Title: Analysis of seabird observation and satellite tracking data in the Falkland Islands to assess suitability for proposing Marine Important Bird Areas.

Author: Isaac Parlan Forster
BSc. (Hons). University of Melbourne

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Division of Environmental and Evolutionary Biology
Faculty of Biomedical and Life Sciences
University of Glasgow

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Abstract

Developing marine protected areas has become a priority for many conservation organizations and governments worldwide. Defining such areas robustly requires considerable resources, however the use of seabirds as biosystem indicators provides an option to reduce the expenditure and effort required as they are relatively easy to study, and act as bio-monitors of ecosystem change. The Falkland Islands seabird population has been extensively examined both at sea by observers on fishing and research vessels, and on land in telemetry projects. This project collated multiple at-sea observer and satellite tracking dataset sets to examine whether sites of high species numbers or abundance were linked to seabed bathymetry, to assess whether listed threatened species were found in particular locations, and to discover if any areas showed evidence of hotspot foraging locations for multiple species. The study found that data collected by at-sea observers showed no demonstrable link between seabed bathymetry, and distance from land with areas containing a high number of unique species, aggregations of listed threatened species, or locations with high seabird abundance. Despite using the same observation techniques, the study also showed a large variation between the observer data sets, and with previously conducted at-sea survey research in the Falklands. The collation and analysis of multiple satellite data sets found small geographic areas of high usage by the four tracked species in comparison to their total foraging range. With the application of additional data through further satellite studies, there is the potential to designate these high usage areas as marine IBAs under the criteria proposed by BirdLife International.

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Author's Declaration

I declare that the work described in this thesis has been carried out by myself unless otherwise acknowledged or cited, under the supervision of Professor Robert W. Furness and co-supervision of Dr. Ben Wilson. I further declare that this thesis has not, in whole or in part, been submitted for any other degree.

Isaac Forster

February 2010.

1.0 General Introduction

As the adverse effects of human exploitation on marine flora and fauna have been progressively demonstrated, the concept of marine protected areas has become a globally significant issue. This stems from overwhelming evidence suggesting that human activities affect virtually every described marine ecosystem (Loreau *et al.*, 2001, Glover, 2003, Hooper *et al.*, 2005, Worm *et al.*, 2006, Halpern *et al.*, 2007, Danovaro *et al.*, 2008, Halpern *et al.*, 2008). Faced with the threat of serious reductions in marine biodiversity the most common approach of conservation organizations and scientists has been to develop prioritization models for the conservation of geographic areas, identified from site specific algorithms. This method allows both managers and scientists to make "explicit, effective and accountable decisions about the allocation of scarce conservation resources" (Pressey & Cowling, 2001). The work of Kirkpatrick (1983) was the first to utilize the algorithm method, which has since been adapted to identify representative protected area networks in the marine environment (Olson & Dinerstein, 1998, Beck & Odaya, 2001, Cook & Auster, 2005, Richardson *et al.*, 2006) and in many terrestrial applications (Cowling *et al.*, 2003, Kerley *et al.*, 2003, Warman *et al.*, 2004, Shriner *et al.*, 2006). In addition methods such as gap and complimentary analysis have also been developed and tested for evaluating conservation concerns in terrestrial environments (Fjeldså & Rahbek, 1998, Williams, 1998, Abellán *et al.*, 2007, Araújo *et al.*, 2007, Maiorano *et al.*, 2007). However, the recognition of important marine areas and establishment of integrated marine management zones has, for the most part, not occurred. This is due mainly to issues such as the lack of obvious definable boundaries, reliable quantitative information on marine species, and jurisdiction issues with regards to international waters (Skov *et al.*, 2007).

Being highly visible, and to many people aesthetically pleasing, birds have captured our imagination sufficiently to become high conservation priorities and important topics for scientific research. This is especially true for seabirds. Seabirds need to breed on land and are therefore relatively accessible, rendering them easier to study than most other marine life-forms. Also, at sea they are relatively straightforward to observe and enumerate as they travel together or forage in marine hotspots (Sydeman *et al.*, 2006), areas that are detectable via remote sensing from their distinct oceanographic signatures (Moore *et al.*, 1999, Valavanis *et al.*, 2004, Polovina & Howell, 2005, Palacios *et al.*, 2006). Importantly as seabirds occupy high level positions in marine food-webs, they require a functioning ecosystem to ensure their viability, therefore potentially may be valuable indicators of ecosystem health and function. For example, a pivotal paper by Aebischer *et al.* (1990) demonstrated a remarkable parallel between long term (decadal) trends across four trophic levels (phytoplankton, zooplankton, herring and kittiwakes) and the frequency of westerly weather in the North Sea. Numerous other studies have identified links between seabird populations and ecosystem components: Frederiksen *et al.* (2007) highlighted links between Black-legged Kittiwake *Rissa tridactyla* population dynamics in Britain and Ireland and winter sea-surface temperatures (SST), Montevecchi (2007) linked breeding outcomes of Northern Gannets *Morus bassanus* with a prey shift caused by decadal changes in regional SST, Hedd *et al.* (2006) also demonstrated decadal changes in prey and reproductive performance Rhinoceros Auklets *Cerorhinca monocerata* in northern Canada, and Irons *et al.* (2008) found that synchronous population fluctuations in two congeneric seabird species across the Arctic and sub-Arctic region were related to SST shift. Reviews on the subject have been composed (Montevecchi, 1993, Furness & Camphuysen, 1997), and in 2007 an international symposium 'Seabirds as Indicators of Marine Ecosystems' was held at the 33rd Pacific Seabird Group meeting to specifically discuss the best use of seabirds as ecosystem indicators. The symposium and workshop concluded that:

1. Seabirds can act as bio-monitors for ecosystem change (e.g. contaminant loading indicating pollution) and quantitative indicators of ecosystem components, provided a detailed knowledge of the functional response to the relevant ecosystem parameter.
2. In some cases seabird parameters could be predictive, and potentially important for commercial concerns, e.g. fisheries management where seabird responses to ecosystem variability indicate changes in fish stocks.
3. Although seabirds are not needed to indicate atmospheric and oceanic changes directly, they provide timely and accurate information on the ecological consequences of these changes, and do so in a more rapid and detectable fashion than other organisms.
4. The spatial as well as temporal scale of seabird parameter response is critical to detecting and understanding environmental changes.

(See Piatt *et al.*, 2007 for full workshop outcomes).

By designating identified high priority conservation areas for seabirds as Marine Protected Areas, the benefit from a conservation standpoint is the conferred protection to species within the defined area. And although it is highly unlikely that this designation could unequivocally protect the marine biodiversity of a region, there is evidence in the terrestrial domain that key conservation sites for birds do correspond with important areas for other species. Garson *et al.* (2002) found that by selecting areas where 10 observations (presence only) of a particular at risk bird species had been recorded over a 10 year period (1984-1994), 87% of all at risk species considered in their study were incorporated into these areas. Brooks *et al.* (2001) compared East African important bird area (IBA) performance for conservation with a simple greedy complimentarity (a technique that aims to identify a minimum network of sites containing at least one representation of each species identified within the overall study area). Findings showed that the IBA network contained over 90% of terrestrial vertebrates, mammals and birds, but required substantially less data than the complimentary method, which missed three key bird sites. Additionally, although Harris *et al.* (2007) did not perform any comparative analysis, their study of seabirds-at-sea observations found that areas identified as high priority (areas that had high levels of species richness, density, and IUCN threatened classification status) agreed with pilot Marine Protected Areas (MPAs) proposed at the Malaga high seas MPA workshop (Gjerde & Breide, 2003), as well as corresponding with areas identified by Birdlife International (BirdLife, 2004, 2006) as important for albatrosses and petrels.

The establishment of marine protected areas based on seabird data is now receiving much research and management attention around the globe, and the general approach taken has been to build upon site based conservation for birds in terrestrial, limnic, and coastal ecosystems (e.g. EU network of specially protected areas (E.U. Birds Directive, 1979), Birdlife International IBAs (Heath *et al.*, 2001)). The overall goal of site based conservation is to identify areas that are exceptionally important for birds during some period of the year and ensure conservation of these features that make these areas important (Skov *et al.*, 1995, Skov & Durinck, 2000). The quantification for this approach for coastal and inland wetland areas has been based upon a widely agreed set of international criteria, the Convention on Wetlands of International Importance especially as Waterfowl Habitat (commonly referred to as the Ramsar Convention). To be considered for admittance into Ramsar, a site has to meet at least one of two criteria (Ramsar Convention Bureau, 2006):

1. It must regularly support at least 20,000 waterbirds
2. It must regularly support at least 1% of the individuals in a population of species, or subspecies of waterbird

Although it is now a widely established and internationally accepted procedure, there is no objective scientific basis for setting a 1% population threshold, nor the 20,000 individuals criteria. Furthermore, in the context of defining Important Bird Areas in the marine environment, Ramsar does not apply to wetlands of greater than 6m depth. However these criteria have been applied to truly marine areas as well as suggested in other classification systems (Jensen, 1993, Skov *et al.*, 2007), although the 20,000 individuals rule was deemed inappropriate by Skov *et al.* (2007) because of the spatial scale of the analysis. The acceptance of the 1% tool is realistically because it can be easily achieved by site counts, whilst estimates of bird numbers offshore are becoming available through large scale at-sea surveys via ships and aeroplanes (Tasker *et al.*, 1984, Webb & Durinck, 1992, Skov *et al.*, 1995). However, there have been methodologies suggested for the selection of bird protection areas in the marine environment, as seaward extensions of breeding colonies (Johnstone *et al.*, 2002) and analyses of tagging data (BirdLife, 2004).

In an effort to determine quantitative, standardized, and widely accepted criteria for effective definition of marine IBAs, the conservation organization Birdlife International, are refining their globally agreed criteria used for the terrestrial IBAs program. This program has been implemented in many countries and regions throughout the world (see www.birdlife.org for details). Their work undertaken to date indicates that there are four main aspects of distribution patterns of seabirds that are most likely to affect how marine IBAs are to be selected:

1. Coastal foraging areas adjacent to breeding grounds, especially during the chick rearing phase of the avian lifecycle.
2. Coastal concentrations of non-breeding waterbirds.
3. Migratory hotspots.
4. Important foraging areas for pelagic species such as upwellings, shelf breaks, and eddies.

Gathering the required data to propose areas that encompass any of these distribution patterns is a formidable task for any given region, requiring a combination of the previously discussed at-sea survey techniques and tracking of large distance foraging species. The most advanced example of utilising these methods is in the Iberian region where satellite and radio tracking of multiple bird species, has been combined with ringing recoveries and at-sea surveys to create a database of seabird distribution that is still a work in progress (SPEA-SEO/Birdlife, 2005). The Iberian project is particularly resource intensive, and is not a realistic undertaking for many areas of the world, where scientific budgets, social issues or politics prevent the commissioning of such a project. However, combining existing data sets from independent scientific projects, and conservation monitoring programmes could provide a significant temporal database of knowledge that is ideal for marine IBA definition. An example of an area where a body of appropriate data exists is the Falklands Islands.

The Falkland Islands, a United Kingdom overseas territory, are situated in the South Atlantic, approximately 500km from the South American mainland. Both within the Falkland Islands, and on the nearby South American mainland large breeding colonies of a variety of seabirds and marine mammals exist. They are supported by cold nutrient rich waters transported from the Antarctic convergence zone, to higher latitudes via the Falkland current (Acha *et al.*, 2004). Specifically for seabirds, the Falkland Islands hold large breeding populations of the families Procellariidae (albatrosses, petrels, shearwaters) and Spheniscidae (penguins), and are a significant area for conservation attention. Five globally threatened or near threatened seabird species breed in the islands, and a further eight known to forage in Falklands Exclusive Economic Zone (EEZ) waters (IUCN, 2007).

The body of research undertaken on the seabirds of the Falkland Islands is very extensive, and includes whole island breeding population surveys on several species (Reid & Huin, 2005, Huin, 2007, Huin & Reid, 2007), satellite telemetry (Boersma *et al.*, 2002, Huin, 2002, Clausen & Putz, 2003, Putz *et al.*, 2003), and global location sensor (Putz, 2002, Phillips *et al.*, 2007) foraging range studies, at-sea surveys for seabirds (White *et al.*, 2002), and anthropogenic effects on seabird populations (Reid *et al.*, 2004, Sullivan *et al.*, 2006, Otley *et al.*, 2007). In addition, in the case of at-sea survey information, there exists a large quantity of unpublished data collected by observers on board fishing vessels, fishery patrol, and military ships. Thus the numbers and general ecology of the seabirds that breed in the Falklands are quite well known. Chapter 2 reviews seabird biology of the Falkland Islands in more detail.

Whilst the Falklands has participated in the terrestrial IBA program of Birdlife International, assigning 22 sites for protection of important breeding populations on land (Falklands Conservation, 2006), in the marine environment there are very few protective measures for conservation of marine life. A three mile exclusion limit from terrestrial baselines, and small areas of the EEZ are off limits to fishing activities (Falkland Islands Fisheries Department web site). However given the large foraging ranges of breeding seabird species, these provide inadequate protection. Human based threats to marine life are present, currently seismic surveys for oil exploration are taking place, and test wells have been drilled (Falkland Islands Department of Mineral Resources web site). There are also large fisheries which are known to cause direct seabird mortality, although mitigation measures have reduced deaths locally within the EEZ (Sullivan *et al*., 2006).

Due to the Falkland Islands government being a signatory state to the Agreement on the Conservation of Albatrosses and Petrels (ACAP) treaty (www.acap.aq), which binds parties to ensuring protection of these species in the marine environment, there is significant support and political will for the assignation of marine IBAs within the Falklands EEZ. This study will follow the Iberian example of analyzing at-sea observer data and satellite tracking studies, to determine whether there is enough evidence to objectively propose marine IBAs. Tracking data using satellite devices exist for the following species:
Black-browed Albatross (*Thalassarche melanophris)*; Gentoo Penguin (*Pygoscelis papua*); Rockhopper Penguin (*Eudyptes chrysocome*); Magellanic Penguin (*Spheniscus magellanicus*)
At-sea observer data have been collected from naval ships, fishing boats, and patrol vessels continuously for the last 10 years, with sporadic records continuing back to the mid 1980’s.

In particular the aims of this study are to:

1. Examine the unpublished at-sea observer data to determine if areas with particularly high species richness or numerical abundance vary with location.
2. Collate and analyze satellite tracking results to determine if any areas show high densities of all tracked species.
3. If appropriate recommend potential Marine IBAs on the basis of at-sea observation and/or satellite tracking results.

2.0 Falkland Islands Seabird Biology

The avifauna of the Falkland Islands is fairly well documented, with a total of 227 species recorded, although this includes some unsubstantiated sightings.

Woods & Woods (2006) provides the most comprehensive, up to date general resource, listing 21 resident land birds, 18 resident water birds, 22 breeding seabirds, 18 annual non-breeding migrants, and at least 143 occasional visiting species. Although there have been several revisions of the numbers of species and subspecies of various avian groups, especially of Procellariiformes, for simplicity and convenience in this thesis I follow the species names and classification used by Woods & Woods (2006), as the data follows this format. The large number of visiting species is due to the close proximity of the islands to the South American mainland, and additionally because foraging ranges of many breeding seabird species from sub-Antarctic islands, especially South Georgia, overlap the area (Otley *et al.*, 2008). Seabirds are the most important component of the islands' avifauna due to their numerical abundance and number of species (Woods & Woods, 2006), with eight of the breeding species having global conservation status listed by IUCN as being of concern (IUCN, 2007), and three of these also falling under the Convention on the Conservation of Migratory Species of Wild Animals (CMS), and its daughter agreement, ACAP (Table 1). Seabirds are attracted to the Falklands region by the upwelling of the northerly flowing Falkland current, which brings cold, deep, nutrient rich water from the Antarctic. In contrast Falkland terrestrial habitats are comparatively poor for supporting birdlife (Woods, 1988).

2.1 Historical Records

The first recorded seabird data derive from over 200 years ago, with some population and ecology data collected from the 1930s onwards (Otley *et al.*, 2008). From then until the early 1980s some ad-hoc surveys and independent studies were conducted, which, although sometimes questionable in methodology, have been useful for evaluating trends in numbers (Cawkwell & Hamilton, 1961; Croxall *et al.*, 1984; Woods, 1975, 1988; Strange, 1992).

Species	**IUCN classification**	**CMS**
Black-browed Albatross *Thalassarche melanophris*	Endangered	ACAP treaty
Gentoo Penguin *Pygoscelis papua*	Near threatened	
Macaroni Penguin *Eudyptes chrysolophus*	Vulnerable	
Magellanic Penguin *Spheniscus magellanicus*	Near threatened	
Southern Rockhopper Penguin *Eudyptes chrysocome chrysocome*	Vulnerable	
Sooty Shearwater *Puffinus griseus*	Near threatened	
Southern Giant Petrel *Macronectes giganteus*	Near threatened	ACAP treaty
White-chinned Petrel *Procellaria aequinoctialis*	Vulnerable	ACAP treaty

Table 1: Falkland Islands breeding seabird species listed by IUCN and CMS.

In 1997 the first attempt at a systematic survey was published. The Atlas of Breeding Birds (Woods & Woods, 1997) was based on 10 years of data collecting, from 1983-1993. It still remains the only breeding bird atlas for any South American country, providing a valuable baseline. Since 1985/86, an annual seabird monitoring program has been conducted by Falklands Conservation, a local environmental charity, and several short, and long term scientific studies have been conducted by various organizations. The following review highlights relevant information on species that forage in open water areas, from these studies. Figure 1 displays a map of the islands showing relevant study areas and locations that are referred to later in the text.

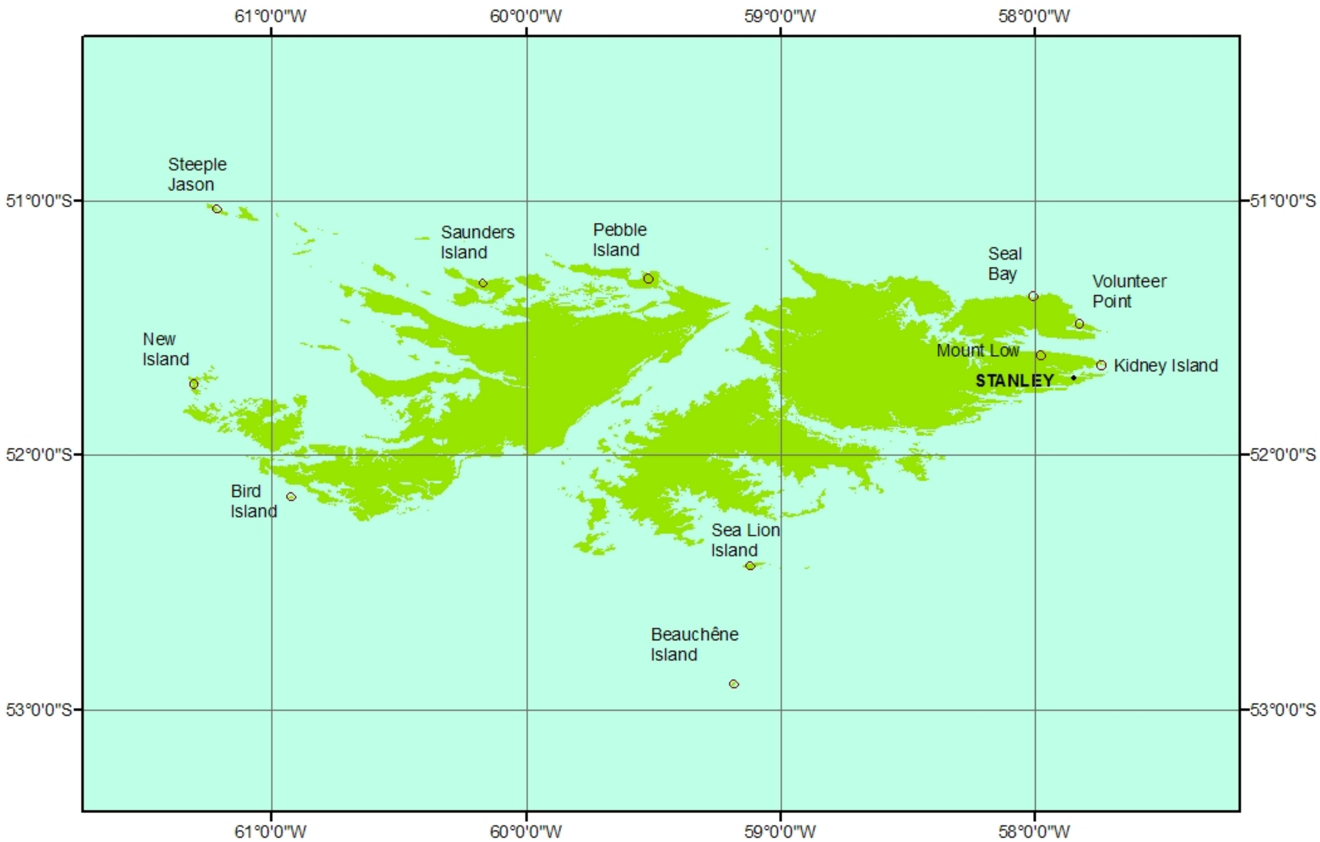

Figure 1: Map of the Falkland Islands showing sites of scientific studies referred to in the species review and utilized in project data analysis.

2.2 Penguins

Ten species of penguins have been recorded in the islands, with five species breeding regularly (descriptions follow). The recorded vagrant species include Emperor Penguin (*Aptenodytes forsteri*), Adelie Penguin (*Pygoscelis adeliae*), Chinstrap Penguin (*Pygoscelis antarctica*), Snares Erect-crested Penguin (*Eudyptes robustus*), and Erect-crested Penguin (*Eudyptes sclateri*). These species commonly occur and breed in Antarctic or New Zealand areas (Woods & Woods, 2006).

2.2.1 King Penguin (*Aptenodytes patagonicus*)

The King Penguin has a circumpolar distribution, with the Falklands population at the most extreme northerly edge of its range (Woods & Woods, 2006). The Falklands population occurs almost entirely at one site, Volunteer Point, with a few other individuals nesting amongst Gentoo Penguin colonies at 4-6 locations around the islands (Huin, 2007). As the breeding cycle of the King Penguin extends beyond 12 months, colonies hold breeding pairs at different stages of the breeding cycle, and other studies have confirmed that pairs are able to raise one or two chicks over a three year period (Weimerskirch *et al.*, 1992). Because of this, the total breeding population size is difficult to calculate, and was estimated between 344 and 516 breeding pairs during the last census. The population appears to have increased by approximately 12-15 chicks per year since the early 1980s, but the increase has shown some signs of slowing in the last three years (Huin, 2007). The increase is likely to be due in part to immigration from South Georgia, one bird banded there was sighted in the Volunteer Point colony (Olsson, 1997). However high local breeding success may also be a factor. Behavioural studies conducted from 2001-02 showed that the majority of eggs were laid between November and March, and that chick survival rates were high, at 89%. This was considered to be due to lower rates of avian predation, and milder weather conditions in comparison with major King Penguin breeding areas such as South Georgia (Otley *et al.*, 2007a).

Analyses of summer and winter diet have shown that myctophid fish, especially *Promyctophum choriodon*, are the most important dietary component, with smaller amounts of a variety of squid species also consumed. These results are similar to those from other studied populations (Piatkowski *et al.*, 2001, Cherel *et al.*, 2002).

Birds from the Volunteer Point population have been tracked using geolocation (GLS) and satellite (Platform Terminal Transmitter, PTT) devices, in May, June, August and February. Findings showed that in May and June, individuals foraged outside of the Falklands EEZ, south of the Antarctic Polar Frontal Zone (APF). This is the same strategy adopted by sub-Antarctic populations. However in August and February birds foraged north of the APF (Putz, 2002; Putz & Cherel, 2005). These findings were also reflected in at-sea survey results (White *et al.*, 2002).

2.2.2 Gentoo Penguin (*Pygoscelis papua*)

The Gentoo Penguin occurs throughout the Falklands archipelago in 101 colonies of varying sizes. Three complete censuses conducted in 1995/96, 2000/01, and 2005/06, recorded 64,426, 113,571, and 65,857 breeding pairs respectively. In worldwide terms this represents the second largest of 12 breeding regions after South Georgia (Huin, 2007). The decline between the 2000 and 2005 census figures can be attributed to a red algal bloom that occurred in November 2002. Paralytic shellfish poisoning subsequently resulted in a high level of adult mortality and total breeding failure at some colonies for the 2002/03 breeding season (Huin, 2003). Productivity is highly variable in the Falklands population and the reasons for this are unclear, but it does not appear to be linked to weather, predation, or other terrestrial elements of the breeding cycle (Putz *et al.*, 2001; Clausen & Putz, 2002).

The diet of Gentoo Penguins varies according to season and colony location, although as a general rule it is predominately fish-based and overlaps with several commercial species. Nototheniids such as *Patagonotothen ramsayi*, *P. tessellata* and *P. wiltonii* are most prevalent, followed by juvenile *Salitola australis* and *Micromesistius australis* (Putz *et al.*, 2001; Clausen & Putz, 2002). Other diet items included crustaceans and cephalopods. Individuals in western and southern colonies had higher proportions of crustaceans, whilst individuals in northern colonies took larger proportions of squid (Clausen & Putz, 2002). There is also evidence of dietary shifts across years, samples taken from 1986 to 2004 showed that crustaceans replaced some of the cephalopod component in southern individuals, whilst, despite high levels of cephalopods in their diet, northern individuals exhibited increasing amount of krill (Clausen & Putz, 2002; Clausen *et al.*, 2005,).

PTT tracking and at-sea surveys have shown that individuals remain within Falklands waters during the summer breeding period, often within 10 km of the coast (Boersma *et al.*, 2002; White *et al.*, 2002). By contrast, during winter individuals forage as far as 300km offshore (Clausen & Putz, 2003).

2.2.3 Southern Rockhopper Penguin (*Eudyptes chrysocome chrysocome*)

The Southern Rockhopper Penguin breeds at 52 locations, mostly on the western isles of the Falklands archipelago. Breeding colonies are highly variable in size and are often mixed with Black-browed Albatrosses and King Shags (Clausen & Huin, 2003). The total Falklands population at last census (2005/06) was estimated to be 211,000 breeding pairs, representing 29% of total world population (Huin, 2007). However the population is estimated to have drastically fallen by 80% since the 1930s, a re-evaluated figure suggested that the original population size was approximately 1.5 million breeding pairs (Putz *et al.*, 2003a). This represents a decline of 2.75% per annum since the 1930’s, and comparable figures for other studied populations on Marion, Auckland and Campbell Islands have also been recorded (Putz *et al.*, 2003a). Annual surveys at selected colonies suggest that the breeding population is stable during most years, however periodic declines occur due to starvation during moulting, and toxic poisoning from red algal tide events (Keymer *et al.*, 2001; Huin, 2003; Uhart *et al.*, 2004; Huin, 2007).

All three subspecies of Rockhopper Penguin have exhibited population declines over large spatio-temporal scales, suggesting ecosystem wide disruption. An analysis of stable isotope concentrations in feathers at a number of different breeding sites (excluding the Falkland Islands) by Hilton *et al.* (2006) indicated that there has been a shift to prey of lower trophic status, which is probably related to changes in SST and primary productivity.

Rockhopper Penguin diet in the Falklands is primarily crustacean based with varying amounts of several species. Cephalopods and fish are secondary components (Croxall *et al.*, 1985; Putz *et al.*, 2001; Clausen & Putz, 2002). Contemporary stable isotope analysis of feathers has shown a strong bi-modal pattern, suggesting two alternate foraging regions (Otley *et al.*, 2008).

Tracking using PTT devices has taken place at two colonies during incubation, brood, pre-moult, and winter dispersal periods. Birds tracked at a northern site (Seal Bay) during breeding generally followed an anticlockwise track following the major ocean currents, whilst in winter ranged in a vast triangle from near shore areas, to the Straits of Magellan at the southernmost extreme, and as far north as 39^{o}S (Putz *et al.*, 2002; Putz *et al.*, 2003b). Birds from a western colony (New Island) have only been tracked during breeding where they showed no particular pattern, foraging both inshore, and west of the colony almost as far as the coast of South America. Few tracks were observed travelling east or southward (Boersma *et al.*, 2002). Overall the tracking results reflect at-sea sightings (White *et al.*, 2002).

2.2.4 Macaroni Penguin (*Eudyptes chrysolophus*)

The Macaroni Penguin is the least populous of the Falkland's breeding species, although worldwide it is the most numerous (Croxall *et al.* 1984). In total 24 breeding pairs were recorded at 19 different colonies during the 2005/06 penguin census (Huin, 2007). Mixed pairs of Macaroni and Rockhopper Penguins have also been recorded breeding (White & Clausen, 2002). No information on diet or range from Falkland individuals exists.

2.2.5 Magellanic Penguin *Spheniscus magellanicus*

In contrast to the Falklands' other breeding species, the Magellanic Penguin is a loose colonial breeder that nests in burrows. This complicates population estimates; 200,000 breeding pairs over 90 locations was the last reported figure, which at the time was thought to represent a third of the global population (Thompson, 1993). Study plots have shown breeding success at 0.78 chicks per year, a figure that implies a just stable population (Putz *et al.*, 2001).

Magellanic Penguins have a broad diet in the Falklands, taking varying proportions of several fish and squid species, as well as lobster krill *Munida gregaria* (Putz *et al.*, 2001; Clausen & Putz, 2002)

PTT tracking has taken place at Seal Bay and New Island colonies. Seal Bay individuals undertook trips during the breeding season of varying time and distances. Trips ranged from less than four days and 50km from the colony, to over 11 days and up to 320km from the colony. The longer trips tended to follow a roughly anticlockwise direction with the ocean currents (Putz & Smith, 2000). During winter, individuals migrated out of Falkland waters to the coast of Argentina, from Puerto Deseado to Puerto Madryn and further north along the

Patagonian shelf and shelf break (Putz *et al.*, 2000). New Island individuals foraged between 10 and 90km from the colony during the breeding season (Boersma *et al.*, 2002).

2.3 Albatrosses

2.3.1 Black-browed Albatross *Thalassarche melanophrys*

The Black-browed Albatross is the only species of albatross that breeds on the Falklands. It has a circumpolar distribution, however the Falklands population has been shown to be genetically distinct from those at other sites, although individuals on Crozet, Heard, and Antipodes Islands have not been sampled (Alderman *et al.*, 2005). In the Falklands the albatross is found in 17 predominately island sites, often in colonies associated with Rockhopper Penguins (Strange, 1992). It is undoubtedly the most extensively researched seabird on the islands, with a range of studies including breeding behaviour, diet, fisheries interactions and tracking having been performed on the species. Two currently operating long term study colonies hope to further examine population dynamics through monitoring of known age individuals at New Island and Steeple Jason (Falklands Conservation unpubl. data, New Island Conservation Trust, 2007).

Three complete Falklands wide censuses have been conducted with numbers estimated at approximately 438,000 breeding pairs in 1995/96, 414,000 pairs in 2000/01, and 400,000 pairs in 2005/06. In addition, using old data from a variety of unpublished sources, an extrapolated figure of 506,000 pairs was estimated for 1980/81 (Huin & Reid, 2007). The Falklands population represents 70% of the global Black-browed Albatross population, and because of the decline of 1% per annum over the last five years, as well as previous historic declines, the IUCN has upgraded the conservation status from Vulnerable to Endangered (IUCN, 2007). However there is some conjecture over population figures, as aerial surveys conducted by I. Strange of a number of sites in various years, have shown an increase in population at those sites of between 21 and 141% (New Island Conservation Trust, 2007). Breeding success has been estimated at approximately 60%, which is particularly good when compared with other sites worldwide (Huin, 2000, Strange, 2001).

Black-browed Albatrosses have been tracked throughout their breeding cycle with PTT and GLS devices, at three separate sites (Gremillet *et al.*, 2000; Huin, 2002a, 2002b). During incubation, foraging trips are from between the Falklands and Peninsula Valdez to Cape Horn, on the Patagonian shelf. Birds from northern colonies forage only to the north, whilst birds from southern colonies forage both south and north (Gremillet *et al.*, 2000, Huin, 2002a, 2002b). During the chick rearing phase feeding takes place exclusively within Falkland waters. Overall between northern and southern colonies during the breeding season 70% of foraging is within Falklands waters, 27% in Argentine waters, whilst 3% is in international waters (Huin, 2002b). At-sea sightings confirm these findings (White *et al.*, 2002). In winter birds disperse throughout a vast area from the Drake passage to northerly waters off the coast of Brazil, and as far east as halfway to South Africa (Huin, 2002b). Females on average travel further north than males, up to 30^{o}S as opposed to 42^{o}S for males, and also disperse over a wider area of 2.3 million km^2 compared with 1.5 million km^2 for males (Huin, 2002b). Fledgling juveniles disperse further north and further offshore than both males and females, possibly due to exclusion behaviour by adults (Woods & Woods, 1997; Sullivan, 2004; Falklands Conservation unpubl. data.).

Diet of Black-browed albatrosses has been examined via stomach contents analysis of chicks, and observations of items scavenged from fishing vessels. They feed on a variety of prey items including several species of fish, squid, with some jellyfish, octopus, lobster krill, and other crustaceans (Thompson & Rothery, 1991, Thompson & Riddy, 1995, Huin, 2003).

2.3.2 Other Albatrosses (non-breeding)

Nine other species of albatross have been observed foraging in Falkland waters (White *et al.*, 2002, Falklands Conservation unpubl. data). All of these are red listed by the IUCN (IUCN, 2007), and listed under ACAP, see Table 2 for details.

Endangered	Southern Royal Albatross Sooty Albatross Yellow-nosed Albatross	*Diomedea epomophora* *Phoebetria fusca* *Thalassarche chlororynchos*
Vulnerable	Wandering Albatross Northern Royal Albatross Grey-headed Albatross Buller's Albatross	*Diomedea exulans* *Diomedea sanfordi* *Thalassarche chrysostoma* *Thalassarche bulleri*
Near Threatened	Light-mantled Sooty Albatross Shy Albatross	*Phoebetria palpebrata* *Thalassarche cauta*

Table 2: IUCN red list status of observed albatross species in Falklands waters.

2.4 Other Procellariformes

2.4.1 Southern Giant Petrel *Macronectes giganteus*

The Southern Giant Petrel has a circumpolar distribution, breeding in a number of different regions (Woods & Woods, 2006). Both it, and its congener the Northern Giant Petrel (*Macronectes halli*) are seen throughout Falklands waters, with the highest numbers over the Patagonian shelf, particularly around fishing vessels (White *et al.*, 2002). The at-sea population is likely to be enlarged by foraging birds from South Georgia, the South Orkneys, South Shetlands, and the Antarctic Peninsula (Croxall & Wood, 2002, Quintana & Dell'Arciprete, 2002).

Breeding takes place at 38 locations around the islands, with solitary nests up to colonies of 11,000 breeding pairs. The total population of the islands is almost 19,810 pairs, which is approximately 40% of the world population (Reid & Huin, 2008). Whilst no previous census has been conducted there is significant anecdotal evidence that the population has increased since the 1950's (Otley *et al.*, 2008).

No tracking studies have been conducted on individuals in the Falklands due to the sensitivity of the species to disturbance. In addition no program of diet sampling has taken place in the Falklands, although it is recognized from anecdotal sources that Southern Giant Petrels are predominantly scavenging birds, and will take a wide variety of dead or weakened seabirds, seals, sheep, animal regurgitates and faeces, and sewage on land, whilst at sea they take a variety of live prey and discards from fishing vessels (Woods, 1975).

2.4.2 White-chinned Petrel (*Procellaria aequinoctialis*)

Only small numbers of White-chinned Petrels breed in the Falklands, but the waters around the islands have large foraging numbers which are most likely to be from South Georgia, where a large population is resident (Berrow *et al.*, 2000). In total 55 breeding pairs were found at three sites on the islands during surveys conducted in 2004/05 and 2005/06 (Reid *et al.*, 2007). At-sea sightings have shown seasonal differences with birds being more widespread in shelf and oceanic waters in summer, but found in more shallow inshore locations in winter (White *et al.*, 2002). No further studies on distribution or diet have been conducted in the Falklands, although diet is considered to comprise squid, fish and crustaceans taken from the surface or caught from diving, based on findings from South Georgia (Berrow & Croxall, 1999).

2.4.3 Sooty Shearwater (*Puffinus griseus*)

The sooty shearwater is found on the islands of New Zealand, Australia, and in the southern regions of South America. Total world population is estimated to be in the millions (Marchant & Higgins, 1990). No accurate survey has been carried out in the Falklands because of the logistical difficulties in counting burrowing birds, and because they nest in very soft substrate that is prone to disturbance. One site, Kidney Island, has an estimated 100,000 breeding pairs (Woods & Woods, 1997). Little other information is known about the Falklands population, although a tracking study is currently underway using GLS devices. Two banding recoveries from individuals ringed on Kidney Island are recorded, one from Barbados in the West Indies (9,200km) and one off Newfoundland, Canada (10,800km) (Woods, 1997), and during the breeding season as-sea sightings suggest they are generally found inshore and on shelf areas (White *et al.*, 2002).

2.4.4 Thin-billed Prion (*Pachyptila belcheri*)

The most abundant petrel species in the Falklands, the Thin-billed Prion has large breeding colonies in the western isles (Woods & Woods, 1997). Global distribution includes Kerguelen and Crozet Islands, and Isla Noir (Chile). Of these three areas the Falklands is probably the most important (Croxall *et al.*, 1984). No complete estimates have been made of the Falklands population, although one survey was made of the New Island South National Nature Reserve in 2002, which estimated 1,081,000 active burrows. Extrapolated to the rest of the island would give a population of approximately two million breeding pairs (Catry *et al.*, 2003). There are several other offshore islands which are though to also hold significant populations.

No tracking studies have taken place, at-sea surveys show the species present in Falklands waters at all times of the year, although with much higher concentrations during the breeding season (September – February) and mainly over Patagonian shelf waters (White *et al.*, 2002).

Diet studies have shown that the main prey items are amphipods, and when sea-surface temperatures are elevated, food availability is lower, which reduces breeding success (Quillfeldt *et al.*, 2007).

2.4.5 Lesser known species

A very small number of Great Shearwaters *Puffinus gravis* (~20 pairs) breed on Kidney Island with perhaps a few more occurring on other offshore tussock islands (Woods, 1975). At-sea surveys have shown that the Great Shearwater is the seabird most frequently associated with cetaceans (White *et al.*, 2002).

The Fairy Prion (*Pachyptila turtur*) is an uncommonly observed species in the Falklands, with a breeding population on Beauchêne Island in the region of several thousand pairs (Strange, 1992). More colonies may exist on other remote outlying islands, although at-sea surveys indicate that Beauchêne is the principal colony (White *et al.*, 2002).

Wilson's Storm Petrel (*Oceanites oceanicus*) is a trans-equatorial migrant that is known to breed at a number of western isles in the Falklands archipelago (Woods & Woods, 2006). It is most frequently seen in Falkland waters between November and January (White *et al.*, 2002).

The Grey-backed Storm Petrel (*Garrodia nereis*) has two confirmed breeding locations in the Falklands, but freshly killed remains have also been found at other locations that are free of mammalian predators (Woods & Woods, 1997). The bird is seen in Falkland waters year round with the highest concentrations between November and March (White *et al.*, 2002).

The Falklands race of Common Diving Petrel (*Pelecanoides urinatrix berard*) breeds on offshore tussock islands (Woods & Woods, 1997). It is also observed year round in the Falklands with highest frequency between September and February over the Patagonian shelf (White *et al.*, 2002).

2.5 Pelicaniformes (Comorants and Shags)

Two species of shag breed in the Falklands. The Rock Shag (*Phalocrocorax magellanicus*) is widely distributed around coastal areas, and nests singly or in colonies of up to six or seven hundred pairs (Woods & Woods, 1997). At-sea surveys have shown that during summer months the shag stays within 5km of shore, whilst during winter it has been seen as far offshore as 27km (White *et al.*, 2002). There have been no diet studies conducted in the Falklands, but a study in coastal Patagonia showed small fish, crustaceans, and cephalopods taken from the seabird in water depths from 2-12m (Wanless & Harris, 1991).

The Falklands race of the King Shag (*Phalacrocorax atriceps albiventer*) breeds solely in the Falklands. No up to date population information is available, although counts were performed at a number of sites between 1986 and 1996 by Falklands Conservation, which indicated a slight decline (Woods & Woods, 1997). They are widely distributed around coastlines and are commonly found in association with Gentoo and Rockhopper Penguins, and Black-browed Albatrosses (Woods & Woods, 2006). Foraging is generally further offshore than the Rock Shag, at-sea sightings found mean distances from the shore of 12km during summer, and 37km from June to October (White *et al.*, 2002). No information is diet in the Falklands is available. Diet samples from other populations consist of crustaceans and small nototheniid fish species (Marchant & Higgins, 1990).

2.6 Charadriiformes (Gulls, Skuas and Terns)

2.6.1 Falkland Skua (*Catharacta antarctica*)

This species is mostly restricted to the Falklands, but also breeds on the Argentinian coastline. Other closely related taxa, which are sometimes treated as distinct species and sometimes as subspecies, breed on South Georgia and the Antarctic Peninsula (Woods & Woods, 1997). During the breeding season they are commonly found offshore in association with fishing boats (Falklands Conservation unpubl. data), but after April, the adults and juveniles disperse across pelagic waters as far north as 20^{o}S (White *et al.*, 2002). GLS studies have shown that during winter, shelf break areas off central Patagonian are common foraging areas (Phillips *et al.*, 2007). A study of regurgitated pellets and prey remains revealed a summer diet predominately of goose barnacles, Thin-billed-Prions and lobster krill (Reinhardt *et al.*, 2000).

2.6.2 Gulls & Terns

Three gulls species are resident breeders in the Falklands: Dolphin Gull (*Leaucophaeus scoresbii*), Kelp Gull (*Larus dominicanus*) and Brown-hooded Gull (*Larus maculipennis*). Four others are vagrants (Woods & Woods, 2006). There is little information on all species. Generally gulls do not venture far offshore, however they are often observed in association with fishing vessels when close to coastlines (Falklands Conservation unpubl. data).

Only the South American Tern (*Sterna hirundinacea*) breeds in the Falklands, whilst seven other species are observed as vagrants (Woods & Woods, 2006). From late September to early April the South American Tern has a wide distribution around coastal sites, but in winter the birds venture further offshore, especially north of West Falkland (White *et al.*, 2002). Their diet consists of lobster krill and small fish (Woods, 1988).

2.7 Threats to Seabird Populations

There are a number of actual or potential threats to seabird populations in the Falklands, but due to uncertain habitat requirements for some species, assessing the threat level on a species by species basis is difficult. As threats may occur in both the terrestrial and marine domains they are discussed collectively.

2.7.1 Human predation

Collection of penguin eggs for human consumption has undoubtedly been practiced since the islands became inhabited, and records from the 1940s show that 4,000 Gentoo, 5,000 Rockhopper, and 2,000 Magellanic Penguin eggs were licensed for collection per annum (Falkland Islands Government (FIG) archives data). Currently eggs are permitted to be collected from Gentoo and Magellanic Penguins, and Kelp Gulls. However in practice egg licenses are only requested for Gentoo Penguins. A license for up to 33% of nests can be issued, and 15-20 colonies are egged annually, with a total of 2-2,500 eggs taken. This is considered to be sustainable (Otley *et al.*, 2008).

2.7.2 Disturbance of breeding areas

Grazing of livestock is the most common usage of land in the Falklands and is not thought to have any direct effects on seabird populations (Otley *et al.*, 2008). However grazing has reduced by over 80% the original cover of tussac grass (Strange, 1992), a habitat type that is important for burrowing petrels and penguins (Woods & Woods, 2006). Fencing off of areas, and replanting schemes have begun in an attempt to re-establish cover, and tussac has been identified as a high priority habitat (Otley *et al.*, 2008). Some rural areas are also routinely burned to improve pastures, and the effects of this are not well understood. Burning is regulated by the FIG Environment Planning Department (EPD), however if fires become uncontrolled they do have the potential to enter the numerous deep peat beds on the islands, and threaten seabird colonies. In practice the likelihood of this is low because the majority of burning takes place in areas away from seabird colonies (Otley *et al.*, 2008).

Nature based tourism is a well established although relatively new industry in the Falklands, and with large numbers of tourists landing from cruise vessels some wildlife areas are exposed to considerable levels of disturbance. Studies have been carried out at two well visited sites, comparing the breeding successes of Gentoo Penguins, Black-browed Albatrosses, King Cormorants and Rockhopper Penguins with breeding success achieved in areas that are not disturbed, and have found no deleterious effects (Otley, 2006, New Island Conservation Trust, 2007). The most easily disturbed seabird, the Southern Giant Petrel, is not on the list for most tour itineraries, and where they are viewed, a 200m exclusion zone is enforced for their protection (FIG, 2001). Warning signs, wardens, and management plans have also been introduced in areas of high tourist numbers (Otley *et al.*, 2008).

2.7.3 Invasive species

A wide range of plants and animals have been introduced into the Falkland Islands, with mammalian predators (particularly cats, rats, and mice) considered to have the biggest environmental effects. Nine Falkland passerine bird species have restricted ranges due to mammalian predators and many burrowing petrel species are only found in rodent free areas (Hall *et al.*, 2002). The remains of penguins and small petrels have been found in the diet of cats, although one study concluded that the overall effects of cat predation were not significant for the one species of penguin assessed (Matias, 2005). Similarly, it seems that rats and seabirds are coexisting on New Island with little or no impact of rats on recorded petrel breeding numbers (Quillfeldt *et al.*, 2008). Nevertheless, rat and cat eradication programmes have been successfully conducted on some islands, and further programmes are ongoing. Increased bio-security measures are currently being implemented to reduce the risks of accidental introductions (Forster, 2007, Otley *et al.*, 2008). Despite their detrimental effects on native flora, invasive plants are not thought to affect seabird populations.

2.7.4 Wildlife diseases

The health of some seabird species has been evaluated in the Falkland Islands. Gross pathology, ecto-parasites, endo-parasites, and levels of heavy metals, and radioactivity were determined for a number of Rockhopper Penguins that died in 1986 and healthy individuals in 1987 (Keymer *et al.*, 2001). In 2003 and 2007 samples of healthy Black-browed Albatrosses, Gentoo, Rockhopper, and Magellanic Penguins were tested for infectious diseases by the Field Veterinary Program of the Wildlife Conservation Society (Uhart *et al.*, 2004). Both of these studies showed that seabird populations in the Falkland Islands have had very little exposure to diseases compared to populations sampled on the mainland of South America, therefore could be at risk from accidental introductions via tourism or research activities.

Toxic algal blooms affected large numbers of seabird species in November 2002, particularly in northern and western areas of the Falklands (Huin, 2003). Analysis of tissue samples revealed paralytic shellfish poisoning, resulting from bio-toxins produced by red algae (Uhart *et al.*, 2004). This event is considered at least partially responsible for the decline in Gentoo and Rockhopper Penguin numbers seen between censuses in 2000/01 and 2005/06 (Huin, 2007). Harmful Algal Blooms are difficult to predict, but they may form an important, and currently understated, role in the life history of Falkland Island seabirds (Shumway *et al.*, 2003).

2.7.5 Pollution

Although there is yet to be commercial oil extraction in the Falklands Islands, test drilling is underway, and there have been a number of small acute light fuel (i.e. marine gas oil) spills, from vessels that have run aground, experienced mechanical problems, or from unknown sources. Few long lasting inshore or offshore environmental effects have been documented (Nicholson & Harrison, 2001). Random incidents are still a potential threat, for example in May 2008 a fishing vessel sank whilst transshipping cargo inshore, discharging heavy crude oil in the vicinity of several Rockhopper and King Shag colonies. The effects are still being evaluated by Falkland Conservation. Historical records show the number of oiled seabirds reported in the Falklands is low (Smith, 1998).

The incidence of chemical pollutants was measured during the late 1970s, with levels of organochlorines (e.g, DDT pesticides) and polychlorinated biphenyls in the eggs of seabirds measured. The levels were a magnitude less than reported for comparable northern German seabird species (Hoerschelmann *et al.*, 1979).

Marine debris is a serious threat for seabirds worldwide, with amounts in oceanic systems doubling in the last decade, particularly in the form of plastics (Barnes, 2002). In the Falklands, monthly beach surveys showed an accumulation rate of 77 large items per km of beach per month, with a mean weight of 17.3kg. Most of the debris was discarded fishing equipment and household waste that also appeared to come from fishing vessels (Otley & Ingham, 2003). No studies have been conducted quantifying the effects of debris on wildlife in the Falklands, however 36% of all seabird species are known to ingest small pieces of plastic which can contain toxic chemicals, and cause obstruction to the digestive systems of both adults and chicks (Derraik, 2002). There is also no provision under any Falkland Islands fishing license legislation to set specific standards of waste management, for example having an incinerator.

2.7.6 Fisheries interactions

The incidental mortality of seabirds from interactions with fishing gear, is widely acknowledged as being responsible for population declines of many species of albatross and petrel (BirdLife, 2004). However, within Falklands waters, a range of protective measures including adopting bird scaring devices (Sullivan *et al.*, 2006), developing National Plans of Action, and changing fishing techniques have reduced mortalities in the longline fishery to almost negligible levels (Otley *et al.*, 2007b), and by 90% in assessed trawl fisheries (Reid & Edwards, 2005). Unfortunately most of the islands' breeding seabirds spend considerable amounts of the breeding cycle outside of Falklands waters where they interact with a range of less-well managed fisheries, and high rates of mortality have been estimated or suspected in these (Neves & Olmos, 1997; Seco-Pon *et al.*, 2007, Bugoni *et al.*, 2008). This issue is being tackled on a regional scale, using the support of ACAP. Although scavenging seabirds may be negatively affected by mortality at fishing vessels, they may also benefit from feeding at fishing vessels. The balance between these two opposing effects is uncertain, but it appears that recent high rates of bycatch have outweighed any beneficial effects of increased feeding opportunities.

Within the Falklands the ultimate solution to alleviating seabird mortality, is better management of offal discarding practices, and a report identifying various management options was conducted (Munro, 2005). No further progress has since been made, mainly due to space and capital cost issues of installing processing equipment on the current trawling fleet.

The squid jigging fishery in the Falklands does not directly catch seabirds, however there have been reports of jigging vessels trailing baited hooks, presumably to catch fish and seabirds for consumption, as well as anecdotal evidence from fisheries observers that seabirds are being targeted (Reid *et al.*, 2006). Educational materials have been distributed in an attempt to alleviate this problem (Otley *et al.*, 2008).

A number of seabird species in the Falklands utilize as food species that are commercially taken, however there is no conclusive evidence that direct competition exists or that impacts are negative at the population and individual breeding success levels (Thompson & Riddy, 1995, Putz *et al.*, 2001, Clausen & Putz, 2002). No studies have been carried out examining whether removal of certain size ranges of commercial species indirectly affects marine predators through changes in stock structure and food webs. There is one example of a seabird species in the Falklands that utilizes a commercially targeted species, at the commercial size as a component of its diet. This is the Gentoo Penguin, which takes the squid *Loligo gahi* (Putz *et al.*, 2001, Clausen & Putz, 2002). Decreases in catch per unit effort for *L. gahi* over the licensed fishing periods (two spatially and temporally restricted fishing periods for *L. gahi* are permitted) mirror a declining incidence in the species in Gentoo Penguin diets. This appears to be replaced by an increase of nototheniid fish species. However it is not possible to conclusively say that the change in diet is due to fishery activities, or whether catching fish requires a greater foraging effort than catching *L. gahi* (Putz *et al.*, 2001).

2.7.7 Climate change

Examination of meteorological data collected in the Falklands between 1923 and 1981 indicates a drying and warming of the Falklands environment (Otley, 2008). More recent data have not been comprehensively analysed. Sea surface and land temperatures globally have been analysed by the UK Climatic Research Unit of the University of East Anglia, and they have shown a steady increase in the number of warmer than normal sea conditions since the 1960's (Rayner *et al.*, 2003, Parker *et al.*, 2004). Unpublished data collected by the Falkland Islands Fisheries Department since 1999 also show large fluctuations of sea surface temperatures on the Patagonian shelf compared to the predicted values. Sea level has been measured at various sites with the longest monitoring occurring in Port Stanley since 1964. Data suggest a 0.7-1.3mm rise in sea level over the last 40 years (Woodworth et al., 2005).

The latest report from the Intergovernmental Panel on Climate Change records a declining trend in precipitation across southern Argentina, and predicts atmospheric temperatures in South America to rise by between one and six degrees by the end of the century, although the increase in the Patagonian region is thought to be at the low end of these figures as cooling has been recorded in southern Chile (Magrin *et al.*, 2007). Quite what these recorded effects of sea surface temperature increase, drying and uncertain temperature rises will have on wildlife populations is not clear, but evidence suggests that it will most likely be detrimental. As highlighted earlier, breeding studies on Thin-billed Prions have shown that during periods of higher sea surface temperatures fledging weights of chicks are lower (Quillfeldt *et al.*, 2007), and Rockhopper Penguin global population declines appear to be linked with a shift in prey, which may be caused by sea-surface temperature changes (Hilton et al., 2006). In southern Argentina during periods of colder than normal sea-surface temperatures, survival rates of adults, and breeding success increased in Rockhopper Penguins (Rey *et al.*, 2007), and research on the French sub-Antarctic islands suggested that the predicted southward shift of the Polar Front caused by oceanic warming could lead to a significant decrease in breeding productivity of top predator seabirds (Inchausti *et al.*, 2003). With a significant database on penguin productivity existing from previous studies in the Falklands, an analysis comparing this historical information with oceanic temperature anomalies would clearly be beneficial for elucidating climatic effects.

3.0 Methodology

Data for this project were collated from several sources, and consisted of two collection methods, satellite telemetry and shipboard observations.

3.1 Satellite telemetry

Three species of penguin, Gentoo (*Pygoscelis papua*), Southern Rockhopper (*Eudyptes chrysocome chrysocome*), Magellanic (*Spheniscus magellanicus*); and the Black-browed Albatross (*Thalassarche melanophris*) have been tracked using Platform Terminal Transmitter (PTT) type tags, from various locations around the islands. Dates and locations of tracking, numbers of individuals, and further study details are listed in the following sections for each individual species. All data collated from these species were filtered for accuracy, initially by using only positions with the highest quality rating of 3, and a lowest of 0 (errors associated with fixes are 3 = <150m, 2 = > 150m, 1 = < 1km, 0 = >1km; (Argos, 1996)), and were further validated by first removing locations that implied excessive speed, and then by inspecting individual tracks and removing outliers. This follows the methods recommended for interpreting satellite data with confidence, demonstrated in Hays *et al.*, 2001.

Gentoo Penguin data were received from a study conducted at Kidney Cove, East Falkland (51^{o}38′S, 57 ^{o}48′W) between May and September 2000 during the winter non-breeding period. Two individuals were fitted with ST10 type units (Telonics, AZ, U.S.A., www.telonics.com) set to a duty cycle of 6 hours on/ 18 hours off with a repetition rate of 60 seconds, set to uplink at 2200 local time (= GMT – 3 hours). The individuals were tracked for 91 and 95 days respectively. Full details of the study can be found in Clausen & Putz, 2003.

Rockhopper penguin data were requested from two sources, which had conducted tracking during the breeding and winter periods at a variety of locations, however only one source supplied information. Breeding data from two colonies was received, Seal Bay, East Falkland (51^{o}23′S, 58^{o}02′W), and Mount Low, East Falkland (51^{o}36′S, 57^{o}35′W). Bird Island (52^{o}12′S, 60^{o}53′W) data were recorded over the late chick rearing and moult period. Winter dispersion data were acquired for Seal Bay, Sea Lion Island (52^{o}45′S, 59^{o}12′W), and Saunders Island (51^{o}20′S, 60^{o}10′W). Breeding season deployments at Seal Bay were on 26 October 1998 (n=1), 12 November 1998 (n=3) and 15 November 1999 (n=5). Just the one bird at Mount Low was equipped with a transmitter on 20 November 2000. For both Seal Bay and Mount Low only males were used. ST10 units with a duty cycle of 6 hours on/ 18 hours off, and a repetition rate of 60 seconds were used, with transmission times set to begin at 2200 local time. Deployments ranged from 11 to 27 days in length, for all other study details see Putz *et al.*, 2003. Bird Island data consisted of three individuals, who were tracked from the 26 January until 2 April 2000. Tag type and setup were the same as for the Seal Bay and Mount Low deployments with methodology as per Putz *et al.*, 2003. Winter deployments took place at Seal Bay on 24 March 1998 (n=5), 19 March 1999 (n=6) and 4 April 2000 (n=6); Sea Lion Island on 26 March 1999 (n=6) and 27 March 2000 (n=6) and Saunders Island on 30 March 2000 (n=5). ST 10 units were used in 1998 and 1999, whist in 2000 Kiwisat devices were deployed (Sirtrack, New Zealand, www.sirtrack.com). Duty cycles were 8 hours on/ 64 off in 1999, 6 hours on/ 42 off in 1999, and 6 hours/ 18 hours off in 2000. In all cases the repetition rate was 60 seconds with the transmitters being switched on at night. For more details see Putz *et al.*, 2002a.

Magellanic Penguin data were requested from two studies conducted in the Falklands, but were only received from one location at Seal Bay, East Falkland (51^{o}23′S, 58^{o}02′W). Five male and two female individuals were tracked during the breeding season 1998/99. Devices were attached during the incubation period and were all recovered after deployments ranging between 14 and 104 days, except for one device which failed after 140 days. ST10 type units with a duty cycle of 6 hours on/ 18 hours off, and a repetition rate of 60 seconds, set to uplink at 0100 local time were used. The timing of uplink represented the best satellite coverage and minimal penguin activity period. All other study details can be found in Putz *et al.*, 2002. Winter dispersion data was also collected from Seal Bay, with ten deployments taking place between the 24th and 28th of March 1998. ST10 units were also used, with a duty cycle of 8 hours on/ 64 hours off, and a repetition rate of 60 seconds, giving position fixes approximately every three days. Total deployment time ranged from 15 to 99 days before batteries were exhausted. Further details can be found in Putz *et al.*, 2000.

Black-browed Albatross tracking data were collected from three colonies, Saunders Island, Beauchêne Island (53^{o}54′S, 59^{o}11′W) and Steeple Jason (51^{o}03′S, 61^{o}12′W). Incubation period deployments took place at Saunders Island (n=11) from 4 November 1998 until the 23

December 1998, Beauchêne Island (n=4) from 21 October until 4 December 2000, and Steeple Jason (n=8) from 3 November until 27 November 2006. Chick rearing deployments were undertaken at Saunders Island (n=8) from 18 January until 8 March 1999, and Beauchêne (n=4) Island from 3 February until 26 April 2000. Data on the dispersal of chicks post fledging were also acquired from Steeple Jason (n=3), where the first chick left the colony on 19 April and the last transmission was received on 16 August 2007. At all colonies the devices used were 30gm PTTs from Microwave Telemetry (Columbia, MT, U.S.A., www.microwavetelemetry.com). During the breeding period the tags were set to transmit every 90 seconds, which resulted in around 10-20 fixes per day. For chick deployments at Steeple Jason, tags were duty cycled 6 hours on/ 18 hours off with a 60 second repetition rate, and were set to switch on at 2200 local time. Further information on deployments conducted at Beauchêne and Saunders Islands can be found in Huin, 2002a, with deployments conducted on Steeple Jason following the same protocols as this study.

Satellite data were pooled and analyzed using Kernel distribution analysis. This technique has been used successfully in tracking studies to quantify habitat use and identify home ranges (e.g. Wood *et. al*, 2000, Matthiopoulos, 2003, BirdLife International, 2004). When using Kernel analysis the single most important step is the selection of the smoothing or *h* parameter as this can highlight or smooth over areas of high density. This study examined the methods of BirdLife International (2004), another study which used Kernel analysis for examining density distributions from multiple satellite tracked species. However after initial analyses, a lower *h* value of 0.2 decimal degrees was selected, as with a one degree grid square as per Birdlife International (2004) the resolution is very large within the Falklands EEZ. Grid size was set to 0.1 of a decimal degree. Weighting factors were applied to the data to adjust how many times each tracking point was counted in the analysis. This was to account for the variation in the number of individuals tracked from each site, and for the number of individuals tracked for each species.

3.2 Shipboard observation

Two data sets were acquired which used the shipboard observation method. The first was obtained from amateur observers stationed on several naval vessels operating around the Falkland Islands, who recorded observations between mid 1983 and early 1995. Records were collected sporadically during this period, with observations taking place seemingly randomly during daylight hours. The second data set was obtained from Falklands Conservation's Seabirds at Sea Team (SAAS), which stations observers on commercial trawlers to monitor seabird bycatch. Observations have been made by SAAS from 2001 until the present, with recordings taken during both daylight and night time operations. For this study data analysed covered the period from September 2001 until March 2008.

For both data sets species identification was recorded and abundance was calculated in a 500m X 500m sampling area (500m astern of the vessel, 250m to both port and startboard sides). Due to the high abundance of birds around vessels (often > 1500 birds) numbers were not recorded precisely, but classified into 5 categories (1 = 1-10, 2 = 11 -50, 3 = 51-200, 4 = 201-500, 5 > 500) as per Weimerskirch *et al.*, 2000. A range of environmental and operational variables were also recorded.

When analyzing the observer data several factors required the exclusion of some data points so as to render the two data series as comparable as possible. Firstly, observations less than one hour in duration were not considered, since for the SAAS observations, most of these occurred during shooting and recovery of the trawl nets. During these periods, bird abundance often increases greatly because of potential access to catch through nets or discards falling from the trawl deck as the net is paid out (personal observation). Secondly, any observations conducted whilst SAAS vessels were discarding offal during processing were not included as availability of food may affect species abundance. Thirdly, any observations where other commercial fishing vessels were visible from the observers' vessel bridge, or present on the ship's radar within a radius of 10 nautical miles (approximately the range to the horizon during daylight hours of unrestricted visibility) were discounted as their presence may have affected species abundance. Lastly SAAS observations made during the hours of darkness were not included as they only recorded species presence due to restricted visibility and not numbers.

For statistical analysis of at-sea observer data in all stated tests data were first checked for normality and equal variance.

3.3 Software and other data utilised

Raw sorting of data was performed with Microsoft Excel, and Notepad PC software packages. Statistical analyses were performed using the Minitab package. Geodatabasing, raster analysis, Kernel analysis and mapping were performed using the ESRI ArcGIS v9.3 software suite (www.esri.com).

Data for land outlines was received from Falklands Conservation and Maritime EEZ boundary data was downloaded from the VLIZ Maritime Boundaries Database (www.vliz.be). Bathymetry data was downloaded from the General Bathymetric Chart of the Oceans, available on the British Oceanographic Data Centre website (www.bodc.ac.uk).

4.0 Results – Shipboard Observations

Figure 2 shows the locations of where observations commenced, from the two shipboard data sets. A total of 516 naval and 334 SAAS observations were considered, with visual examination of the map showing that naval observation points are clustered closer inshore than the SAAS observations, as well as a series of observations leading eastwards away from the islands. This eastwards line represents the transit route of naval vessels that historically supplied the garrison on South Georgia. Most of the SAAS observations occur to the south and west of the islands and around the 200m contour line. This is because trawling for the main commercial species in the Falklands generally occurs at this depth (FIFD unpubl. data).

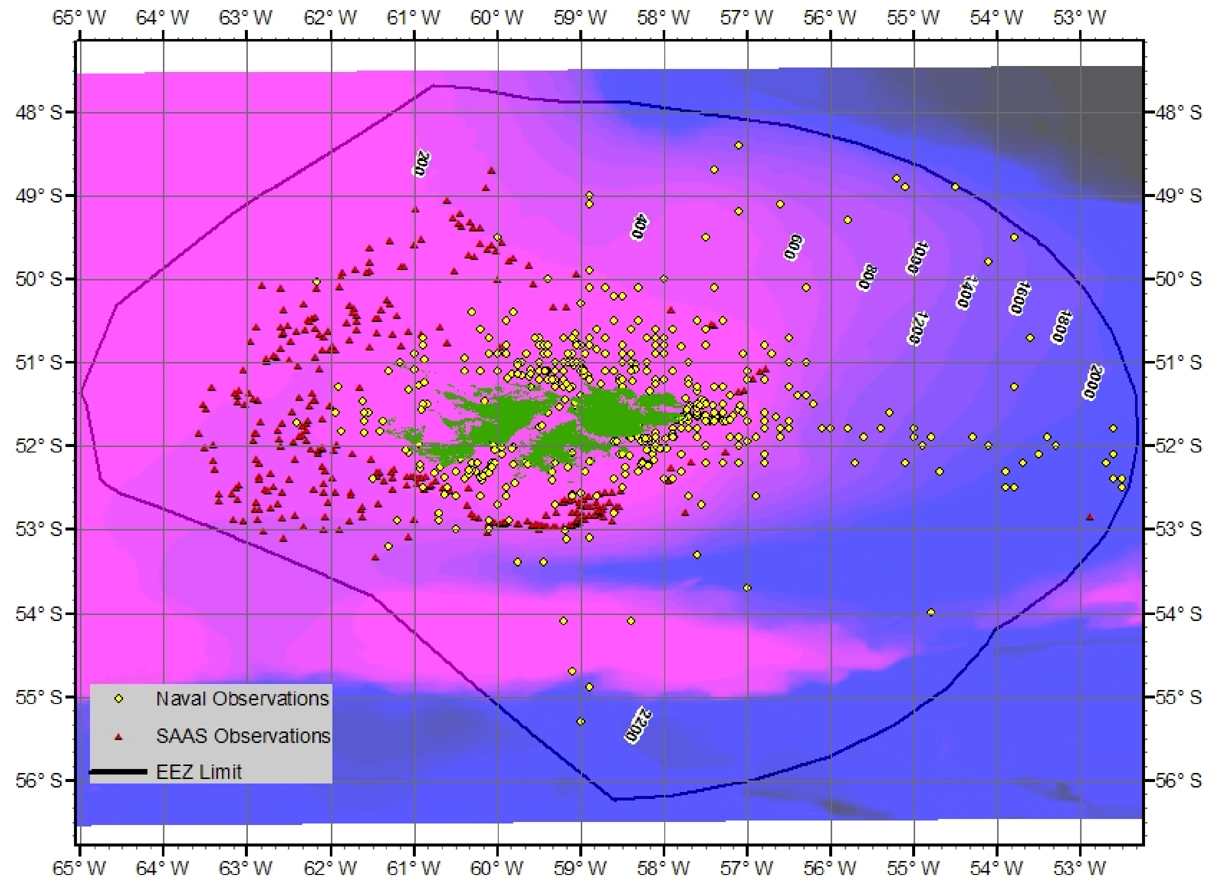

Figure 2: Shipboard observation commencement points. Bathymetry contours within the EEZ are indicated on the map in metres.

Figure 3 displays the number of species recorded for each observation on the naval vessels. Cell extents and dimensions are based on locations at the beginning and end of the observations and vessel speed during the observation period. Where observation transects overlap the shading of the cell reflects the mean number of species observed between the observations to account for observer effort. Visual examination suggests that there areas that contain high species number observation points are fairly randomly distributed regardless of water depth or distance from shore. The eastern track does show some cells with high species numbers in deeper water, but has a low number of observations.

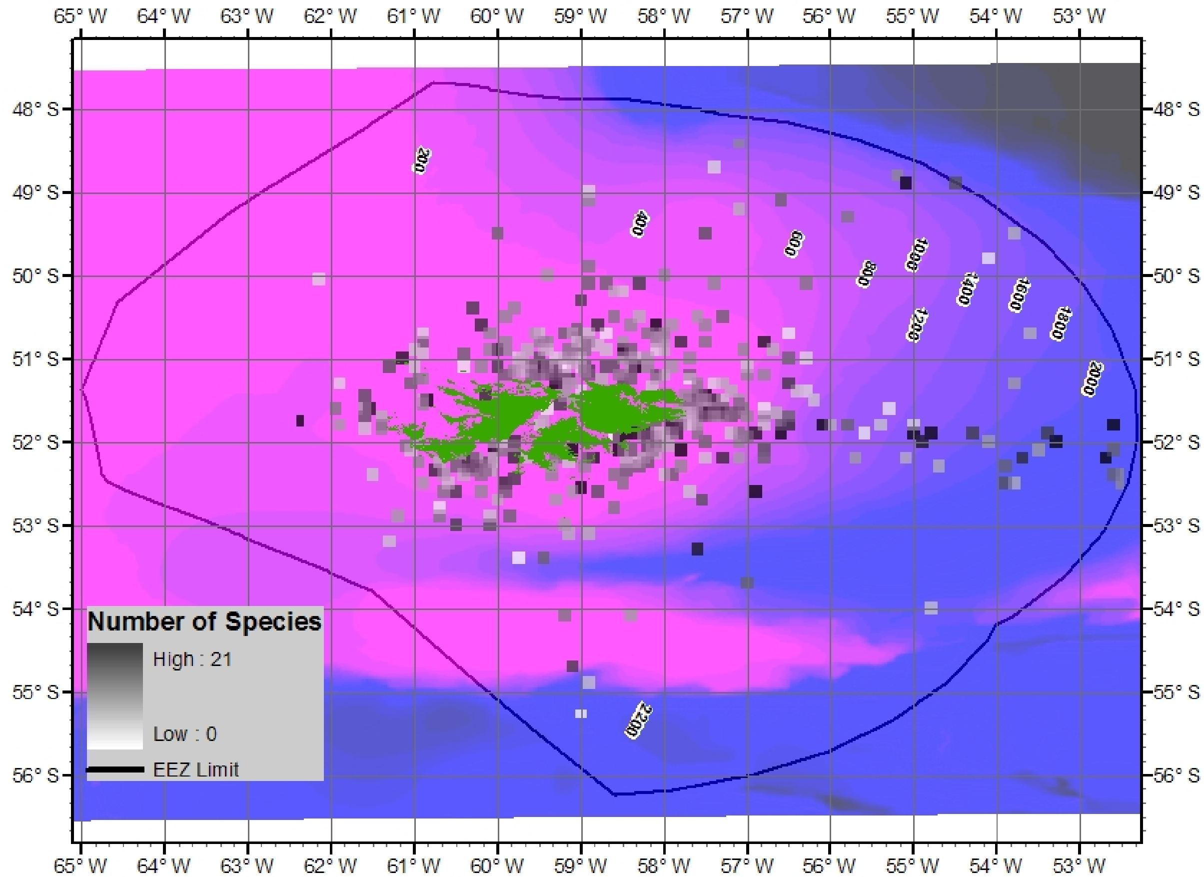

Figure 3: Number of species recorded at naval observation points. Bathymetry contours in the EEZ are indicated in metres.

Descriptive statistics for the number of species observed on the naval vessels are as follows:
Mean = 7.49
Median = 7
Variance = 13.16

Correlation coefficients (Pearson correlation) were calculated to determine whether there were any relationships between the number of species observed on the naval vessels, depth of water and distance from shore. In both cases there was no apparent relationship between these factors:
r (number of species, depth) = 0.071, p = 0.075
r (number of species, distance from shore) = 0.054, p = 0.178

Figure 4 shows the number of species recorded at each SAAS observation point. Cell size was calculated as per the naval observations. Visually in comparison with the naval observations it appears that surveyed areas closer to the shore may have lower numbers of species than areas further away.

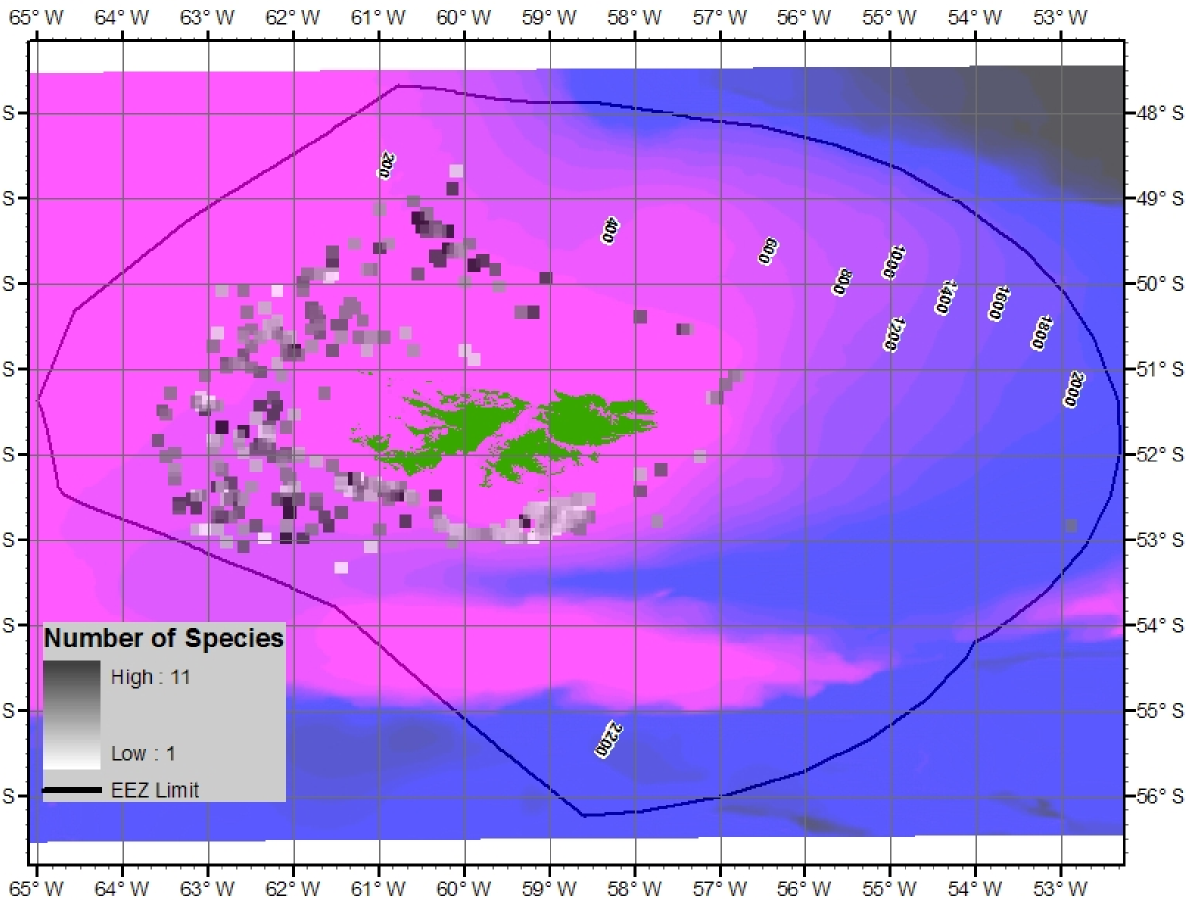

Figure 4: Number of species at each recorded SAAS observation point. Bathymetry contours within the EEZ are indicated in metres.

Descriptive statistics for the number of species observed on the SAAS vessels are as follows:

Mean = 5.55

Median = 6

Variance = 3.96

Correlation coefficients (Pearson correlation) were calculated to determine whether there were any relationships between the number of species observed on the SAAS vessels, depth of water and distance from shore. In both cases there was no apparent relationship between these factors:

r (number of species, depth) = -0.063, p = 0.209

r (number of species, distance from shore) = -0.029, p = 0.557

Figure 5 displays observations where high abundance numbers of individual species were recorded on the naval observations. Species recorded with an abundance category of four or higher (<201 individuals per observation, n = 207) are tallied, as virtually all observations had multiple species with an abundance category of three. Observations where no species with greater than 201 individuals were recorded are also displayed for visual comparison.

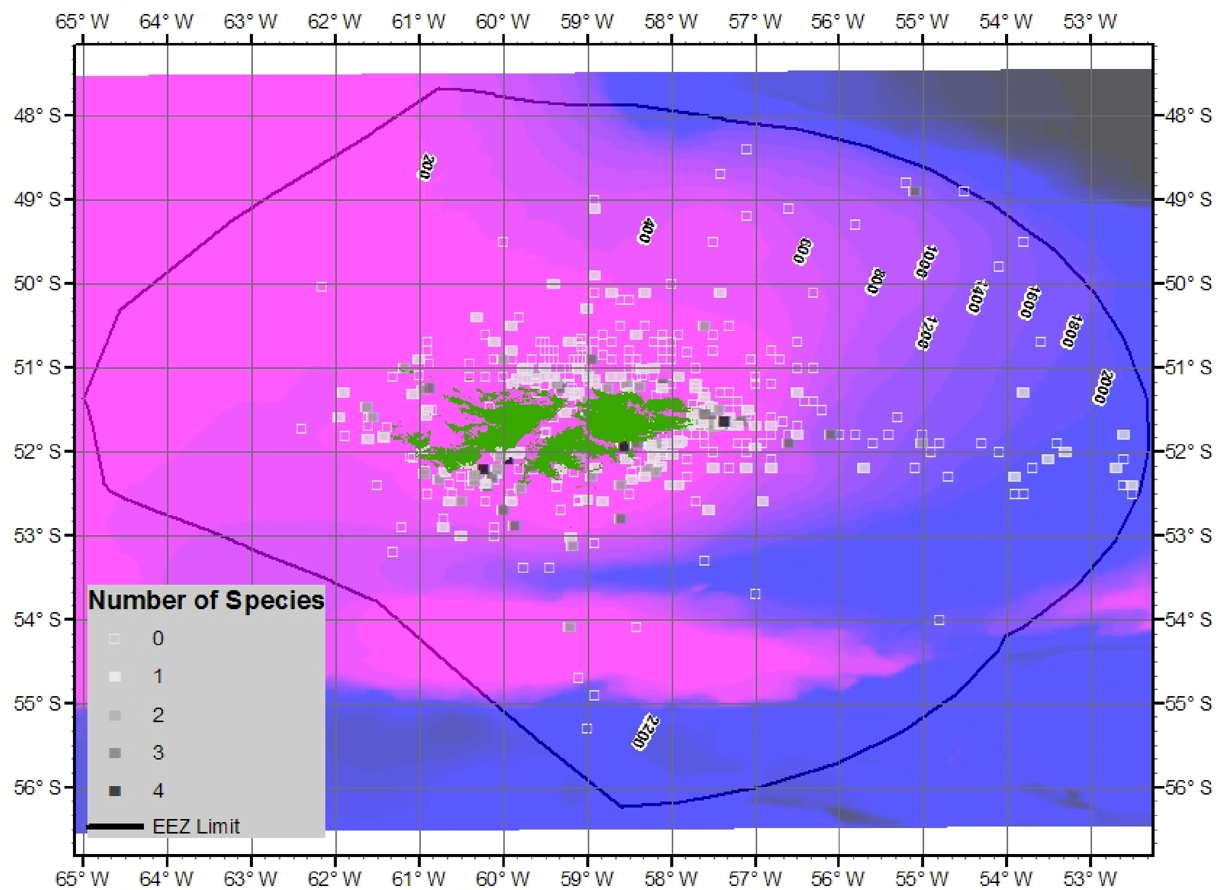

Figure 5: Number of species observed with greater than 200 individuals during naval observations. Bathymetry contours within the EEZ are indicated in metres.

Analysis of the naval observations with greater than 201 individuals per species show no particular relationships with depth (Pearson correlation *r* = -0.024, p = 0.555) or distance from shore (Pearson correlation *r* = -0.024, p = 0.312)

Figure 6 displays areas where high bird numbers were recorded in the SAAS observations. As per the Naval observations only species with an abundance category of 4 or higher are shaded (n = 103), with other observations included for visual comparison.

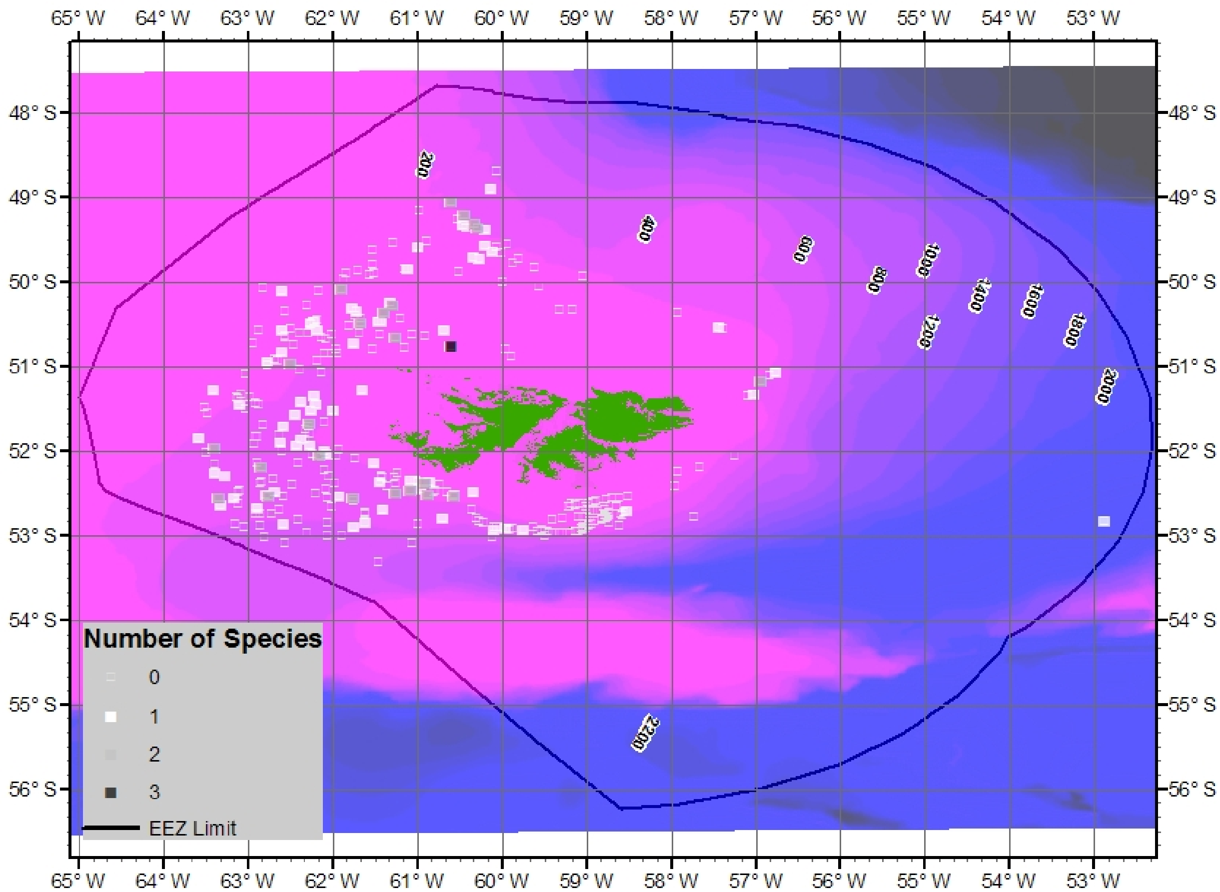

Figure 6: Number of species with greater than 200 individuals recorded during SAAS observations. Bathymetry contours within the EEZ are indicated in metres.

Analysis of the SAAS observations with greater than 201 individuals per species show no particular relationships with depth (Pearson correlation $r = 0.040$, $p = 0.423$) or distance from shore (Pearson correlation $r = 0.013$, $p = 0.797$)

Figure 7 maps areas where species with an IUCN threatened listing were recorded during naval observations. Observations without any species classified as threatened are included for visual comparison.

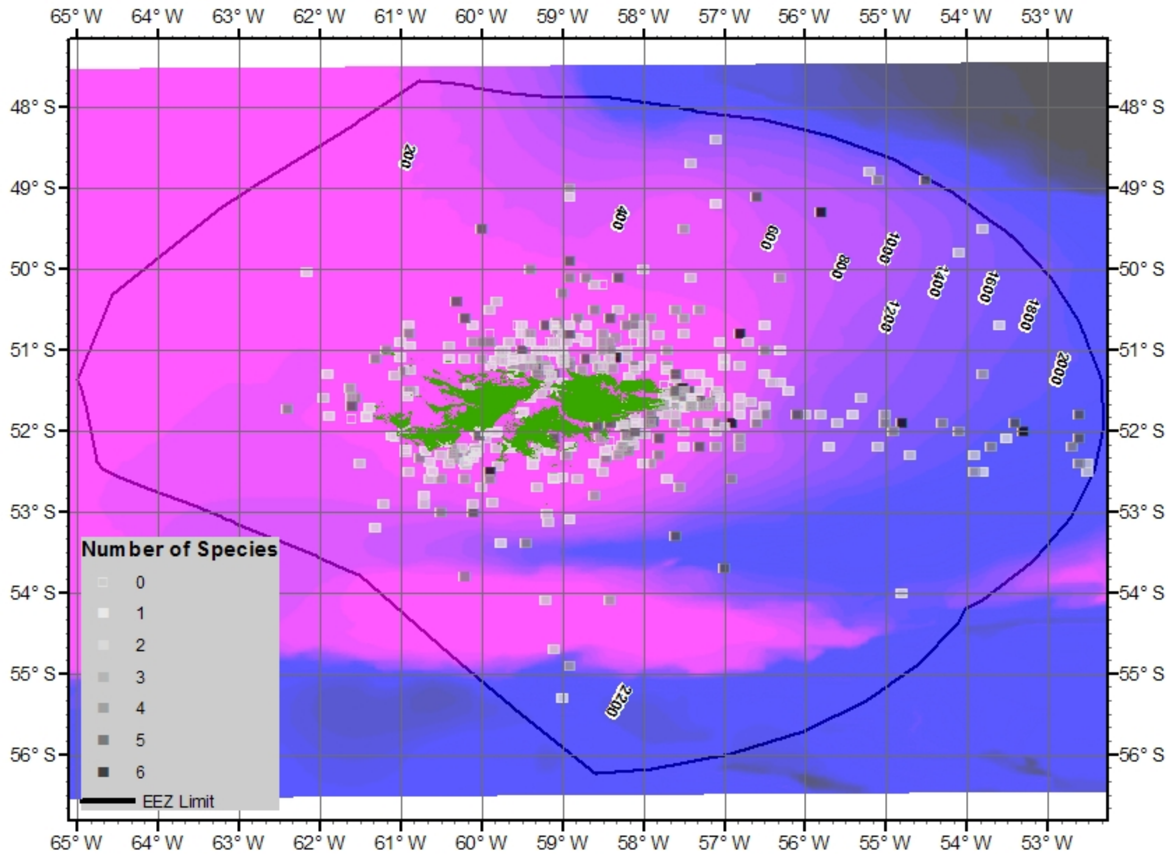

Figure 7: Number of species with a threatened IUCN classification status recorded during naval observations. Bathymetry contours within the EEZ are indicated in metres.

Analysis of the naval observations with IUCN threatened species showed a very weak positive correlation between number of threatened species and an increase in depth (Pearson correlation r = 0.119, p = 0.003), however there was no indication of any relationship between the number of threatened species and distance from shore (Pearson correlation r = 0.057, p = 0.153)

Figure 8 displays species with an IUCN threatened classification listing observed during SAAS observations. Observations without any species classified as threatened are included for visual comparison.

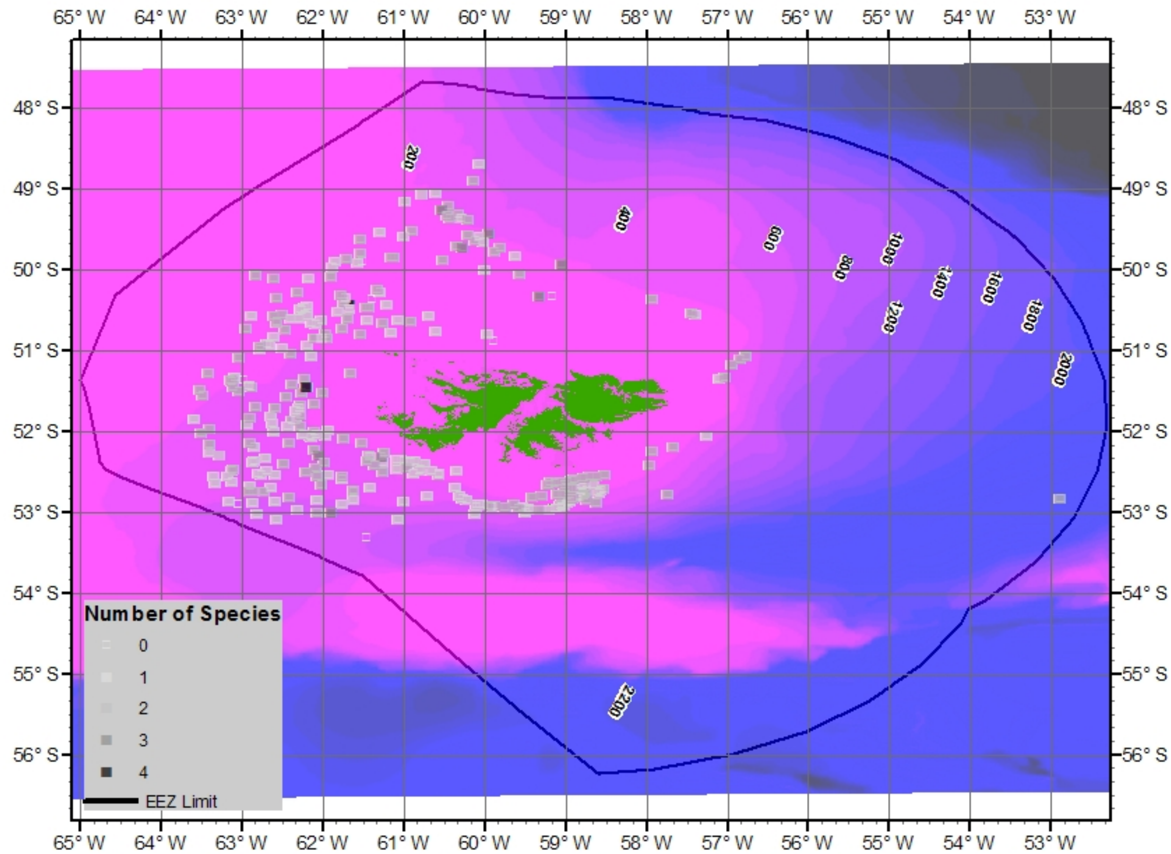

Figure 8: Number of species with an IUCN threatened classification observed on SAAS vessels. Bathymetry contours within the EEZ are indicated in metres.

Analysis of the SAAS observations with IUCN classified species showed a weak negative correlation between number of species observed and depth (Pearson correlation r = -0.201, p > 0.000), however no relationship was observed between number of species and distance from shore (Pearson correlation r = 0.005, p = 0.926).

4.1 Comparing naval and SAAS observations

Visual examination of figure 2 suggests that naval and SAAS vessels performed their observations in different areas, and statistical analysis confirms that a significant different between naval and SAAS observations can be attributed a difference in longitude (t_1 = 32.99, p < 0.001).

Summary statistics for number of individual species recorded, species with an abundance of greater than 201 individuals, and IUCN listed species for each observation type are listed in Table 3.

OBSERVATIONS ***NAVAL = 516*** ***SAAS = 334***	**No. of Individual Species** NAVAL	SAAS	**No. of Species <201 Individuals** NAVAL	SAAS	**No. of IUCN Threatened Classified Species** NAVAL	SAAS
Mean	7.490	5.552	0.412	0.324	2.323	1.678
Median	7	6	0	0	2	2
Variance	13.158	3.960	0.667	0.364	2.099	0.695

Table 3: Summary statistics for naval and SAAS observations and recorded factors.

Analysis of the figures show that there are significant differences between naval and SAAS observations with naval observations recording a higher number of individual species (t_1 = 96.42, p < 0.001) per observation, and a higher number of IUCN listed threatened species recorded per observation (t_1 = 103.62, p < 0.001).

Average speed of vessels were examined to assess whether similar areas were covered during observational transects between naval and SAAS observations. Naval vessels had a significantly higher average speed for all observations than the SAAS vessels and therefore would have covered larger observation areas (Naval mean speed = 12.15 ± 5.48 knots; SAAS mean speed = 2.77 ± 1 knots; t_1 = 4462.95, p < 0.001)

Locations where naval and SAAS observation transects overlap were examined (n=20). In all cases no significant relationships were demonstrated between naval and SAAS observations for number of individual species (Pearson correlation *r* = 0.173, p = 0.466), number of species with an abundance of <201 individuals (Pearson correlation *r* = 0.275, p = 0.241), and number of IUCN listed threatened species (Pearson correlation *r* = 0.171, p = 0.471).

Because the number of overlapping transects represent a small fraction of total observations (Naval 3.9%, SAAS 6%), demonstrated differences in geographical overlap and vessel speed, and the lack of strong positive correlations between species recorded by the two observation types, it was considered inappropriate to pool naval and SAAS data for further analysis.

5.0 Results – Satellite tracking data

Data derived from satellite observations were collated for four species which are listed in the following sections. The raw data has first been presented for all tracking events regardless of the phase of the breeding cycle, as the at-sea observer data has been analyzed without such temporal considerations.

5.1 Black-browed Albatross

Figure 9 shows all recorded fixes from Black-browed Albatrosses tracked from breeding colonies on Beauchêne (n=8), Steeple Jason (n=11) and Saunders Islands (n=19). For full details of periods of study see methods section. The map show that tracked individuals utilized areas to the north, west and south of the islands, however few foraging points were recorded in an easterly directon. Also noteworthy is the fact that recorded points are generally within shallower areas of the EEZ.

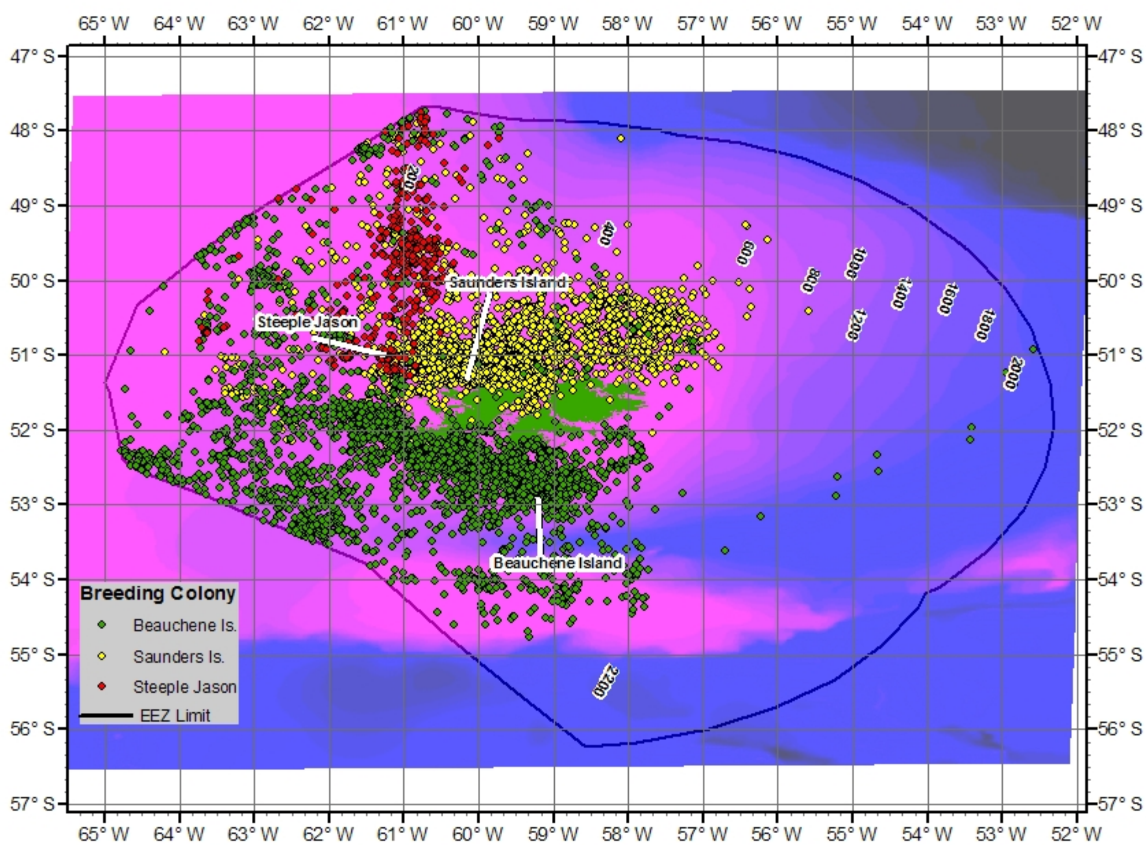

Figure 9: Satellite derived locations of foraging Black-browed Albatrosses. Depth contours within the EEZ are indicated in metres.

5.2 Rockhopper Penguin

Figure 10 displays all recorded fixes acquired for Rockhopper Penguins tracked from Bird Island (n=3), Mount Low (n=1), Saunders Island (n=5), Seal Bay (n=26), and Seal Lion Island (n=12). Study periods for each colony can be found in the methods section. In the display the one individual recorded at Mount Low has been pooled with the Seal Bay individuals because of the small sample size, and the close proximity of the two colonies.

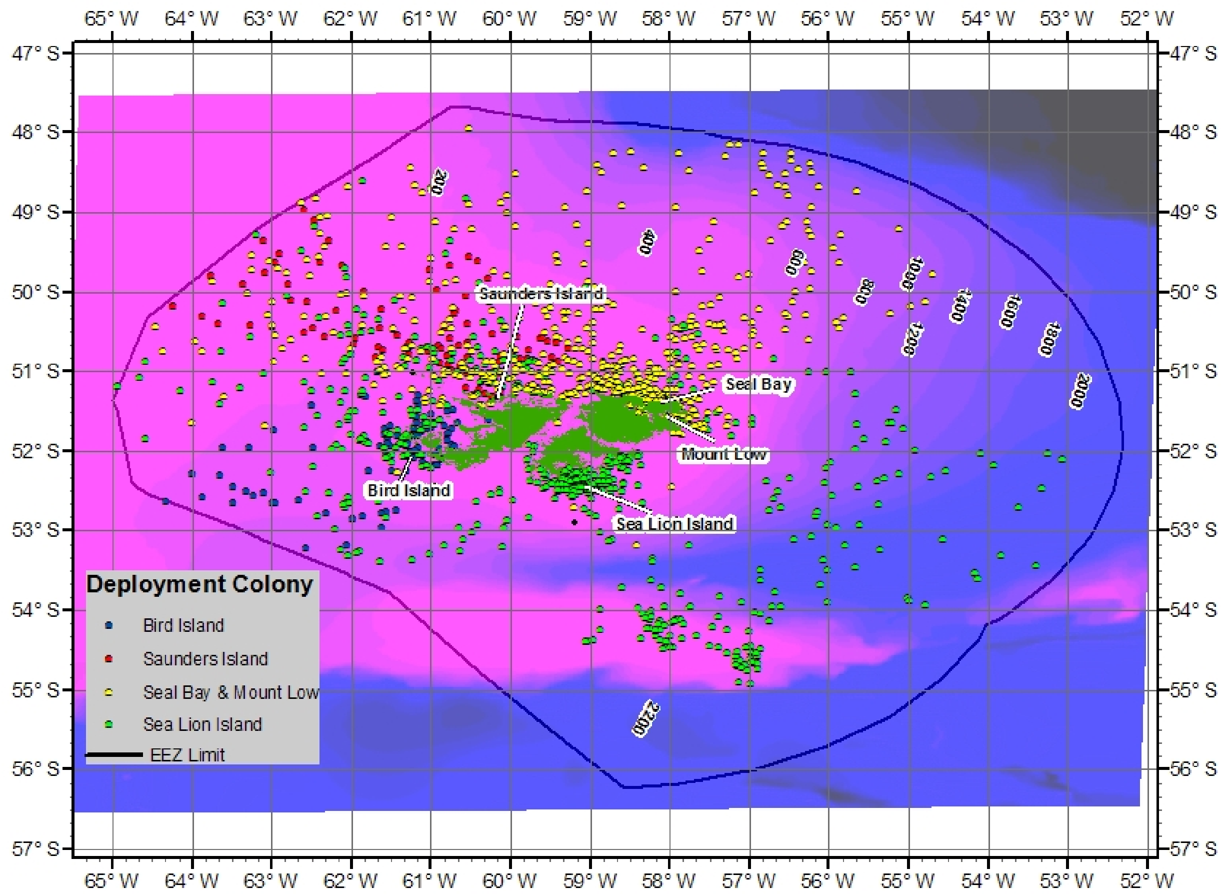

Figure 10: Satellite derived locations of foraging Rockhopper Penguins. Depth contours within the EEZ are indicated in metres.

5.3 Magellanic Penguin

Figure 11 maps displays all recorded foraging locations from deployments conducted at the Seal Bay colony (n=17). Details on timing of deployments can be found in the methods section. Foraging areas range widely north of the colony, which appears similar to Rockhopper Penguins tracked from the same site (figure 10).

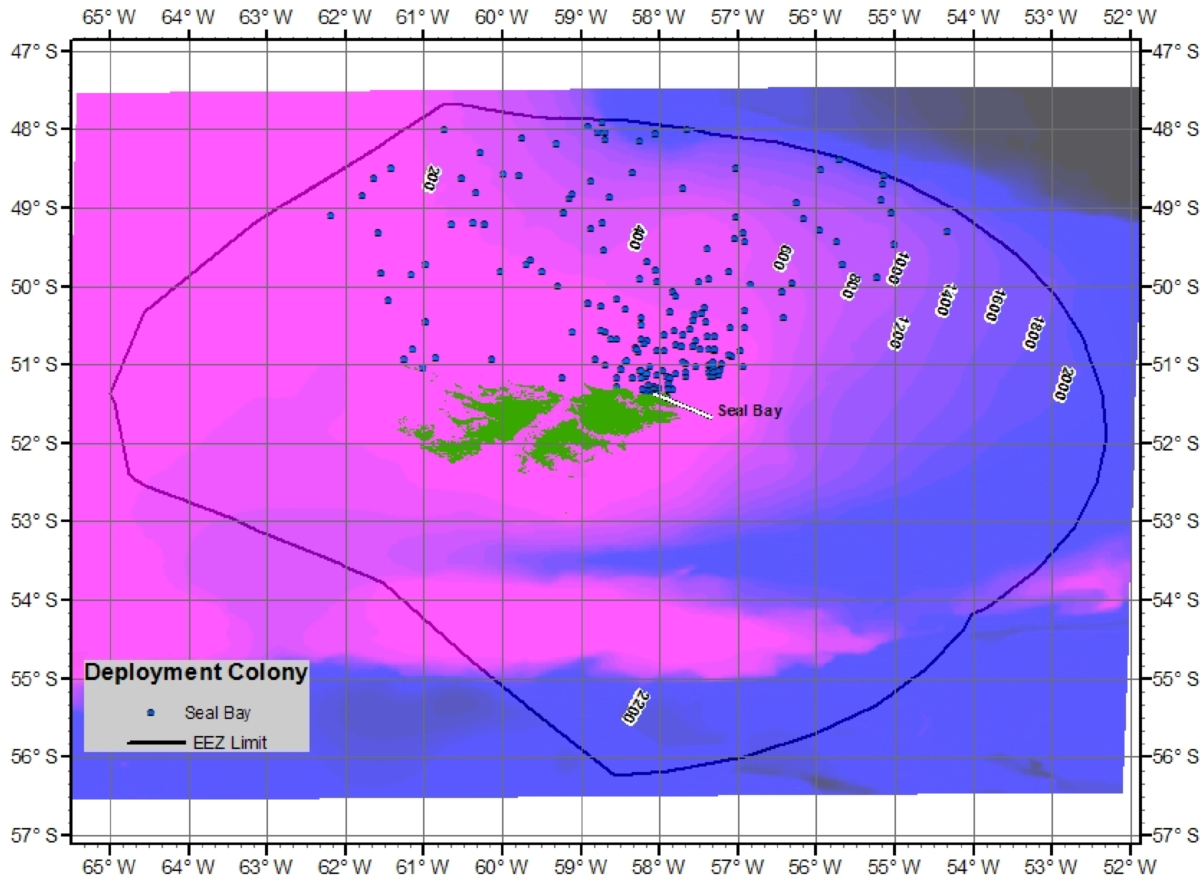

Figure 11: Satellite derived locations of foraging Magellanic Penguins. Depth contours within the EEZ are indicated in metres.

5.4 Gentoo Penguin

Figure 12 displays Gentoo Penguin tracking data recorded at the Kidney Cove colony (n=2). Details on the timing of deployments can be found in the methods section. Although the sample size is small the data indicates that an area on the north east coast is frequently visited location.

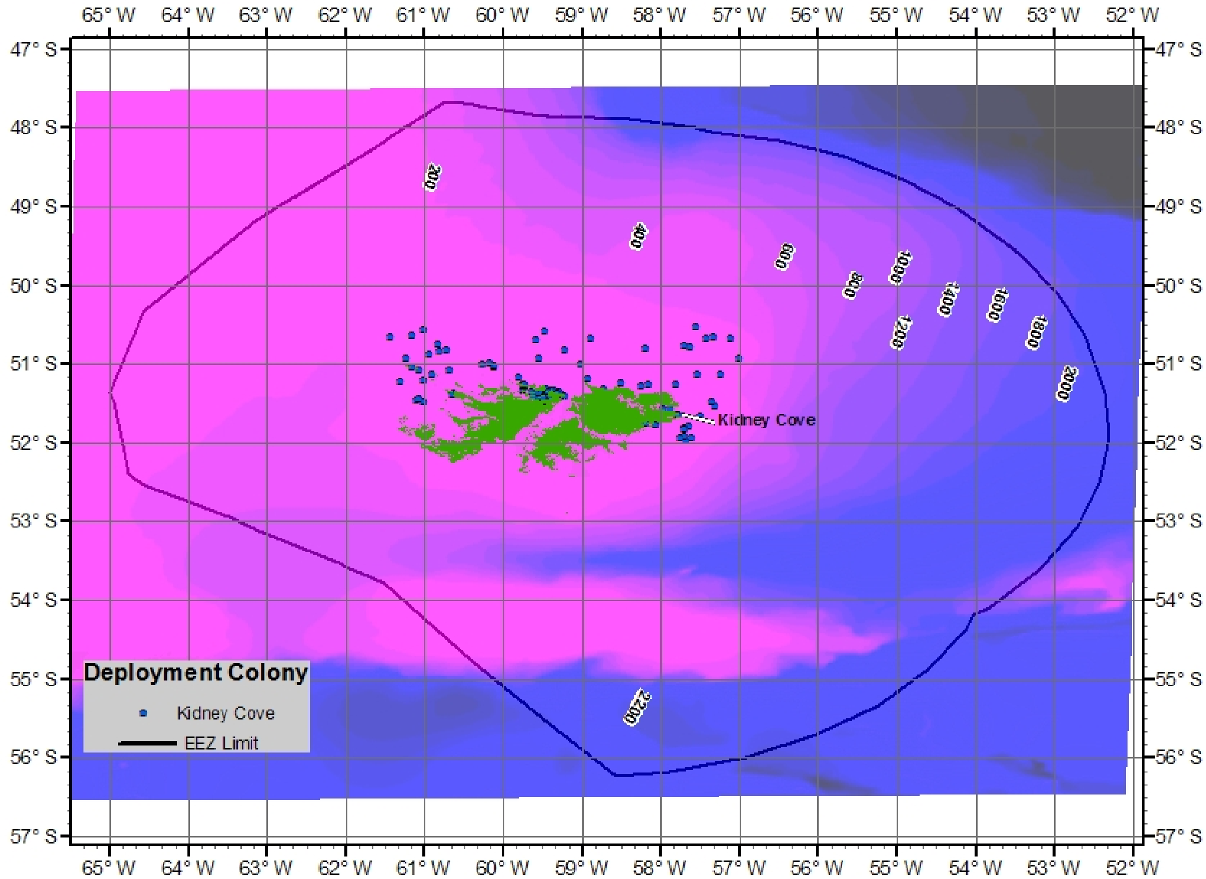

Figure 12: Satellite derived locations of foraging Gentoo Penguins. Depth contours within the EEZ are indicated in metres.

5.5 Pooled satellite tracked species

To investigate whether the satellite tracked species favoured particular foraging areas, data from all four tracked species were pooled and density of locations were analyzed using Kernel analysis. Details on smoothing parameter *h* value and grid size can be found in the methods section. Figure 13 displays the density distribution plot using the collated satellite tracking data. The results display the estimated geographic area covered by increasing proportions of satellite fixes. An estimated 50% of the recorded points lie in small geographic areas around the islands of Beachene, Pebble and Saunders Islands.

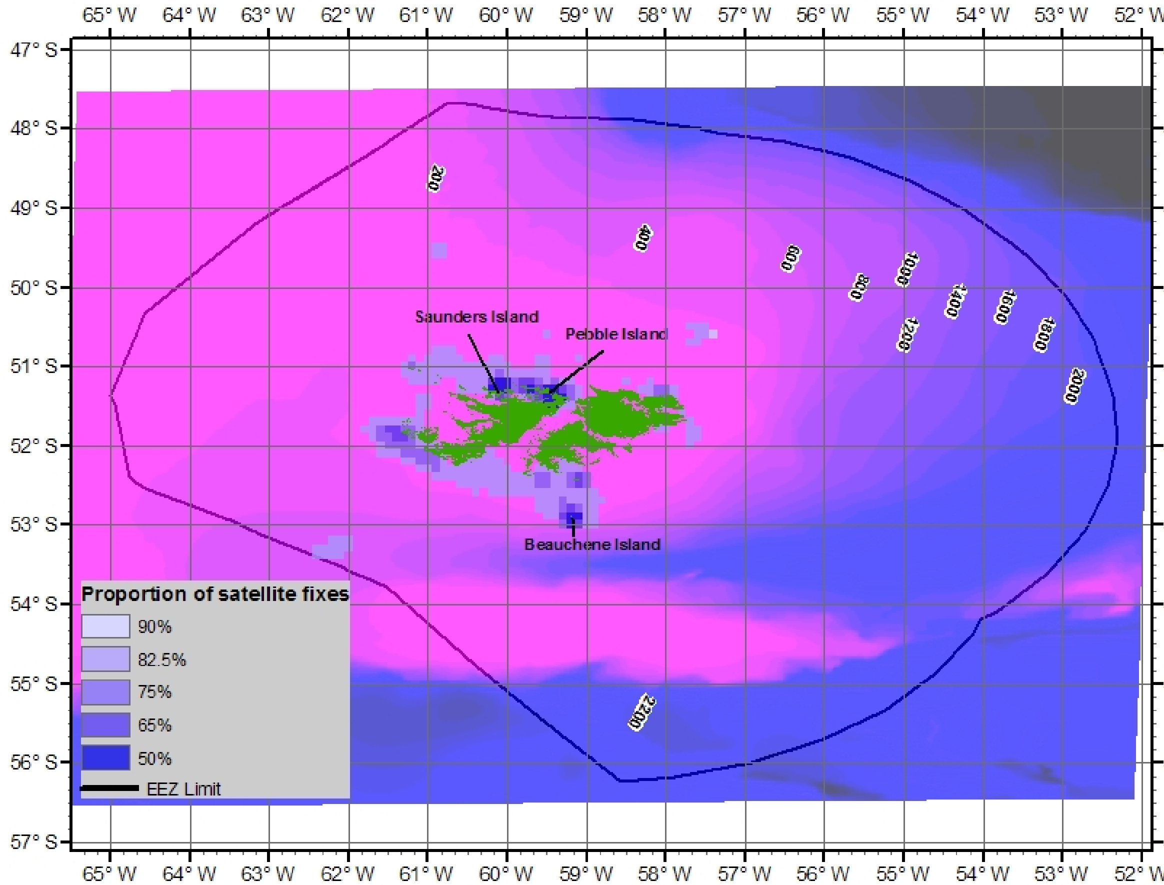

Figure 13: Kernel density analysis plot of pooled satellite tracked species. Depth contours within the EEZ are indicated in metres.

6.0 Results – Satellite and at-sea data comparison

Because penguin species are more considerably more difficult to observe from vessels at sea than flying birds, due to their short time spent at the surface when foraging, and difficulties in identifying species when sea state is moderate or poorer (pers. observations) the only species considered for comparison was the Black-browed Albatross. Figures 14 & 15 displays a Kernel density analysis of the Black-browed Albatross satellite data, and the number of Black-browed Albatross individuals recorded per naval and SAAS vessel observations (at-sea observations are treated separately due identified differences in section 4.1). A weighting factor was calculated and applied to the Black-browed Albatross data to balance the unequal numbers of individuals tracked from each colony. Smoothing parameter size *h* and grid size are the same as the pooled species analysis in section 5.5.

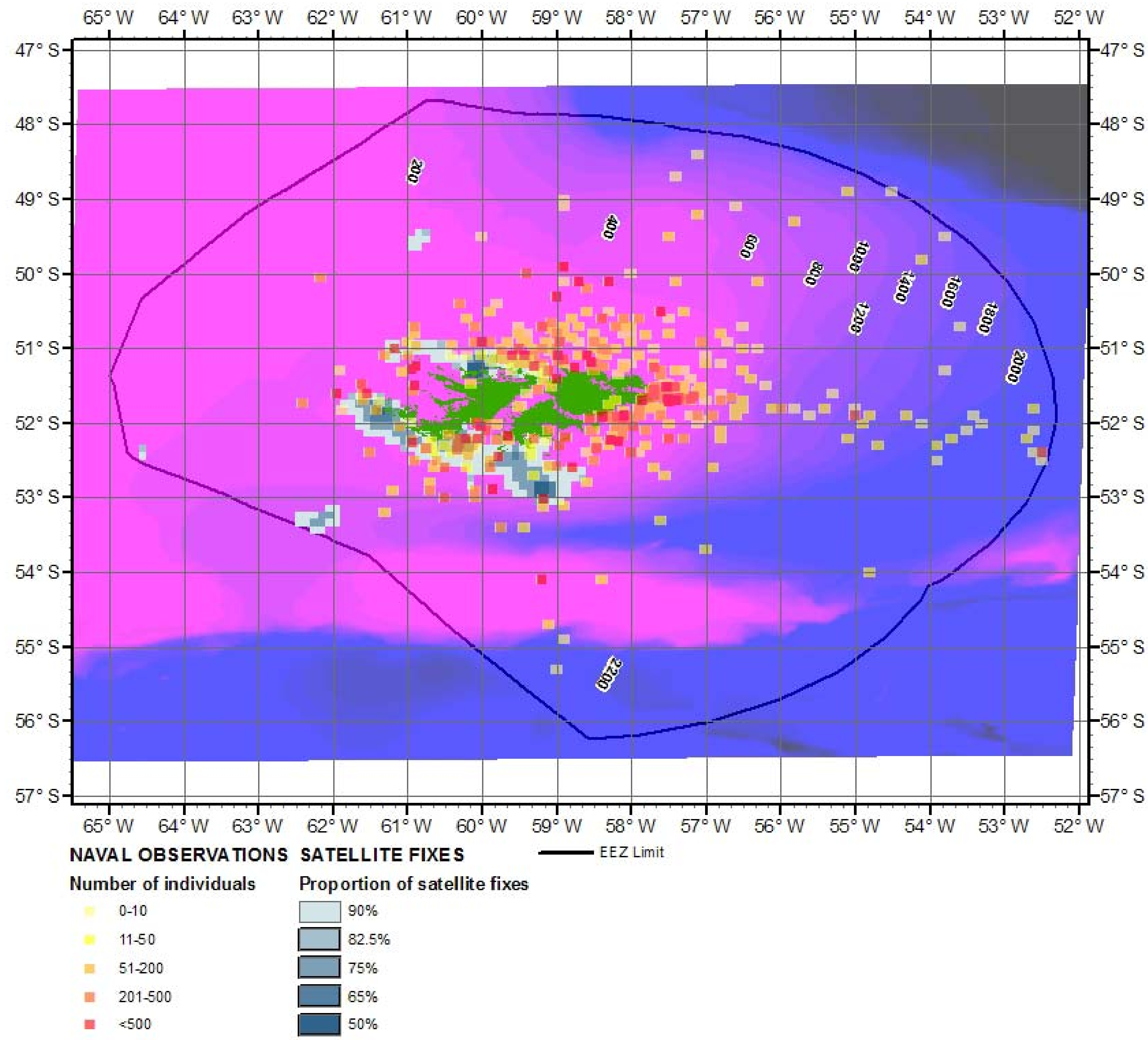

Figure 14: Kernel density of Black-browed Albatross satellite data, and numbers of individual Black-browed Albatrosses recorded on naval vessels. Bathymetry contours within the EEZ are indicated in metres.

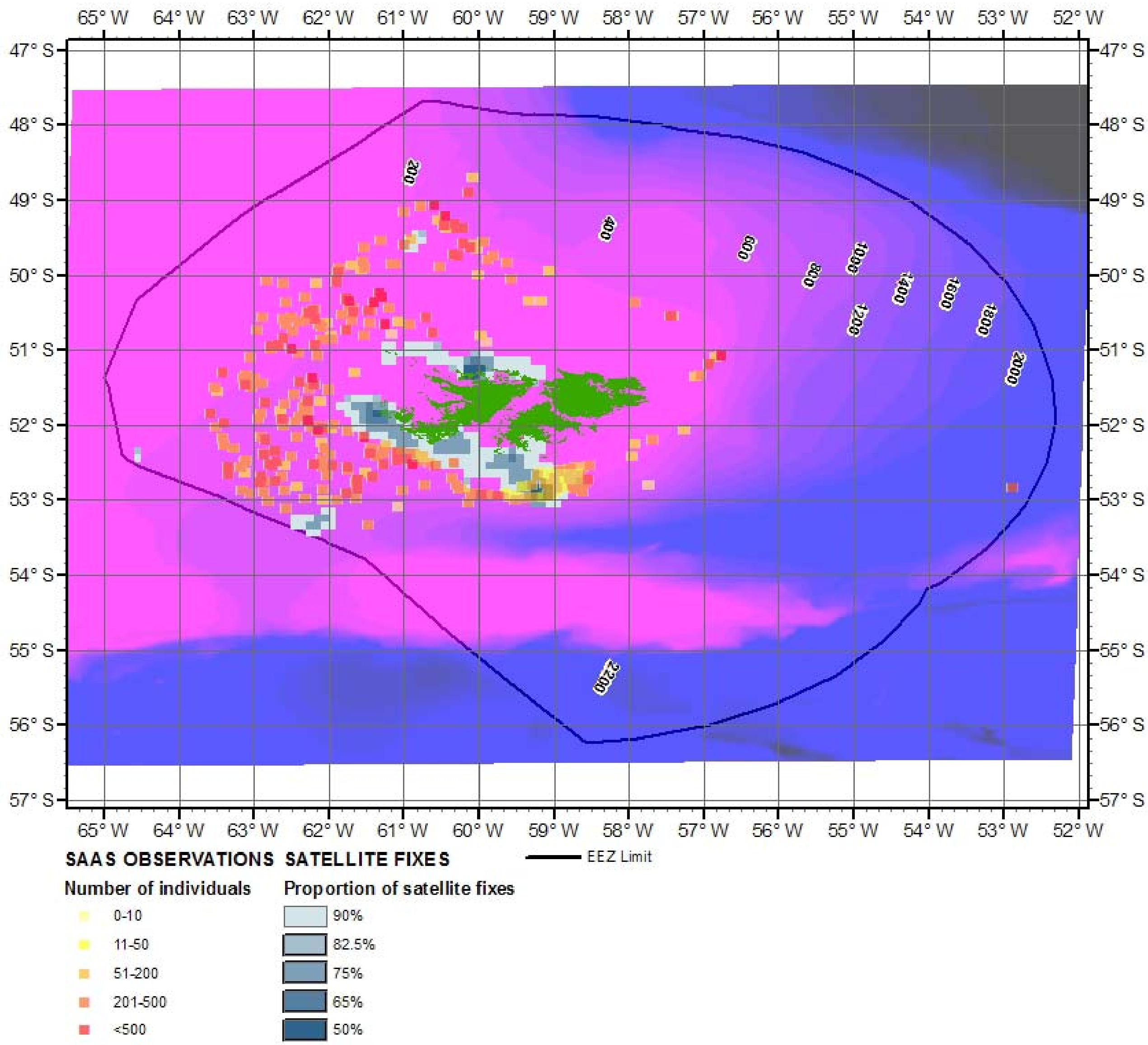

Figure 15: Kernel density analysis of Black-browed Albatross satellite data, and numbers of individual Black-browed Albatrosses recorded on SAAS vessels. Bathymetry contours within the EEZ are indicated in metres.

Formal statistical testing of the overlap between areas of high density from the satellite data, and areas where high numbers of individuals were recorded on naval or SAAS vessels is not appropriate. This is due to the fact that Kernel density analysis of satellite observations are calculated from discrete point locations, and are not strictly independent individuals, whereas data from at-sea observations are assumed to be discrete individuals over an observation transect area. However both figures 14 & 15 indicate that areas of the highest numbers of birds recorded from at-sea observations do not visually correspond with the calculated areas of highest density from satellite tracked individuals, as the Kernel density plot shows very little overlap with high scoring cells from the at-sea observations.

7.0 Discussion

The first aim of this study was to identify and link potential areas of high species richness or numerical density with oceanographic features, through analysis of the collected at-sea observer data. The second aim was to collate and analyze satellite data for multiple species to identify areas of high density. The discussion examines these aims through the outcomes of the analysis for each observation type, and considers the third aim of potentially proposing marine IBAs given findings from the two data collection methods.

7.1 At-sea observer data

By collecting two unpublished at-sea observer data sets with a considerable spread of temporal and spatial data, there was potential through pooling of the data to cover a wide geographic region and minimise any seasonal biases that might be present. And although the two data sets spanned a large number of years and thus can be assumed to smooth the effects of seasonality, the aim of pooling the at-sea observer data to increase the geographic area covered for analysis was unfortunately not realized due to two main factors.

Firstly data from the fishing vessels appear to be located more towards western areas of the Falklands EEZ (figure 2) than naval vessels, and this was confirmed by a significant difference in longitudinal locations. The most logical explanation is that fishing vessels tend to utilize areas within and around the 200m depth contour, and there are greater areas within 200m depth to the west of the islands (summary statistics on location by year and catch type can be found at http://fis.com/falklandfish/html/publications.html). The study by White *et. al.* (2002) also found the highest number of fishing vessels in this area. Secondly, a significant difference in species numbers recorded per observation was found between naval and SAAS observations. Thirdly, a significant difference was found in average vessel speeds. This may explain why naval vessel observations had significantly higher numbers of species than SAAS vessel observations, as naval vessels would have covered longer transects during their observation periods during to a higher mean speed. However it has been shown in other studies that covariates such as sea state, observer and vessel type can have significant effects on accuracy of results. Ronconi & Burger (2009) recommended using distance modelling methods to improve the accuracy of observer results recorded over three years because of variation in observer records of smaller species, Garthe & Huppop (1999) postulated that vessel speed affected numbers of attending species after discovering that dominant scavenger species in their study showed greater abundance at lower vessel speeds, as well as recording fewer numbers of non scavenging species, VanderMeer & Camphuysen (1996) found considerable observer differences between six international teams conducting strip transects over the same region of sea, and Sauer *et al*. (1994) reported a 'learning process' by which observers tended to record more birds as their experience increased. Interestingly in line with this, results from another at-sea survey study conducted by White *et al.* (2002), which using strip transects in Falkland waters to determine ranges of species, recorded 57 unique species. This is far higher than either of the survey results used in this analysis, although areas surveyed in White *et al.* (2002) included areas not covered by this study. Therefore it must be accepted that shipboard observer data sets are variable on both temporal and spatial scales, and subject to considerable variation from a number of other factors. The results from the analysis of the small number of overlapping transects which demonstrated no significant correlations between numbers of individual species recorded, species with high numerical abundance, and IUCN listed threatened species for the two data sets further reinforce the problems with variation between at-sea observer data sets.

Results from individual analyses of naval and SAAS observations found no strong positive or negative correlation relationships between number of individual species, number of IUCN listed threatened species, and observations with high numerical abundance of species; with either depth of ocean, or distance from shoreline variables. These results are in contrast to the study by White *et al.* (2002) which found that the distribution of multiple species foraging in the Falklands area was linked to depth of water. However unlike this study, the majority of observations by White *et. al.* (2002) were undertaken in water depths of greater than 1000m. Numerous other studies (e.g. Hunt *et. al.,* 1996, Pakhomov & McQuaid, 1996, Spear *et. al.* 2001) have shown a strong link between seabird abundance, seabird distribution and frontal systems, rather than discrete oceanic parameters such as depth. Although the Falklands area is recognized for high productivity due to the presence of the Falkland current, a spin off of the Antarctic circumpolar current (Acha *et. al.*, 2004), the closest frontal system is the Antarctic polar front, located outside of the Falklands EEZ. The productivity of Falklands waters is considered to be due to upwelling of nutrients from the Falklands current (Otley *et. al.* 2008) rather than frontal areas.

7.2 Satellite data & comparison with at-sea observer data

The majority of the individual satellite data sets used in this study have already been published by several authors (see introduction section for details of published studies), therefore this study will not discuss this individual findings of each dataset. However the pooling of multiple species for analysis has shown some interesting results.

Despite the raw satellite distributions demonstrating that satellite tracked species cover most of the Falklands EEZ for foraging (figures 9-12), the Kernel density distribution plot calculated for multiple species estimated a number of small discrete areas where 50% of data points were located. These areas are centred around the islands of Beauchêne, Pebble and Saunders Islands, which are all recognized terrestrial IBAs in the Falklands for their important seabird colonies (Falklands Conservation, 2006). The areas also cover on their periphery two other terrestrial IBAs, Keppel and West Point Islands. Whilst seabirds are constrained to feeding close to breeding colonies during specific periods of the life-cycle (Ricklefs, 1983), and both Saunders and Beauchêne Islands were tracking locations for a number of species, the analysis demonstrates that individuals outside the Saunders and Beauchêne Island colonies also utilize these areas as foraging grounds. The fact that multiple species from multiple areas forage in similar locations is not an unusual result, however in the context of this study it has implications for marine IBAs which are discussed in section 6.3.

The comparison of at-sea observation data and satellite tracking information was complicated by the low number and type (i.e non-flying seabirds) of seabirds tracked, and the incompatibility of the data sets for formal statistical analysis. To the best of the author's knowledge there have been no comparable studies which have attempted to interpret at-sea observations and satellite tracking results for seabirds. A study Block *et al.* (2005) using electronic tags and observer data from fishing boats, has shown the potential of such an approach by highlighted hotspots in the Gulf of Mexico visited by Atlantic Bluefin Tuna (*Thunnus thynnus*). However in this study the at-sea observer data collected information on a point basis rather than a transect/ area basis, which allowed direct comparison with the electronic tagging information.

In the case of this study it is therefore only appropriate to make general observations when comparing the Black-browed Albatross Kernel density analysis distribution with abundance figures collected during at-sea surveys in figures 14 & 15. However these figures do suggest somewhat of a disparity between areas of high abundance of Black-browed Albatross found in at-sea observations at the areas of highest usage display in the Kernel distribution. The possible explanation for this is that at-sea observations were collected in all months of the year, whilst the satellite information collated for Black-browed Albatrosses did not include winter non-breeding distribution information (see methods section for dates of deployments). Therefore these areas could represent winter foraging sites for the species, or additionally could represent foraging areas of birds from colonies that have had no tracking studies conducted.

7.3 Proposing of marine IBAs from findings

Birdlife International currently considers four seabird distribution patterns that will be most likely to determine defined marine IBAs. They are:

1. Seaward extensions to breeding colonies that would be contiguous with current terrestrial IBAs
2. Coastal congregations of non-breeding seabirds
3. Migration bottlenecks
4. High seas foraging sites for areas such as shelf breaks, eddies or upwellings

Results from the data analyzed for at-sea observations did not suggest any particular foraging areas which may be related to oceanographic bathymetry, and as seasonality effects were not taken into account in either the at-sea observation data or satellite data analyses, proposing marine IBAs that meet the distribution patterns in points two, three and four are not appropriate. However the Kernel analysis of pooled satellite has highlighted areas of high usage by multiple species that potentially meet the distribution pattern outlined in point one. There are issues with this proposal that need some discussion.

As outlined in the introduction of this study, marine IBAs proposed to date have used criteria based on Ramsar sites, i.e sites must support at least 20,000 waterbirds, or sites must support at least 1% of a population. The areas of high usage identified in the Kernel analysis obviously do not meet either of these criteria as satellite tracking is not a census method. If we presumed that the estimated coverage by the Kernel analysis method was an accurate reflection of the total foraging population of the four species tracked, then Marine IBAs could be prosposed on the basis of areas containing just 1% of points, covering virtually the whole of the Falklands EEZ. This would be a rather unselective method!

Supporting the argument of using the 50% coverage of satellite points as potential marine IBAs rather than Ramsar criteria, is the study conducted by Birdlife International (2004) of albatross and petrel distribution worldwide. Findings from this study found that areas of which included 50% of data coverage identified foraging hotspots for a range of species from breeding colonies worldwide. However to reduce the influence of a single individual track on the overall results a minimum sample size of 12 individuals was necessary. In this study, although weighting factors were applied due to the unequal numbers of individuals tracked between sites and species, this does not take into account any spatial variation that may occur due to a low number of tracked individuals. Therefore to objectively propose marine IBAs on the basis of tracking data, further satellite studies at locations where fewer than 12 individuals have currently been tracked should be considered to increase the sample size to this number.

The satellite tracking results should also be in no way seen as a comprehensive assessment of the island wide foraging distribution of the four species utilized. For three of the species (Black-browed Albatross, Gentoo & Rockhopper Penguin), there are a total of 170 breeding locations, and the Magellanic Penguin potentially breeds anywhere on the coast of the Islands where nesting burrows can be constructed, although 90 main areas are recognized. The eight locations where satellite tracking studies have been conducted represent only a small fraction of total breeding locations.

8.0 References

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