796072(logage) + 0.259923(num) - 0.035301(num^2) + 0.001235(num^3)
		Logarithmic	-2.19139 + 1.841285(logage) + 0.099899(lognum)
Foria	Simple	Simple	-3.594938 + 0.270018(age) + 0.005291(num)
		Polynomial	-2.937157 + 0.267053(age) - 0.1175(num) + 0.006067(num^2) - 0.00008141(num^3)
		Logarithmic	-3.82767 + 0.269436(age) + 0.272224(lognum)
	Polynomial	Simple	-1.055685 - 1.746626(age) + 0.444658(age^2) - 0.029221(age^3) + 0.005476(num)
		Polynomial	-0.041361 - 1.835238(age) + 0.458374(age^2) - 0.029757(age^3) - 0.151488(num) + 0.007478(num^2) - 0.0000981(num^3)
		Logarithmic	-1.270254 - 1.745116(age) + 0.445123(age^2) - 0.029308(age^3) + 0.254782(lognum)
	Logarithmic	Simple	-3.389378 + 1.662286(logage) + 0.005946(num)
		Polynomial	-2.844318 + 1.611188(logage) - 0.099519(num) + 0.005458(num^2) - 0.0000752(num^3)
		Logarithmic	-3.676706 + 1.656127(logage) + 0.325777(lognum)

Table 31. Equations for curves for age and numbers in households of height-for-age z-scores.

Community	Age Equation	Number Equation	Equation
Kroo Bay	Simple	Simple	-1.46039 - 0.003448(age) + 0.004995(num)
		Polynomial	-1.440026 - 0.003481(age) - 0.015573(num) + 0.001717(num^2) - 0.000029(num^3)
		Logarithmic	-1.665155 - 0.003115(age) + 0.245666(lognum)
	Polynomial	Simple	-0.149351 - 2.07175(age) + 0.5969(age^2) - 0.04501(age^3) - 0.0007814(num)
		Polynomial	-0.023568 - 2.067347(age) + 0.584929(age^2) - 0.044806(age^3) + 0.023604(num) - 0.000805(num^2) + 0.000007(num^3)
		Logarithmic	0.093528 - 2.06388(age) + 0.585242(age^2) - 0.44898(age^3) + 0.027833(lognum)
	Logarithmic	Simple	-1.21225 - 0.589041(logage) + 0.000222(num)
		Polynomial	-1.289987 - 0.584808(logage) - 0.000313(num) + 0.000685(num^2) - 0.000015(num^3)
		Logarithmic	-1.290757 - 0.582652(logage) + 0.067935(lognum)
Rowollon	Simple	Simple	-2.185172 + 0.094487(age) + 0.036122(num)
		Polynomial	-2.865617 + 0.088759(age) + 0.666103(num) - 0.144677(num^2) + 0.00333(num^3)
		Logarithmic	-2.371634 + 0.094002(age) + 0.505305(lognum)
	Polynomial	Simple	-1.572028 - 0.929771(age) + 0.350446(age^2) - 0.031437(age^3) + 0.037121(num)
		Polynomial	-2.129333 - 0.856372(age) + 0.328347(age^2) - 0.029705(age^3) + 0.5168(num) - 0.113382(num^2) + 0.007446(num^3)
		Logarithmic	-1.751276 - 0.915757(age) + 0.346354(age^2) - 0.031116(age^3) + 0.488646(lognum)
	Logarithmic	Simple	-1.963747 + 0.275041(logage) + 0.036328(num)
		Polynomial	-2.732255 + 0.268046(logage) + 0.730166(num) - 0.159443(num^2) + 0.10289(num^3)
		Logarithmic	-2.160253 + 0.27555(logage) + 0.516949(lognum)
Foria	Simple	Simple	-2.167157 + 0.140055(age) + 0.0005052(num)
		Polynomial	-1.742114 + 0.138647(age) - 0.084006(num) + 0.004343(num^2) - 0.00006(num^3)
		Logarithmic	-2.170815 + 0.140202(age) + 0.011096(lognum)
	Polynomial	Simple	-1.762086 - 0.334625(age) + 0.127974(age^2) - 0.009648(age^3) + 0.000327(num)
		Polynomial	-1.277383 - 0.323027(age) + 0.120909(age^2) - 0.008872(age^3) - 0.091775(num) + 0.004602(num^2) - 0.000062(num^3)
		Logarithmic	-1.746413 - 0.335973(age) + 0.128569(age^2) - 0.009704(age^3) - 0.006455(lognum)
	Logarithmic	Simple	-1.953372 + 0.708973(logage) + 0.000383(num)
		Polynomial	-1.598219 + 0.69935(logage) - 0.075282(num) + 0.04045(num^2) - 0.000057(num^3)
		Logarithmic	-1.967218 + 0.709339(logage) + 0.017076(lognum)

Table 32. Equations for curves to fit age and numbers in households of weight-for-height z-scores.

Community	Age Equation	Number Equation	Equation
Kroo Bay	Simple	Simple	-0.630155 - 0.004331(age) - 0.010981(num)
		Polynomial	-1.026191 + 0.003585(age) + 0.064729(num) - 0.003947(num^2) + 0.000053(num^3)
		Logarithmic	-0.39837 - 0.003431(age) - 0.355863(lognum)
	Polynomial	Simple	-1.736147 + 0.958459(age) - 0.2402(age^2) + 0.017836(age^3) - 0.009956(num)
		Polynomial	-2.198213 + 1.015623(age) - 0.258635(age^2) + 0.019632(age^3) + 0.073796(num) - 0.004388(num^2) + 0.000060(num^3)
		Logarithmic	-1.572533 + 0.984912(age) - 0.244887(age^2) + 0.01807(age^3) - 0.314165(lognum)
	Logarithmic	Simple	-0.653916 + 0.1038(logage) - 0.010949(num)
		Polynomial	-1.050455 + 0.064121(logage) + 0.065526(num) - 0.003998(num^2) + 0.000054(num^3)
		Logarithmic	-0.426316 + 0.023211(logage) - 0.354836(lognum)
Rowollon	Simple	Simple	-1.42985 - 0.008651(age) + 0.03678(num)
		Polynomial	-1.704151 - 0.014583(age) + 0.308767(num) - 0.062271(num^2) + 0.003999(num^3)
		Logarithmic	-1.56775 - 0.10157(age) + 0.455872(lognum)
	Polynomial	Simple	-3.991239 + 2.108898(age) - 0.499079(age^2) + 0.35443(age^3) + 0.029134(num)
		Polynomial	-4.331839 + 2.132728(age) - 0.508267(age^2) + 0.036225(age^3) + 0.334197(num) - 0.069006(num^2) 0.004395(num^3)
		Logarithmic	-4.120033 + 2.11761(age) - 0.501903(age^2) + 0.035674(age^3) 0.373788(lognum)
	Logarithmic	Simple	-1.504874 + 0.071334(logage) + 0.036356(num)
		Polynomial	-1.750908 + 0.023516 + 0.28544(num) - 0.05709(num^2) + 0.003669(num^3)
		Logarithmic	-1.63752 + 0.058825(logage) + 0.447238(lognum)
Foria	Simple	Simple	0.145850 - 0.075524(age) - 0.00054(num)
		Polynomial	-0.258565 - 0.080509 + 0.047596(num) - 0.001257(num^2) + 0.000008(num^3)
		Logarithmic	0.086226 - 0.076749(age) + 0.040596(lognum)
	Polynomial	Simple	-0.678232 + 0.502823(age) - 0.107532(age^2) + 0.005691(age^3) - 0.001195(num)
		Polynomial	-1.244669 + 0.547686(age) - 0.118578(age^2) + 0.006415(age^3) + 0.062468(num) - 0.001902(num^2) + 0.000016(num^3)
		Logarithmic	-0.735885 + 0.514566(age) - 0.111912(age^2) + 0.00608(age^3) 0.021932(lognum)
	Logarithmic	Simple	0.060968 - 0.418433(logage) - 0.000808(num)
		Polynomial	-0.306371 - 0.446107(logage) + 0.041649(num) - 0.001061(num^2) + 0.000006(num^3)
		Logarithmic	0.021493 - 0.428035(logage) + 0.020716(lognum)

Table 33. Multiple regression analysis of weight-for-age z-scores for age of individual and number of individuals in a household.

Community	Age Equation	Number Equation	F value	df	p	r^2
Kroo Bay	Simple	Simple	3.606	2,73	0.0321	0.06498
		Polynomial	1.916	4,71	0.1172	0.04658
		Logarithmic	3.587	2,73	0.0327	0.06454
	Polynomial	Simple	3.418	4,71	0.0130	0.11424
		Polynomial	2.332	6,69	0.0414	0.09633
		Logarithmic	3.425	4,71	0.0128	0.11453
	Logarithmic	Simple	2.530	2,73	0.0866	0.03920
		Polynomial	1.324	4,71	0.2696	0.01697
		Logarithmic	2.497	2,73	0.0894	0.03838
Rowollon	Simple	Simple	2.457	2,100	0.0908	0.02778
		Polynomial	1.368	4,98	0.2507	0.01421
		Logarithmic	2.481	2,100	0.0888	0.02822
	Polynomial	Simple	3.387	4,98	0.0122	0.08560
		Polynomial	2.277	6,96	0.0425	0.06986
		Logarithmic	3.391	4,98	0.0121	0.08571
	Logarithmic	Simple	3.518	2,100	0.0334	0.04706
		Polynomial	1.871	4,98	0.1216	0.03302
		Logarithmic	3.531	2,100	0.0330	0.04729
Foria	Simple	Simple	7.681	2,106	0.0008	0.11010
		Polynomial	4.436	4,104	0.0024	0.11289
		Logarithmic	7.683	2,106	0.0008	0.11012
	Polynomial	Simple	5.539	4,104	0.0004	0.14392
		Polynomial	4.276	6,102	0.0007	0.15398
		Logarithmic	5.523	4,104	0.0005	0.14347
	Logarithmic	Simple	4.376	2,106	0.0149	0.05884
		Polynomial	2.714	4,104	0.0339	0.05968
		Logarithmic	4.404	2,106	0.0145	0.05930

Table 34. Multiple regression analysis of height-for-age z-scores for age of individual and number of individuals in a household.

Community	Age Equation	Number Equation	F value	df	p	r^2
Kroo Bay	Simple	Simple	0.162	2,113	0.8502	-0.01478
		Polynomial	0.228	4,111	0.9221	-0.02759
		Logarithmic	0.210	2,113	0.8112	-0.01394
	Polynomial	Simple	8.235	4,111	0.0000	0.20105
		Polynomial	5.450	6,109	0.0001	0.18844
		Logarithmic	8.234	4,111	0.0000	0.21003
	Logarithmic	Simple	3.416	2,113	0.0363	0.04033
		Polynomial	1.806	4,111	0.1327	0.02727
		Logarithmic	3.432	2,113	0.0357	0.04059
Rowollon	Simple	Simple	2.109	2,118	0.1259	0.01815
		Polynomial	1.461	4,116	0.2186	0.01513
		Logarithmic	2.210	2,118	0.1142	0.01977
	Polynomial	Simple	2.778	4,116	0.0301	0.05594
		Polynomial	2.001	6,114	0.0712	0.04765
		Logarithmic	2.801	4,116	0.0291	0.05664
	Logarithmic	Simple	0.902	2,118	0.4084	-0.00163
		Polynomial	0.943	4,116	0.4416	-0.00189
		Logarithmic	1.119	2,118	0.3640	0.00032
Foria	Simple	Simple	5.152	2,129	0.0070	0.05960
		Polynomial	3.160	4,127	0.0163	0.06188
		Logarithmic	5.150	2,129	0.0071	0.05958
	Polynomial	Simple	2.818	4,127	0.0279	0.05258
		Polynomial	2.268	6,125	0.0412	0.05489
		Logarithmic	2.817	4,127	0.0279	0.05257
	Logarithmic	Simple	3.602	2,129	0.0300	0.03821
		Polynomial	2.370	4,127	0.0560	0.04014
		Logarithmic	3.602	2,129	0.0300	0.03821

Table 35. Multiple regression analysis of wiehgt-for-height z-scores for age of individual and number of individuals in a household.

Community	Age Equation	Number Equation	F value	df	p	r^2
Kroo Bay	Simple	Simple	0.722	2,73	0.4891	-0.00746
		Polynomial	0.516	4,71	0.7241	-0.02649
		Logarithmic	0.450	2,73	0.6392	-0.01488
	Polynomial	Simple	0.611	4,71	0.6558	-0.02116
		Polynomial	0.526	6,69	0.7871	-0.03946
		Logarithmic	0.491	4,71	0.7423	-0.02790
	Logarithmic	Simple	0.719	2,73	0.4905	-0.00754
		Polynomial	0.520	4,71	0.7212	-0.02627
		Logarithmic	0.450	2,73	0.6396	-0.01489
Rowollon	Simple	Simple	0.360	2,100	0.6988	-0.01271
		Polynomial	0.241	4,98	0.9147	-0.03070
		Logarithmic	0.361	2,100	0.6979	-0.01269
	Polynomial	Simple	0.290	4,98	0.4555	-0.00314
		Polynomial	0.657	6,96	0.6847	-0.02062
		Logarithmic	0.929	4,98	0.4504	-0.00279
	Logarithmic	Simple	0.359	2,100	0.6994	-0.01273
		Polynomial	0.230	4,98	0.9211	-0.03115
		Logarithmic	0.355	2,100	0.7023	-0.01282
Foria	Simple	Simple	1.427	2,105	0.2447	0.00791
		Polynomial	1.076	4,103	0.3724	0.00283
		Logarithmic	1.431	2,105	0.2436	0.00800
	Polynomial	Simple	1.321	4,103	0.2672	0.01186
		Polynomial	1.163	6,101	0.3314	0.00913
		Logarithmic	1.313	4,103	0.2703	0.01155
	Logarithmic	Simple	0.678	2,105	0.5096	-0.00605
		Polynomial	0.652	4,103	0.6265	-0.01317
		Logarithmic	0.672	2,105	0.5128	-0.00617

Appendix V

Simulation model of roaches being infected.

roach2.c

```
#include <graphics.h>
#include <stdlib.h
#include <mouse.h
#include <conio.h
#include <math.h>
#include <time.h>
#include <stdio.h>
```

Header files which provide function prototype declarations for library functions:	
graphics.h:	Declares prototypes for graphics functions
stdlib.h	Declares commonly used routines
mouse.h	Declares prototypes for the mouse functions
conio.h	Declares functions used in calling DOS console I/O routines
math.h	Declares prototypes for the math functions
time.h	Defines a structure filled in by the time-conversion routines and provides prototypes for these routines
stdio.h	Defines the standard I/O predefined streams *stdin*, *stdprn*, and *stderr*

```
#define NOTEGA 0
#define YC      175
#define RADIUS          170
#define LEFT        0
#define RIGHT       1
#define MAXSPOTS        50
#define MAXROACH        50
#define EGGSPERSPOT     10
#define RADI        2
#define STOP_EATING_HEALTHY     200
#define START_EATING_HEALTHY        80
#define STOP_EATING_INFECT          200
#define START_EATING_INFECT     80
#define PI      3.1415926535897
#define TWOPI       PI *  2.0
```

Construction allowing the definition of a symbolic name or constant; allows for ease of changing	
NOTEGA	allows for the use of both ega (=0) and vga (=1) graphics
XC, YC, RADIUS	used to define circular roach enclosure
LEFT, RIGHT	left and right mouse buttons
MAXSPOTS	number of total food spots
MAXROACH	total number of cockroaches
EGGSPERSPOT	number of infective stages present at each 'infected food spot'
RADI	used for drawing small circular roaches
STOP_EATING_HEALTHY/_INFECT	sets 'hunger' level that tells roaches to stop eating at a food spot
START_EATING_HEALTHY/_INFECT	sets 'hunger' level that tells roaches, on encountering a food spot to start eating--these may be different for infected versus uninfected roaches
PI	used in calculating movement of roaches
TWOPI	used for distributing food spots

```
typedef   enum   roach_mode {
      walking, resting, hunting,
feeding
}  r_mode;
```

redefines the name of an existing variable, calls roach_mode r_mode
enum sets each of the items enclosed within the brackets to respectively; one, two, three, and four.

```
typedef   struct cockroach   {
      float      x_pos:
      float      y_pos:
      float      di;
      float      dj;
      int        food;
      void  *    image;
      int        hunger;
      int        hun_lo;
      int        hun_hi;
      r_mode     mode;
      int        no_para
}  cockroach;

cockroach       roach[MAXROACH];
```

Defines the structure cockroach, which will have information on where it is (x_pos and y_pos), its movement (di and dj), where it is eating (food), hunger levels that tell it to stop eating (hun_lo) and start eating (hun_hi), its behaviour type, (r_mode) as defined above, and the number of parasites that are infecting it (no_para). There is also a place to store the image of this structure.
It then defines the name of this structure to be cockroach.
It then declares that there will be as many of these structures allowed as are specified in MAXROACH, defined earlier, and these will be referred to as roach, i.e. roach[roach_no].

```
typedef   struct spot   {
      int     x_pos;
      int     y_pos;
      int     occupied;
      int     parasite;
      int     amount;
      int     allgone;
}  spot;

spot food[MAXSPOTS];
void move_roach(int  roach_no)
```

Defines a structure spot which will have information on its position (x_pos, y_pos), whether these is roach there (occupied), whether there are infective stages there (parasite), how much food is there (amount) and if the food is gone (allgone).
It then defines the name of this structure to be spot.
It then declares that there will be as many of these structures allowed as are specified in MAXSPOTS, defined earlier, and these will be referred to as food[spot_no].

Void : function that does not return a value.
In this case it tells each roach (0 through 49) how to move.

```
{
    float     R, ratio, theta, phi, thetax coordy, coordx, t tt, s, di, dj, sr, st;
    float     i, j;
    int       I, k, oldi, oldj, yasp, xasp, spot_no;
    float     v_par, v_per;

        i = roach[roach_no].x_pos;
        j = roach[roach_no].y_pos;

        di = roach[roach_no].di;
        dj = roach[roach_no].dj;

        if(random(100) > 90)  {
            float x, y;

            theta = ((random(100) - 200.0/400.0) * PI;
            x = di * cos(theta) + dj * sin(theta);
            y = - di * sin(theta) + dj * cos(theta);
            di = x;
            dj = y;
        }

    oldi = i; oldj = j;
    i +=di; j +=dj;

    R=(float) (i - XC) * (float) (i - XC) + (float) (j - YC) * (float) (j - YC);
    if (R > (float) (RADIUS * RADIUS)) {

            coordx = (i -= di);
            coordy = (j -= dj);


            phi = atan2(-(coordy - YC), (coordx - XC));
            theta = atan2(-dj,di) - phi;
```

Defines things needed for roach movement and whether they are to be integer or floating point values.

The x and y position of each roach.

Used for designation of changes in roach position

Allows for random deviations from roaches straight path by a random angle.

Used for moving to next x and y of roach position, for animation of roaches

R is defined as where each roach is within the circle; if refers to if the roach hits the edge of the circle

Immediately undo last step if hit side

```
            v_par = -dj * sin(theta) + di * cos(theta);
            v_per = -dj * cos(theta - di * sin(theta);

            v_par = -v_par;

            dj = v_par * sin(theta) + v_per *cos(theta);
            di = v_par * cos(theta) - v_per * sin(theta);

            roach[roach_no].di = di;
            roach[roach_no].dj = dj;
        }

        roach[roach_no]. hunger++;

        putimage( oldi-RADI, oldj-RADI, roach[roach_no].image, XOR_PUT );
        putimage (i-RADI, j_RADI, roach[roach_no].image, XOR_PUT );
        roach[roach_no].x_pos = i;
        roach[roach_no].y_pos = j;
}

void draw_a_roach(int i, int j, int colour, int roach_no)
{
        setcolor ( colour );
        circle (i, j, RADI);
        setfillstyle ( SOLID_FILL, colour );
        floodfill (i, j, colour );

        getimage (i-RADI, j-RADI, i+RADI, j+RADI, roach[roach_no].image);
}


void change_roach_colour (int roach_no, int colour)
{
        int i, j;
```

Reflect off wall of circle in billiard fashion;
Movement refers to roach of a certain number

Increase hunger rating for each change in position.

Used to draw an image (stored in memory) on the screen;
Used for animation, as images are just re drawn quickly in slightly different places to give the illusion of movement

Drawing a roach, which has elements i, j, colour and number.
The roach is circular, with dolour as defined, location of centre, i, j and radius as defined in RADI.
The circle is filled in with solid colour.
The function getimage stores the image of the circle in memory, can now use the above putimage function
for roach animation.

```
        i = roach[roach_no].x_pos;
        j = roach[roach_no].y_pos;
        putimage(i - RADI, j - RADI, roach[roach_no].image, XOR_PUT );
        draw_a_roach(600, 300 - 5 * roach_no, colour, roach_no);
        putimage ( 600 - RADI, 300 - 5 *roach_no - RADI, roach[roach_no].image, XOR_PUT );
        putimage(i - RADI, j - RADI, roach[roach_no].image, XOR_PUT );
}
```

Changing roach colour (when infected). Need roach and colour to change it to.
Take roach centre (x,y), draw a roach off screen of new colour
then replace old roach image with new roach image.

```
main()
```

This is the actual beginning of the program. The above commands have constructed objects to be used in the program and instructed the program how to manipulate these objects.

```
{
    float       R, ratio, theta, phi, thetax coordy, coordx, t, tt, s, di, dj, sr, st;
    float       i, j;
    int         I, k, oldi, oldj, grdr=DETECT, grmode yasp, xasp, spot_no, roach_no;
    unsigned size;

    initgraph (  &grdr, &grmode, "" );

getaspectratio( &xasp, &yasp );
    ratio = (float)yasp / (float)xasp;
    setbkcolor( BLACK );
    setcolor( BLUE );
#if NOTEGA
    circle( XC, YC, RADIUS + RADI );
#else
    ellipse( XC, YC, 0, 360, (RADIUS+RADI), (RADIUS+RADI);
#endif
    setfillstyle( SOLID_FILL, BLACK );
    floodfill( XC, YC, BLACK );


    if(!check_mouse_driver (1) exit(0);

    init_mouse (1, grdr, grmode);
```

Definition of items to be used in main program
Defining what type of format specifiers.

Loads graphic driver. Using DETECT for driver causes it to choose the highest resolution and mode available on the computer running the program

Draws circle for roaches to move in.
It has a black background, blue circle and is filled with black.

Initialises mouse and clears buttons

```
mouse_on (0);

button_press(LEFT);
button_press(RIGHT);

randomize();
for(spot_no = 0; spot_no < MAXSPOTS; ){
    float r, t;
    r = sqrt(random(RADIUS * RADIUS));
    t = random(1000);
    i = r * cos( t = (t * TWOPI / 1000.0) ) + XC;
    j = YC - r * sin(t);

    food[spot_no].x_pos = i;
    food[spot_no].y_pos = j;
    food[spot_no].occupied = 0;
    food[spot_no].amount = 100;
    food[spot_no].allgone = 0;


    food[spot_no].parasite = (random(1000) >= 750) && i >= 320? EGGSPERSPOT: 0;
    mouse_off(0);



    if food[spot_no++].parasite == 0) putpixel(i,j, WHITE);
    else putpixel(i,j, GREEN);
    mouse_on(0);
}


for(roach_no=0; roach_no<MAXROACH; )    {
    float r;
```

Puts in food spots in a random arrangement throughout the circle.

Sets position of food spots (0 through MAXSPOTS) as i and j;
sets its score for occupied to zero - unoccupied;
the amount of food at 100 and the allgone value to zero.

Used to determine which food spots have parasites
by using a random number
and their arrangement within the circle
if the two arguments are true then the food spot
will be given the number
of parasites previously defined in EGGSPERSPOT
if false, it will be given no parasites.

If food spot has no parasites they are white;
otherwise they are green.

Movement of roaches from zero to MAXROACH

```
        while(!button_press(LEFT) );
        mouse_on(0);

        i = mouse_grph_x;
        j = mouse_grph_y;

        roach[roach_no].x_pos = i;
        roach[roach_no].y_pos = j;

        roach[roach_no].di = r = (50.0 - random(100))/7.07107;
        r = sqrt(fabs(50.0 - r*r));
        roach[roach_no].dj = (random(100) > 50)? r: -r;

        roach[roach_no].hunger = 0;
        roach[roach_no].hun_lo = STOP_EATING_HEALTHY;
        roach[roach_no].hun_hi = START_EATING_HEALTHY;

        size = imagesize (i-RADI, j-RADI, i+RADI, j+RADI);
        roach[roach_no].image = malloc(size);

        mouse_off(0);
        draw_a_roach(i, j, MAGENTA, roach_no);

        roach[roach_no].mode = walking;
        roach[roach_no].food = -1;
        roach[roach_no++].no_para = 0;
        mouse_on;
}


mouse_off(0);

while(!kbhit())  {

        int     atfood;
```

Use mouse to place roaches, with i referring to the x position of the roach
j to the y position

Which direction to move if you're a roach, determined by random,
whether negative or positive

Sets levels for stopping and starting eating and sets the beginning level at zero.

Figures out the size of roach with RADI as defined earlier
and allocates memory space to roach image.

When mouse button pressed and released, draw a roach as defined earlier with location i, j,
of magenta colour and referred to subsequently as roach of number from zero to MAXROACH

While roach is in walking mode, put food level down one
and set parasites at zero at start for all roaches.

Turn off mouse after used to draw roaches

Until a key on the keyboard is hit, keep running the following loop.

Define types of format specifiers

```
float       v_par, v_per;

for(roach_no = 0; roach_no < MAXROACH; roach_no++) {

    if(roach[roach_no].mode == feeding)  {
        roach[roach_no].hunger -= 1;
        l = food[roach[roach_no].food].amount--;

        if((k = food[roach[roach_no].food].parasite) >= 1)   {
                float       x;
                x = ((float)k/(float)l * 1000.0;
                if(random(1000) < (int)x) {
                        i = roach[roach_no].no_para++;
                        food[roach[roach_no].food].parasite--;

                        if(i == 0) {
                                change_roach_colour(roach_no, GREEN);
                                roach[roach_no].hun_lo = STOP_EATING_INFECT;
                                roach[roach_no].hun_hi = START_EATING_INFECT;
                        }
                }

        }
        if(roach[roach_no].hunger < roach[roach_no].hun_lo    ||
                food[roach[roach_no].food].amount <= 0) {
                roach[roach_no].mode = walking;
                food[roach[roach_no].food].occupied -= 1;
                goto walk;
                }
        continue;
}

walk:
    move_roach(roach_no);
```

Run through the following for all roaches from zero to MAXROACH

If roach feeding, reduce hunger levels by one for each time through the loop and set l = new food amount at the food spot

If there are parasites at a food spot, infection will occur at random, based on the proportion of parasites to food which allows more parasites to infect the roach if there are more there to begin with

If the number of parasites in the roach is not equal to zero, then change the colour of the roach to green and also change the levels where the roach stop and starts eating

If hunger level of roach is below stop-eating level or amount of food at spot is zero, then go to walking mode immediately and change the occupied level of the food spot by subtracting one.

Skips rest of loop and goes back to top; in this case if hunger is no less than hun_lo or food amount is greater than zero, it goes back to where the roach mode is feeding

The goto walk that was mentioned above, instructs the roach to move

```
if(roach[roach_no].hunger > roach[roach_no].hun_hi)  {

    atfood = 0;
    i = roach[roach_no].x_pos;
    j = roach[roach_no].y_pos;
    for(k = 0; k < MAXSPOTS; k++){

        if(food[k].allgone) continue;

        if((int)i - RADI > food[k].x_pos   ||
            (int)i + RADI < food[k].x_pos ||
            (int)j - RADI > food[k].y_pos  ||
            (int)j + RADI < food[k].y_pos)   {

            if(food[k].amount <= 0)   {
               if (!food[k].occupied)  {

                    food[k].allgone = 1;
                    putpixel(food[k].x_pos,
                        food[k].y_pos, BLACK);
               }
            }

            continue;
            }

        atfood = 1;
        break;
    }

    if(atfood) {
        food[k].occupied += 1;
        roach[roach_no].food = k;
        roach[roach_no].mode = feeding;
```

If hunger levels are greater than start eating level, meaning that the roach is told to eat no further from the present spot

Atfood will then equal zero for food spots at certain roach locations if the following loop is followed.

If food is already allgone, go back to the top of the main loop

Make sure that the roach in question is not setting on top of the food spot by checking to make sure the circle drawn for a roach image is ot equal to the food spot in location (i,j)

If food amount is less than or equal to zero and if it is not occupied by another roach

Then food allgone is set equal to one and the pixel for it is turned black

Then go back to the top of the loop

Atfood then equals one and the loop is broken out of.

If atfood is 1 or any non-zero integer, then this if statement is true, if atfood is zero, then it is false. If atfood is one, then the food spot has one added to its occupied level, the roach food is k (the level of food at that spot) and the mode for a roach is feeding.

```
            }
        }
    }
}
    closegraph();

    for(roach_no = 0; roach_no < MAXROACH; roach_no++) {
        fprintf(stdprn, "\n%d, %d", roach[roach_no].no_para);
    }


}
```

Shut the graphics system down .
Happens when a key on the keyboard is hit.

Sends to the printer stream the roach number
and the number of parasites now in each of the roaches.