

**The effects of human disturbance and climatic
condition on breeding Cassin's auklets**

Yuri Vladimir Albores-Barajas

Division of environmental and evolutionary biology
Institute of Biomedical and Life Sciences
University of Glasgow

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Declaration

I declare that this thesis is my own work and no part of the work submitted here has been submitted as part of any previous examination. Supervision by R. W. Furness has helped develop ideas throughout the thesis.

Summary

Human disturbance has been observed to have effects on wildlife. These effects can be either positive or negative, depending on the study species; however, most of the research done to date has demonstrated negative effects that are reflective in the behaviour and reproductive biology of the organisms. I focused on Cassin's auklet, a burrow-nester species to study the effects of increasing tourism on the islands along the peninsula of Baja California, Mexico. I also studied the effects of adverse climatological conditions on breeding success of this species.

First, using some biometrics of the individuals captured, I tested a method for aging Cassin's auklet based on the iris colour. My results corroborate what was proposed before, juveniles have a dark-brown iris that shades into a complete white as they become adults. I also used morphometrics to determine the sex of the individual. When making intra-pair comparisons, it is possible to estimate the sex of the individual based on bill measurements. In 100% of the cases, individuals were correctly sexed using bill depth and width, as corroborated with DNA analysis.

Second, using distance as a measure of disturbance, I looked onto the effects of people walking around the island. In general, breeding success was lower in those sites closer to the path or the village; older and more experienced individuals represented the vast majority of the burrows further away from the disturbance source. After that, using an experimental approach, I manipulated the amount of disturbance received by the chicks

and recorded growth rate, as well as fledging weight, that may influence the possibility of survival for the chicks. I found that at the early stages of development, chicks grew at the same rate; however, chicks in the experimental groups reached a lower peak weight, compared to chick in the control group, and once fully feathered, chicks in the experimental group had a higher rate of weight loss, fledging lighter and earlier than control chicks.

I also had the opportunity to explore the effects of adverse climatic conditions on breeding success. My results show that under a warming of the upper layer of the ocean, as was registered in 2005, Cassin's auklets struggle to maintain a good body condition and, although attempting to breed, abandon the nest later on, to guarantee survival and another attempt to breed the following season should the condition improve. Breeding success decreased from nearly 70% in 2004 to less than 10% in 2005. Body condition was also lower in 2005, with a slight improvement the following year.

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Chapter 1

Study site and species description

1.1 San Benito Islands

The San Benito Islands are located in the west of the Peninsula of Baja California c. 65 km west of Point Eugenia, (28° 18' 30" N; 115° 34' 00" W). They comprise three islands (East, Middle and West) with an area of 195, 104 and 548 ha respectively, with a maximum altitude of 200 metres above sea level (m asl) (UNEP, 2003). The mean annual temperature is 22.6 °C, and the precipitation ranges from 15.4 mm to 244.1 mm per year, with a mean of 163.8 mm (Crosswhite et al., 1982, INEGI, 2006). These Sonoran desert islands are low in biodiversity but high in endemism, including at least eight endemic plant species (Junak and Philbrick, 2000). They have no native terrestrial mammals.

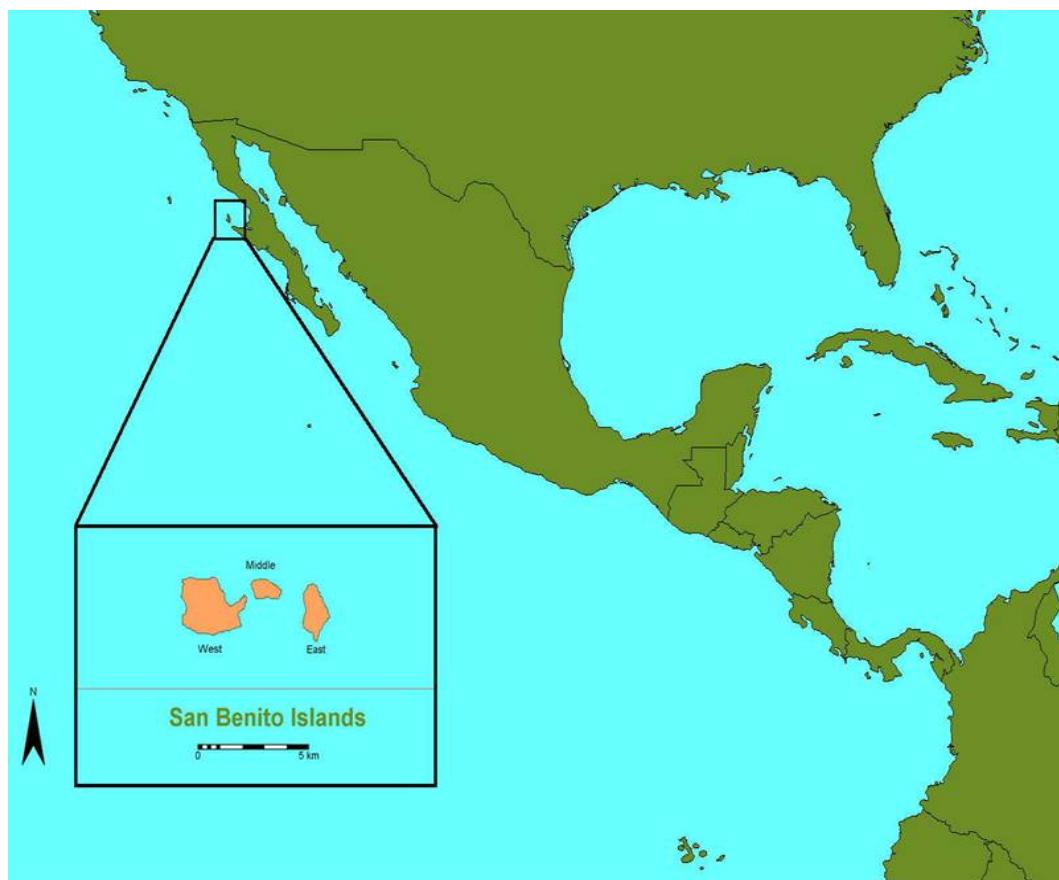


Figure 1.1 Geographical location of the San Benito Islands

The vegetation of the islands is categorised as mainly Vizcaino desertscrub and maritime desert scrub (Junak and Philbrick, 2000); this is mainly because the lack of fresh water, and soil conditions, are not appropriate for agriculture or cattle raising. This limits the presence of humans to temporary settlements, mainly fishermen or tourists (INEGI, 2006). The dominant plant community of the islands is maritime desert scrub, consisting of shrubs and perennials *Agave sebastiana* (Greene), *Atriplex barclayana* (Benth.), *Euphorbia misera* (Benth.), *Frankenia palmeri* (I.M. Johnst.), *Lycium brevipes* (Benth.), *L. californicum* (Nutt.), *Malva pacifica* (M.F. Ray), *Suaeda moquinii* (Greene) and two species of cacti, as well as winter annuals, *Cryptantha* spp., *Eschscholzia ramosa* (Greene), *Hemizonia streetsii* (A. Gray) and *Perityle emoryi* (Torr.) (Junak and Philbrick, 2000).

The San Benito Islands are an important seabird nesting site, with 12 species breeding in large numbers (Boswell, 1978). The islands hold the southernmost breeding colony of Cassin's auklet (*Ptychoramphus aleuticus*), with an estimated population of 30,000 individuals (Manuwal and Thoresen, 1993); it is also the northernmost breeding site for Craveri's murrelet (*Synthlyboramphus hypoleucus*) and one of two breeding sites in the Pacific for Heermann's gull (*Larus heermanii*) (Moran and Lindsay, 1951). Due to their large numbers, seabirds probably play an important role in terms of nutrient input to the islands (Anderson and Polis, 1999).

Introductions of alien animals to islands may have devastating effects, especially in areas with no native predators, where local fauna

may not have developed appropriate defence behaviour (Alvarez-Castaneda and Ortega-Rubio, 2003). European rabbits *Oryctolagus cuniculus* were introduced to the San Benito Islands during the early 1990s and have caused significant damage to the vegetation (Donlan et al., 2000), and they also compete for burrows with the burrowing seabird species. On West San Benito Island, rabbits were introduced in 1991; goats *Capra hircus* and donkeys *Equus asinus* have had a discontinuous presence since 1948 (Junak and Philbrick, 2000). At the beginning of the study, a few donkeys (5 in total) were present on West San Benito Island.

On East San Benito Island, rabbits were introduced between 1995 and 1996; rabbits were abundant by March 1996 (Donlan et al., 2000). There is no history of goats or donkeys being present on East San Benito. Given the small numbers of donkeys (one to five) and goats present on West San Benito, both historically (Moran and Lindsay, 1951) and just prior to the study, rabbits were considered the primary vertebrate herbivore on both islands. However, rabbits were recently eradicated from all three islands, with the last few individuals eradicated early in 2001 (Aguirre-Munoz et al., 2003).

1.2 Cassin's auklet (*Ptychoramphus aleuticus*)

1.2.1 Description

Cassin's auklet is one of the most widely distributed of the Pacific alcids, and one of the best studied. It has an overall length of approximately 23 cm, and weighs between 159 and 200 g. It is dark grey

on the upper parts, fading to paler grey below and whitish on the belly. Legs are bluish, with black claws. Juveniles have a brown iris that fades into white as they grow to adults. Two subspecies have been identified, the northern and larger *P. a. aleuticus* and the southern, smaller, *P.a. australis* (Nettleship, 1996). The latter is the form that is found on the San Benito Islands, and this subspecies is the smallest of all the Auklets (Manuwal, 1974b).

1.2.2 Distribution and habitat

Cassin's auklets can be found on the east coast of the Pacific. The largest colony is located in Triangle Island, British Columbia, with a total of 1,100,000 breeding individuals (Manuwal and Thoresen, 1993). In Mexico, the population is calculated to be around 40,000 individuals, most of them breeding in San Benito Islands (~30,000 individuals) (Manuwal and Thoresen, 1993).

Cassin's Auklets nest on small offshore islands that are far from human activities and other mammals. They spend their life on the open sea along the edge of the continental shelf and are rarely seen on the mainland (Manuwal and Thoresen, 1993). They come ashore only during the nesting season, from late December to late May in the San Benito Islands. Even then, they arrive on the colony well after dark and, unless they are incubating eggs or brooding small chicks, return to sea before dawn.



Figure 1.2 Cassin's auklet range and main colonies.

1.2.3 Feeding

Cassin's Auklets spend the daylight hours resting and feeding on the open ocean. The auklets are pursuit divers, feeding on small oil-rich crustaceans such as copepods and euphausiids that can be caught in the top 30 m of the sea. In spring and early summer, the auklets feed on larval or juvenile fish, which are also rich in oil and very abundant (Nettleship, 1996). Once captured, the prey is stored in a subgular pouch if the auklet is feeding a chick.

Food for Cassin's auklets is especially plentiful and available along continental shelf edges where upwelling currents carry nutrients to the surface. In most places, this shelf edge is only 20 to 30 km offshore; so

the auklets do not have to fly far when they carry food home to the chick (Manuwal and Thoresen, 1993, Abraham and Sydeman, 2006).

As Cassin's auklets dive, the preferred habitats are highly productive regions such as the subpolar areas or the boundaries where currents meet, as in these places there are dense prey aggregations that allow the birds to meet their energetic requirements (Piatt et al., 1990, Hodum et al., 1998).

1.2.4 Breeding

In addition to being better protected from many predators, birds nesting in burrows or rock crevices are apparently subjected to less environmental extremes than birds nesting on the ground surface, which are exposed to direct sunlight, rain, wind and other factors (Manuwal, 1974a).

Following on this point, temperature of the nest site is very important for the reproductive success of the birds, as it provides a stable and relatively warm environment that minimises the heat loss of the birds and also minimises heat loss between the bird (brood patch) and the egg (Manuwal, 1979).

Cassin's auklets breed from middle Baja California Peninsula to the Aleutian Islands in Alaska. They nest in either natural cavities, such as rock crevices or in burrows excavated in soft soil or sod. If breeding adults are successful, the burrow is used repeatedly year after year by the same pair (Manuwal and Thoresen, 1993). They lay one egg and incubation takes an average of 40 days to hatch (Manuwal, 1974b). Both parents

incubate for approximately 24 h before they are substituted by the partner. When the egg hatches, the parents will stay in the burrow until the chick is capable of thermoregulation, after that, they will leave the chick alone during the day and will return to the burrow at night to feed the chick (Albores-Barajas pers. obs.). When the chick has reached approximately adult size and is fully feathered, the parents will stop bringing food, and the chick will leave the burrow after a couple of days (Morbey et al., 1999).

The average length of the nestling period is 40 days, but it can vary latitudinally depending on the length of season of food availability (Morbey and Ydenberg, 1997).

Cassin's auklets are the only Alcid known to lay a second clutch. Around 90% of birds in Triangle Island, British Columbia relayed after the first egg was removed (Hipfner et al., 2004), but they don't usually in natural conditions lay a second clutch after successful rearing of the first. Only the southern subspecies (*P.a. australis*) lays a second clutch after a successful fledging (S. Wolf pers. comm.). This happens mainly for early breeders that lay the first egg in early January and incubate the egg for 40 days and attend for another 35-40 days until the chick fledges. They still have enough time to lay a second brood during mid-April. It has been noticed that mainly older and more experienced females lay eggs early in the season (Hipfner et al., 2004). Cassin's Auklets can start breeding as young as two years old, this being dependent on the resources available (Pyle, 2001).

The breeding season in San Benito Island starts in early January, much sooner than the other populations of Cassin's auklet, as conditions

in this area are not as severe as in places where the northern populations live.

Cassin's auklets apparently avoid interspecific nest-site competition, as it is a smaller species compared to other burrow nesters on the Pacific islands so can breed in smaller cavities and holes (Cody, 1973). Large populations, and hence intraspecific competition has probably forced a proportion of the population to breed in rock crevices (Manuwal, 1974b), whereas most of the individuals excavate the burrow by digging with their sharp claws in soft ground.

1.2.5 Conservation issues

The species is not threatened globally. Recently the population has shown a slow decline, mainly due to the introductions of non-native predators and to habitat alteration (Burger and Gochfeld, 1993), and to more frequent El Nino events that reduce breeding success.

Human disturbance may have a big effect on breeding birds (Reijnen et al., 1997). Each pair of auklets lays only one or two eggs a year. Disturbance by a curious tourist will cause the adult to abandon the egg, out of fear of a more dangerous predator. However, once an egg has hatched, the adult will rarely abandon its young (Albores-Barajas, Pers. obs.).

Tourism also threatens the habitat of colonies. The burrows are fragile and collapse when a person stands on one. Fortunately, many of the small wooded islands with auklet colonies are safe for the birds because they are inhospitable to visitors and offer neither drinking water

nor campsites. On the other hand, the grass-covered islands that hold most of the breeding population present a higher tourism presence and the consequences are more obvious (Bertram et al., 1999).

Changes in weather conditions have had enormous detrimental effects on seabird populations and especially the decrease of some populations by more than 50% as a result of a very severe El Niño phenomenon in 1997-98 (Jahncke and Goya, 2000, Mellink, 2000). These events could in the long-term take the populations to critically low levels as the kind of situations seem to be increasing in frequency, originally happening every 7 years but recently with successive events on two following years or on a periodicity from two to four years (Fedorov and Philander, 2000).

Recent studies have shown seabirds to be valuable indicators of marine pollution (Goutner et al., 2000, Arcos et al., 2002). Some seabirds, such as the Cassin's Auklet, travel widely over the oceans, feeding throughout the marine food chain and potentially accumulating persistent chemical contaminants. They return each year to the same breeding colony to lay their eggs, and the feathers contain a sample of the chemicals they acquired (Manuwal, 1979), so they could be used to assess the quality or the state of the areas frequented by that particular species.

1.2.6 Burrow displacement

Inter-specific competition seems to be a big issue for conservation strategies. Burrow displacement has been observed for storm-petrels in New Zealand (Imber et al., 2005). The same happens in San Benito Islands, when at the end of the breeding season of Cassin's Auklets, Leach's storm-petrels arrive and use the same burrows as the auklets. Many times chicks are still inside the burrows, so storm-petrels throw up on them and that way they are wet the whole day and may die of hypothermia, or are simply kicked out of the burrow (Albores-Barajas, pers. obs.)

The main objectives of this research were to determine the effects of disturbance on breeding success and on chick growth. I also wanted to investigate the effects of variable climatic conditions on breeding success and body conditions of Cassin's auklets.

In Chapter 2 I wanted to confirm with my own data what had been previously suggested as indicators of age and sex in Cassin's auklets. First, from individuals that I followed on all three years, I could corroborate how iris becomes paler as the individual grows old, until becoming completely white. Also, a method for estimating the sex of an individual while on the field could be useful; comparing biometrics from both, males and females, it is possible to tell the sex. A further corroboration was done using DNA sexing techniques.

In Chapter 3 I investigated the effects of disturbance on adult Cassin's auklets. Using distance as indicator of disturbance, I tested if individuals breeding further away from the disturbance source (either the camp or the path) had a better breeding success compared to those breeding nearby.

Chapter 4 was focused on the effects of experimental disturbance on chick growth and fledging weight. I considered the different factors that may have influenced growth such as parent's body condition, egg volume, hatching weight, etc.

Chapter 2

Aging and sexing Cassin's auklets

2.1 Abstract

It has been suggested that Cassin's auklets can be aged according to colour of the iris, and that sexing of breeding adults may be possible from their biometrics. I tested these hypotheses. For aging Cassin's auklets, I compared iris colour change in individuals that were measured in all three years of the study and found that iris colour is a good predictor of age for birds entering the breeding component of the population. For sexing this species, I took biometrics of both of the individuals within a pair, and by differences in the size of the bill, I assumed the male to be larger than the female. To confirm this assumption, a blood sample was taken and analysed and the results show that in 100% of the cases sex determination was correct. When using discriminant analysis based on morphometrics of adults, sex of 85% of the birds was predicted correctly. Therefore measuring both members of pairs provides the most reliable sexing based on morphometrics.

2.2 Introduction

In population dynamics studies, age and sex of the individuals are important factors to consider in order to establish how a phenomenon may affect a certain age-class or sex in one way or another (Nisbet, 2001). Also, it has been reported that age, or experience, has an influence on breeding success of several species (Ratcliffe and Furness, 1999).

For many species, aging can be a difficult task, and the only way to know the age is by long term monitoring programmes, where large-scale ringing of chicks is used to establish a population of known-age birds.

Several methods have been proposed to estimate the age of birds, such as differences in plumage quality or colour (Fancy et al., 1993, Jeffrey et al., 1993, Ortega et al., 1996), use of discriminant analysis to estimate age of tern chicks based on head size or bill length (Sanchez-Guzman and Del Viejo, 1998), use of other biometrics (Palomares et al., 1997) or eye colour (Manuwal, 1978, Newton and Marquiss, 1982).

The use of eye colour (specifically the colour of the iris) is well established as a means of classifying many species of birds of prey as juveniles, immatures or adults (Newton, 1986). For example, in the Sparrowhawk *Accipiter nisus*, iris colour changes from “lemon” in birds less than 1 year old, to “yellow” mostly in birds aged 1 and 2 years old, to “orange” in birds aged mostly 2 years old and older, and “red” in a few males of three years old or older (Newton and Marquiss, 1982). In seabirds, there are many species where eye colour appears to be the same in juveniles, immatures and adults, as for example in Common Guillemots *Uria aalge*, Atlantic Puffins *Fratercula arctica*, skuas and terns, and most (but not all) Procellariiformes (Cramp and Simmons, 1977, Cramp, 1985, Onley and Scofield, 2007). However, there are also many species where eye colour changes from juvenile to adult. For example, juvenile Shags *Phalacrocorax aristotelis* have pale eyes while adults have green eyes, juvenile Crested Auklets *Aethia cristatella* have dark yellow-brown eyes while adults have bright yellow-white eyes, juvenile Great Black-backed gulls *Larus marinus* have brown eyes, while adults have pale yellow eyes (Cramp and Simmons, 1977, Cramp and Simmons, 1982, Cramp, 1985). In these seabirds, changes in eye colour occur alongside

changes in plumage from juvenile to adult plumage, the adult plumage normally being attained before or just at the age at which birds start to breed (Cramp and Simmons, 1977, Cramp and Simmons, 1982, Cramp, 1985). So, for most seabirds where changes are evident with age, the changes in plumage provide a simpler guide to age than do changes in eye colour, and these both limit age-class classification to birds of pre-breeding ages and “breeders”. Birds that have reached breeding age appear generally to be homogeneous in terms of eye colour or plumage, although in some populations of some of the larger gull species, a few birds may occasionally start to breed still retaining small traces of immature plumage when environmental conditions permit early recruitment (Cramp and Simmons, 1982). Cassin's auklet is unusual among seabirds in apparently showing strong age-related changes in iris colour which occur despite no significant alteration in plumage details with age, and which apparently may continue after the age at which birds first breed. Thoresen (1964) assumed that juvenile Cassin's Auklets could be identified by their brown iris colour. Adult Cassin's Auklets have white irides (Type I, Fig. 2.1). After a nestling fledges, the iris colour apparently changes slowly over time from dark brown to the white of the adult and iris colour can be classified into a number of “Types” or classes, from brown to white. The iris colour first becomes lighter around the pupil and begins to extend outward as the fledgling matures. The irides change from Type IV to Type II or I in about two years. However, about 10% of the adults at least three years old are thought to retain a Type II or III iris colour (Manuwal, 1978).

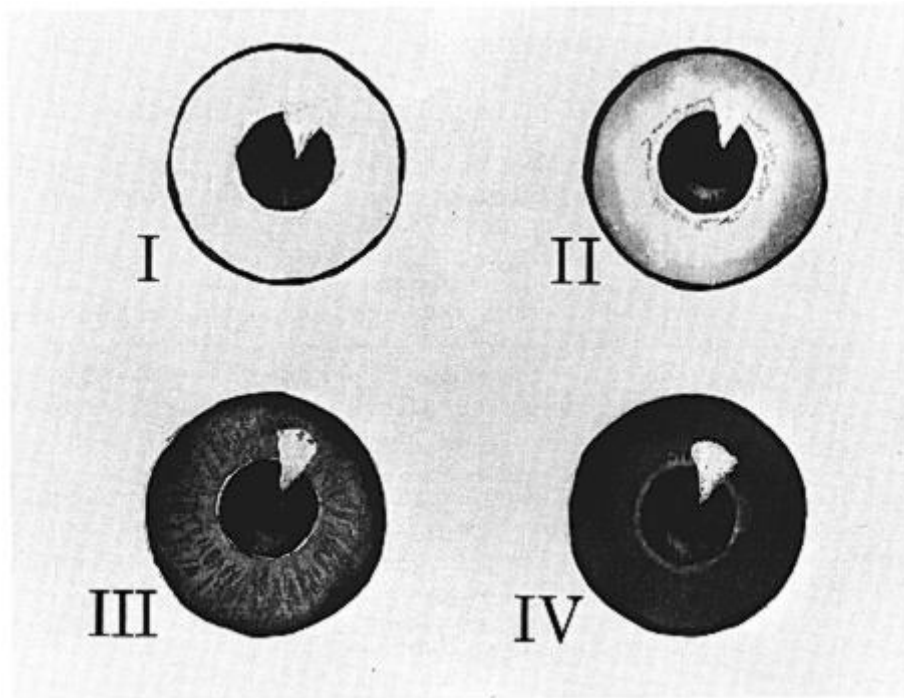


Figure 2.1. Iris colour types of Cassin's auklets. Type I, white iris (adult); Type II iris whitish around pupil, brown periphery (subadult); Type III iris light brown or mottled with brown flecks (juvenile); Type IV iris uniform dark brown (fledgling) (Manuwal 1978).

Sexing individuals can also be a problem in many species that do not present sexual dimorphism of plumage. The availability of increasingly simple and generally applicable molecular techniques for sexing birds may have a great impact on avian research (Lessells and Mateman, 1996). In conservation practice, adequately sexing an individual can determine the success of a conservation programme when talking, for instance, about captive breeding, colonisation of new areas or monitoring of populations (Lessells and Mateman, 1996). Sexing is also important in order to determine how some bird species have adapted to changing environmental conditions regulating the sex of the offspring according to resource availability (Ellegren et al., 1996). In fieldwork, it is sometimes necessary to determine immediately the sex of individuals in order to have

deeper detail and to be able to analyse sex-related differences in behaviour for instance (Setiawan et al., 2004).

In the case of some monomorphic-plumaged species, capturing both birds of the pair makes possible the sexing of birds based on measurements of the bill and tarsus from the relative size of the two birds within the pair (Nelson, 1981). Here I present two methods that can be used for aging and sexing Cassin's auklets in a quicker way, without involving long-term studies or laboratory analysis.

2.3 Method

2.3.1 Age

From the data obtained from birds breeding in the nestboxes followed from 2003 to 2006, I selected the individuals that were measured in all three years, as eye colour had been recorded in each year. Individuals were grouped according to eye colour and ANOVA was done in order to identify changes in iris colour for the individuals selected. Only birds that were breeding in all three years were included in this analysis.

2.3.2 Sex

Cassin's auklet is a species that shows no apparent sexual dimorphism; however, it has been suggested (Nelson, 1981, Manuwal and Thoresen, 1993) that differences in biometrics could tell us the sex of an individual. To test this, I took biometrics (wing length, using a stopped wing-rule, to the nearest 0.1 mm; tarsus, from middle of midtarsal joint to distal end of tarsometatarsus; head size (from point A to point C in Figure

2.2), bill depth and bill width (at point B in Figure 2.2), to the nearest 0.01 mm using Vernier callipers) from 10 pairs, so a total of 20 individuals, breeding in nestboxes in San Benito Island. As this species alternates incubation duties every day, and the individuals were ringed, I can be sure that both members of the pair were measured. From these 20 individuals I obtained blood samples from the *Vena ulna*. Blood was preserved dried in filter paper inside an Eppendorf tube until analyses were done. To determine sex from the blood samples through identification of sex-specific DNA, the DNA was extracted from the blood on the filter paper using ammonium acetate, then I followed the method developed by Griffiths et al. (1998). I used PCR amplification of the CDH gene fragments with the primer pair P2/P17 that was developed for sexing zebra finches (Arnold et al., 2003). This was the primer pair that worked best for Cassin's auklets. Also the Fridolfsson/Ellegren's primer was used to corroborate and compare this results with the analysis done with other species of auklets (Dawson et al., 2001). A discriminant analysis was then carried out to test whether biometrics were a good predictor of the sex of an individual, based on the known sexes of these birds determined from molecular analysis.

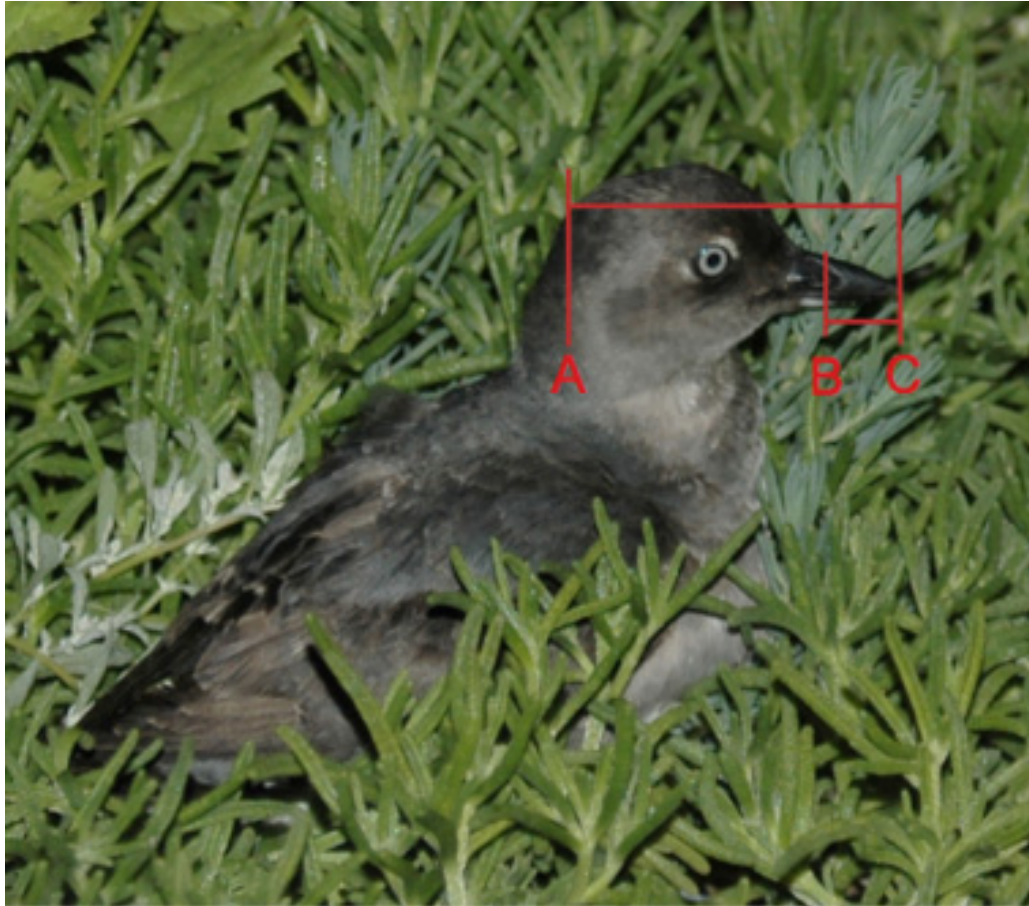


Figure 2.2. Measurements taken to sex Cassin's auklet are head size (from A to B), bill depth (at point B, from the upper to the lower part) and bill width (at point B, from left to right).

2.4 Results

2.4.1 Age

For aging Cassin's auklets I compared the eye colour change for each year in 33 individuals that were monitored in all three years. Individuals were grouped in one of three groups of iris colour, 1 for "adults", 2 for "adults-subadults" and 3 for "subadults". In Figure 2.3 we can see that in the first year of the study most individuals had not reached adulthood, whereas this proportion was lower in 2005 and finally in 2006 almost all of the study birds had reached complete adulthood in terms of

their iris colour. The change in iris colour is significant ($F_{2,96}=6.2$, $P<0.01$) from year to year.

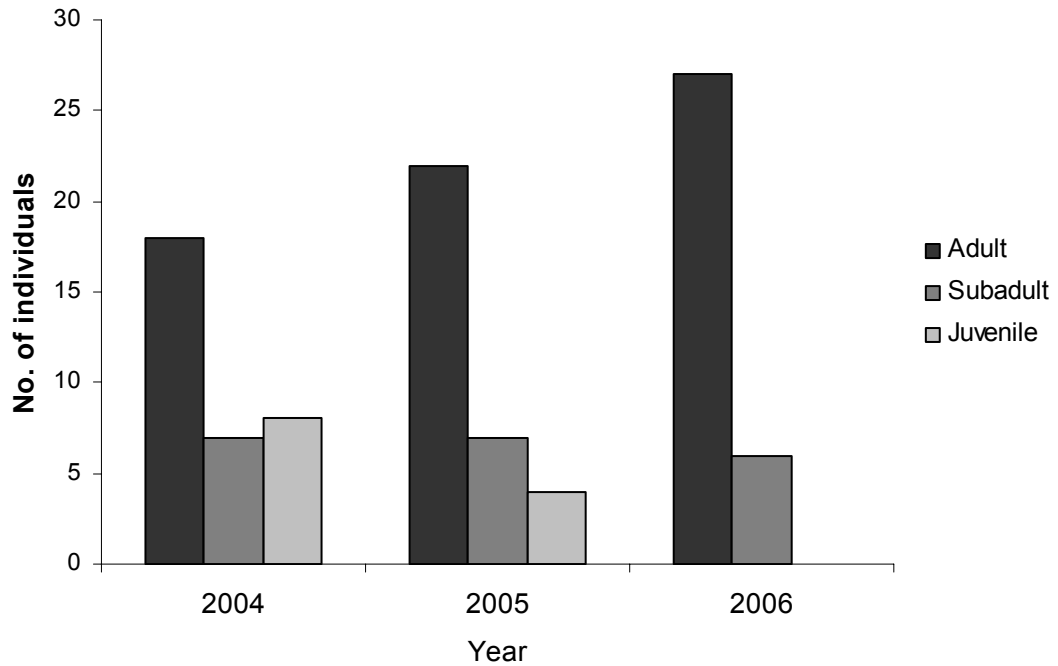


Figure 2.3. Age composition (assessed as iris types) of 33 individuals followed from 2004 to 2006. Following criteria in Fig.1 to determine the age, we can see the changes from younger individuals in 2004 to mostly adult type by 2006 ($X^2_4=9.92$, $P<0.05$)

2.4.2 Sex

Biometrics and a blood sample were collected from 10 pairs, then I compared between males and females bill depth and width (Figure 2.4). All the biometrics were comparing expressing females' measurements as percentage of the males' (Figure 2.5). In this figure it is possible to see that wing, weight and tarsus length do not differ between males and females; but when comparing head size, and bill depth and width, I found

that there were significant differences between the sexes in each of these measures ($F_{(1,18)} = 4.66$, $P=0.04$; $F_{(1,18)} = 11.714$, $P = 0.003$ and $F_{(1,18)} = 11$, $P = 0.003$, respectively).

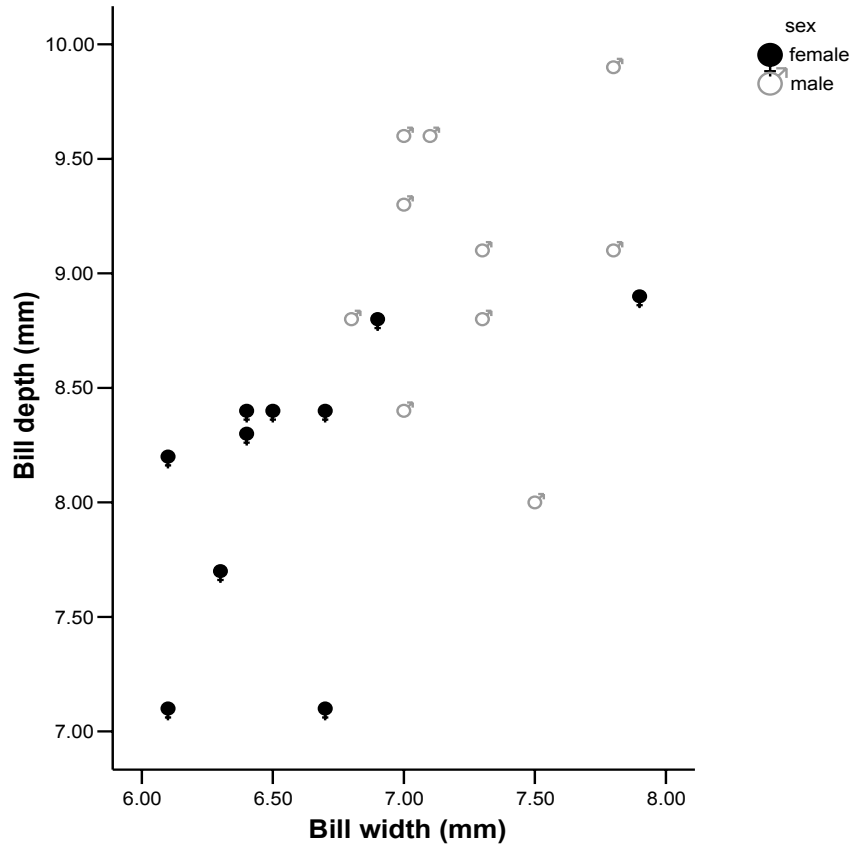
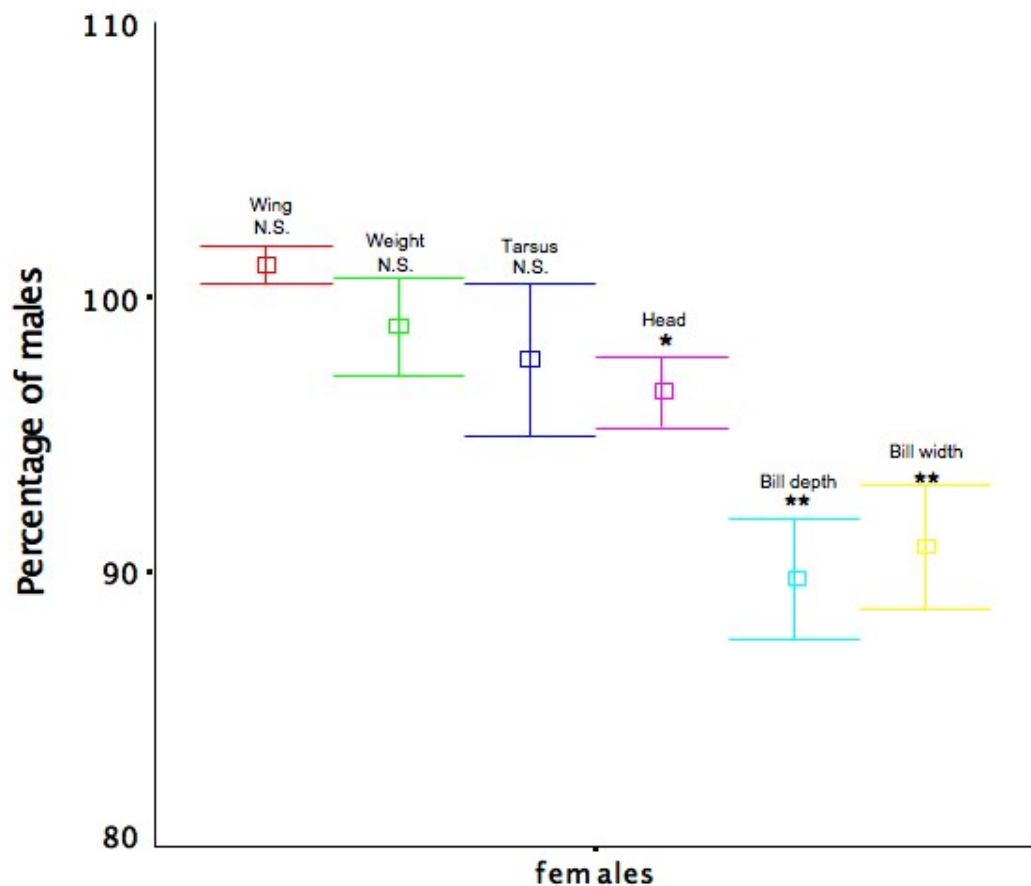


Figure 2.4. Overlapping of bill measurement between males and females. Males have a deeper and wider bill, allowing sexing them when comparing both individuals of the pair.

Means, standard deviation and standard error of each of the biometrics considered for sexing adult Cassin's auklets are presented in Table 2.1.

Table 2.1 Mean, standard deviation and standard error of biometrics considered for sexing adult Cassin's auklets

| | Mean | S.D. | S.E. |
|-------------------|--------|------|------|
| Head male | 53.16 | 1.63 | 0.52 |
| Head female | 51.32 | 2.14 | 0.68 |
| Bill depth male | 9.06 | 0.58 | 0.18 |
| Bill depth female | 8.13 | 0.63 | 0.20 |
| Bill width male | 7.26 | 0.35 | 0.11 |
| Bill width female | 6.60 | 0.52 | 0.17 |
| Wing male | 117.70 | 2.45 | 0.78 |
| Wing female | 119.10 | 2.64 | 0.84 |
| Weight male | 151.70 | 7.65 | 2.42 |
| Weight female | 150.10 | 8.70 | 2.75 |
| Tarsus male | 25.97 | 1.97 | 0.62 |
| Tarsus female | 25.38 | 2.27 | 0.72 |

**Figure 2.5.** Differences in measurements from males and females. Flattened wing-length ($F_{1,18} = 1.507$, $P = 0.23$), weight ($F_{1,18}=0.19$, $P=0.66$) and tarsus ($F_{1,18}=0.385$, $P=0.54$) are not significantly different; however head length ($F_{1,18}=4.66$, $P=0.04$), and bill depth ($F_{(1,18)} = 11.714$, $P = 0.003$) and width ($F_{(1,18)} = 11$, $P = 0.003$) are significantly different, with males being larger.

As bill depth and width showed clearest differences, I made a discriminant analysis considering these two variables. All the individuals with a discriminant score >-0.2 were classified as males (Figure 2.6, $P=0.004$). Following this criterion, 17 of the 20 individuals were sexed correctly, representing a correct classification of 85%, comparing with the results obtained from DNA.

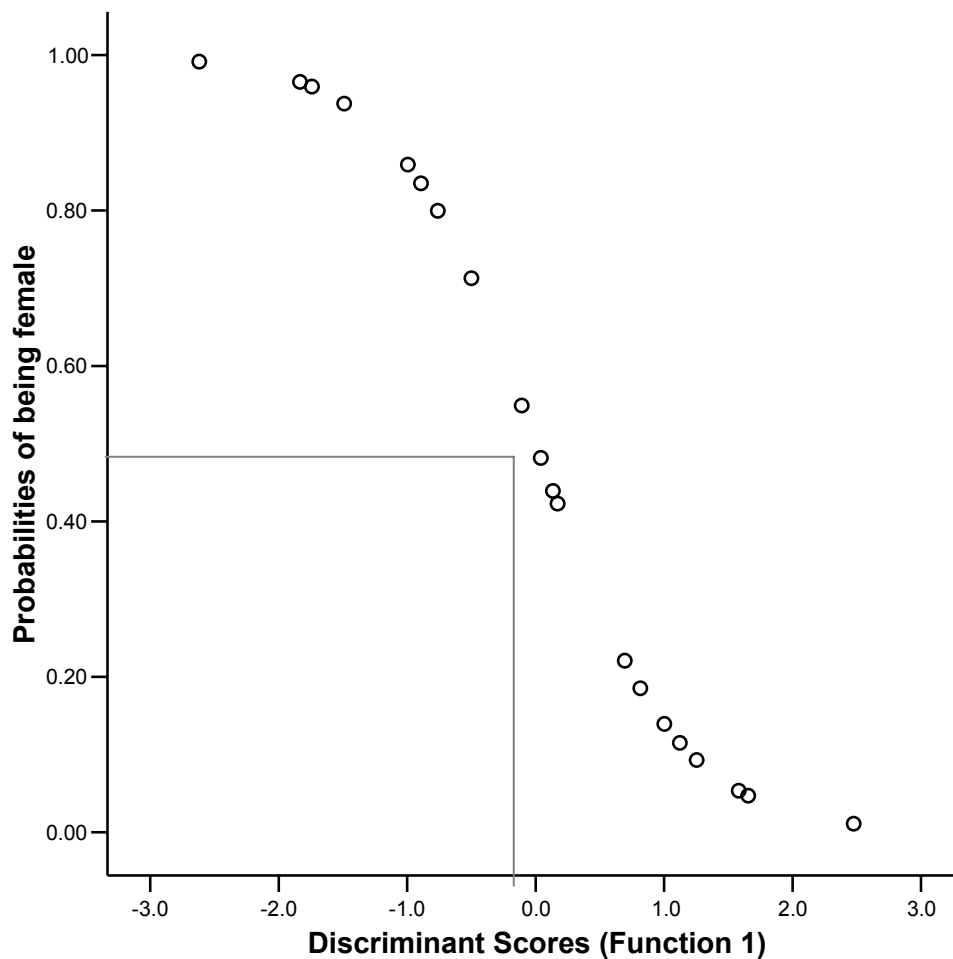


Figure 2.6. Probability of being female in relation to Discriminant score from function 1. Individuals above a Function 1 score >-0.2 were considered to be males.

As all the males were larger than the females with which they were paired, I did a scatterplot of the biometrics of the males vs. those of the females to see if there was any indication of size-assortative mating. I found a negative slope for head size (Figure 2.7) and bill width (Figure 2.8), while for bill depth it was only slightly positive (Figure 2.9),

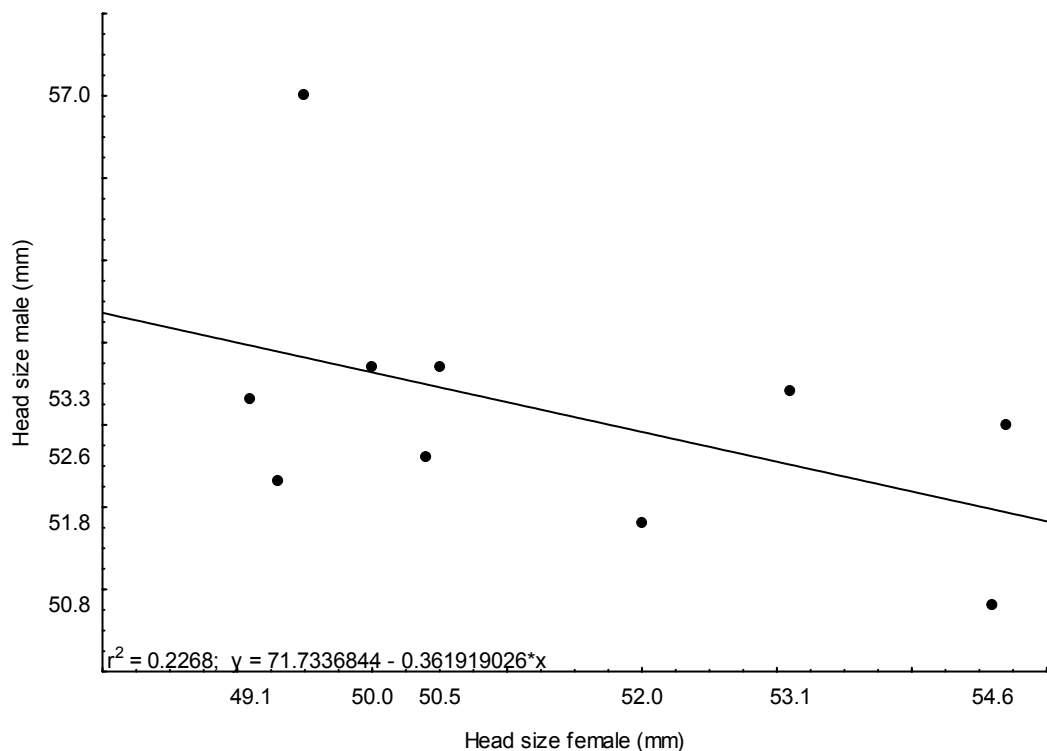


Figure 2.7. Scatterplot of the head size of the female vs. the head size of her partner. There is no relationship suggesting assortative mating as that should lead to a positive slope.

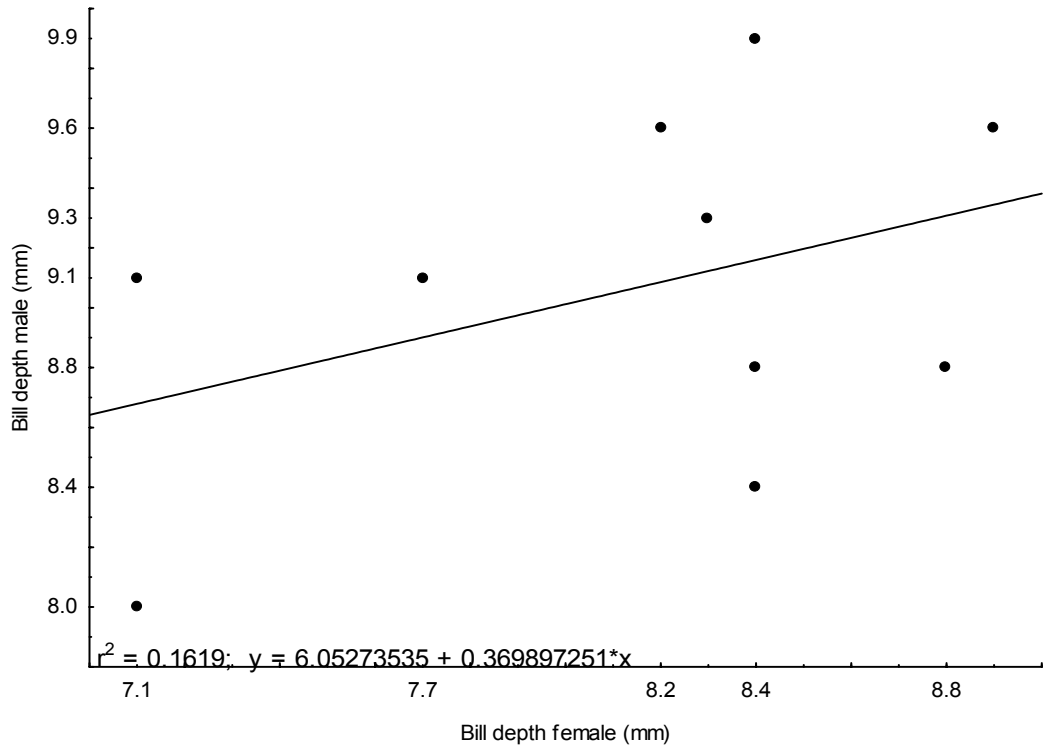


Figure 2.8. Scatterplot of bill depth of the female compared to bill depth of her partner.

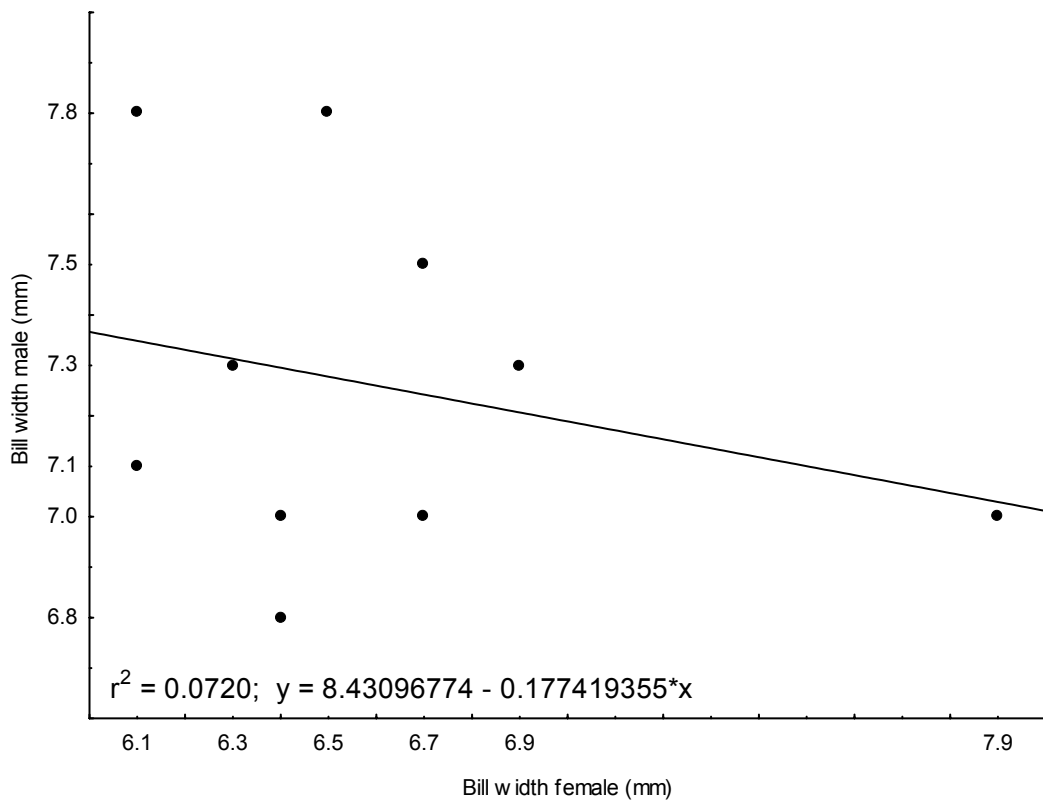


Figure 2.9. Scatterplot of bill width of the female compared to bill depth of her partner.

2.5 Discussion

2.5.1 Age

Many methods have been proposed to estimate the age of adult birds. Coulson et al. (1981) found that herring gull (*Larus argentatus*) showed a difference in bill depth as the individual grew older. On the other hand, Fancy et al. (1993) found that for two species of Hawaiian birds, the adults had longer tails, as well as longer skeletal measures in bill and tarsus. Regarding the red-billed quelea (*Quelea quelea*), it was found that there was a difference in the bill and iris colour, so it was possible to tell apart juveniles from adults (Jones et al., 2002). McCloskey and Thompson (2000) also propose a method for aging common snipe (*Gallinago gallinago*) by means of the presence of the *bursa di Fabricius*; however, this method can only age between first year and older individuals, and also involves the killing of the animal, which is not very useful for conservation purposes. Brown-headed cowbirds (*Molothrus ater*) were also aged using feather colouration (Ortega et al., 1996), separating first years from second years and older. Aging the chicks is also important, as it would be possible to estimate hatching date when there is no certainty of it. Gull-billed tern (*Sterna nilotica*) chicks reach a maximum head size and wing length at different ages (Sanchez-Guzman and Del Viejo, 1998). Many different approaches have been used to determine the age of the birds, such as biometrics (Sanchez-Guzman and Del Viejo, 1998, Childress et al., 2005), colouration, either of bill or feathers (Jeffrey et al., 1993,

Ortega et al., 1996, Simon et al., 1998 Jones et al., 2002) and eye colour (Manuwal, 1978, Jones et al., 2002).

I used eye colour as an estimate of age for Cassin's auklets, as these birds do not have significant changes in biometrics or plumage colours as they grow from fledglings to adults. With the data obtained during the three years it was possible to see how the iris colour of Cassin's auklets changes, fading from a dark brown when they are juveniles to a complete white once they reach adulthood. However, once an individual is fully mature, this method is not useful to age mature adults; so far, ringing the individuals as chicks would be the best option.

2.5.2 Sex

For sexing individuals based on DNA analysis, other species of auklets have been sexed using P2/P8 primers (Dawson et al., 2001). Dawson and collaborators successfully sexed whiskered auklets (*Aethia pygmaea*), least auklets (*A. pusilla*), crested auklets (*A. cristatella*) and parakeet auklets (*Cyclorhynchus psittacula*). They found a polymorphism in the Z chromosome of the auklets that they were working with when using molecular methods for sex identification. The polymorphism only occurred in the region of the Z chromosome which is amplified by Griffiths et al. primers P2/P8. This means that there were two copies of the Z chromosome which differed in intron size, and could therefore be seen as two individual Z bands on an agarose gel. The Fridolfsson/Ellegren primer pair 2550/2718 amplifies a different region of the Z chromosome, to

P2/P8. The Z chromosome amplification products from this primer pair are of identical size, and therefore for males, the two Z's cannot be distinguished as two separate bands on a gel (ZZ rather than ZZ').

It is important to note the differences found between the species sexed by Dawson et al. (2001) and Cassin's auklets. The other species of auklets show a polymorphism for the region of the Z chromosome that is amplified using Griffiths et al.'s (1998) primer, P2/P8, while using the Fridolfsson /Ellegren primer pair 2550/2718 that amplifies a different region of the chromosome, only one band is distinguished on a gel. The opposite happens with Cassin's auklets, showing no polymorphism on the region amplified by P2/P17 primers (that cover the same intron as the P2/P8 primer). However, the region amplified by Fridolfsson/Ellegren's primers was polymorphic, there was a difference in intron size, which could be seen in the form of two distinct Z bands on a gel.

Discriminant analysis seems to be a good method for sexing individuals (Hamer and Furness, 1991, Henderson, 1991, Phillips and Furness, 1997, Palomares et al., 1997), especially when both members of the pair can be measured. The results obtained in this study show that for sexing Cassin's auklets, the use of biometrics is a good method. All the samples analysed coincided with the predictions made from the measurements of the bill. The other measurements (wing length, tarsus and weight) did not show any significant difference. Based on the P values, it is recommended to use bill measurements to sex these birds, bill depth preferably. Sexing and aging of Cassin's auklet can be done while

on the field site, reducing logistical problems and the cost of investigation and speeding the research process and policy implementation.

Also, while the discriminant analysis accurately predicted the sex of 80% of the individuals, when comparing the bill measurements within a pair this was accurate 100% of the time. This may lead us to think about a process of assortative mating happening within Cassin's auklets. However, when plotting the biometrics (head size and bill depth and width) of males vs. females, I found a negative slope for head size and bill width, while for bill depth it was only slightly positive, eliminating the possibility of assortative mating, as a positive slope would be expected.

The fact that bill measurements differ between the sexes whereas plumage and other biometrics do not, is consistent with the situation in many other seabirds, such as least auklets (Jones and Montgomerie, 1992, Jones et al., 2000) and shearwaters (Bretagnolle et al., 2000, Lo Valvo, 2001, Genovart et al., 2003, Guicking et al., 2004). Sex-differences in bill morphology in otherwise monomorphic seabirds are rather commonly found, and are thought to arise either as a result of sexual selection (Szekely et al., 2000), where females prefer males with larger bills, which may be particularly likely to arise in burrow-nesting nocturnal birds where tactile stimuli may be stronger than visual ones, or as a mechanism to reduce intersexual competition for food, favouring trophic niche segregation between the sexes. It remains unclear which of these two mechanisms is the more important.

Therefore, the best way to sex Cassin's auklets would be to make within-pair comparisons of the bill measurements, as it was 100% accurate

as tested with the DNA technique. The disadvantage of this method would be the difficulty of finding both individuals, however, as the Cassin's auklets share incubation and switch every day, the partner could be found the following day.

Chapter 3.

**Effects of disturbance on breeding success and
occupancy.**

3.1 Abstract

During 2004, I followed 72 natural burrows to determine the effects of disturbance on breeding success of Cassin's auklets. I used distance from the village, or the path, as a measure of disturbance and my results show that birds whose burrows are closer to the path or the village have a higher rate of nest abandoning, therefore a lower breeding success compared to birds nesting further away from the path and the village. Also, older and more experienced individuals represented a larger proportion of the breeding population on less disturbed areas than on highly disturbed ones.

3.2 Introduction

The rapid growth of wildlife-based tourism and recreation presents opportunities for significant economic benefits but also raises concerns about the potential effects on many seabird colonies (Anderson and Keith, 1980).

As a result of human population growth, the competition for resources and land has increased over the last few years. Change in land-use has been incremental, with activities such as leisure and resource extraction being the main threats for species survival, especially in coastal ecosystems (Backhurst and Cole, 2000). These activities need a regulatory management to lessen the effects on local flora and fauna. In order to plan precisely these management actions it is necessary to have a more accurate knowledge of how the species are being affected.

The effects of resource extraction are well documented. Egging has caused total failure of some gull colonies (Vermeer, 1991) while hunting has led to the extinction of several species and habitat degradation has had an effect on abundance of large bird species (Tamisier et al., 2003). Also a redistribution of the species has been recorded in areas where hunting is allowed, leading to an under-exploitation of the resources in that area and affecting survival and body condition of the disturbed species (Carney and Sydeman, 1999).

On the other hand, there is the effect of non-consumptive activities, such as eco-tourism, bird-watching, jogging, etc., on natural areas. This effect is apparently lower than that caused by extraction activities, however, in the long term, the population may be subjected to the same pressure in both of them, such as decrease in numbers, or reduction of the range (Robert and Ralph, 1975, Safina and Burger, 1983).

Disturbance is any activity that interrupts natural processes to take place (Burger, 1981a). Human disturbance has been recorded since decades ago (Hunt, 1972, Duffy, 1979, Piatt et al., 1990), and on a wide variety of species, from reptiles (Burger and Gochfeld, 1993a, Romero and Wikelski, 2002) to sea mammals (Croll et al., 1998, Ficetola et al., 2007) reporting negative effects, mainly as declines in populations as a result of loss of viable areas for breeding or stopovers during migration. In this chapter I will focus on the effects of human disturbance on seabirds, particularly Cassin's auklets.

First of all, it is important to separate the short term disturbance effects, such as flushing, stopping feeding, etc., from the long term effects,

that would lead to a decrease in the population, a decrease in breeding parameters, a change in distribution, etc. This topic has been approached using different perspectives, such as distance at which birds flush from the nest or feeding sites when a person or disturbing object (such as boats, cars, airplanes, etc.) is approaching (Fretwell and Lucas, 1970), changes in behaviour in presence of disturbance (Bolduc and Guillemette, 2003) and disturbance affecting distribution of food sources or feeding habits or efficiency of certain species (Hunt, 1972, Cornelius et al., 2001). Individuals select the best foraging sites (Gill et al., 2001), meaning that if they are disturbed then they will have to move to a lower quality site, where they will spend more time in search for food, or looking for predators or disturbance source, so they have an extra energetic waste when they have to leave the affected area and may not be able to regain that energy (Burger and Gochfeld, 1993b). Those effects may influence the entire bird assemblage, rather than a single species, affecting the whole community (Cornelius et al., 2001). It has also been pointed out that behavioural responses may not be the best approach to study this kind of problem (Gill et al., 2001). They suggest that if a species has somewhere else to go, that is undisturbed, then they will move; but if this species does not have other undisturbed places to go, then they will stay, despite the disturbance. This results in a higher risk for the species that cannot move, contradicting what was normally thought before, that a species remaining in the same site despite disturbance is not affected by it.

The behaviour of the disturbing person may also have an influence on the perception of the disturbance by the animal. If a person walks on a straight line or on a sinuous or random direction, if the person is approaching or retiring (Burger and Gochfeld, 1993a), if the person is quiet or noisy, etc. (Lord et al., 2001).

On the other hand, there is the effect of disturbance by investigators. We can have sites with minimum disturbance, but not a site completely undisturbed (the investigators will disturb when they set foot on the site). There is a controversy about the effect of investigators on breeding success, because some authors report that this disturbance is minimal and can be neglected (Hull and Wilson, 1996), or that there is an increase in the chick loss rate but there is no statistical evidence of how it affects chick growth (Gillet et al., 1975); others report that there is a reduction in chick productivity, but this effect remained just for one year after the disturbance and then disappeared (Saffer et al., 2000). It has also been noticed that birds become adapted to human presence and the behavioural response decreases (Walker et al., 2006) after a time exposed to such “benign” disturbance, and even some researchers have suggested to increase the number of visitors to a colony of seabirds to speed up the process of habituation (Nisbet, 2000).

However, species differ in their sensitivity to human disturbance and, although birds may habituate to visitors, inappropriate intrusions at poorly managed sites may result in adverse effects on breeding individuals (Beale, 2007).

Human disturbance of wildlife is of important concern if it affects survival and breeding success, leading to a decrease in the population (Blanc et al., 2006). Negative effects on seabird reproduction are through direct destruction of nests or their contents and desertion of offspring, particularly at locations where seabirds nest in association with or near to colonies of avian predators (Burger and Gochfeld, 1991, Fernandez-Juricic, 2000, Langston et al., 2007).

The risk of exposure to disturbance can be compared to the risk of exposure to predation (Burger, 1981b), if an animal has an alternative site, where disturbance is lower, then it will move to the other site; however, if the condition on other places are not good enough, then the animal will remain on the disturbed site (Gill et al., 2001). But site characteristics and species requirements may vary in time and space, leading to the utilization of several areas.

It is difficult to analyse behavioural responses to disturbance in burrow nesting species, and as mentioned before, these behavioural responses may not be the best method when studying the effects of disturbance on birds; therefore the approach I used was to test for differences in breeding success between control and experimental groups.

Because of the great uncertainty emerging from several studies it is necessary to shed light on this topic to understand and have a clearer idea of the interaction between humans and the environment. I will contribute in this by studying the effect that human presence, in terms of ecotourism, research, or fishing, may have on a breeding seabird colony, the Cassin's auklet, in the San Benito Islands in the Pacific coast of Mexico. During the

breeding season of 2004, I measured the effects of human presence on these seabirds. The effects were considered in terms of breeding success reduction and site selection.

3.3 Methods

From the 6th of February to the 26th of May in 2004, 72 natural burrows were followed using an infrared camera mounted on a plastic probe (for detailed description see (Keitt et al., 2003). The infrared camera was introduced in the burrow and the contents were recorded every five days. Only occupied burrows were selected because I wanted to establish breeding success in natural burrows.

Burrow clusters were selected at three different distances from the fishing village and from the path that is highly frequented by the fishermen after they finish working. This is also the path that tourist coming on boats from San Diego walk to see the local fauna. Nine burrow clusters were selected at different distances from the village or the path (Figure 3.1) and within each cluster I selected eight occupied natural burrows. Each burrow was marked with a stick and flag for easy identification. In total, 24 burrows were used for each of three disturbance levels: Burrows in the low disturbance group were located more than 100 m from the path (green dots on Fig. 3.1), medium disturbed burrows were located between 50 and 90 m from the path (yellow dots on Fig 1) and highly disturbed burrows were at a distance closer than 30 m from the path or the village (red dots on Fig. 3.1).



Figure 3.1. Distribution of the burrow clusters followed during this study. High disturbance areas are represented with red dots, while medium disturbance zones are represented with yellow dots and low disturbed areas with green dots. The path followed by tourists and fishermen as well as the fishing camp are also marked as well as the areas where it is possible to find burrow clusters (Breeding grounds)

Due to the nocturnal habits of the Cassin's auklet, it is relatively easy to catch them at night using a headlamp, as they are disoriented by the light and stay on the ground. From these caught birds, following Manuwal's criteria for aging Cassin's auklets (Figure 2.1, Chapter 2) (Manuwal, 1978), I recorded eye colour as an estimate of the bird's age. Aging was done to test what has been found in other studies, where older and more experienced individuals choose better quality sites (Newton and Marquiss, 1982, Draulans and Vanvessem, 1985, Pyle et al., 2001,

Velando and Freire, 2001, Rounds et al., 2004), in this case, supposed to be the ones away from disturbance.

Breeding success was registered for these burrows, and the age of 140 individuals was estimated, as some of them were caught at night when returning to changeover with the partner or to feed the chick. I consider these factors because it is thought that older and more experienced birds will choose the best burrows, tending to return to the same burrow if they are successful, or will move to a different one if they fail (Thompson and Furness, 1991).

Physical characteristics from the burrows (depth, orientation of the tunnel, vegetation cover on the entrance) and the burrow cluster (soil type, distance from the sea, inclination) were recorded as these factors have been reported to affect breeding success (Thompson and Furness, 1991, Velando and Freire, 2003).

The analysis was done using contingency tables to see differences within broods, and ANOVA's at a significance level of 0.05 to test for differences among the different levels of disturbance. Also, a multiple regression analysis was done to estimate the effects of the physical characteristics of the burrow on the breeding output of the pair occupying that burrow. The statistical packages used for these analyses were SPSS and Statistica.

3.4 Results

At the beginning of the season, I chose burrows that were occupied. Burrows that were closer to the path had a higher variation in occupancy, some of them being abandoned early but then reoccupied (Figure 3.2). Generally, low and medium disturbance groups behaved in a similar way, but highly disturbed burrows were empty, either with a successful fledgling or abandoned, at least 10 days before the other two groups.

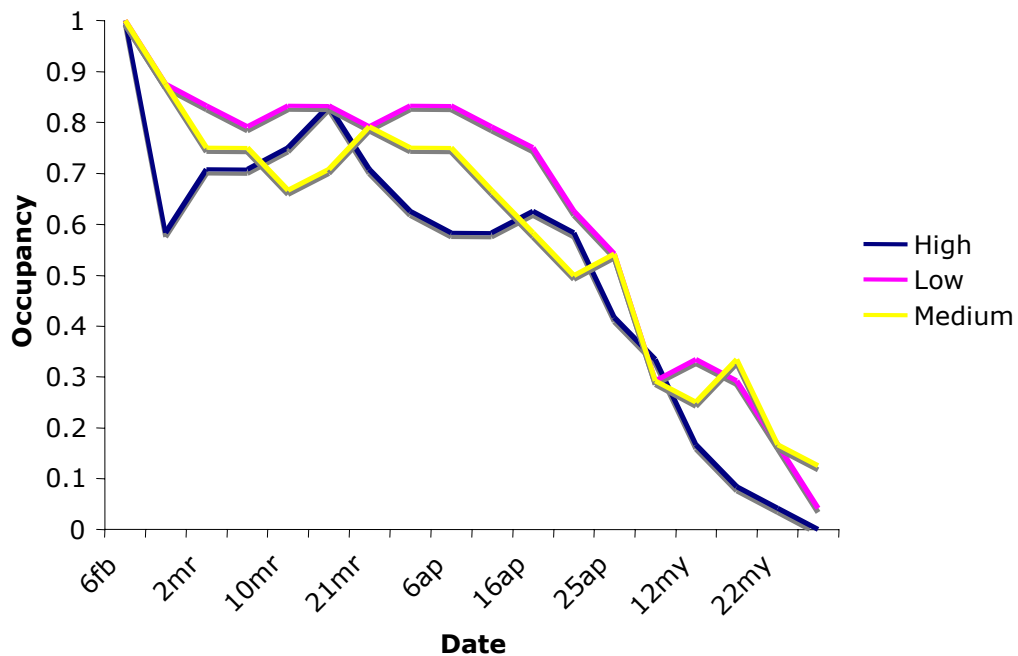


Figure 3.2. Occupancy on the different levels of disturbance. Burrows in the high disturbance level were empty earlier than those on the other two groups, however, differences are not significant.

In general terms, there are slight differences in breeding success between burrows with different levels of disturbance. There are no significant differences in hatching success at different levels of disturbance ($F_{2, 69} = 0.74$, $P = 0.39$), but in fledging success, burrows in more disturbed

areas tended to have a significantly lower success ($F_{2, 69} = 4.47$, $P = 0.01$; Figure 3.3).

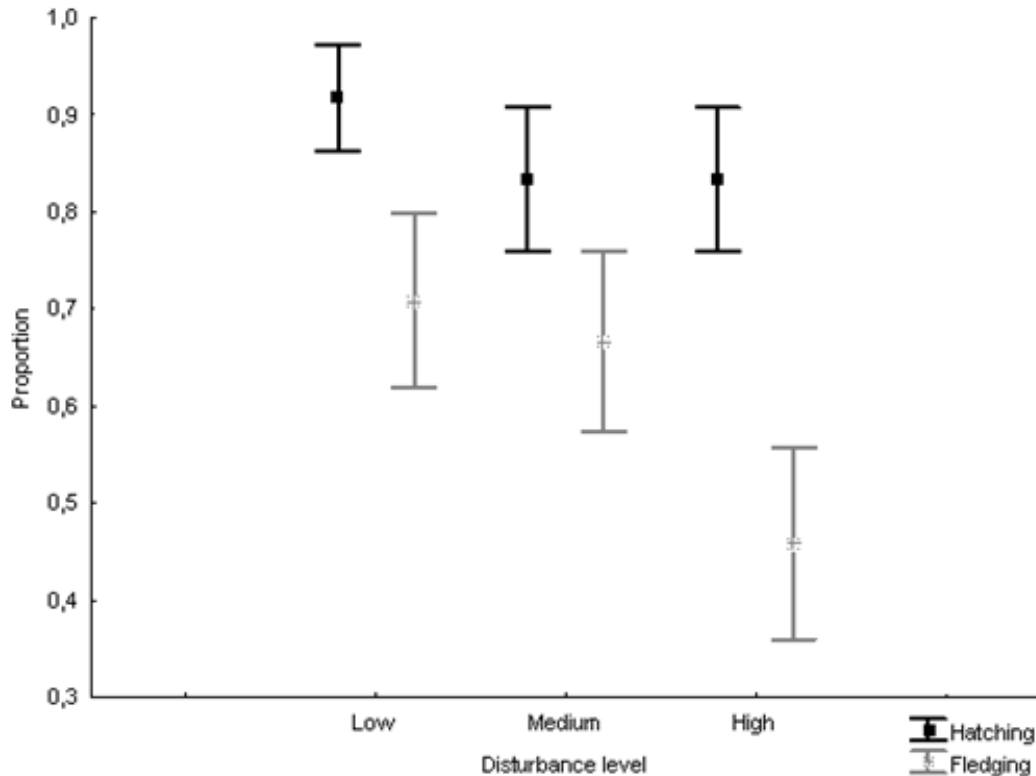


Figure 3.3. Hatching and fledging success (mean \pm S.E.). There are no differences in hatching success, but fledging success is significantly lower in the highly disturbed burrows, closer to the path or the village.

When comparing the first and the second broods, most of the pairs in the first brood fledged a chick, while the vast majority of pairs that attempted a second brood resulted in failing ($\chi^2_2 = 13.71$, $P=0.001$). In the first brood there is no significant difference between the different levels of disturbance when comparing the number of eggs abandoned ($\chi^2_4 = 3.29$, $P = 0.51$) or chick mortality ($\chi^2_4 = 1.2$, $P=0.87$), but there is a trend comparing fledging success between low and high disturbance areas ($\chi^2_4 = 18.19$

$P=0.051$; Figure 3.4) showing that burrows located in high disturbance areas have lower success.

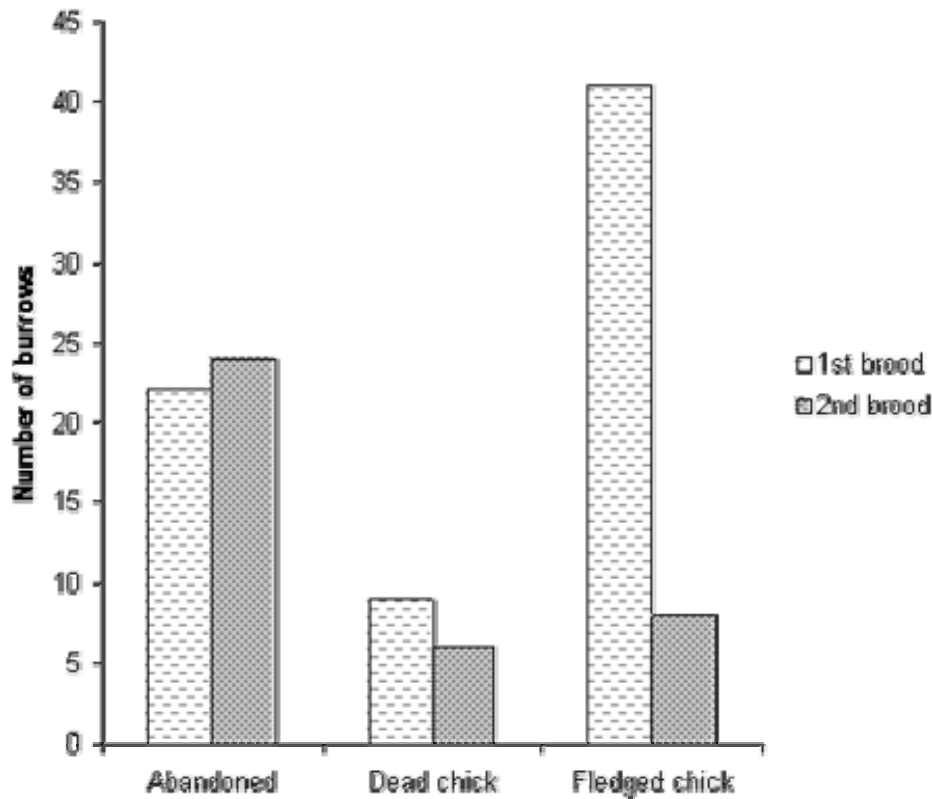


Figure 3.4. Comparison of the first vs. the second brood. Nearly 60% of the pairs in the first brood successfully fledged a chick, while nearly 70% of second clutches were abandoned or the chick died.

In the first brood around 60% of clutches produced a fledgling, considering the three different disturbance levels. For the second brood there are no significant differences between burrows that were abandoned ($\chi^2_2=2.35$ $P=0.32$), where the chick died ($\chi^2_2=2.35$ $P=0.32$) or the chick fledged ($\chi^2_2=2.49$, $P=0.35$), but in this case, in more than 70% of the burrows an abandoned egg was found (Figure 3.4), in contrast with the first brood.

Regarding the age distribution according to disturbance levels (Figure 3.5), there are differences between burrows in the low disturbance group and the higher disturbance groups. Most of the birds in the low disturbance group are adults (>2 years). In fact a significantly higher number of older individuals was recorded in low disturbance areas ($\chi^2_4 = 14.13$, $P < 0.001$). On the other hand, in medium and high disturbance areas, there is no difference between these two groups in the age of the adults breeding on those sites.

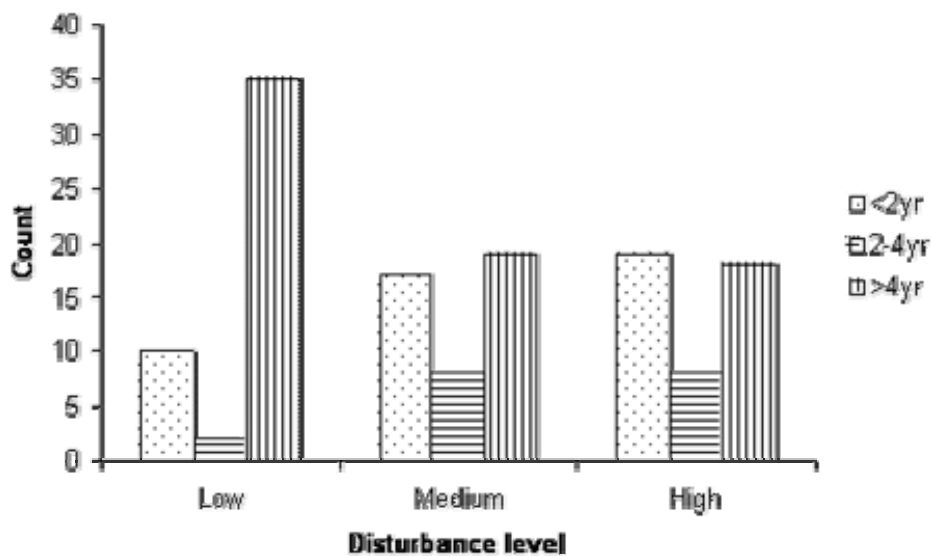


Figure 3.5. Age distribution according to disturbance level. Most of the immature-eye coloured birds are in burrows where disturbance is high, while on undisturbed burrows the proportion is equal.

The physical characteristics of the burrow did not have an influence on the breeding output of that burrow ($R^2 = 0.04$, $p = \text{NS}$) and there were no

differences in the depth of the burrow for each level of disturbance (Table 3.1).

Table 3.1. Effects of the physical characteristics of the burrow on the breeding output.

| | Hatching success | Fledging success |
|----------------------------|------------------------------|------------------------------|
| Depth | $R^2 = 0.034$ $P = 0.11$ | $R^2 = 0.0009$ $P = 0.30$ |
| Vegetation | $R^2 = 0.0005$ $P = 0.76$ | $R^2 = 0.0001$ $P = 0.57$ |
| Orientation | $R^2 = 0.006$ $P = 0.288$ | $R^2 = 0.002$ $P = 0.5$ |
| Distance to the sea | $R^2 = 0.02$ $P = 0.7$ | $R^2 = 0.0003$ $P = 0.9$ |

3.5 Discussion

Burrow breeding birds may be more susceptible to disturbance events, as they don't have a direct view of it (unless the burrow is trampled), and they may perhaps be equally stressed by a disturbance event that is happening 50 m away as well as by one happening 10 m away.

There were no differences in hatching success between the three treatments. However, differences became apparent comparing fledging success. Chicks may be more susceptible to disturbance, as they have to stand it every day, while adults alternate incubation and only face disturbance every other day.

Early breeders often attempt to lay a second brood after a successful fledging, however, most of the burrows with a second brood were abandoned, desertion rate reaching almost 70% of the burrows. Having enough available food, it would be expected that the second brood was successful, but there was a high competition with early Leach's storm-petrel (*Oceanodroma leucorhoa*) breeders, that forced the adults or the chicks out of the burrow.

Distance seems to be a good indicator of disturbance. As in many other studies (Roberts and Evans, 1993, Klein et al., 1995, Gutzwiller et al., 1998, Fernandez-Juricic et al., 2003, Taylor and Knight, 2003, Mullner et al., 2004, Laursen et al., 2005), I also found that distance at which birds showed a response to the disturbing source can be used; in this sense, breeding success increased as the distance from the path to the burrow cluster increased. However, breeding experience may have an influence on this, as we can see on Figure 5, where the burrow clusters that are further away from the path have a higher proportion of older individuals. Older and more experienced breeders tend to arrive earlier in the season compared to first time breeders (Greig et al., 1983, Forslund and Part, 1995, Mauck et al., 2004), having a wider option of burrows available, they also have greater experience in handling and catching prey allowing them

to better exploit food sources. The fact that older and more experienced individuals are occupying the majority of the burrows on the low disturbance group may be an indication that Cassin's auklets choose to breed far from human disturbance, while younger individuals have to use the burrows that are available, closer to the disturbance source.

Burger (1991) and van der Zande et. al (1980) found that migratory birds are more sensitive to disturbance than conspecific residents but some sort of habituation has been observed by the end of the breeding season. For Cassin's auklets we can consider them to be a migratory species, coming to the islands only to breed. However, Cassin's auklets may not have time to habituate to the disturbance, as by the end of the breeding season there is a strong burrow competition with the storm petrels (pers. obs.).

A successful example of management of natural areas is that of Patagonia (Yorio et al., 2001). Given the rapid increase in the interest of visiting seabird colonies in Patagonia, several management tools such as sanctuaries, the limitation of visitor numbers and both temporal and spatial zoning, needed to be implemented in the short term (Yorio et al., 2001). Yorio and colleagues (2001) found that areas where access was restricted by limiting number of people, had a lower abandoning rate, and therefore a higher breeding success.

Blanc et al. (2006) reported that in France, 56.8 % of the vulnerable species were affected by walkers, while 2.4% of the species were affected by motor vehicles; something similar may happen elsewhere, as in most of these important bird areas the use of motor vehicles is forbidden. This is

an important result, most of the species are disturbed by walkers, the activity that is more widespread on natural areas and breeding grounds.

Some sort of habituation to disturbance has been reported for several species to walkers; for instance, Burger (1998) found that common terns were not too responsive if people remained on the signalled paths; however, they showed a strong response if they left the path. Nisbet (2000) even recommends a higher exposure of seabird colonies to disturbance in order to speed up the process of habituation (should it occur). This assertion, however, does not take into consideration the breeding period, where chicks do not have enough time to habituate and some negative effects have been noted, as we'll see in the next chapter.

Finally, as tourism is expected to increase in the near future along the peninsula of Baja California, and a part of the tourist flow will be directed towards the San Benito Islands, I recommend that a better control of the number of visitors is imposed on the island, either by keeping off limits some areas with larger numbers of burrows, by only allowing qualified people to enter the island and do the least possible damage, or by closing the island during the breeding season. However, the island is used by several seabird species as breeding ground throughout the year, and it would be impossible to keep it closed the whole year.

Chapter 4

Effect of recreational disturbance on Cassin's auklet chicks

4.1 Abstract

This study examines the effects of human disturbance on chicks of Cassin's auklets (*Ptychoramphus aleuticus*). 73 chicks were followed during their development. Each chick was under one of three different levels of experimental disturbance. For each chick I recorded weight and wing length that allows the estimation of the growth curve. With these data it is possible to compare the effects of disturbance on chick growth and fledging weight. I observed that there are differences in peak and fledging weight between the individuals of the three treatments, with the chicks in the control group having a higher peak and fledging weight, compared to the chicks in the highly disturbed group, where disturbance affects them significantly. These differences are very likely to be the effects of disturbance, as there were no significant differences between the adults of the three groups.

4.2 Introduction

Disturbance is "the disruption of normal activity patterns" (Lord et al., 1997) or "those human activities that occur within or adjacent to a colony of seabirds" (Burger and Gochfeld, 1994).

Human disturbance of bird populations has been recorded for a long time (Robert and Ralph, 1975, Safina and Burger, 1983). Humans are not only direct predators of the birds, we can, directly or indirectly, influence the number of other predators, native or introduced that may affect the population of birds (Paine, 1966). We also modify the habitat where these bird populations live and feed (Burger and Gochfeld, 1994).

Disturbance ranges from human presence itself, making birds fly away, exposing the nest to the weather, sometimes harsh on seabird breeding grounds; direct use of the birds, such as eggging and harvesting of chicks and adults; habitat modification; introduction of predators; military activities on some southern Pacific Islands; to a more subtle disturbance, that of ecotourism (Safina and Burger, 1983). The case of seabird ecotourism is very interesting, as all these people practicing this activity are interested on the conservation of the species, and they visit the colonies only with the purpose of watching the birds and take photographs, without harming them (Burger, 2000). However, many of these visitors also disturbed the birds only with their presence by standing close to the nest for too long to take photographs, etc. (Klein et al., 1995, Gossling, 1999); but this effect of ecotourism could be decreased by a good implementation of access restrictions.

Seabirds do not respond all in the same way to disturbance, the responses varies according to each species and its reproductive behaviours, habituation, degree of exposure and amount of habitat available (Humphrey et al., 1987, Gill et al., 2001). Because of these differences, disturbance has been approached using different perspectives, such as distance at which birds flush from the nest or feeding sites when a person or disturbing object (such as boats, cars, airplanes, etc.) is approaching (Stillman and Goss-Custard, 2002, Bolduc and Guillemette, 2003,). Others have focused on changes in bird behaviour in the presence of disturbance (Swarthout and Steidl, 2003), disturbance affecting food sources of certain species (Backhurst and Cole, 2000). These two methods may not reflect the reality, in the sense that this flushing distance may vary depending on different factors

such as habituation (Walker et al., 2006), period of the year (a bird in migration may be more willing to risk when a person is approaching than will a bird on a different period of the year) (Burger and Gochfeld, 1991, Wingfield and Sapolsky, 2003, Lind and Cresswell, 2006). Another approach is to measure the extra energetic costs when the birds leave the affected area and may not be able to regain that energy, or reduced time spent feeding because the birds have to be on alert in search of the disturbing object (Bolduc and Guillemette, 2003), this has happened with snow geese (*Chen caerulescens*), where Belanger and Bedard (1990) found that they had an increased energy expenditure because they were flushed and increased their alertness, and a reduced energy intake due to lower feeding rates. The same has been observed for waders, that increased the vigilance when a person was approaching (Fitzpatrick and Bouchez, 1998), rather than browsing for food. Energy requirement measurement is a very interesting method, as an individual that cannot meet its energy requirements will be under stress; however, it is difficult to measure the amount of energy expenditure, as the bird has to be caught, handled and kept for several hours (Moore et al., 2000), representing a very stressful situation that may lead to confusion of the results. Also a community approach has been used, studying the entire bird assemblage, rather than a single species (Cornelius et al., 2001). The study of a whole community under stress can provide information that leads to management policies, however, as mentioned before, species react differently from one another, and even within species there is variability in the response according to the time of the year, so studies have to be carefully designed to take into consideration these factors. It has also been pointed out

that behavioural responses may not be the best approach to study this kind of problem (Gill et al., 2001). Gill et al. (2001) suggest that if a bird has somewhere else to go, that is undisturbed, then it will move; but if this bird does not have other undisturbed place to go, then it will stay, despite the disturbance. This can result in a negative effect for the species that cannot move, decreasing breeding success or lowering body mass. This is opposite of the general idea that a bird is not disturbed if it remains in the same site despite the disturbance. Something similar has been observed with the African (*Spheniscus demersus*) and Gentoo penguins (*Pygoscelis papua*), where some heart-rate monitors disguised as eggs showed that these species do not show a behavioural response under human disturbance but their heart rates increases dramatically (Wilson et al., 1991, Nimon et al., 1996). However, if the disturbing human was too close, then it would leave the nest.

Studies of the effects of disturbance have focused primarily on adults, with only a few studies centred on the effects on chicks (Lord et al., 1997, Giese and Riddle, 1999, Kitaysky et al., 2003, McClung et al., 2004, Mullner et al., 2004). Many of these studies have found that a chick growing under severe disturbance will have its future compromised due to an impaired immune system. It was also reported that there is an increased mortality in chicks in a glaucous-winged gull colony subject to disturbance (Gillet et al., 1975); most of this increased mortality is caused by predation of conspecific neighbours, and also the inability of the chicks to find again their nest once abandoned (Robert and Ralph, 1975), dying through exposure to cold or sun, or being taken by predators.

The stress response is very important to the survival of an organism as energy is mobilised from energy storage to the muscles, allowing the organism to escape under a stressful or threatening situation (Wingfield and Sapolsky, 2003). However, if the hormones involved in the stress response are present in the organism for a long time, they can have a negative effect (Mostl and Palme, 2002). The negative effects recorded from high levels of stress hormones range from weight loss (Mullner et al., 2004), to reduced breeding success (Carney and Sydeman, 1999), and reduced chick growth (Saffer et al., 2000). In this study I chose to study the effects of disturbance on chicks for two reasons, first, the fact that they are always inside the burrows and are relatively easy to follow. The conditions inside the burrows are more or less equal. Second, in a relatively short time, chicks undergo development that follows the same pattern for all the chicks, thus differences in chick growth may be the result of different external pressures (Giese and Riddle, 1999, Mullner et al., 2004).

Here I present the results of an experimental approach to determine the effect of human disturbance on the chick growth of a burrow-nesting species, the Cassin's auklet (*Ptychoramphus aleuticus*) in San Benito Islands, in the Mexican Pacific.

Cassin's auklets breed in natural cavities, mainly in rock slopes or in burrows excavated with their own feet. Cassin's auklets lay single-egg clutches, and have a monogamous mating system (Manuwal, 1979), with intensive biparental care during incubation and chick-feeding (Manuwal and Thoresen, 1993). In this southernmost population, when breeding pairs lay

early in the season they have enough time to produce a second clutch (Thoresen, 1964).

At present, the Cassin's auklets do not have any kind of protection from the IUCN, as they are not included in the Red List of Endangered Species (BirdLife-International, 2004), but a decline in the overall population has been observed (Ackerman et al., 2004). The declines are thought to be mainly due to the effects of climate change (Hyrenbach and Veit, 2003); introduced species (Aguirre-Munoz et al., 2003) such as ravens, rabbits, goats and perhaps to impacts of human disturbance.

4.3 Methods

The study was carried out from January to May 2006, when I followed the first brood of some pairs of Cassin's auklet breeding on San Benito Islands in the Mexican Pacific. On these islands, the first eggs are laid in early January, and by the end of January most of the breeding birds are incubating. The peak of chick-hatching is in the first half of February, but there is considerable variation in hatching date within the colony (e.g. 35-43 days; this study). Chicks are left unattended in the burrow during the day when only a few days old, and they are fed by their parents until a few days before fledging, after this, hunger forces them to leave the nest. Fledging starts in the first half of March.

A total of 148 nestboxes had been installed in previous years. These nestboxes are distributed in several clusters along the island, in zones that had been previously occupied by pairs breeding in natural burrows. The nestboxes are made of wood, 30x20x20 cm approx. One part of the top was

covered with a removable lid to allow easy access to the bird inside. The lid was covered with a sandbag for protection. A PVC pipe, approximately 40 cm long, was put on one side of the nestbox and made the role of the tunnel.

Breeding activity was monitored in all the nestboxes from the beginning of the breeding season every five days until an adult was found incubating, then biometrics (weight –to the closest 5g-, wing-length, tarsus, head, bill length and width and egg length and width –to the closest mm) and eye colour were taken. Eye colour was recorded in order to establish if older and more experienced individuals perform better during the breeding season. Eye colour has been reported to be a good predictor of the age of the individual in Cassin's auklet (Manuwal, 1978), with juveniles having a dark brown iris, that fades until it becomes completely white in the adult . As Cassin's auklets exchange incubation duties daily, it is possible to measure the partner the following day. After both parents had been measured, the nestbox was left unchecked for 35 days, the average time incubation takes, to reduce disturbance on the breeding pair, and then I started checking it every five days. Egg volume was estimated from egg width and length using the formula proposed by Preston (1974) for seabirds, that takes into account the length (L) and breadth (B) of the egg: $V=0.51LB^2$.

To measure the effect of disturbance on chick growth, the chicks from the first brood were subjected to one of three treatments after hatching weight and wing were measured. Treatment was randomly assigned. Control group chicks were not subjected to experimental disturbance. Low disturbance group chicks were disturbed 4 times a day (at 8, 11, 14 and 16 hrs) by a person walking within 2 m from the nestbox entrance, for approximately 5 s,

while chicks in the high disturbance group were disturbed 8 times a day (at 7, 8:30, 10, 11:30, 13, 14:30, 16 and 17:30 hrs), also by a person walking within 2 m from the nestbox entrance, for approximately 5 s. Disturbance protocol was applied until the chicks fledged. Chicks from all groups were measured (wing to the nearest mm (using a wing-rule) and weight to the nearest g (using a pesola scale)), every five days until they were fully feathered, then they were ringed and measured daily to record the weight peak and fledging weight. I consider fledging weight as the weight recorded the last time the chick was measured before it abandoned the nest.

From the measurements taken every five days and then daily, it is possible to estimate the growth curve of single individuals, as well as from treatment groups. To compare the three groups, I used NCSS software (Hintze, 2006) to estimate the area under the curve (from hatching until fledging) of each chick individually, then for the analysis considered each value as an individual.

As it has been found that better quality parents are capable of producing better offspring (Chastel et al., 1995), I used the data from biometrics (wing length, tarsus, bill depth and width and head size) and using Factor One of a Principal Components Analysis (Tabachnick and Fidell, 1996) as a measure of body size, then this Factor 1 was plotted against the weight of the individual and the residuals were used as an indicator of body condition (Catry and Furness, 1999), I did a correlation analysis in order to establish if the body condition of both parents had an effect on hatching, peak and fledging weight of the chick.

The same has been found for older and more experienced individuals, that arrive earlier to the breeding grounds and have a wider option of burrows available. Using eye colour from the parents, and following what was presented in Chapter 3 of this thesis, I assigned the parents to one of three age groups, juvenile, subadults or adults, and using ANOVA compared if there were differences in the area under the curve, and fledging weight of their offspring.

4.4 Results

Body condition of the adults was estimated using PCA; the contribution to the body size index of each variable can be seen on Table 4.1, where bill depth has the largest contribution (30%) to the body size index of the individual, followed by head and tarsus. When comparing body condition index of the parents and chick growth I found no significant correlation ($R = -0.02$, $P = \text{NS}$). I also analysed if body condition of the parents of the chicks from the three experimental groups were different between them, but there were no significant differences (Figure 4.1; $F_{2,66} = 2.71$, $P = \text{NS}$) between them, so we can assume that subsequent results are not influenced by body condition of the parents.

Table 4.1. Contribution of each variable to each factor of a Principal Component Analysis. Biometrics are from the parents of the chicks that were subjected to the experimental disturbance. Total variance explained by the two factors is 52%.

| <i>Variable</i> | <i>Factor 1</i> | <i>Factor 2</i> |
|------------------------|------------------------|------------------------|
| Wing | 0.176 | 0.073 |
| Tarsus | 0.223 | 0.008 |
| Head | 0.282 | 0.057 |
| Bill depth | 0.304 | 0.063 |
| Bill width | 0.015 | 0.799 |

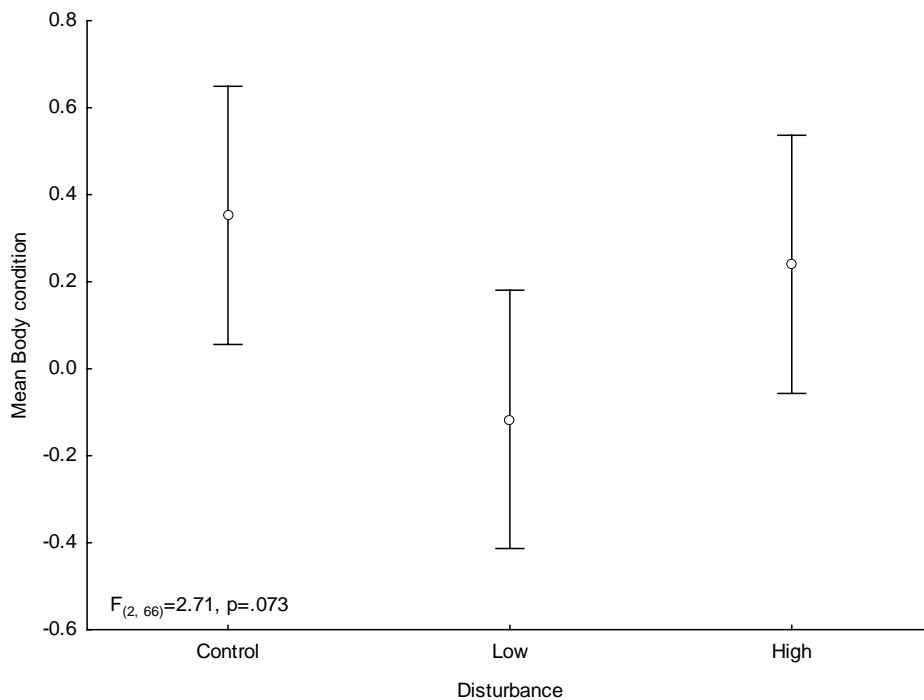


Figure 4.1. Mean body condition index of parents from each chick in the experimental groups. Body condition index was obtained from a PCA factor 1. Variables are those shown in Table 1. Then Factor 1 was plotted against weight and the residuals are used as an indicator of body condition.

Body condition of the parents did not determine the volume of the egg ($r=-0.29$, $p=NS$). Egg volume was estimated for 43 eggs, the rest of the eggs showed signs of hatching, therefore measurements were not taken. Mean egg volume was 22.84 ± 0.28 (Mean \pm SE; Figure 4.2) cm^3 . Egg volume did not influence hatching weight ($r=0.204$, $p=NS$).

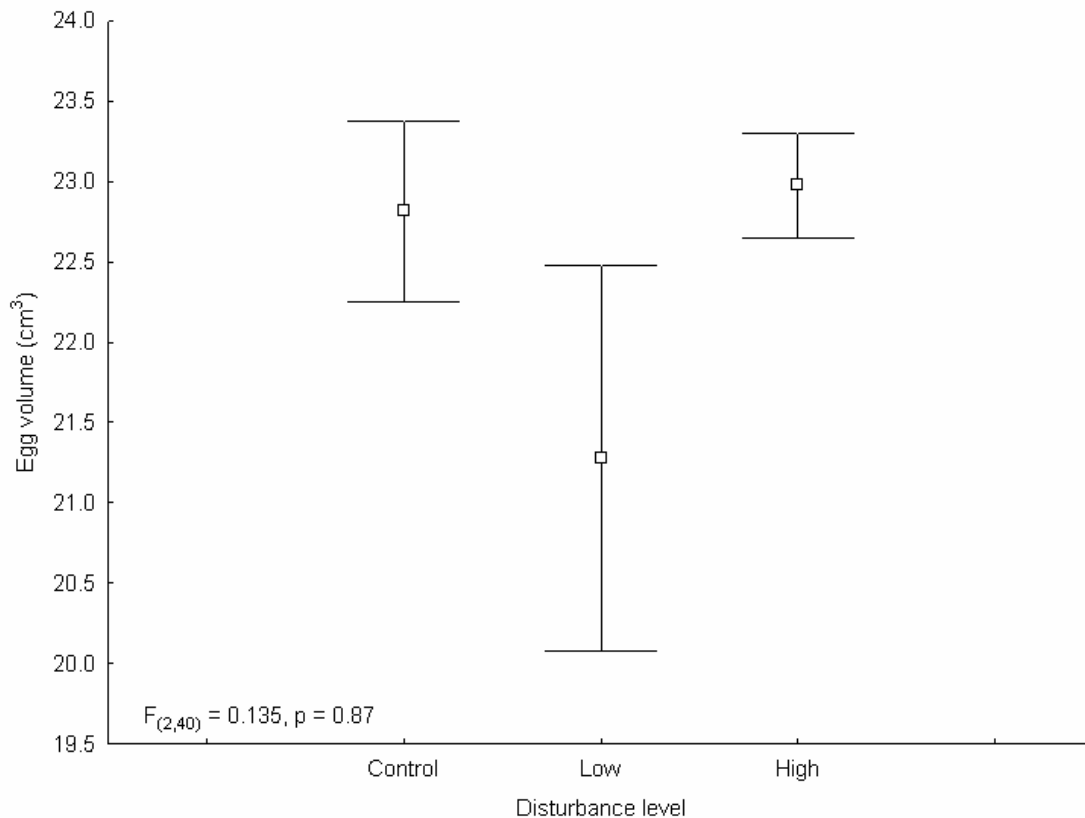


Figure 4.2. Egg volume of the chicks that were subjected to experimentation. Volume was estimated using the formula $V=0.51LB^2$, where L= length of the egg and B= breadth on the broadest part of the egg.

Age of parents was determined using eye colour as mentioned in Chapter 3. All three groups had individuals from all categories, from first time breeders to more experienced breeders with a total of 71 chicks both of whose parents were measured. They did not show any significant difference between all three groups ($F_{(2,68)} = 0.733$, $p = 0.48$; Figure 4.3).

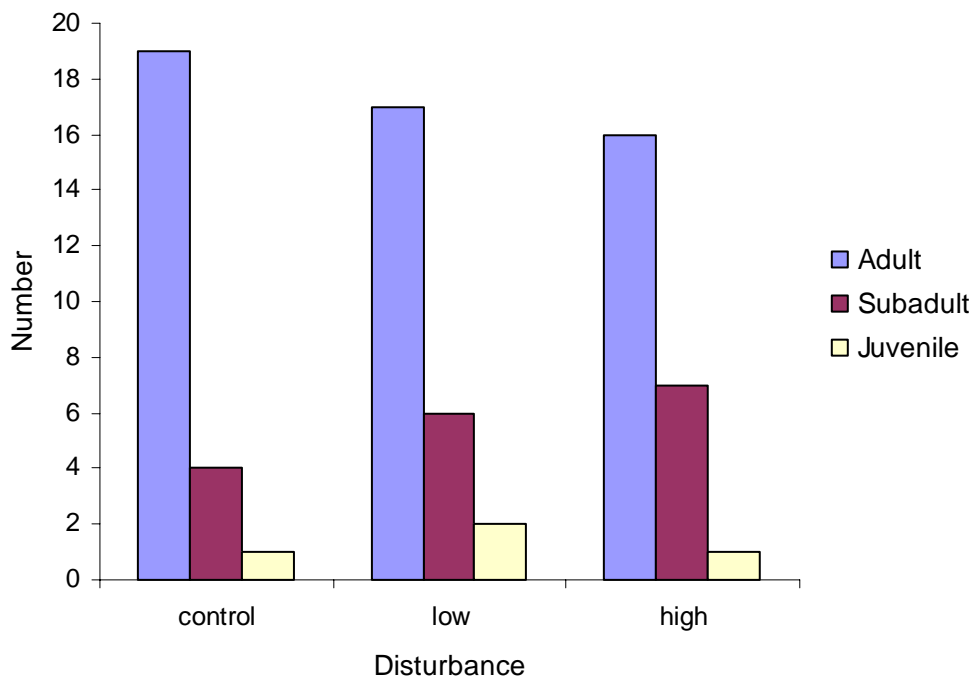


Figure 4.3. Age of the parents of the chicks in each experimental group. Age was estimated using eye colour, as indicated in Chapter 3 of this thesis. There are no significant differences between the number of adults in the three sites

A total of 73 chicks were followed from the first brood, so there were 24 chicks in the control and low disturbance groups and 25 in the high disturbance group. One chick from the control group and one from the low disturbance group died at the age of 5 and 10 days respectively. For all the chicks, biometrics were taken every five days from hatching until fully feathered, after that, they were ringed and I started measuring them daily.

There were no significant differences in hatching weight between the chicks in all three groups (Figure 4.4), meaning that results obtained afterwards are not the direct effect of hatching weight or egg volume.

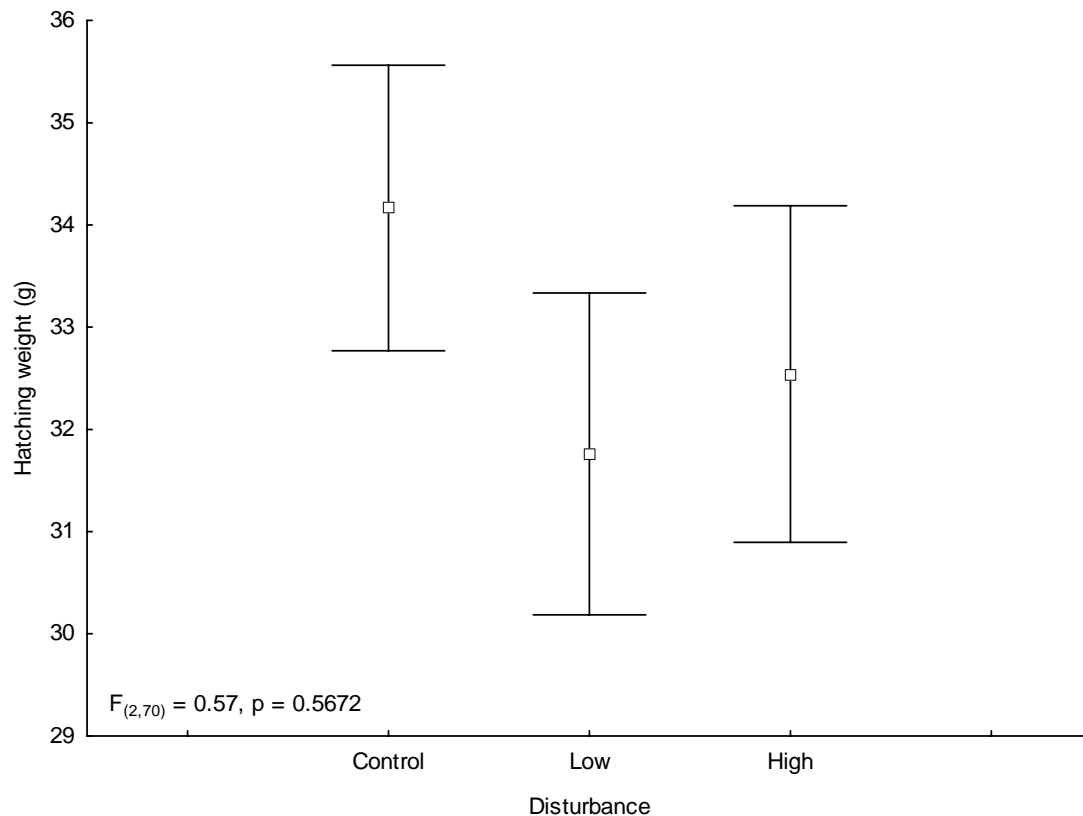


Figure 4.4. Mean hatching weight (\pm SE) of individuals subjected to different levels of disturbance. Differences are not significant, this implies that differences observed in peak and fledging weight are not due to hatching weight.

As can be seen in Table 4.2, chicks in the control group (23) had a mean hatching weight of 33.63 ± 1.42 g (mean \pm SE); a hatching wing-length of 20.92 ± 0.61 mm. The maximum weight they reached before the parents stopped feeding the chicks was 132.87 ± 0.90 g, and the last weight taken on the day before their fledging was 128.87 ± 1.21 g and wing length was 112.61 ± 0.5 mm.

Table 4.2. Descriptive statistics for the chicks in the three groups

| | Units | Control | Std Dev | Std error | Low dist | High dist |
|-----------------------------------------------------------------------|-------|---------|------------|--------------|-------------|--------------|
| Hatching weight | g | 33.63 | 6.99 | 1.42 | 31.7 | 31.6 |
| Hatching wing-length | mm | 20.92 | 2.99 | 0.61 | 20.0 | 20.6 |
| Peak Weight | g | 132.87 | 4.34 | 0.90 | 127.1 | 124.5 |
| Fledging wing-length | mm | 112.61 | 2.44 | 0.50 | 112.8 | 112.3 |
| Fledging weight | g | 128.87 | 5.82 | 1.21 | 119.8 | 116.5 |
| Growth before peak* | g | 98.43 | 7.55 | 1.57 | 95.2 | 92.6 |
| Growth after peak* | g | -4.00 | 5.317 | 1.10 | -7.3 | -7.7 |
| Mean body condition of parents of the control chicks** | | 0.35 | 0.73 | 0.15 | -0.11 | 0.23 |

*Peak was considered to be day 31st after hatching

**Body condition was estimated from Factor 1 of a PCA using wing-length, tarsus, head size and bill width and depth, then it was plotted vs. weight and the residuals are used as an indicator of body condition.

A general description of the growth of the chicks in the control group can be seen in Table 4.2. They had a mean growth of 98.43 ± 1.57 g from hatching to peak weight and then after the parents stopped feeding them, when they starve and abandon the nest in search of food, chicks had a weight change of -4 ± 1.1 g.

When comparing the growth curves of the chicks of the three treatments (Figure 4.5), we can observe that all three groups do not show an effect of disturbance during the first 25-30 days, but when chicks are fully feathered and are getting ready to abandon the nest, these differences become apparent. The area under the curve (Figure 4.6) shows differences between the control group and the two experimental groups ($F_{(2,68)}=6.09$,

$P=0.003$). The parents remained with the chick for four days maximum after hatching.

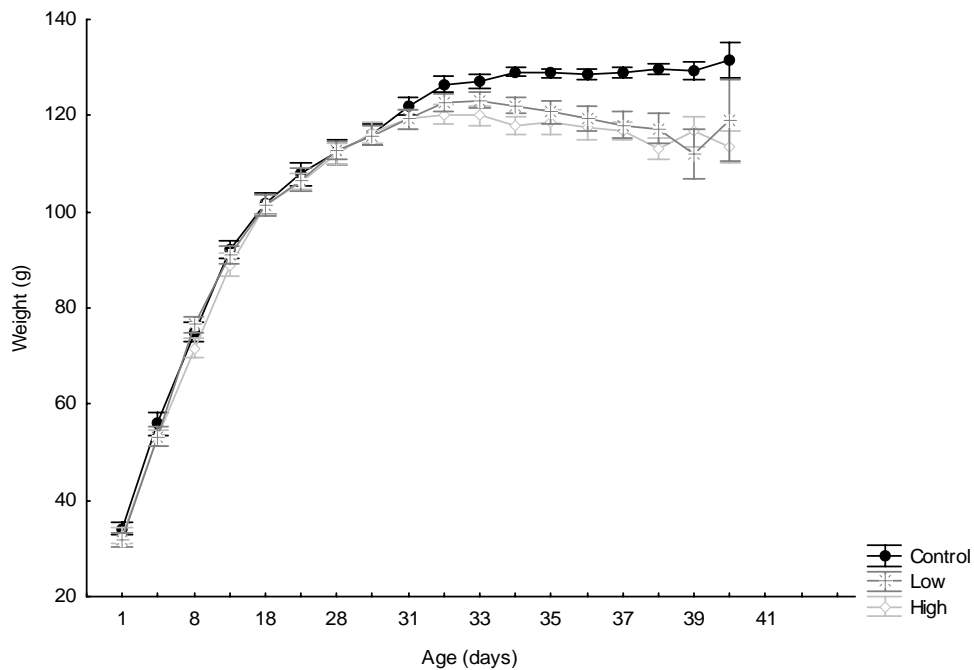


Figure 4.5. Chick growth curves in different treatments. Chicks were measured every five days until fully feathered, then daily to measure fledging weight. Chicks indicated with blue are from the control group (no extra disturbance provided) , chick on the green line are the low disturbance group (chicks disturbed 4 times a day) and chicks on the red line are the highly disturbed group (disturbed 8 times a day).

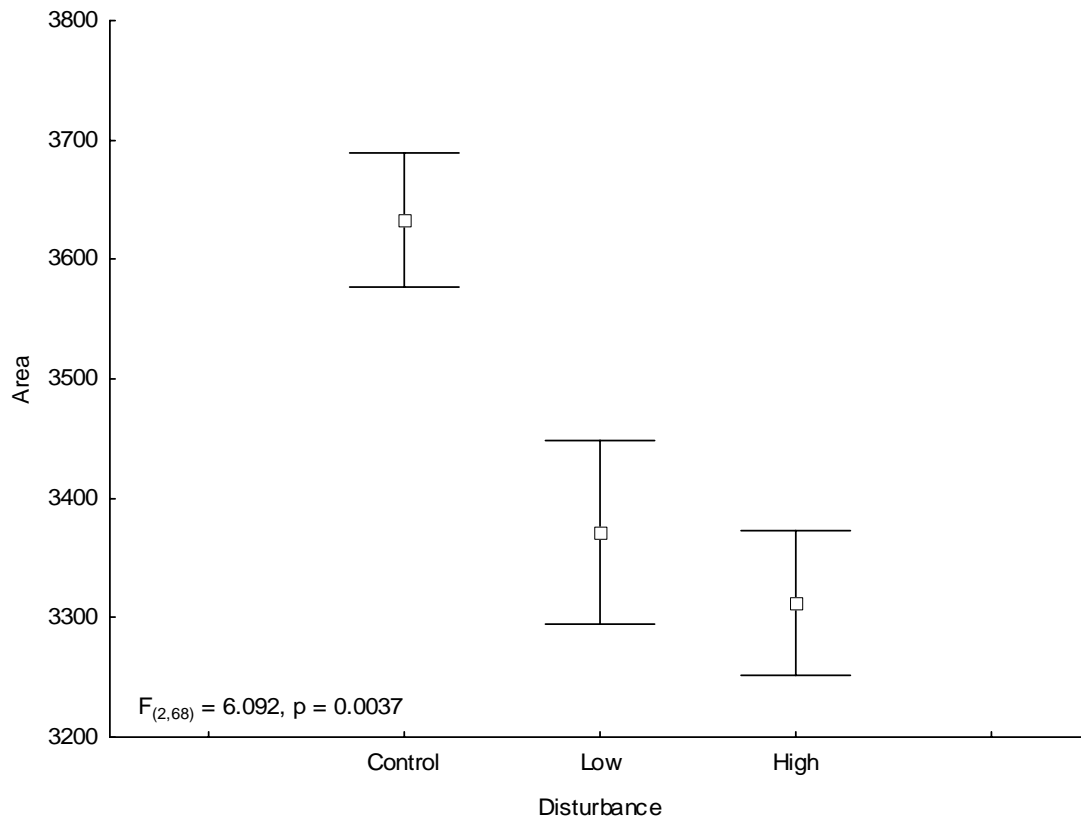


Figure 4.6. Differences in the mean area (\pm SE) under the growth curve for chicks under different levels of disturbance. Area was estimated using NCSS (Hintze, 2006) for each chick, from hatching to fledging, then the areas were grouped into disturbance level and an ANOVA was done.

If we focus on peak weight (the maximum weight that a chick reaches before the parents stop feeding the chick, three or four days before fledging) we can observe that chicks in the control group reach a mean weight of 133 grams, before starting to lose weight. On the other hand, chicks in the low disturbance group reach a lower mean peak weight (128 g), and chicks that were disturbed more times during the day reached a maximum mean peak weight of 124 g (Figure 4.7). The chicks in the high disturbance group show a significant difference from the chicks in the control group ($F_{2,68}=7.53$, $P<0.001$; Tukey test: $P<0.01$ for Control-High; $P=NS$ for Control-Low).

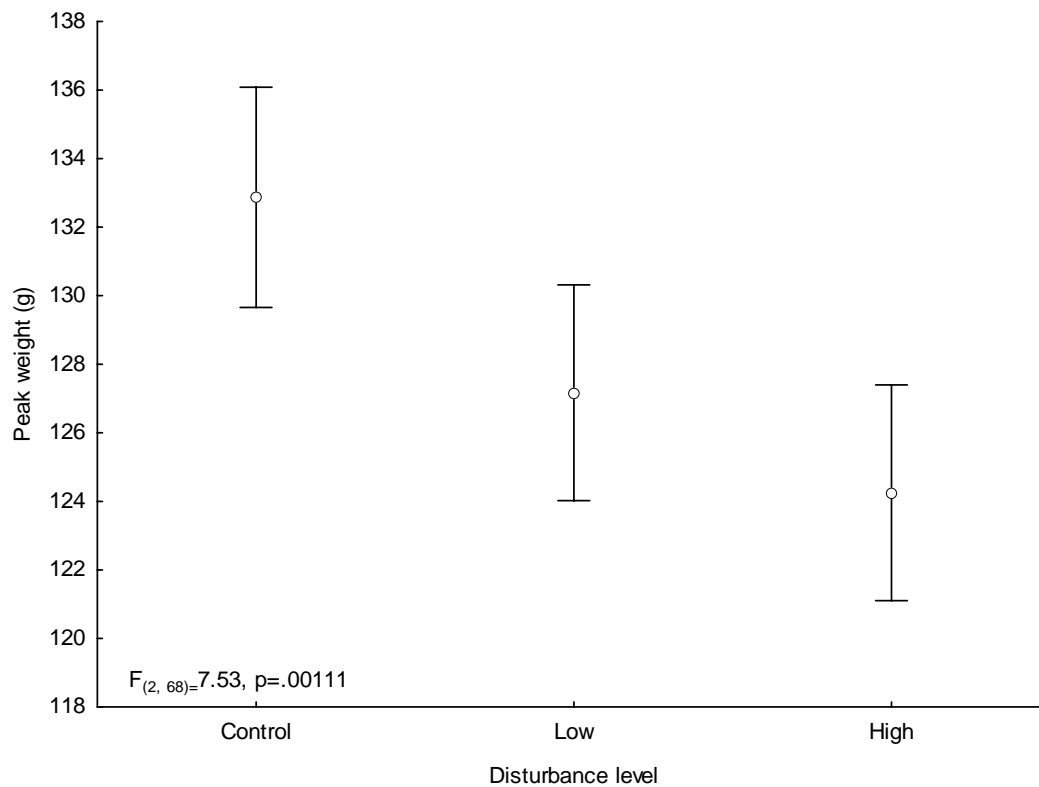


Figure 4.7. Mean peak weight (\pm SE) of chicks under different levels of disturbance (N=23 control, 23 low and 25 disturbance).

Regarding fledging weight, control chicks had a mean fledging weight of 129 grams, compared to the 120 of the low disturbed chicks and 117 of the high disturbance group (Figure 4.8). Chicks in both groups have a significantly lower fledging weight than the control group ($F_{2,68}=17.274$, $P<0.001$; Tukey test: $P<0.001$ for both experimental groups).

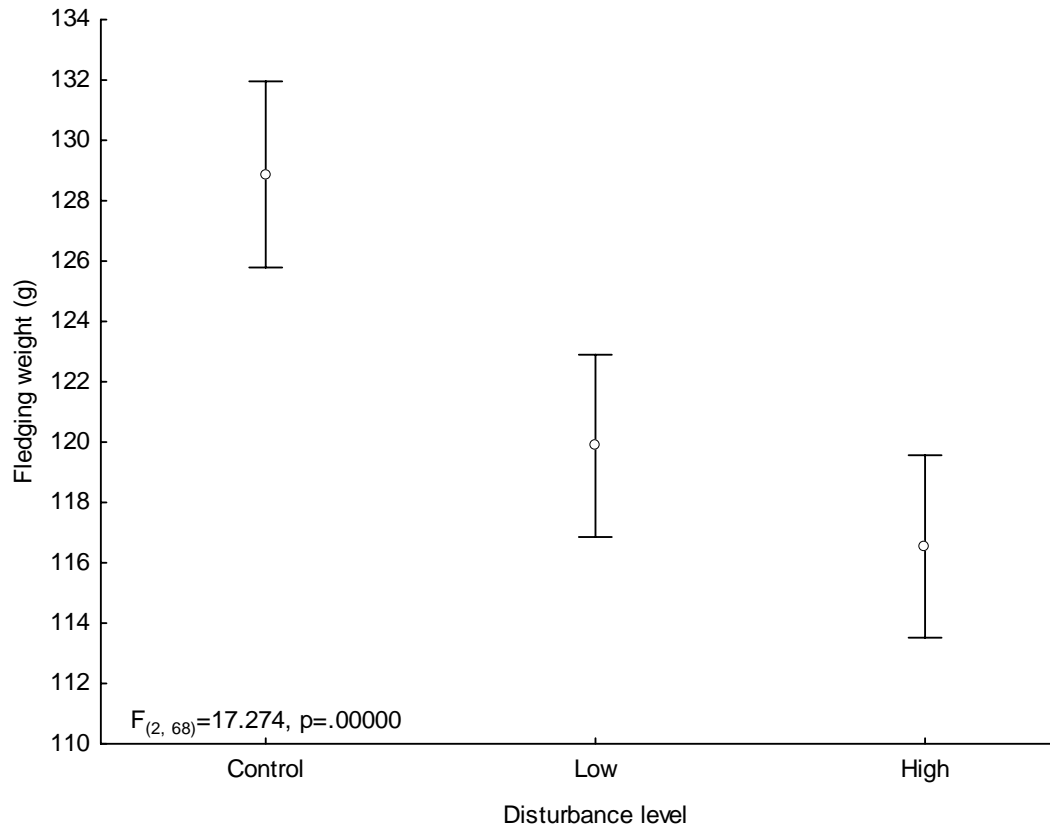


Figure 4.8. Differences in mean chick fledging weight (\pm SE) according to disturbance levels (control=no disturbance, low disturbance: disturbed 4 times a day, high disturbance, disturbed 8 times a day); chicks in the control group (0) show the highest fledging weight, while chicks on high disturbance group (2) show the lowest fledging weight.

I ran a linear regression using SPSS and in the model I entered fledging weight as dependent variable, and treatment (disturbance level), laying date, egg volume and body condition and age of the parents, as explanatory variables. Using a stepwise method, the only variable that entered in the model was disturbance level, but the variation explained is low ($R^2=0.23, p<0.001$).

4.5 Discussion

2006 was a good year for breeding Cassin's auklets in San Benito Islands. Usually after a year with adverse climatological conditions, as the El Niño event in 2005, comes a year with opposite conditions where the resources are abundant (Stapp et al., 1999, Jenouvrier et al., 2003) which allows the birds to compensate and regain a good body condition and therefore increase breeding success overall (Grant et al., 2000). Birds in San Benito Islands behaved similarly, they performed poorly in 2005 (pers. obs.) but compensated in 2006 with a high breeding success and most of the pairs double-brooding.

Body condition of the parents may determine the output of a breeding season, meaning that individuals that have better reserves in preparation for a stressful period, such as incubation, may face adverse conditions in a better way than will individuals in poor body condition. The age of the parents may also influence the breeding success of a pair because they are more experienced individuals that may have bred before or because they have improved their ability to locate, catch and handle the prey, leading to a higher amount of food delivered to the chick (Greig et al., 1983, Reid, 1988, Daunt et al., 1999, Reid et al., 2003,). My results suggest that the age of parents did not influence the output in terms of peak and fledging weight of their chick. This could be because Cassin's auklets may take advantage of group knowledge, that is, they observe other individuals and follow their way in search for food. Also, krill does not have any kind of protection against being predated, making it an easy prey for the auklets. On the other hand, 2006 being a year with abundant resources allowed all parents to provide enough

food for their chicks, and so permitted high success among all pairs, whether experienced or not.

When comparing the growth curve for the chicks under three different treatments, we see that control chicks show a constant increasing weight, until they reach a maximum (peak) weight and at that point it starts to decline. This is a typical growth curve for Cassin's Auklets (Morbey and Ydenberg, 1997), and many other bird species, especially nocturnal burrow nesting birds (Masello and Quillfeldt, 2002, Ritz et al., 2005, Tobon and Osorno, 2006), as parents provision their chicks up to a certain point, when they are fully developed and capable of flight. After this, the parents stop feeding the chick, so hunger forces them to fly out to the sea.

But when observing the growth curves of the two experimental groups, we see the differences between them and the control chicks. We see that all three groups grow at the same rate during the first stage of growth, but chicks in the experimental groups start losing weight when they are fully feathered and are getting ready to fledge, probably as a result of an increased metabolic rate caused by stress, that doesn't allow them to accumulate enough reserves. Because I did not measure stress hormones in these birds I can only infer that the loss of weight in the experimental birds was caused by elevated levels of stress hormones, and cannot rule out the possibility that experimental birds lost weight simply as a result of higher levels of locomotory activity in the burrows caused by the disturbances. Walker et al. (2002), found that newly hatched Magellanic penguin (*Spheniscus magellanicus*) chicks did not show a significant stress response to disturbance provided by tourists. They suggest this can be in order to avoid the negative effects of stress

hormones at early stages of development. Mullner et al. (2004) compared hoatzin chicks at disturbed and undisturbed areas in the Amazonian rainforest and observed something that can be comparable to the results obtained by me: younger chicks seemed to be relatively unaffected by disturbance, while there was an increased mortality in chicks ready to fledge. Mullner et al. (2004) also measured corticosterone levels in chicks' blood after handling, and observed that chicks in disturbed areas showed a stronger stress response (higher levels of corticosterone) than chicks in undisturbed areas. At the same time, chicks in disturbed zones kept a very high level of stress hormones in blood compared to control chicks, that after 20-30 minutes had reduced the stress hormones level to the initial point.

Kitayski et al. (2003) suggest that an increased corticosterone level can either increase the energy expenditure, by increasing the metabolic rate, or can reduce the effectiveness of the assimilation of the food provided by the parents. In this case, lower body weights of tourist-exposed juveniles could most likely be a result of repeatedly elevated levels of corticosterone, which in turn are known to metabolise fat and protein reserves (Ramage-Healey and Romero, 2001).

Differences in fledging weight are likely to be the effects of stress hormones, as it has been reported that a high concentration of corticosterone will have a negative effect on muscular tissue and bone strength (Hood et al., 1998, Mostl and Palme, 2002). As the treatments were randomly assigned it is very likely that the differences in fledging weight are mainly due to the experimental disturbance.

Moreno et al. (1997) observed that chicks from broods laid late in the season showed a negative effect on the growth curve, as well as fledging age and weight if the chicks were subjected to disturbance. In my study, the effect of laying date did not have a significant effect either on hatching or fledging weight. What Moreno et al. (1997) tested was based on the assumptions that lower quality pairs breed later in the season and at the same time these pairs are constrained to make a decision between feeding the chick or feeding for themselves, in order to gain weight and accumulate reserves for the moulting period. My study was carried out early in the season and based on the same assumptions that better quality pairs will start breeding earlier in the season (Hipfner, 1997, Nager et al., 2000, Reid et al., 2003), so that differences in chick growth between the treatments are likely to be the effect of the disturbance provided to them during the experimentation.

It has also been observed that chicks with higher levels of corticosterone, will beg more than chicks with normal levels (Kitaysky et al., 2003), resulting in more feeding trips from the parents to satisfy the needs of the begging chicks. For Wilson's storm-petrel, a one-chick brood species it was found that begging was not the result of competition with their siblings, but an exchange of information between the chick and the parents about the body condition of the chick, i.e. a chick with lower condition begs more than a chick in good body condition, resulting in larger meals for chicks with low body condition (Quillfeldt, 2002). In the case of the Cassin's auklets, a chick under a higher level of corticosterone may also beg more, and get larger meals, but because of the nocturnal behaviour of the species, they may not

have the time for another trip at night, as they spend the daylight out at sea, coming just at night to feed the chick.

Once fledged, a chick is independent at sea, the parents do not provision them any more (Manuwal, 1974), so they have to find the food. Kitayski et al. (2003) found that chicks' ability to find and handle prey can be compromised; they found that chicks with a high level of corticosterone during development took twice as long to master the skill of handling the food in an experiment they developed with black-legged kittiwakes. In this study, as the disturbance was provided during the day, when the chicks were left alone at the nest, this should not have an effect on the provisioning behaviour of the parents, and even if begging increases, as parents only do one feeding trip each night, this behaviour may not have changed while a chick under a stressful situation has an increased metabolic rate, therefore needing more food to compensate for the excess.

Regel and Putz (1997) detected an increase due to human disturbance in the metabolic rate of up to 10% of the daily energy expenditure of moulting chicks, while another study found that the effect of disturbance was negligible (Jakubas, 2005). This variation may be due to species-specific behaviour. Regel and Putz (1997) worked with penguins, and their breeding grounds represent harsher conditions and probably less opportunity of escaping the disturbance source; while Jakubas (2005) worked on grey heron, a tree-nester species that may be covered by the branches of the tree.

In adults, high levels of corticosterone have been found to have a deleterious effect, such as immunosuppression, muscle wasting, reduced reserve accumulation, and, ultimately, death (Walker et al., 2005). On the

other hand, these effects can be even more harmful in chicks that are not able to escape from the disturbance.

Other studies have found that chick growth of Cassin's auklet is closely linked to the type of food provided by the parents; chicks fed with copepods had a maximal growth rate compared to chicks fed with other types of prey (Hedd et al., 2002). However, chick growth differences were noted among all the chicks born in the breeding seasons of 1996 to 1999, meaning that the differences were noted between years, and not within each season. Taking this in consideration, in the present study, differences in growth cannot be due to differences in food quality, as the experiment was carried out in one breeding season, and there is no reason to think that chicks in different groups were fed different diets.

It has also been observed that an individual that faces higher pressure will take greater risks (Clark, 1994). Chicks under constant disturbance may be forced to fledge younger, taking advantage of their current weight, without waiting too long until weight drops lower, while chicks under no stress wait until development has concluded and they are ready to face life out of the burrow. For example, in areas with high predation risk, chicks fledged younger and lighter (Harfenist and Ydenberg, 1995). Harfenist (1995) observed that faster growing nestlings fledged heavier and younger.

A colony of ravens in the island may also be an important factor for producing stress in the birds, as ravens have adapted their behaviour to take advantage of birds resting close to the entrance of the burrows (pers. obs.). Another study recorded that corvids represented 32% of the predated nests of marbled murrelet (*Brachyramphus marmoratus*), which may prevent

conservation plans from being fully successful (Marzluff and Neatherlin, 2006), so this raven population could have a more important effect on the population, that may eventually lead to a drastic reduction of the population, and not the direct effect of tourism and human activities.

Fortunately, the experiments carried out for this project did not have an effect on the survival of the chicks until fledging age. Although there were two dead chicks, they died for reasons not linked with the research (i.e. parent's abandonment).

Chapter 5.

The effects of climatic conditions on breeding

Cassin's auklets

5.1 Abstract

Adverse climatic conditions have often been reported to have negative effects on seabird species, reducing breeding success, body condition, survival, etc. In this chapter I analyse how a local El Nino event affected breeding Cassin's auklets in San Benito Islands in 2005, by comparing with a "normal" season in 2004. In 2005, breeding attempts declined by more than 80%, while overall breeding success was just over 5%. The few chicks that survived had lower peak and fledging weight than chicks followed in 2004. Oceanographic conditions may have an important impact on the dynamics of this population.

5.2 Introduction

Ecosystems and populations are known to be influenced not only by long-term climatic trends, but also by short-term climatic modes, such as interannual variations (Gjerdrum et al., 2003, Sydeman et al., 2006). These variations may affect populations in a positive way (increasing food availability, improved weather etc.) or in a negative way, such as consequences of floods or droughts.

Oceanographic events as a result of shifts in currents can have large impacts on marine mammals and seabirds. These two groups are upper trophic-level predators in marine ecosystems, and are sensitive indicators of changes in oceanic environments. Population size and demographic parameters of several seabird species have been related to environmental fluctuations occurring worldwide in marine ecosystems (Croxall, 1992), and more specifically to abiotic components such as sea

ice, sea-surface temperature or air temperature (Weimerskirch, 1992, Barbraud and Weimerskirch, 2001, Wilson et al., 2001, Jenouvrier et al., 2003, Weimerskirch et al., 2003).

These environmental fluctuations occur on the large scale and are localised always on the same area, such as the North Atlantic Oscillation (NAO), that is the difference in pressure between a low-pressure point in Iceland and one high-pressure point in the Azores, (Stenseth et al., 2003), it is the most robust pattern in the north Atlantic region and affects SST, ocean currents and sea-ice cover in the Arctic and sub-Arctic regions (Moller, 2002). During positive phases of NAO there are strong westerly winds across the British Isles causing mild and wet winters and cool and cloudy summers, whereas in the Mediterranean region conditions tend to be very hot and dry. During negative phases of the NAO, the British Isles experience more easterly winds, warmer and drier conditions in summer and colder and drier conditions in winter. The Mediterranean region tends to be cooler and experience more storms and rainfall. The effects on seabirds of changing NAO phases have been noticed in Britain, where breeding success of kittiwakes was correlated with the abundance of herring, zooplankton and phytoplankton, and all of these with the frequency of westerly winds caused by the NAO (Aebischer et al., 1990).

In another region of the world, the cold Benguela current off southwest Africa has a high concentration of seabirds that are exploited for their guano; these birds are highly affected by current shifts and their associated changes in food supply, suffering from mass mortality or

breeding failure (LaCock, 1986). These events happened mostly in the same year as an El Niño or in the year previous to an El Niño (LaCock, 1986).

On a larger time-scale, the Pacific Decadal Oscillation, as its name says, it's a fluctuation occurring every 10 to 12 years and has an influence on the primary production in the North Pacific and also changes the ocean currents and SST as well as the migration patterns of several fish species (Trenberth and Hurrell, 1994).

The best known of these environmental fluctuations is the Southern Oscillation, that affects climate and currents worldwide, but its effects are particularly strong on the Eastern Pacific, where it is known as El Niño, or ENSO (El Niño Southern Oscillation). The causes are not well understood, but seem to begin with the decrease of the strength of the westbound winds. The winds blow steadily and push the surface waters of the Pacific towards the coast of Asia. When these winds fail, all this mass of warm water returns towards South America along the equator and over several weeks to months, increases the temperature of the water by as much as 10° C. Once the mass of warm water reaches the coast, it spreads towards South and North America, causing important changes in the weather patterns of these areas. As seabirds in this coastal region depend on upwelling cold, highly productive waters, they suffer a high mortality and mass breeding failure during these warm water incursions (Schreiber, 1994). The effects are first noticed as a warming of the waters close to the Peruvian coasts that expand along the south American coasts, but they have an effect on both sides of the Pacific and

beyond, such as warm winters in western Europe, drought in eastern Asia and Australia and high summer rainfall in China, as well as high rainfall from Peru to California, all this being the opposite of what would happen in the absence of an El Niño event (Trenberth and Hoar, 1997, Philander, 1999, Jaksic, 2004).

The warming of the waters on the coast of Peru, as in other parts of the world, leads to a shift in the prey species of several seabirds. The Guanay cormorant (*Phalacrocorax bouganvillii*), the Peruvian booby (*Sula variegata*) and the Peruvian brown pelican (*Pelecanus occidentalis*) are very abundant species and the main producers of guano, in quantities that can be commercially exploitable (Zavalaga and Paredes, 1999). With the warming of the waters during an El Niño event, the plankton and the anchovies on which the birds feed disappear (either through death or through changes in spatial distribution such as moving to deeper and offshore waters), provoking a decrease in the population in the millions of individual seabirds (Crawford and Jahncke, 1999). These events happened on an average of every five years in the last 100 years, but with some events more severe than others (Hughes, 1985). After each decrease of the population, the numbers recovered progressively until the next El Niño event (Hughes, 1985).

5.2.1 The El Niño phenomenon and its relevance in the California Current System

El Niño-Southern Oscillation (ENSO) refers to a warm ocean current that typically appears around Christmas-time and lasts for several

months, and may persist into May or June (NOAA, 2007). The warm current influences storm patterns around the globe. As a result, these "El Niño" climatic events commonly cause heavy rains and storms on the eastern part of the Pacific, and drought on the Western coast. Basically, the mass of warm water normally seen in the Pacific Ocean near the southwest Pacific, spreads towards the centre of the ocean during an El Niño (Trenberth, 1997).

The California Current System (CCS) is located from the coast of British Columbia in Canada to the middle part of the Peninsula of Baja California, in Mexico. The CCS is a highly productive area, but at the same time it is also highly variable (Lee et al., 2007). The California Current System (CCS) is an area where cold subarctic water mixes with warmer water from the south and west (Bograd and Lynn, 2003). This encounter of masses of water at different temperatures provokes the upwelling phenomenon, which carries the nutrients that accumulate on the bottom of the ocean and brings them to the surface, making it an area with very high primary productivity and creating an environment that can support a wide range of complex communities (Hyrenbach and Veit, 2003, Bertram et al., 2005).

The CCS has recently seen a continuous warming that started in the early 1970's (Roemmich and McGowan, 1995). The warming of the upper 10 m of the sea indicates a movement of warmer water from the south. This incursion of warm water leads to an increase in the depth of the thermocline to more than 100 m and, as a consequence, there is less nutrient supply as upwelling is slower or completely stops. The main

effect of this decreased nutrient availability is a reduction in primary productivity, affecting all the upper levels in the food web (Hyrenbach and Veit, 2003). This long-term warming of the CCS has had implications such as slow declines of the seabirds that feed in the area (Oedekoven et al., 2001).

In the California Current System, El Niño conditions become evident after up to six months of El Niño's presence in the tropical Pacific (Oedekoven et al., 2001). This warming can also be related to an increase in the Aleutian Low Pressure System, resulting in a weakened flow (Norton and McLain, 1994). A dramatic decrease in Cassin's auklets numbers in front of the coast of California, took place in 1989, a year with unusually high sea-surface temperatures (SST) (Oedekoven et al., 2001). As a result of that increase in the SST, there was a shift in the seabird community in the area, from cold-water seabirds, to warmer-water species (Hyrenbach and Veit, 2003).

During an El Niño event, there is also an increase in rainfall (Philander, 1999), that can have a direct negative effect on breeding success of burrowing species. For example, it has been noticed that heavy rainfall results in abandonment of the nest by some Manx shearwaters *Puffinus puffinus* in the west of Scotland, due to flooding (Thompson and Furness, 1991), thus, making burrow selection an important decision for the birds in order to increase breeding success.

Although the California Current has undergone substantial environmental shifts in the past few decades, the summer of 2004 exhibited highly anomalous conditions relative to all previous recorded

summers in terms of late initiation of upwelling and the resulting elevated surface temperatures and depressed productivity through September 2005 (Brodeur et al., 2006). The origin of this seems to be extratropical, as in other areas the conditions remained El Nino neutral, but in the CCS the conditions during this time were very similar to those present during an El Nino event (Sydeman et al., 2006). Because of these conditions, 2005 was a particularly adverse year for breeding seabirds on the east coast of the Pacific (Peterson et al., 2006). Cassin's auklets were affected greatly, from the Triangle Island population down to San Benito islands (Sydeman et al., 2006). For instance, in South Farallon islands and in Triangle Island there was a mass abandonment between the 10th and the 20th of May, a phenomenon that had never been reported in 35 years of continuing studies on Cassin's auklet (Sydeman et al., 2006). In this chapter, I compare breeding efforts during two different years, one normal year, 2004, where departures from the average temperature were close to 0 degrees; and one El Nino-like year, 2005 and I report on the body condition of the adults from 2004 to 2006.

5.3 Method

In 2004, nine burrow clusters were randomly selected on the West San Benito Island and in each cluster, eight single burrows were followed using an infrared camera mounted on a plastic probe following Keitt et al. (2003). These burrows were checked every five days and the contents recorded from the 26th of January until the 30th of April. For 2005, 18 burrow clusters were selected randomly on different areas of the West

San Benito Island. In each cluster, 10 natural burrows were followed from the 1st of February to the 24th of April. For each burrow, occupation was recorded (presence of an incubating bird, only an egg, a chick or empty), as well as orientation (degrees from the magnetic North), burrow density (number of burrows per square meter), soil type (rocky, sandy, mix), depth (from the entrance of the burrow to the deeper end of the nest chamber) and vegetation cover (percentage of the area around the entrance covered by vegetation) to understand the characteristics that increase the possibility of breeding successfully. Burrows were checked every five days using an infrared camera. The burrows selected didn't necessarily have to be occupied at the beginning of the season. The burrows followed during 2005 included the burrows followed in 2004.

Breeding success was compared between 2004 (considered as a normal year, because the departure from the average environmental conditions was almost null (Goericke et al., 2004), and 2005, that presented El Niño-like conditions in the California Current System. Breeding success was compared using a one-way ANOVA. A General Linear Model was constructed in order to estimate which physical characteristics (depth, orientation, soil type, vegetation cover, burrow density, slope, etc.), have an influence on the breeding output of a certain burrow.

From the nestboxes, individual birds were marked and measured (as indicated in Chapter 3) in 2004, 2005 and 2006. As the adults were ringed and biometrics were taken before the experiments mentioned in the previous chapter started, there is no reason to think that the

experiments carried out in 2006 could have influenced the results from 2006.

A Principal Component Analysis (PCA) using wing length, tarsus and bill size was used to estimate bird size. As seen in Chapter 3, males tend to be larger than females, so I compared PCA1 of all individuals together against the PCA1 of groups separated by sex. Then the PCA1 chosen was plotted against weight of the bird, then the residuals were estimated and the residual is considered to be a measure of body condition (Ratcliffe and Furness, 1999). The individuals that were captured in both years were compared using a paired T-test.

As males tend to be larger than females, body condition was compared separating by sex for each year of all the individuals measured. Body condition was also compared for 33 individuals that were measured in all three years, giving the possibility of determining the effects of climatic adversity on breeding success and body condition of the same individuals, rather than on a larger “random” sample of the population. The comparison was done using a General Linear Model where the variables included were breeding success as dependent variable, and age and body condition as explanatory variables.

Also from the data obtained from the chicks born in the nestboxes it is possible to compare the effects of adverse climatic condition on the chicks. I estimated growth curves and compared hatching, peak and fledging weight, as well as wing length for 2004 and 2005. I also compared fledging period length between these two years. Fledging

period was estimated as the number of days from the first day the chick was found until the last day when the chick was inside the burrow.

5.4 Results

For 2004, initial occupancy of study burrows was 80% and decreased slightly, as a result of nest abandonment, and later on due to chicks fledging until all the burrows were empty by the end of April (Figure 5.1).

2005 was a very unfavourable year for breeding seabirds in San Benito Islands. The initial occupancy of the natural burrows and nestboxes was almost 50% lower than that of 2004. Gradually, this proportion of occupied burrows decreased until reaching less than 7% (Fig. 5.1), with no recorded attempts to relay or double brood. Also the length of the period that birds attempted to breed was much shorter, with most of the nests abandoned by the end of March (Fig. 5.1).

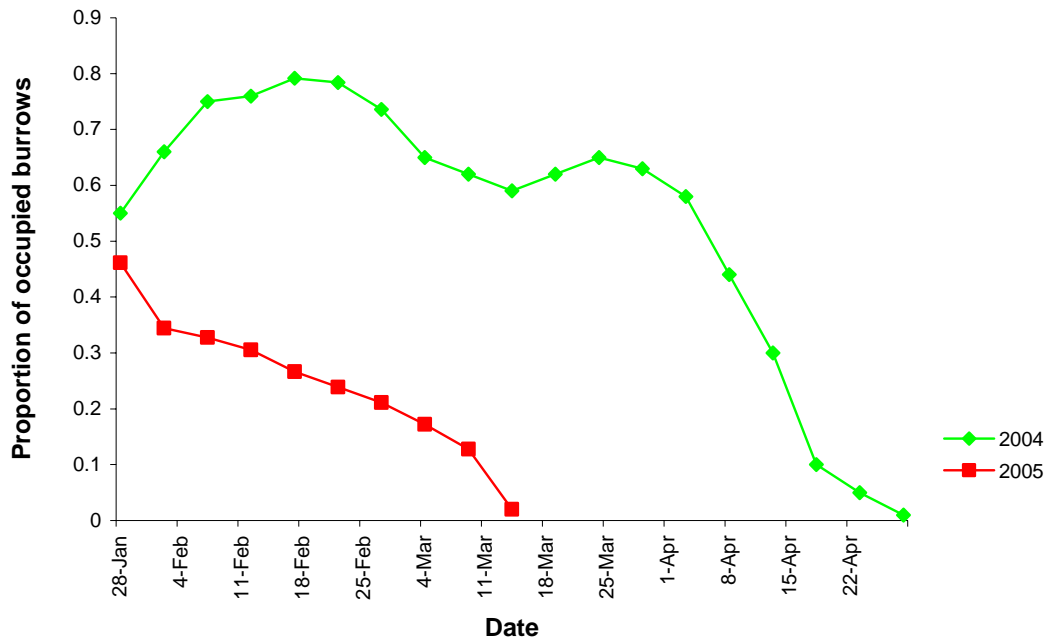


Figure 5.1. Occupancy of the burrows for a “normal” year (diamonds) and a local El Niño year (squares).

In 2004, 86% of the occupied burrows had a successful hatchling, and 70% of those burrows had a successful fledgling. Occupancy and breeding success decreased dramatically for 2005, with a maximum occupancy lower than 50% at the beginning of the season. There were 34 hatchlings out of 85 eggs laid and these produced only 7 successful fledglings during the whole season (Figure 5.2). Heavy rain was present from the 12th to the 15th of February, flooding many of the occupied burrows and preventing new burrows from being occupied.

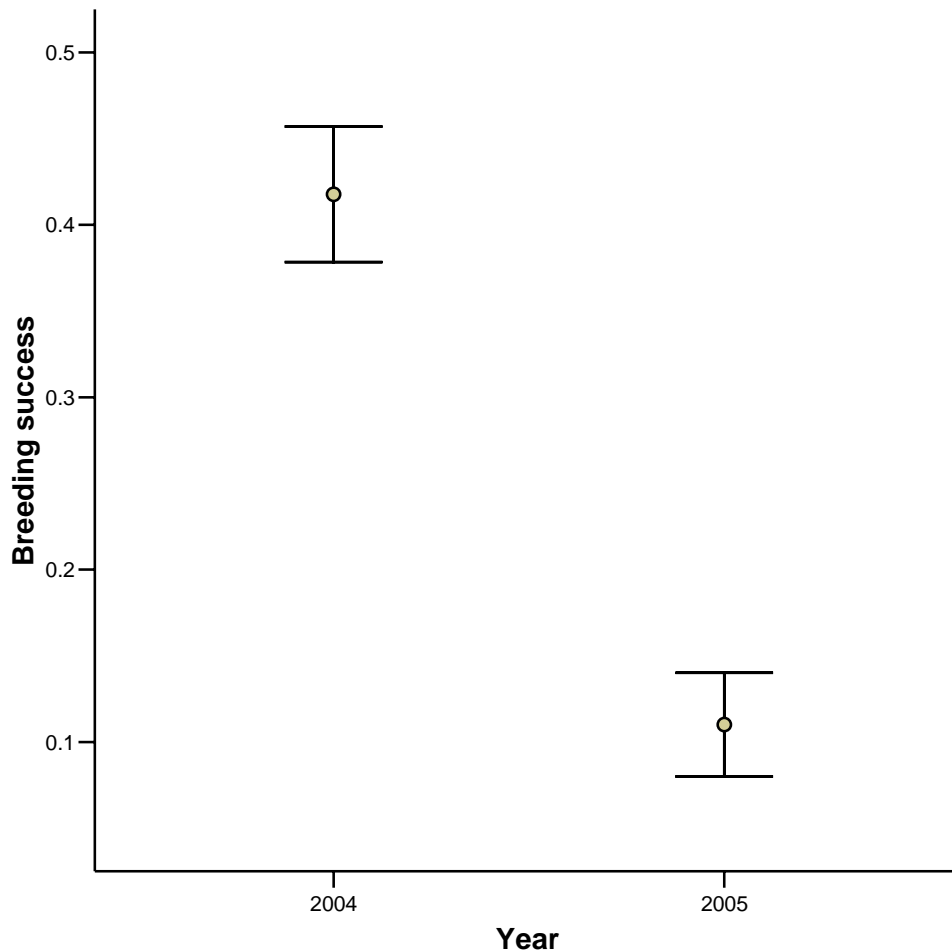


Figure 5.2. Breeding success was much higher for 2004, reaching more than 0.4 chicks per breeding pair than in 2005, when breeding success decreased to 0.1 chicks per breeding pair.

A GLM was run in order to establish if physical conditions had an effect on the breeding output of that single burrow or burrow cluster (for characteristics of the cluster, such as burrow density, soil type, or slope). None of the physical characteristics had an effect on the possibility of a burrow being used, nor on hatching or fledging success.

From the nestboxes it was possible to estimate the body condition of all the adults. A PCA was done including wing-length, tarsus and bill depth and width. Data were analysed separating males from females, as

this represented better the differences in size between sexes. Bill size contributed the most to the PCA Factor 1 (0.82).

PCA Factor 1 was then plotted against the weight of the individual and the residuals of the regression line were considered to be body condition. In Figure 5.3 we can see the overlap of size vs. weight between males and females however, males are significantly heavier than females ($F_{1,451}=28.26$, $P=0.001$).

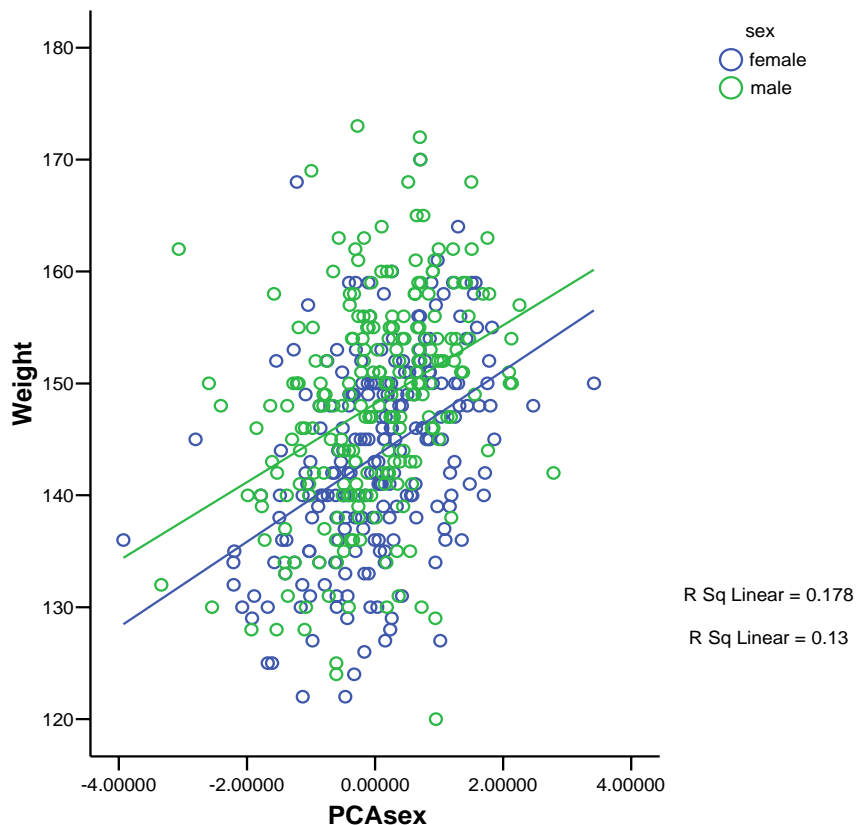


Figure 5.3. Differences in size vs. weight (body condition) of males and females. Males are larger and heavier than females.

Body condition for females was not significantly different in 2004 and 2006, but was significantly lower in 2005 (Tukey, $P=0.01$; Fig. 5.4 and 5.6). The adverse climatic conditions had a similar effect on the

males, with a lower body condition in 2005 and 2006 compared to 2004 (Tukey, $P=0.001$). It is important to note that for males body condition in 2006 was also significantly different to body condition in 2004 (Tukey $P=0.004$; Figures 5.5 and 5.7). Breeding success was determined by age ($P=0.001$) but body condition did not have an influence on it ($P=0.6$). However, R^2 is quite low, 0.01. Older individuals had a better overall breeding success, reaching almost 0.5, adults-subadults had a breeding success of 0.4, while younger individuals had a mean breeding success lower than 0.3 chicks fledged per burrow. Differences in breeding success were significant between adults and younger birds ($P=0.02$; Fig 5.8).

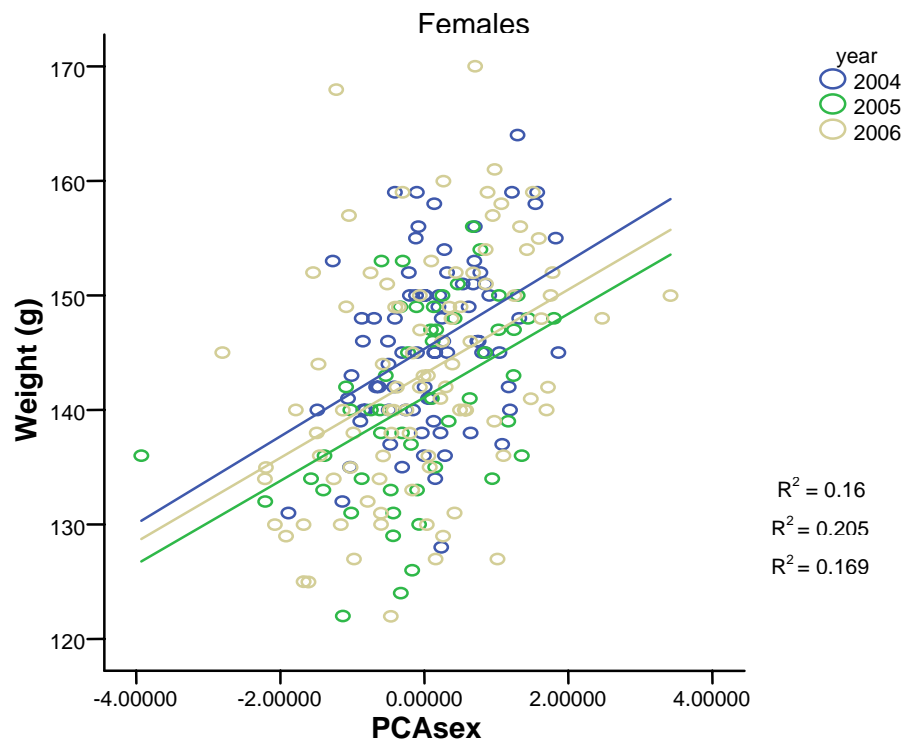


Figure 5.4. Scatterplot with regression lines for body size vs. weight for female Cassin's auklets in three years.

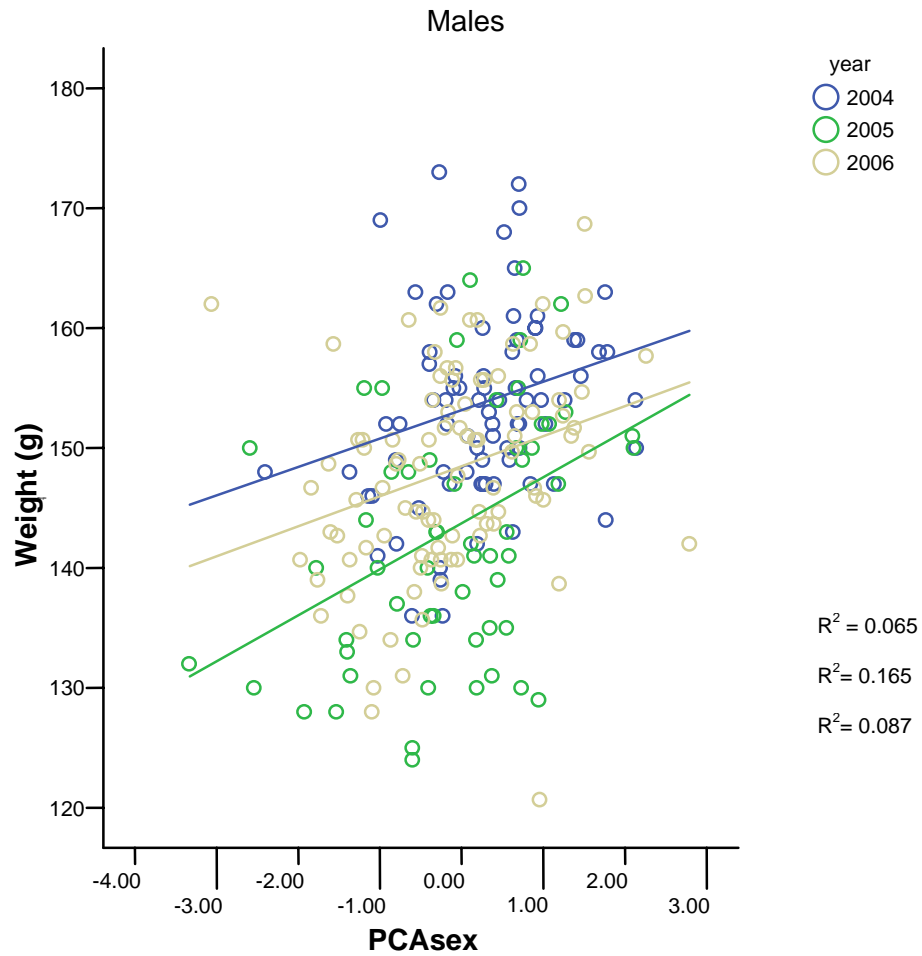


Figure 5.5. Scatterplot with regression lines for body size (PCAsex) vs. weight of male Cassin's auklets followed in 2004 to 2006.

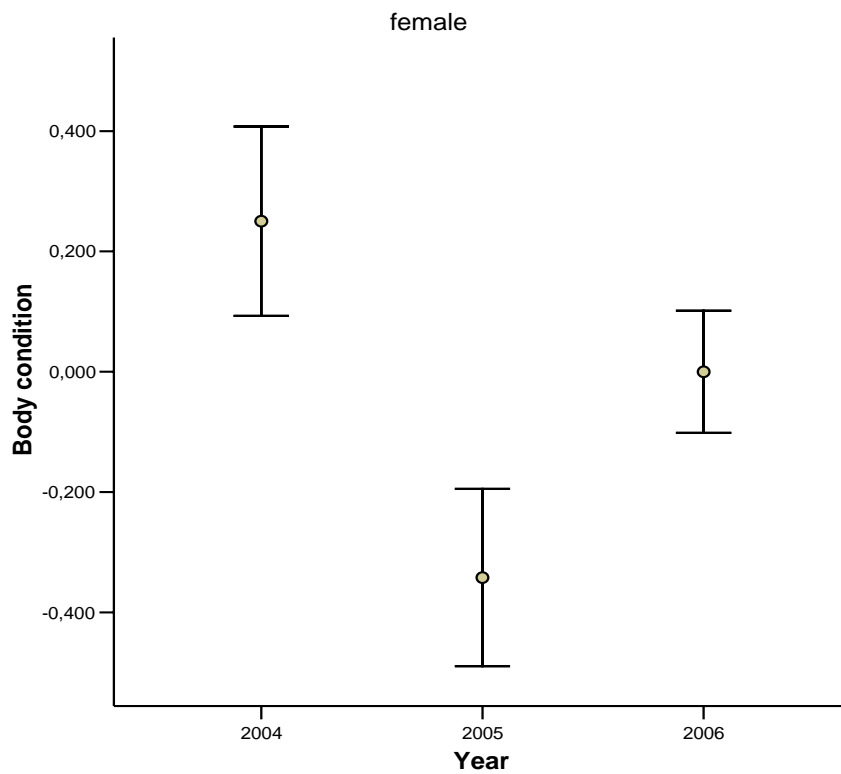


Figure 5.6. Differences in body condition of female Cassins auklets measured from 2004 to 2006. Body condition was significantly lower only in 2005 ($P=0.01$).

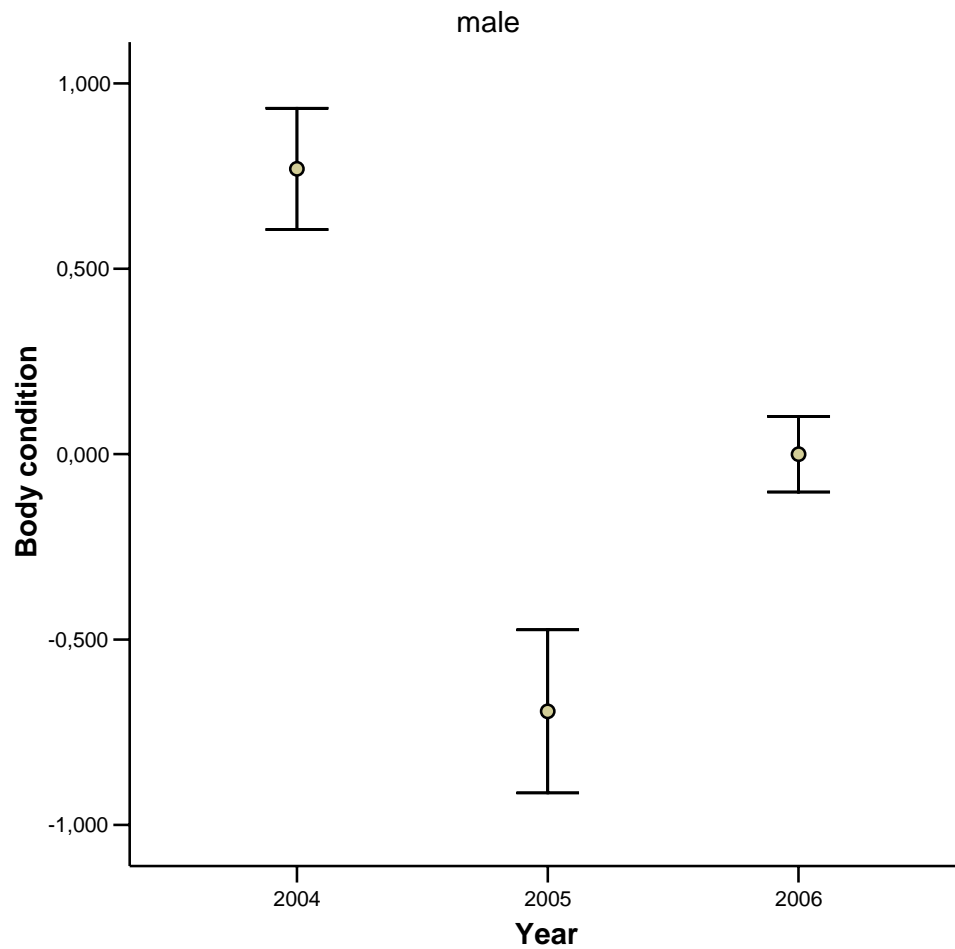


Figure 5.7. Male body condition of all individual Cassins auklets followed from 2004 to 2006. Differences are significant between 2004 and 2005 ($P=0.001$); 205 and 2006 ($P=0.005$) and 2004 and 2006 ($P=0.01$).

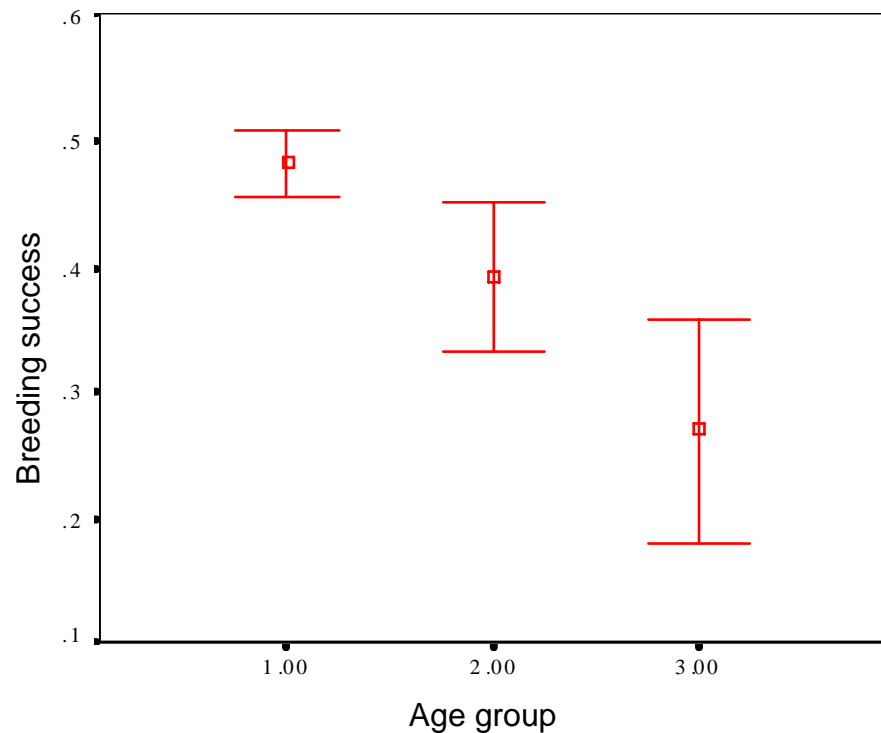


Figure 5.8. Breeding success according to age group of Cassin's auklets. Individuals in group 1 are considered to be fully mature adults; in the group 2, adults-subadults and in the group 3 subadults. Only differences in breeding success for adults (1) and subadults (3) are significant ($P=0.02$).

When focusing on the individuals that were measured in all three years (16 females and 17 males) we can observe that they follow the same pattern. The only difference, although not significant, was that females in 2006 had a better body condition than in the previous two years (Fig. 5.9). Small and large females were affected in the same way during 2005, recovering equally for 2006. My results show that smaller individuals have a larger weight for 2004 than do larger males. Males show a bigger weight loss for smaller individuals, approximately 15 grams, while for larger individuals weight loss was on the range of 7-8

grams. For 2006, both large and small individuals had the same mean weight difference, compared to 2004.

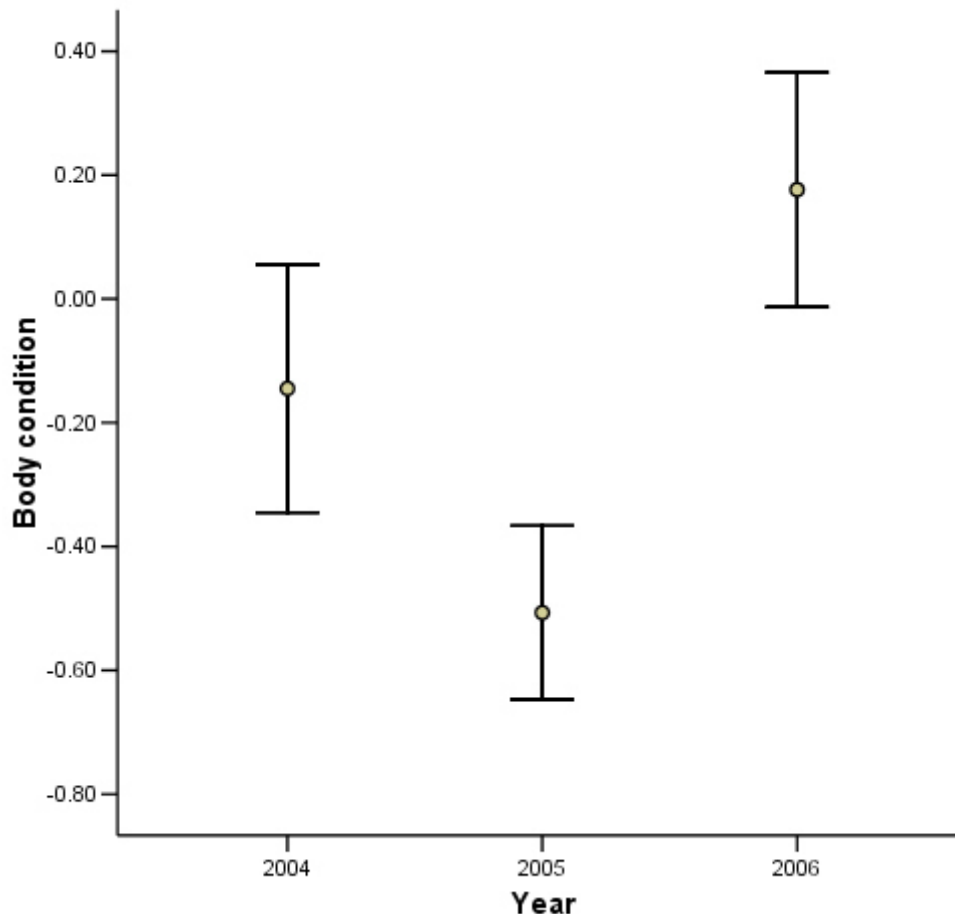


Figure 5.9. 16 repeated females measured in all three years. Body condition significantly improved from 2005 to 2006 ($P=0.04$).

Chicks in 2004 had a mean fledging period of 43 days, while in 2005 it was reduced to 37 days (Figure 5.10). This reduction in fledging period may have had an effect on peak and fledging weight, that in 2004 reached 128 and 123 g respectively, which were dramatically reduced to a peak weight of 109 g and a fledging weight of 105 g in 2005.

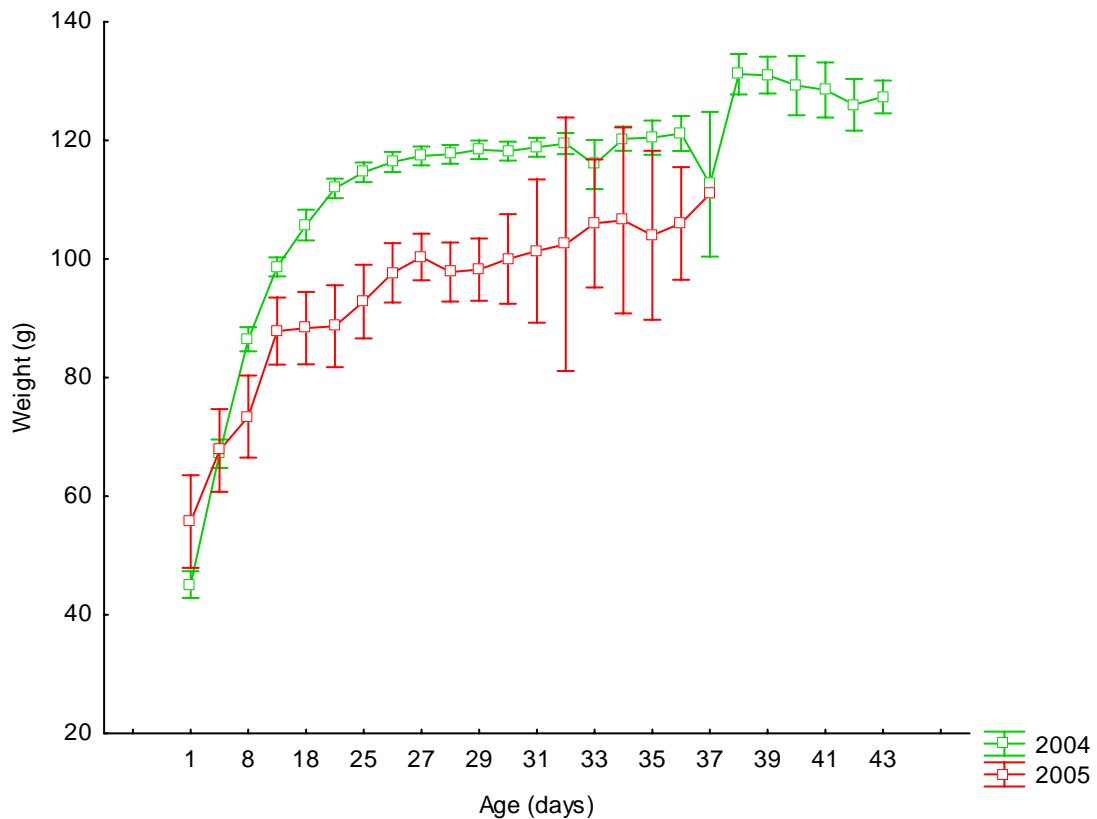


Figure 5.10. Differences in growth curves of Cassin's auklet chicks for a good year (2004, green lines) and an El Nino year (2005, red line). Chicks were weighed every five days at the beginning and then daily when fully feathered.

Chicks did not show a significant difference in wing length between the two years ($F_{1,35} = 0.01$, $P > 0.05$) while there was a difference of peak ($F_{1,35} = 29.4$, $P < 0.001$) and fledging ($F_{1,35} = 23.9$, $P < 0.001$) weights from 2004 to 2005 (Figure 5.11).

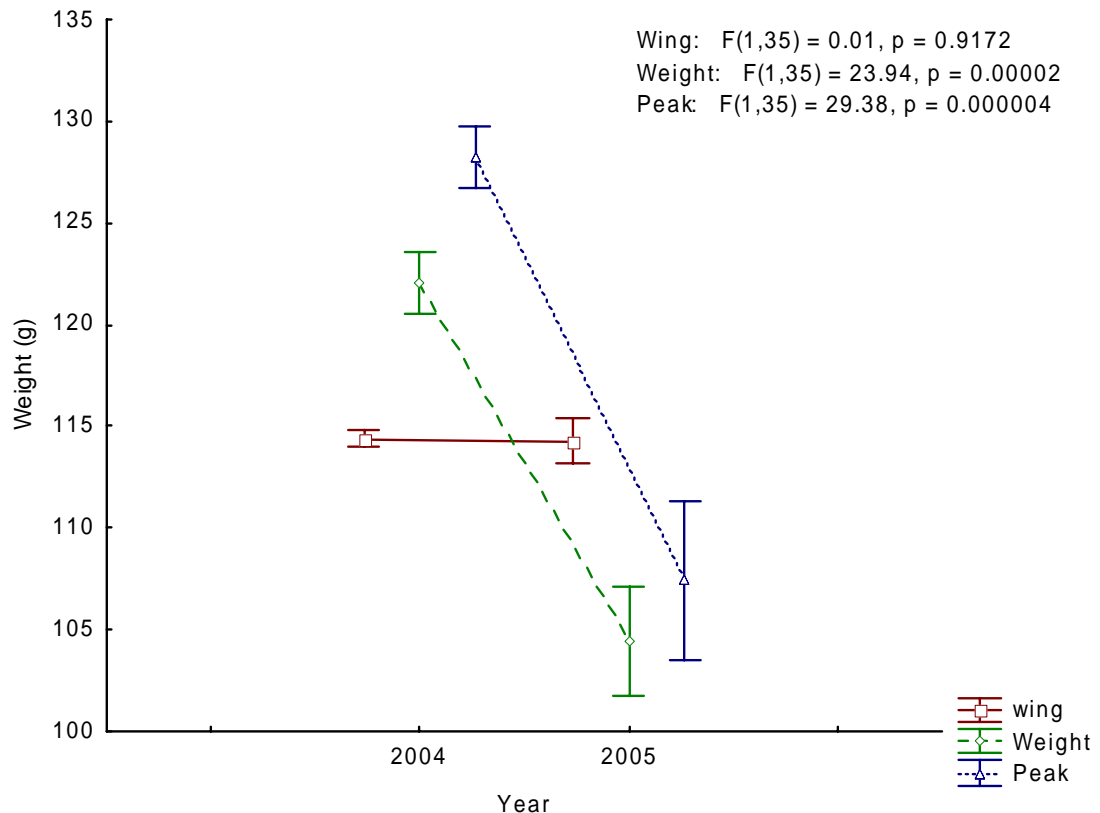


Figure 5.11. Differences in wing-length, peak weight and fledging weight of Cassin's auklet chicks. There is a very big decrease of almost 20% in weight from 2004 to 2005.

5.5 Discussion

Seabirds have some of the highest adult survival rates of all bird species, start breeding after several years as immatures and have low reproductive rates, so their populations vary little from one year to the next (Furness and Camphuysen, 1997), therefore to estimate the immediate effects of climate conditions, it is better to focus on breeding success rather than population size.

Seabird species may be affected differently by an increase in SST, as some populations, or the local distribution of widespread populations, that depend on cold waters and high upwelling may decrease, others that

feed in superficial and warmer waters may increase (Hyrenbach and Veit, 2003).

In general, the effects of adverse conditions during the 2005 breeding season were noted on all the range of Cassin's auklet. Breeding success was 8% at Triangle Island, total failure in the Channel Islands in California (Sydeman et al., 2006) and 7% in San Benito Islands (my data). Although 2005 was not classified as an El Niño event throughout the Pacific in terms of the climatic conditions on the whole range along the equator, locally in the CCS it did behave as if it was an El Niño, affecting upwelling and increasing sea surface temperatures and precipitation (Goericke et al., 2005, Peterson et al., 2006), which may have led to a redistribution of the food resources for Cassin's auklets (Sydeman et al., 2006).

During the 2005 breeding season, I observed a higher rainfall rate compared to the other years, particularly at the beginning of February, when there was a period of 4 days of continuous rain. In the central part of the CCS it was observed that Cassin's auklets switched to a different diet (Abraham and Sydeman, 2006). When this switching of prey occurred before the start of the breeding season, then Cassin's auklets were not deeply affected, however, if the climate anomalies started after the start of the breeding season, then a large proportion of the pairs abandoned the nest (Abraham and Sydeman, 2004).

As the anomalies in the CCS began during the last quarter of 2004, continued during the breeding season and only finished by September 2005 (Brodeur et al., 2006), Cassin's auklets may not have

had enough time to put on the reserves needed to have a successful breeding season in 2005. However, as conditions returned back to normal at the end of 2005, and there was even a low La Niña event (Peterson et al., 2006), in 2006 birds were almost back to the same body condition as in 2004. My results do not agree with what was proposed by Abraham and Sydeman (2004), as the anomalies in 2005 started well before the breeding season and I observed a high desertion rate.

The birds that were affected the most by conditions in 2005 were those ones from the northern part of the range (Sydeman et al., 2006); however, my results also show that the population of San Benito Island was deeply affected. Although the survival of the species on the island is not threatened in the near future, more continuous El Nino events may have a dramatic effect in the long term, as there may be little or no recruitment in the population (Bertram et al., 2005).

Low hatching success in 2005 was mainly due to the flooding of the burrows because of heavy rainfalls early in the breeding season; with many of the surviving nests being abandoned shortly afterwards. In other papers it was reported that rain has an effect on the breeding output of burrowing species (Thompson and Furness, 1991). Nest site characteristics may also influence the breeding success of a certain nest (Ramos et al., 1997, Velando and Freire, 2001, Velando and Freire, 2003). The same has been observed for peregrine falcons in Australia, where the breeding season started later in wet than in dry years (Olsen and Olsen, 1989a) and breeding success was lower during wet years, mainly as a result of flooding of unsheltered nests, as pairs breeding on

sheltered ones were as successful as in dry years (Olsen and Olsen, 1989b). My results suggest that for 2004 none of the physical characteristics of the nest had an influence on the breeding output of that single nest; and this agrees to some extent with what was observed by Ramos et al. (1997), in the sense that vegetation cover did not have an effect, but it was the opposite to the rest of the variables, where none of them (burrow depth, orientation, burrow density, etc.) had an effect. For 2005 any possible effect of burrow quality was apparently obscured by climatic conditions.

As mentioned before, 2005 was a very peculiar year, and the GLM did not reveal any significant effect of the physical conditions of the burrows, as all effects may have been clouded by heavy rain. Other studies have found that under normal conditions, the quality and location of the nest have an influence on the breeding success of the pair. For instance, Ramos et al. (1997) found that physical characteristics greatly influenced hatching success of Cory's shearwater, while burrow density was an important factor for hatching success of Band-rumped storm-petrel. For shags (*Phalacrocorax aristotelis*), Potts et al. (1980) found that younger cormorants moved to better quality sites once they became available, and as a consequence, an increase in breeding success was observed. Also for shags, it was found that they selected sites with more lateral and overhead cover, with better drainage and with average visibility (Velando and Freire, 2003). Velando and Freire (2003) also found that sites where breeding was successful differed from unsuccessful sites, affecting hatching success mainly; they observed

that, nest-site quality declined with density and with seasonal occupancy. Some other factors, not directly linked with the physical characteristic, may also influence the quality of the burrow, such as distance to the foraging areas or access for predators, as well as the composition of the colony where the nest is located, as single or multi-species colonies (Fasola and Canova, 1992) . The position of the nest relative to the colony, i.e. in the centre or on the edge of the colony, influenced the survival rate of kittiwakes (Aebischer et al., 1995) , although breeding success was equal for both areas. In my study, the number of burrows is big enough as to detect any differences in burrow quality, however, because of the high levels of rain presented during incubation most of the burrows failed and the successful nests were too few as to discern in this sense.

The ability of any species to withstand a food shortage depends partly on body size, a larger individual may have more reserves and because of the reduced surface area to volume ratio, the amount of energy expelled is lower (Newton, 1998). Larger birds may need a higher food intake to meet their energetic requirements than smaller birds, therefore during adverse conditions they loose a higher proportion of the weight, compared to smaller birds. From carcasses, it was noted that at starvation to death, small birds usually have lost about one third of the body weight, while larger birds lost up to half of the weight (Harris, 1962).

The 16 females that were followed all three years show an increase of body condition from 2005 to 2006, even reaching a better body condition than in 2004. While in 2004 many of them were on their

first attempts to breed, they gained experience and ability to catch prey in the following years (Pyle et al., 2001), allowing them to recover and reach a better body condition. This was also reflected in breeding success, where all 16 females reached the maximum breeding success in 2006. However, this increase is likely to be due to the increased age and experience of the individual birds rather than to environmental conditions.

The 17 males, although having a lower body condition in 2006 than in 2004 had a higher breeding success, supporting the idea that they gained experience and that has also been observed in other papers (Weimerskirch, 1992, Pyle et al., 2001, Mauck et al., 2004).

For these 33 individuals measured in all three years, there is a significant correlation between body condition and breeding success that is not present in the rest of the population, probably because these are older and more experienced birds, allowing them to arrive earlier to the site and use the burrow they used in previous years.

As expected, chicks did not show a difference in wing length between the two years, but there is a larger variation than in a normal year. It has been observed that under low food conditions energy is mainly allocated to wing development and flight capacity (Anderson and Keith, 1980, Safina and Burger, 1983, Dahdul and Horn, 2003) so chicks can fledge and search for their own food and increase their probability of survival. Based on this, the differences in peak and fledging weight can also be expected (Pinaud et al., 2005), as most of the effort is put in fledging. Since in 2005 the mean fledging weight was less than 105g, and the fledging period much shorter than in normal years, it is expected that

the chicks will not be fully developed (Ritz et al., 2005), compromising the immediate survival and ability to provide for its own food. Dahdul and Horn (2003) point out that chicks on a low energy diet, as that present in an El Nino year, will have a lower lipid reserve that is used during the learning period of the chick to catch its prey, so the chick has to learn quickly or the probability of survival will be reduced.

It is important to highlight that the timing of the anomalies in SST may have an influence on the breeding output of a certain species; in Antarctica, Inchausti and colleagues (Inchausti et al., 2003) found that if the anomalies are present during the winter or the spring just before breeding, the breeding success decreases notably, while if the SST anomaly happens during the breeding season, then the effect is not so pronounced, and some species did not even suffer any consequence, such as the black-browed albatross and the grey petrel. This lack of relationship between breeding success and SST may be due to the exploitation of different areas compared to other species that were affected by high SST.

Several seabird species breeding in Antarctica started arriving later to the breeding grounds (Barbraud and Weimerskirch, 2006), probably as a result of an increase of the period with good weather conditions. On the other hand, long distance migratory species tend to arrive earlier as conditions for breeding improve earlier on the breeding grounds and the migratory routes (Forchhammer et al., 2002, Saino et al., 2004).

It has been suggested that when studying the effects of weather conditions in ecology it is a better option to use the large-scale indices, such as NAO and ENSO, as it was observed that local weather is highly influenced by these; at the same time, ENSO and NAO can be predicted several months ahead, and many of the most important effects of climate on species are the result of interaction of several variables influenced by long-scale phenomena, which may be a better representation of these effects compare to local weather (Stenseth et al., 2003).

Also, different species of seabirds feed on different areas of the ocean, from the coast to the pelagic zones and at different trophic levels (Furness and Camphuysen, 1997), and considering these two factors together we may obtain a clearer idea of what is happening and may somehow predict what the species could face under certain climatic conditions.

Here I observed how seabird breeding success and body condition can vary from year to year, but in order to have a better estimate of the effects in the long term, continuous monitoring projects are needed and should be analysed in relation to climate conditions as it has been reported that the breeding success variations have a very limited impact on breeding population sizes on short time-scales for such long-lived species (Lebreton and Clobert, 1991, Jenouvrier et al., 2003).

Chapter 6

General discussion

During this thesis, I had the opportunity to study several factors that influence the breeding success of Cassin's auklets. I observed that both adults and chicks are affected by human presence on the island, this resulting in a reduction of breeding success or affecting the peak and fledging weight of chicks.

I found that adults under high levels of disturbance were affected, reducing their breeding success. I observed a differentiation in the choice of nest sites: older, and therefore more experienced individuals, prefer sites that are further away from the disturbance source, or moved site from disturbed locations to less disturbed locations. Also effects on chicks were negative: chicks that were disturbed more frequently had a lower peak and fledging weight, which may possibly affect the development of the immune system, and may decrease their survival possibilities. The chicks exposed to disturbance often abandoned the nest earlier than the control chicks.

If I had had the possibility of improving my research, I would have used a non-invasive approach to study the effects of disturbance, measuring stress hormones in faecal samples. It has been observed that stress hormones can be analysed from faecal matter (Mostl and Palme, 2002). However, due to the logistical problems on San Benito Islands, I could not carry out such research, as the samples should have been frozen but there was no electricity to run a freezer, and logistics made it difficult to set up a generator or to use a freezer or freezing system (such as liquid nitrogen) not requiring electricity.

It would also have been interesting to compare the breeding success of the colony in West San Benito Island, where the fishing camp is located and the colonies in East San Benito Island, where human access is restricted to research. However, as the burrow density is extremely high on East San Benito island, there is a high probability of trampling them, so I decided to focus on the West island only.

Another of my plans was to use a temperature datalogger and see if the incubating bird moved away from the egg during a disturbance event, noticing a decrease of temperature inside the nest chamber and taking longer to hatch. However, as the datalogger that was available to me had to be put inside the nestbox and it was the size of a film roll canister, it caused some distress to the bird, making it abandon the nest temporarily. In order to avoid permanent abandonment, I quit this part of the experiment, as 6 out of 6 nestboxes were abandoned temporarily when I inserted data loggers.

A different kind of technology may be used to carry out this test. An external datalogger, small enough as not to cause any interference with the incubating activities might be used. I would expect that when the bird is disturbed and if it moves away from the egg, towards the entrance of the burrow, in order to escape if necessary, a small increase of temperature would be noticeable, as the heat from the egg is released, but then temperature would decline, until the bird returns to incubating position. This lowering of the temperature of the egg should lead to an increase in the incubation period (Baudains and Lloyd, 2007, Hepp et al., 2006, Nuechterlein

and Buitron, 2002). This phenomenon, however, has not been observed in tropical areas. For instance, Tieleman et al. (2004) found that 14 species of birds breeding in tropical areas do not increase the incubation period if they leave the nest.

When talking about the effects of disturbance on seabirds, a lot has been studied, with most of the studies reporting negative effects for many species. However, these negative effects due to disturbance, depending on the intensity of disturbance, may be reduced with time, letting the birds habituate to the presence of humans and their activities. In this sense, more long-term studies are needed to really estimate the amount of habituation that may occur to continuous disturbance.

I also had the opportunity to study the effects of adverse climatic conditions. During the 2005 field season I was prepared to run the experiments on disturbance but the climatic conditions were those of an El Nino event, so breeding conditions were not optimal and I decided instead to prepare a chapter of my thesis describing these effects. This event made me consider the wider range of events that influence seabirds, and put it in a wider context when thinking about conservation alternatives.

To improve the quality of the research regarding the effects of the El Nino phenomenon, I should have increased the number of nests monitored to estimate if the few successful burrows have any physical characteristic that makes them better than the ones with total failure.

Another important factor to analyse was the change in the diet of Cassin's auklets. Sampling the food provided to the chick would have allowed me to see if there was a shift of prey during this warming of the upper layer of water. It has been noticed that for the northern population of Cassin's auklets, there is a shift in the proportion of *Euphasia pacifica* and *Thysanoessa spinifera*. It should be interesting to know if the same phenomenon occurs and how much it influences body condition and breeding output in the San Benito Islands. I didn't have the opportunity of doing this, as I was prepared to implement the disturbance experiments, but once on the island I noticed that conditions were not as expected.

Finally, I would like to make some recommendations that may help keep the numbers of Cassin's auklets on the San Benito Islands. This groups of islands has recently seen an increase in numbers of ravens, from approximately 80 individuals in 2004, the first year I was there to more than 500 individuals counted in 2006. I found some nests on the island, but not enough as to increase the population at this level; I suppose many of the new individuals counted emigrated from nearby Cedros Island, where there is a larger human population. Ravens may be attracted to the rubbish generated by the people in San Benito Islands and migrate. Although this does not represent an immediate threat for the seabirds breeding on the islands, if the number of ravens continues to increase, and being efficient predators as they are, then they may influence the number of breeding seabirds. A programme for controlling the population or to eradicate the ravens from these islands

should start soon if their effects are to be kept to a minimum. At this moment the raven population is relatively low and could be easier to control.

The breeding season of the Cassin's auklets, Xantus' murrelet and black-vented shearwater coincides with the time of year when the grey whales come to this area to give birth; this last event is highly attractive for many tourists that follow the migratory route to see this phenomenon. Many of these people stop on the islands as a stopover during the trip and cause negative effects on breeding seabirds. Boats arrive on the island on a twice a week basis, from January until March, and the passengers spend half a day wandering around on the island.

Furthermore, the breeding season of several species of seabirds also coincides with the harvesting dates for lobster and abalone on these islands. Around 10 lobster fishermen inhabit the island from mid September to mid February. Some 100 abalone fishermen and their families also arrive by mid December and stay until the end of February. They work every day from 6 A.M. until 2 P.M. and then they have all the afternoon free, when they usually walk around the island.

These two groups of people may have a different impact on the seabirds, as tourists are advised to stay inside the path and they are usually guided by a naturalist, with a set route, probably decreasing the possibility of burrow trampling. On the contrary, fishermen just want to spend the time before dinner time, taking them to areas that are outside the path and where the burrow clusters are present. Taking this into account, I would suggest to

reduce the number of people allowed on the island during this period. At present, two of the islands are closed to any human activity except research; but in reality many fishermen go to these islands. The best option would be to keep a guard permanently in order to enforce the law. For the West San Benito Island, where the fishing camp is, I would keep a limit on the number of people allowed on the island at one time, and closing some areas of the island where the burrow density is higher.

Considering my research I may assess that in general, many things went as planned, allowing me to observe the effects of disturbance on breeding success of Cassin's auklets. Some other things did not go as planned and I had to adapt to the changing circumstances of the moment. Some interesting things also came out of that, as the effects of adverse climatic conditions on Cassin's auklets giving me the chance to give a wider view on the topic of my research. One of the most important things learned from the research activities, is that a lot remains to be investigated and many actions should be taken in order to organise effective conservation plans.

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