Foraging and diet of Southern Rockhopper penguins at Steeple Jason and Beauchêne Island, Falkland Islands – a summary report

Falklands Conservation
September 2012

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Falklands Conservation

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Note: The aim of this document is to report on the progress of the project since the completion of the two year field work to the funding bodies of the project. The data has not completely and comprehensively been analysed and therefore this report does not necessarily reflect the final information that will be published as a result of the project.

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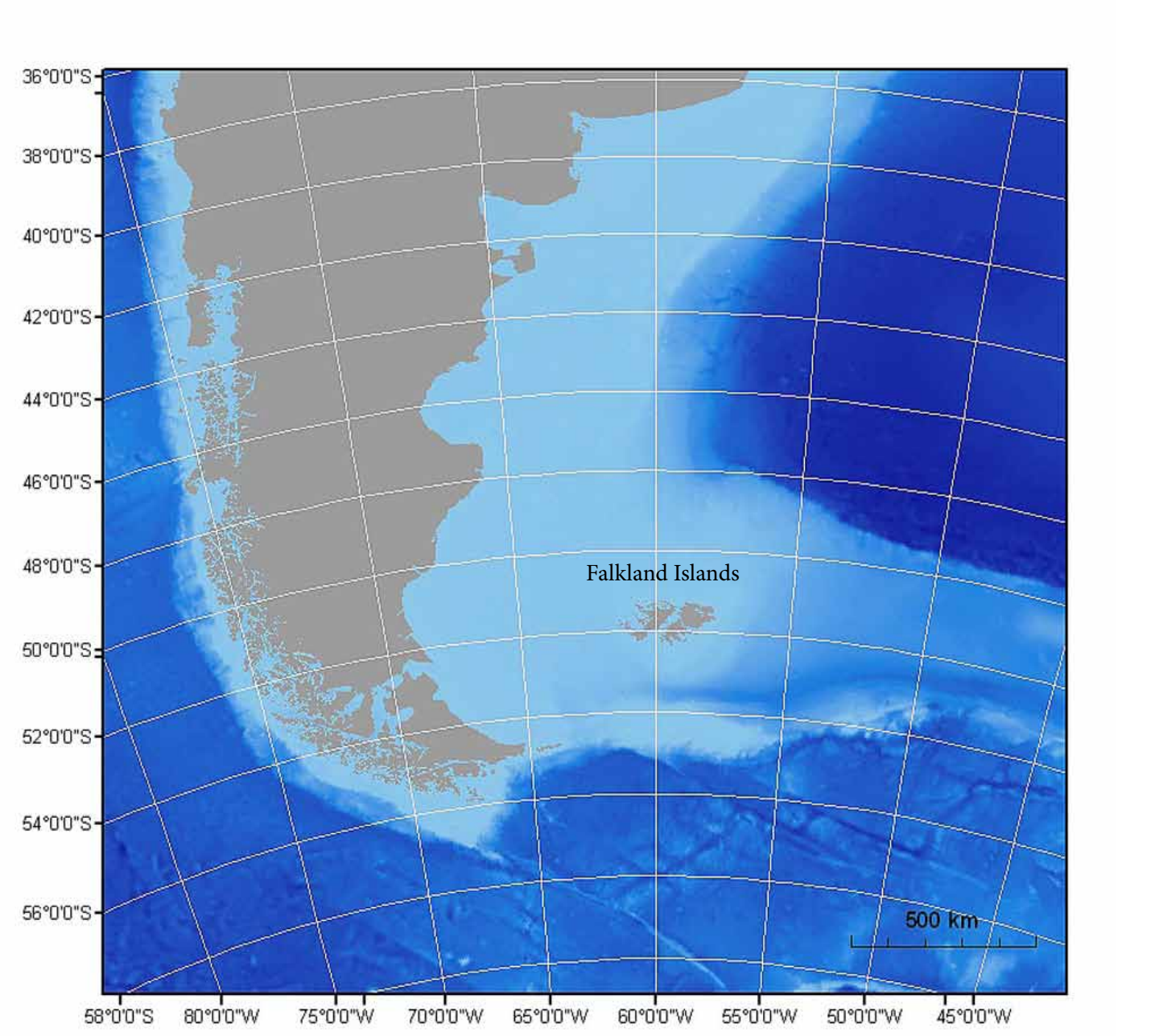


Note: The maps in this report are projected with the co-ordinate grid system shown above. To avoid cluttering the maps the graticule has been removed so tracking data is more clearly displayed. Please bear in mind when interpreting the maps to avoid misreading the latitudes in particular, as they do not run in perpendicular grids and therefore co-ordinates on the map do not align in a straight line with the axes.

Summary

- Southern Rockhopper penguins (*Eudyptes c. chrysocome*) are currently listed as 'Vulnerable' on the IUCN Red List due to reported population declines throughout their breeding range in the last decades.

- This study investigated foraging behaviour and diet at the two largest breeding colonies in the Falkland Islands - Steeple Jason and Beauchêne Island.

- Approximately 70 individual foraging tracks were obtained from adult breeding birds using GPS-TD loggers. Eight satellite trackers were deployed on wintering birds. During the chick-rearing period diet information was obtained in conjunction with tracking.

- Male adult penguins during the incubation period travelled approximately 330 km from their colonies. The Steeple Jason birds exploited the Patagonian Shelf to the west of the Jason Islands and Beauchêne birds exploited the Burdwood Bank and the region south of the Falkland Shelf.

- Female penguins provision the chicks exclusively during the brooding period and thereby are constrained to make shorter journeys. On average, females foraged 40 km from the colony at Beauchêne and 32 km at Steeple Jason. Female penguins at Beauchêne foraged on average 28 h per trip with a maximum duration of 70 h. Birds at Steeple Jason foraged on average 17 h per trip with a maximum of 37 h.

- Female penguins made between 400 and 800 individual dives during a single foraging trip to locate prey and return with provisions for the chicks. The deepest dive recorded was 96 m, but more frequently dives were between 22-32 m depths. The longest dive duration (total time under the water) was 171 seconds.

- Diet items were common and abundant species within Falklands' waters with no overlap with targeted species or sizes in the commercial offshore fisheries. Crustaceans (in particular krill) were the dominant prey item in terms of numbers, although fish, in particular sprat, dominated the diet during periods at Steeple Jason in terms of mass. Some inter-annual variation suggests high dietary opportunism exists.

- Eight satellite trackers were deployed on adult Rockhopper penguins over the winter of 2011. The longest tracking duration was 138 days. Four birds tracked from Beauchêne covered an area of approximately 1,000,000 km^2 in oceanic and shelf-slope waters. The four tracked birds from Steeple Jason exploited approximately 675,000 km^2 and foraging concentrated on the Patagonian Shelf. The two populations showed little spatial overlap.

- Wintering birds from Beauchêne and Steeple Jason spent large portions of their time outside Falklands' waters. Time was spent travelling through waters in jurisdictions of other South American countries, such as Argentina, as well as travelling and foraging in international waters.

- The tracking data highlighted the potential susceptibility of Beauchêne penguins to oil-related activities, given the overlap of their foraging range with the current oil exploration areas in Falklands' waters. The periods of greatest overlap occurred in November, when males forage during the incubation period, and for both sexes during the early part of the winter migration (March - April).

- This study provides new data from the Falkland's largest two breeding colonies of Rockhopper penguins and will help guide management decisions. Along with existing studies on this species in the south-west Atlantic, the information will form recommendations for a "Falkland Islands Rockhopper Penguin Species Action Plan". Ultimately, this may consider the "northern" populations (e.g. Steeple Jason) and the "southern" populations (e.g. Beauchêne) as distinct management units, requiring colony specific management recommendations.

Project rationale

Southern Rockhopper penguins (*Eudyptes chrysocome chrysocome*) are currently listed as 'Vulnerable' on the IUCN Red List due to reported population declines at almost all breeding sites throughout their range within the last several decades. To date major knowledge gaps in the ecology of Falklands' Rockhopper penguins has limited the extent and success of direct conservation efforts. The specific causes of the population declines remain largely unknown, although changes to the marine environment are suspected. Current hydrocarbon exploration and on-going commercial fishing operations within Falklands' waters emphasize the need to identify conservation priorities.

Current conservation status in the Falkland Islands

The Falkland Islands Government Biodiversity Strategy 2008-18 lists the Southern Rockhopper penguin as a designated priority species due to the historical declines of breeding numbers at the Falkland Islands. The strategy emphasises the need for research, conservation initiatives and developing a comprehensive Species Action Plan.

In 2008 an international Rockhopper penguin workshop was hosted by the Royal Zoological Society of Scotland (BirdLife 2008). The purpose of the workshop was to develop research and conservation action, and in particular, to investigate and address, where possible, population declines, with a focus on the south Atlantic region.

Falklands Conservation's programme – Rockhopper penguins 2009 - 2012

During 2009-2010 Falklands Conservation successfully acquired funding from a number of Falkland Islands and United Kingdom funding bodies, including government environmental grant programmes, to carry out research and address recommendations made at the International Rockhopper Penguin Workshop (BirdLife 2008).

The focus of this study was to investigate the foraging behaviour and diet at the two largest breeding colonies – Steeple Jason and Beauchêne Island and subsequently to develop a Species Action Plan. There has been little or no prior research into foraging and diet of Rockhopper penguins at these two sites and this study was the first to track penguins from both locations.

Steeple Jason and Beauchêne account for the majority of the Falkland Islands' breeding pairs (38 % and 33 % of the 2010 estimate respectively, or 26 % of the global population). Population changes at these sites therefore influence disproportionately the overall trends in Rockhopper penguins breeding at the Falkland Islands, and consequently will have important implications for the global conservation status of this species.

1. Background

Study site

The Falkland Islands are situated on a projection of the Patagonian Continental Shelf in the south-west Atlantic region (Fig. 1a). The continental shelf extends some 200 km beyond the Falklands coast to the north, about 50 km to the south-west, and about 50 -100 km offshore on the eastern side. To the south, a deep east-west trough (the Falklands Trough) divides the Falklands Plateau from the Burdwood Bank. Steeple Jason is located at the north-west of the archipelago (Fig. 1b). Beauchêne is located to the south in close proximity to the 200 m slope contour (Fig. 1c).

Ocean environment

The dominant oceanographic feature of the region is the Falklands Current, a strong cold current that branches off the Antarctic Circumpolar Current around the southern tip of South America and travels northwards until it meets the warm Brazil Current.

Upwelling is the major cause of high marine productivity and provides food for the exceptionally rich birdlife and marine mammals found in the region.

In particularly, upwelling as the water is forced up and over underwater ridges is noticeable in the north-west in the vicinity of the Jason Islands. Marine productivity in this area is particularly high and supports some of the largest concentrations of penguin, albatross, and seal numbers in the archipelago. A similar situation occurs to the south-east of the Falkland Islands around Beauchêne Island and the Burdwood Bank, where upwelling at the edge of the continental shelf brings nutrient rich waters and plankton to the surface, resulting in abundant marine life.

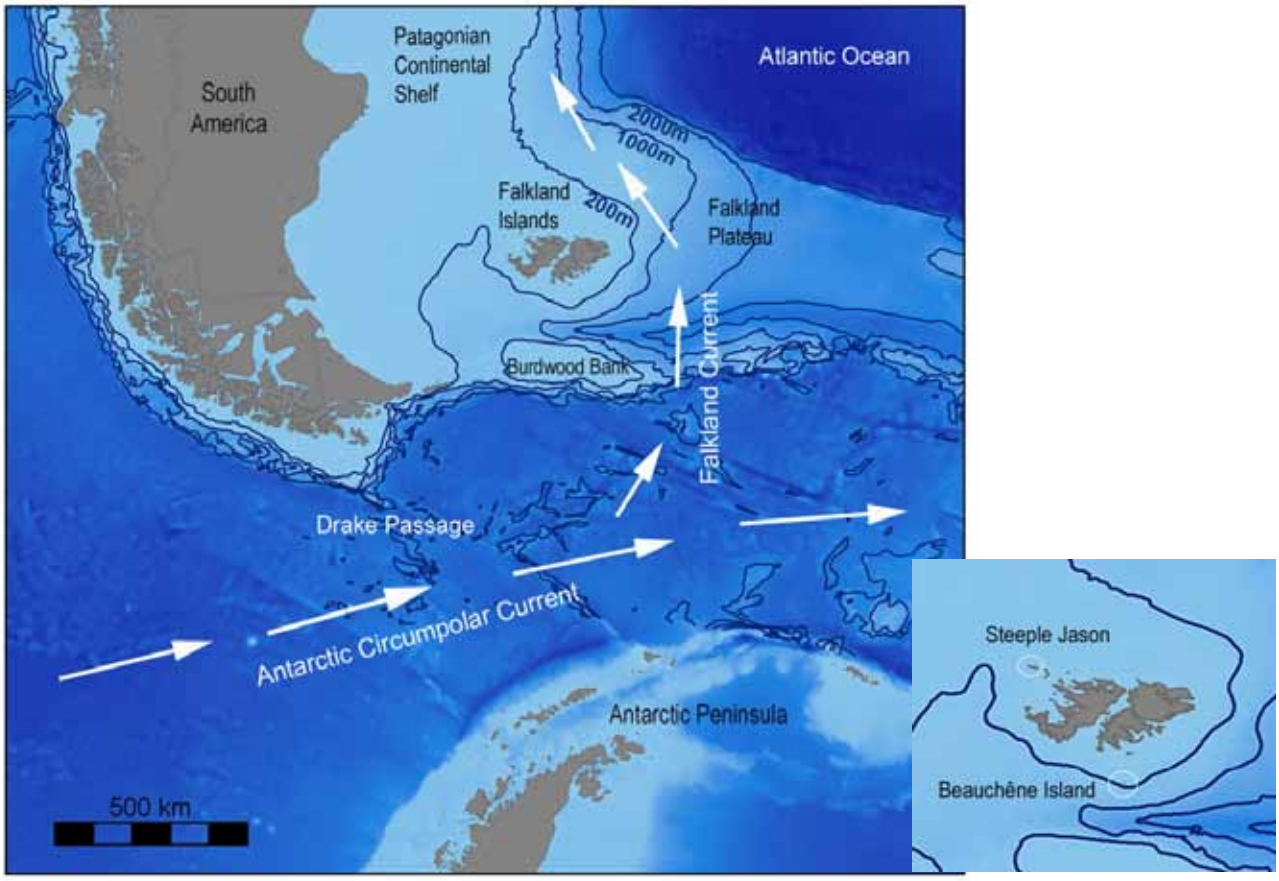


Figure 1a. Ocean environment of the south-west Atlantic region.

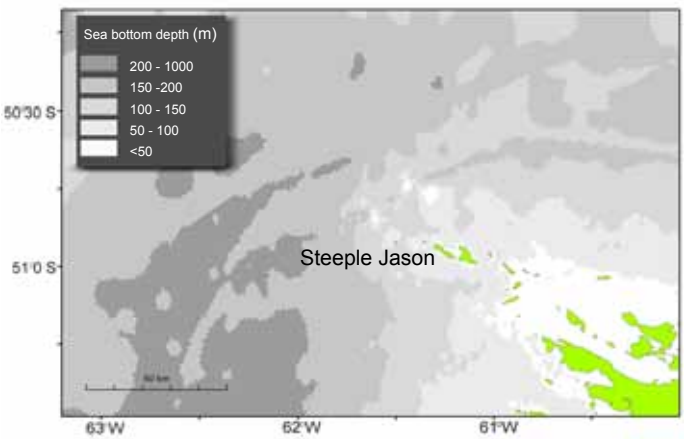


Figure 1b. Bathymetric environment around Steeple Jason.

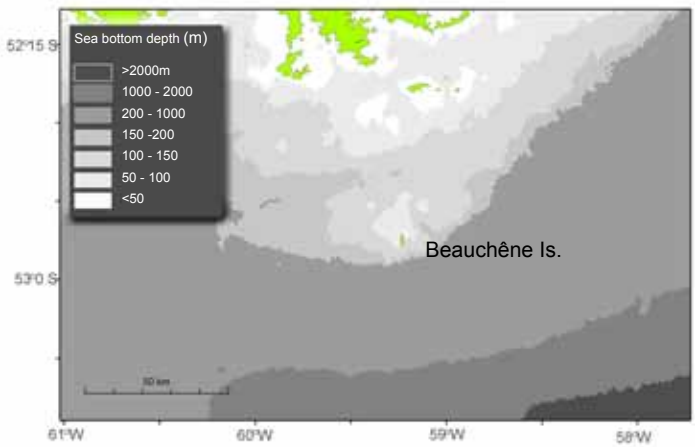


Figure 1c. Bathymetric environment around Beauchêne Island.

Steeple Jason

Steeple Jason is located to the north-west of the Falkland Islands and belongs to the Jason Islands Group, an uninhabited and important sanctuary for wildlife. Steeple and Grand Jason are owned by the Wildlife Conservation Society (WCS), New York, and managed as private nature reserves. Steeple Jason has never been permanently settled, although it was stocked with sheep in the past. Nowadays, small numbers of tourists, research scientists and WCS representatives visit the island for short durations.

Beauchêne Island

Beauchêne is the most southerly island of the Falkland archipelago and the most remote. The island has never been occupied by humans, although sealers intermittently visited during the 19th century. Designated as a National Nature Reserve, it is owned and managed by the Falkland Islands Government. Access is restricted and generally only permitted for scientific studies.

Population status and trends

Falklands Conservation (FC) conducts five-yearly Island Wide Censuses (IWC) of Rockhopper penguins at the breeding sites across the Falkland archipelago (Map 2).

The population of Rockhopper penguins in the Falklands dramatically declined at some point between the first estimates established in 1931 and the first IWC in 1995. Subsequent 5 yearly censuses showed that between 1995 and 2000 the population was stable/increasing but decreased by 90,000 pairs between 2000 and 2005. The most recent IWC results indicated an increase by approximately 50 % between 2005 and 2010, giving a current estimated breeding population for the Falklands at 319,163 ± 24,819 pairs or approximately 36 % of the global population for this species (see Baylis et al. submitted a). Despite the decline between 2000 and 2005 the Southern Rockhopper penguin population in the Falklands has recovered and increased since 1995, but still remains at less than 20% of the 1930's estimate.

Only recent mass mortality events at the Falklands have been documented, including a mass starvation in adult birds during the moult period in 1986 (Keymer et al. 2001) and a toxic red tide (harmful algal bloom) in 2001/02 (Uhart et al. 2004). Specific reasons for the past population declines are generally poorly understood, however larger ecosystem changes in the marine environment have been implicated (Hilton et al. 2006; Croxall et al. 2012).

In recent decades, terrestrial threats have not been inferred as major causes of population declines - although they would have been significant during the period of penguin exploitation by man in the 19th and early 20th century.

The recent increase in the population is likely to reflect a recovery from the periods between 2000 and 2005 when it was thought a combination of unfavourable conditions and the impact of the harmful algal bloom in 2001/02 caused detrimental impacts to the populations. The recent recovery is likely to have been facilitated by immigration, improved survival and higher recruitment of juveniles into the breeding populations. A similar increase in Gentoo penguins and Black-browed albatrosses breeding at the Falkland Islands during the same time period also suggests favourable environmental conditions leading to population increases across species (Baylis et al. submitted b; Wolfaardt 2012).

The census in 2010 was carried out in conjunction with the first season of the two year Rockhopper penguin foraging and diet studies at Steeple Jason and Beauchêne which is summarised in this report. The data that follow are therefore assumed to be a reflection of the bird's behaviour under normal and favourable environmental conditions.

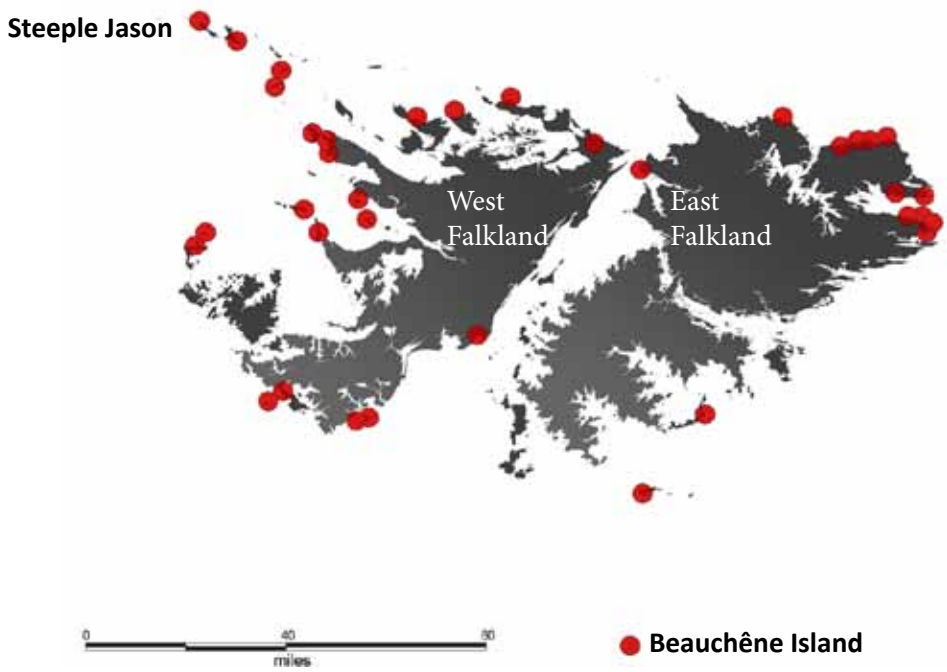


Figure 2. Distribution of Southern Rockhopper penguin colonies at the Falkland Islands.

2. Methods

Dates and timings

Field work was conducted on adult breeding Rockhopper penguins between November 2009 and January 2012 at Steeple Jason and Beauchêne Island (Fig. 3). Due to the remote nature and challenging logistics of access, Beauchêne was visited during only one breeding season. Trips were made in late October during the 2010 IWC and two dedicated trips conducted in December 2010 and in March 2011. Rockhopper penguin work was carried out over two consecutive breeding seasons in 2010/11 and 2011/12 at Steeple Jason.

Figure 4 shows the timing of the field work in relation to the breeding cycle and winter (non-breeding) periods. Groups of data collection reflect a particular period within the breeding season and have been labelled accordingly. For example SJ D10 would refer to Steeple Jason - December 2010 or during the small chick (brooding) period.

Licenses and permissions

All work carried out during this Rockhopper penguin project were approved by the Falkland Islands Government (FIG) Environmental Committee. Licences for all field and data collection procedures were granted by FIG Environmental Planning Department.

Permission was granted from the Wildlife Conservation Society (owners) to carry out work on Rockhopper penguins at Steeple Jason during 2009 to 2012.

The FIG Executive Council granted permission to access Beauchêne Island in 2010 and 2011 in accordance with biosecurity and safety regulations.

Location	Deployment dates GPS /TD loggers	Breeding Period	Sex	Diet Samples	Stable isotope samples - feathers and bloods
SJ	22 Nov - 03 Dec 2009	Incubation (egg)	Male	No	Yes (not analysed in this study)
BCI	7 - 26 Nov 2010	Incubation (egg)	Male	No	Yes (not analysed in this study)
BCI	05 – 17 Dec 2010	Brood (small chick)	Female	Yes	Yes
SJ	09 – 24 Dec 2010	Brood (small chick)	Female	Yes	Yes
SJ	08 – 20 Jan 2011	Crèche (large chick)	Female	Yes	Yes
SJ	15 Dec 2011– 05 Jan 2012	Brood (small chick)	Female	Yes	Yes

Figure 3. Dates and nature of field work carried out on Rockhopper penguins during the project.

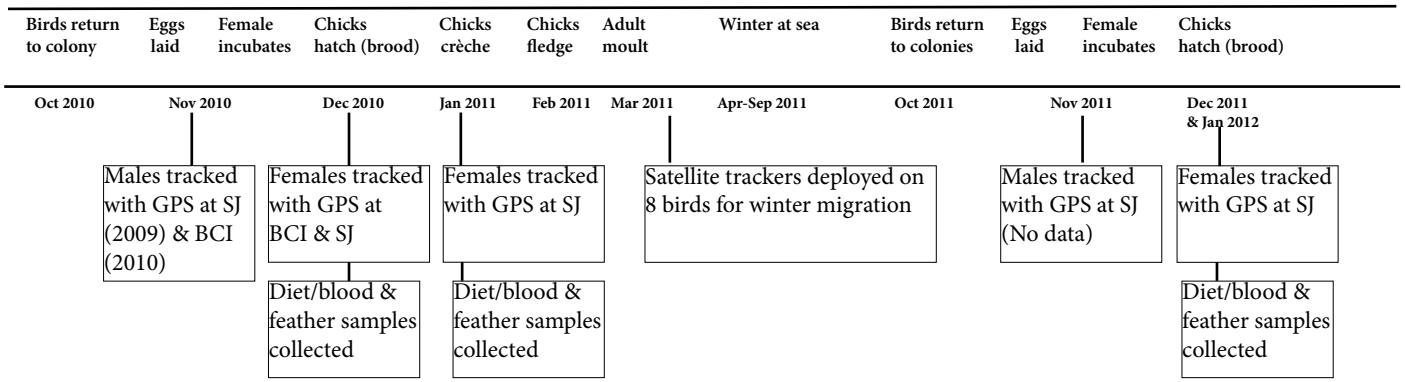


Figure 4. Time line of field work during the summer period for Rockhopper penguins at Steeple Jason and Beauchêne Island. (GPS - Global Positioning System technology for tracking devices)

Global Positioning System (GPS) tracking

Male breeding Rockhopper penguins, prior to their foraging trip in the incubation period, were caught at the nest site in November. Each bird was sampled separately and the head covered to keep it-calm; procedures were restricted to 15 -20 min. The birds were weighed using a 5 kg spring balance and beak measurements were taken to help validate the sex. A template of the tag was taped to the bird's back and strips of Tesa® tape were layered beneath the feathers along the spine. The device was placed and the tape secured over the tag (see Wilson 1997).The tape was further secured with a coat of glue.

Rockhopper penguins exhibit high fidelity to the nest site and birds returned quickly to their nest/partner on release. All field workers moved away from the vicinity to avoid any extra disturbance and minimise the risk of a handled bird deserting the colony. Female breeding Rockhopper penguins were caught at the nest site during December and January whilst both adults were attending the chicks. The procedure above was repeated for each female bird. Nests were closely monitored to ensure the male parent bird remained guarding the eggs / chicks.

The GPS units used were manufactured by earth & OCEAN Technologies, Germany. Each device had a built in temperature and pressure (for depth) sensor (TD) which was calibrated by the manufacturers to the depths normally displayed in Rockhopper penguins. The devices weighed approximately 66 g or less than 3 % of an adult female Rockhopper penguin body weight. The GPS-TD loggers worked on pressure-dependent operations of the GPS-receiver for use in diving animals. By this, the operating time was maximised, in that the receiver was switched on only upon the animal surfacing, saving battery power during submerged operations.

The devices were powered by a CR2 Lithium cell (3V) battery that was exchanged with each new deployment. Battery life was dependent on the number of searches the device took to fix a GPS position from at least 3 satellites. The data points were stored internally within the device and downloaded upon recapture of the bird. Tracked birds and their nests were marked after recapture to ensure they were not handled again.

During the male incubation foraging trip (potential duration of two to four weeks) GPS-TD loggers were programmed to take locational fixes every 60 min to

GPS - TD logger attached to a female adult.

A Sirtrack satellite device ready for deployment.

Step 1. Layering tape along the feathers on the spine.

Step 2. Placing device and securing tape.

prolong battery life. For female foraging trips in the chick-rearing period, the devices were programmed to take location fixes every 1-2 min. The TD sensors were programmed to record every 2 s.

Satellite tracking

A total of 8 satellite tags were deployed on adult Rockhopper penguins in 2011 (Fig. 5). Four tags were deployed at Steeple Jason and 4 tags were deployed at Beauchêne. All tags were attached to newly moulted birds in March. Birds were chosen at a nest site with a partner, in good condition, and had recently shed out all old feathers on the back (where the tracker sits). Rockhopper penguins complete their moult on land, typically at the colony and over a period of 3 – 4 weeks, before they can undertake the winter migration.

Beauchêne was visited from 14 - 19 March 2011 and birds were tracked from a discrete colony of c. 200 pairs on the eastern side of the island. Steeple Jason was visited from 24 - 28 March 2011 and birds were tracked from a discrete colony near the neck.

The satellite device model used was KiwiSat 202 PTT (Sirtrack, New Zealand). These lightweight marine tracking products are designed for animals such as penguins. The transmitters were powered by 2 x 2/3AA batteries with a transmitter life of 160 days. The transmitters were programmed to transmit between 19.00 - 22.59 local time. This was fixed in order to prolong the battery life, as birds are more likely to be resting on the surface during the night optimising locational fixes with satellites. The total weight of each transmitter was 60 g and less than or approximately 3 % of the total weight of the adult rockhopper penguins at their moult.

Birds were caught at the nest site during the moult to ensure breeding adults were selected (even though the chicks had departed the adults still exhibited strong fidelity to the nest site with their partner). The birds were weighed using a 5 kg spring balance. Beak measurements were taken to validate the sex of the bird. The bird was quietly restrained by one person whilst a second person attached the tag. The procedure was similar to that carried out for the deployments of GPS trackers. The tags deployed at Beauchêne were programmed to start using the salt water switch (i.e. when the penguin was immersed in sea water). The tags at Steeple Jason were all programmed to start on the day of deployment (i.e. 25 March 2011).

Tag ID	Study site	Weight kg	Bill length (mm)	Bill depth (mm)	Tracker % of body weight	Probable sex based on bill size
78027	BCI	2.25	48.2	21.6	2.7	Male
78024	BCI	2.1	43.1	19.4	2.9	Female
78025	BCI	1.8	41.4	17.9	3.3	Female
102026	BCI	2.35	45.2	20.6	2.6	Male
78028	SJ	2.45	46.4	20.5	2.4	Male
78022	SJ	2.3	41.8	19.7	2.6	Female
78026	SJ	2.4	41.1	19.6	2.5	Female
78023	SJ	2.4	41.9	23.1	2.5	Male

Figure 5. Sex determination on bill morphometrics based on Hull 1996 and FC unpublished data 2010/11.

Step 3. Coating outer layer of tape with epoxy glue.

Step 4. Bird is ready for release back to the nest.

Device removed - tape peels away leaving the feathers intact and undamaged.

Acquisition of satellite data

The Argos service provided locational data by sending files direct to the registered user. Since 2011, all Argos data were processed using the Kalman filter which offers improvements to greatly increase the number of valid locations, in particular for difficult platforms such as diving animals.

The Argos service calculates the location of the tag and provides a quality score (location class) for each position. Each class requires a different number of messages received per satellite pass. Classes 1 - 3 have an associated error between 250 and 1500 m with 4 satellite messages or more received. Locational fixes in classes A and B have unbounded accuracy estimation with 1 - 3 messages received and Z class locations are invalid. The diving behaviour of penguins mean that they are only on the surface for short periods between rapid diving bouts, so obtaining high quality data (class 3) is limited by their diving behaviour at sea.

A total number of 2,656 positions, excluding Z locations, were recorded for the 8 satellite trackers. The majority (49 %) were B class locations and 40 % classes 1-3. Positional data files were filtered using the Trip package (Sumner 2012) in R 2.13.2 (R Development Core Team 2011) which facilitates screening of spatial data for animal tracking.

Analysis of spatial and temporal data

Positional data were plotted using Hawth's Analysis Tools in Arc GIS 9.3.1. (Beyer 2004) and using the WGS84 coordinate system with UTM zones 20 and 21 for Steeple Jason and Beauchêne respectively, or the Lambert Azimuthal Equal Area projection.

Foraging ranges were calculated by the furthest position from the colony for each bird on a trip. Minimum Convex Polygons (MCP) or the areas at sea used by the birds were calculated for foraging ranges. Foraging durations were considered as the period between the first 3 consecutive dives below 10 m after the bird left the colony and the last three below 10 m before the bird returned to the colony. Trip durations are the complete trip from leaving the colony to arriving back. Outliers (including the birds tracked during a severe storm event on 13 Dec 2010) were not included in the calculations or analyses. Trip locations using Kernel Density Estimate (KDE) analysis were used to determine 50 %, 75 % and 95 % of density contour areas (the estimated foraging range). KDE outputs indicate where birds spend the majority of their trip (Falabella et al. 2009), although as they are location fixes they do not necessarily indicate feeding areas, but provide an indication of intense use. The 50 % zones show the areas where the probability of occurrence is the highest. The outer line represents the 100 % or complete foraging range.

Bathymetric data was downloaded from British Oceanographic Data Centre (www.bodc.ac.uk). Additional shape files for depth contours, Falkland EEZ and offshore hydrocarbon exploration areas in Falklands' waters were kindly provided by the FIG Mineral Department.

Dive parameter analyses.

Pressure profile data was converted into depth using DiveMove package (Luque 2012) in version 2.13.2 (R Development Core Team 2011) to generate a summary of individual dive parameters for each bird. All dives < 5 m were considered as travelling dives and those > 5 m as foraging dives. Data were screened to exclude any overnight periods at sea when foraging dives had ceased and the bird was resting on the surface.

Diving efficiency (DE) was calculated according to Ydenberg and Clark (1989) as DE = bottom time / (dive duration + surface time). In order to eliminate dives followed by extended resting periods at the surface (e.g. at the end of a diving bout) calculation of DE was restricted to dives with a surface time of less than 240 s which corresponded to about 1.5x maximum dive duration (see Pütz et al. 2006).

Diet analyses

Collection of diet samples by lavage

Collection of stomach samples (through stomach lavage) provides quantitative dietary data and taxonomic resolution (i.e. the ability to identify prey species) that cannot be achieved through stable isotope analysis. Identifying key prey species is important in understanding links between foraging ecology and foraging locations.

Diet sampling was carried out using the water offloading technique described by Wilson (1984). Birds were caught at the nest site on return from foraging and typically flushed twice to ensure the stomach contents had been off-loaded. Individuals were marked

prior to release to ensure they were only ever handled once. Samples were drained and placed in sealed plastic bags and either frozen (Steeple Jason) or placed in methylated spirits (Beauchêne) until further sorting.

Collection of samples for stable isotope analysis

The primary use of stable isotopes in seabird ecological studies has been the establishment of trophic position and region of feeding based on values of $\delta^{13}C$ and $\delta^{15}N$ of seabirds and their prey (Karnovsky et al. 2012). Many avian studies focus on collection of whole blood and feathers. The different tissues provide different time-integrated information about the diet. Red blood cells that are constantly renewed have an isotopic half-life of 12- 20 days and therefore reflect the diet in the last weeks prior to sampling. Feathers, metabolically inert keratinous products, are similar in isotopic composition to the diet at the time they were grown, e.g. during the pre-moult foraging period in penguins (Hobson and Clark 1992; Bearhop et al. 2002). Blood sampling for stable isotope analysis is useful when combined with known foraging tracks and foraging locations and is thus desirable to use on birds that are being tracked.

Blood samples were taken via venipuncture of the cutanous ulnar, (vein on the under side of the flipper) or the tarsal vein (foot vein). The process took approximately 5 min for each bird which was then marked and released back into the colony. Bloods were frozen (Steeple Jason) or air dried (Beauchêne) until analysis. Three to six feathers were cut from the breast region and stored in plastic air-tight bags.

Sorting of diet samples

Samples were washed, drained and excess water blotted off. Total sample weight was noted prior to any sorting. Whole and semi intact specimens of fish or cephalopods were removed and separately weighed. The majority of samples were too large to sample completely and 1/8 weight of large samples or 1/4 weight of small samples were sub-sampled. The prey items were then extrapolated to the original sample size (Raya Rey 2005).

Sample contents were separated into categories: Fish, Cephalopod or Crustacean. Any intact whole fish specimens were weighed and measured (total length, TL) and otoliths removed and stored. All loose otoliths in the sub-sample were collected and stored for further

Rockhopper penguin study colony at BeauchêneIsland.


A holed sock is placed over head & eyes to calm the bird.


Measuring bill length with callipers.


Cutting breast feathers for stable isotopes.

identification. Intact cephalopods were measured (mantle length, ML) where possible and weighed. Cephalopod beaks removed from the buccal cavity and loose beaks from the sample were stored in 70 % ethanol until further identification. For crustaceans, all pairs of eyes in the sub-sample were counted and later extrapolated to estimate the number in the original sample (Huin 2005).

In most cases the diet samples were highly digested and impossible to separate into components to weigh. Where possible the wet diet weight has been calculated from the sample. In addition, regression equations based on otolith length and the lower rostral or hood lengths of cephalopods were used to help estimate the total fresh weight of the meal ingested by the penguin (Huin 2005).

Species identification, length frequency and reconstituted masses

Crustacean

Crustaceans were identified where possible to species level and standard lengths, SL,(tip of the telson to the anterior edge of eye ball) were measured to the nearest mm using a binocular microscope. The species *Euphausia vallentini* could be confidently identified. In cases where individuals were insufficiently intact to permit identification to species level the individual was recorded at its genus level.

Cephalopod

Cephalopod beaks were identified and measured using a stage micrometer (regularly recalibrated with a graticule) in a binocular microscope according to the method by Clarke (1986). Beaks were identified to species level (Xavier & Cherel 2009; Falkland Islands Fisheries Department (FIFD) & FC reference collections).

Upper (left) and lower (right) squid beaks from diet.

The majority of cephalopod beaks were from juveniles with features difficult to determine to the non-specialist eye. Specimens were sent to Jose Xavier and Yves Cherel in August 2012 for further identification.

Beaks were recorded as: 1) attached to crown or buccal mass; 2) loose with no erosion; 3) loose with erosion. The lower rostral length (LRL) of squid beaks were used to provide length-frequency data and reconstituted biomass from allometric equations for each species where possible. For octopus beaks the lower hood length (LHL) was measured. Cephalopod beaks can remain in the stomach of predators for a number of days and thus not reflect prey items caught in the last foraging trip. In samples where loose and eroded beaks were found, such items were discarded from calculations of the reconstituted meal mass, but kept for analysis of overall species consumption.

Fish

Fish otoliths were identified using reference collections held by FIFD and FC. Each otolith was measured using a stage micrometer (regularly recalibrated with a graticule). Otoliths were classed as 1) fresh from head; 2) loose with no erosion; 3) loose with erosion. Left and right otoliths were paired in the sub-samples to similar lengths and any supplementary otoliths were taken as being part of another individual. The otolith length (OL) was used to provide length-frequency data and reconstituted mass from allometric equations where possible. For Patagonotothen fish otoliths from juveniles were unidentifiable to species level and the average length and mass was estimated using allometric equations for *P. ramsayii* and *P. tesselata* (the two species most commonly observed in Falklands' waters). Loose eroded otoliths were not used in the calculations of reconstituted meal mass, but used for analysis of the overall prey consumption.

Stable isotopes

Stable isotope analyses of blood and feather samples were carried out at the Scottish Universities Environmental Research Centre's (SUERC) Life Science Mass Spectrometry Facility, Glasgow. Dried feather tip fragments were weighed into 0.70 mg aliquots and dried powered blood weighed into 0.60 mg aliquots and placed in small tin cups. Lipid extraction was performed on all prey samples, to control for differences in lipid content (Bearhop et al. 2002), using a Soxhlet apparatus with a methanol:chloroform 2:1 solvent. Following extraction samples were dried

under a fume hood overnight and ground into a homogenous fine powder with a pestle and mortar.

Sub-samples of crustaceans were acid washed in HCL after lipid extraction to remove inorganic carbonates (Carabel et al. 2006). These samples were used to determine the carbon isotope ratio and the non-treated subsamples of crustacean to determine the nitrogen content. Carbon and nitrogen were measured by continuous-flow isotope ratio mass spectrometer using a Costech Elemental Analyser EA linked to a Thermo Finnigan Delta V Mass Spectrometer. Three laboratory standards were analysed for every 20 samples allowing correction of any instrumental drift. Stable isotope ratios were expressed in δ notation as parts per thousand (‰) deviation from the international standards V-Pee Dee belemnite (carbon) and AIR (nitrogen), according to the following equation $\delta X = [(R_{sample}/R_{standard}) - 1] \times 1000$ where X is ^{15}N or ^{13}C and R is the corresponding ratio $^{15}N/^{14}N$ or $^{13}C/^{12}C$. Based on internal standards (tryptophan), the analytical precision (± 1 SD) was estimated as ±0.18 ‰ and ±0.17 ‰ for $\delta^{15}N$ and $\delta^{13}C$, respectively.

Rockhopper penguin parents attending their chick.

Foraging and diet in the chick-rearing period

Rockhopper penguins are central place foragers during the breeding season, since they must return to their chicks between foraging trips. As a pelagic predator they are highly dependent on predictable food resources in coastal waters near their nesting sites. However, their foraging range is determined by the environmental conditions influencing prey availability and by the physiological and energetic constraints of the birds. In addition, the individual will need to balance the provision of itself and its offspring. Seabirds rear their young on land, typically in large breeding colonies; thus individuals may also be in competition with their conspecifics.

Understanding how the birds respond to their habitat is particularly relevant in top predators such as penguins, as it can infer information on the resources in a known area and on the marine ecosystem in question. In a wider context, this may allow us also to predict how animals might respond to global and regional climatic and environmental changes.

Rockhopper breeding cycle

Rockhopper penguins exhibit a high degree of breeding synchrony and return to breeding sites in October. Two eggs are incubated during November and early December for approximately 32 - 34 days. During this period the male leaves the female incubating the eggs and departs on an extended foraging trip for two to four weeks (Pütz et al. 2006). If the male returns in good time before the eggs hatch this allows the female to also depart on an extended foraging trip, allowing both parents to increase their energy reserves before the chick provisioning period. The duration of incubation forages of both sexes is likely dependable on food availability and in some years the females forgo the trip if the male returns close to the date of the eggs hatching.

Once the eggs have hatched the female alone is responsible for provisioning the offspring over the duration of the brooding period, whilst the male remains at the nest with the chicks. Typically, females undertake daily foraging trips departing for sea at dawn and returning in the late evening to feed the chicks. Only once the chicks are large enough and have begun to crèche (24 - 26 days of age; mid –late January) will both the parents engage in chick provisioning. Both parents will provide for the chick until February when chicks fledge and depart the colony.

3. Results

GPS tracking - incubation period - male foraging characteristics

The GPS tracking of male birds during the incubation foraging trip showed spatial and temporal differences between the two sites (Fig. 6). Birds tracked at Beauchêne completed trips between 07 – 26 Nov 2010, earlier than at Steeple Jason (22 Nov and 03 Dec in 2009). Typically, birds at Beauchêne commence their breeding 10 days earlier than elsewhere in the Falklands (Strange 1982), although there is likely to be inter-annual variation at and between sites.

Tracked males from Beauchêne travelled and foraged in a south-easterly direction over the east end of the Burdwood Bank. Of all location fixes, 75 % were recorded in waters of depths over 1000 m. The furthest location was at longitude 52°W and the furthest south at latitude 56°S (Fig. 6).

Birds from Steeple Jason travelled in a westerly direction onto the Patagonian Shelf (depths of less than 200 m) and concentrated for 50 % of the time between longitudes 65 and 65.7°W. The most northerly position was 50°S and the most southerly 52.5°S (Fig. 6).

The average maximum distance travelled from both colonies for all males was similar, at around 330 km, although there was more variation in distances between individuals from Beauchêne. Beauchêne males also utilised a greater area of sea during the incubation trip than those from Steeple Jason (Fig. 7).

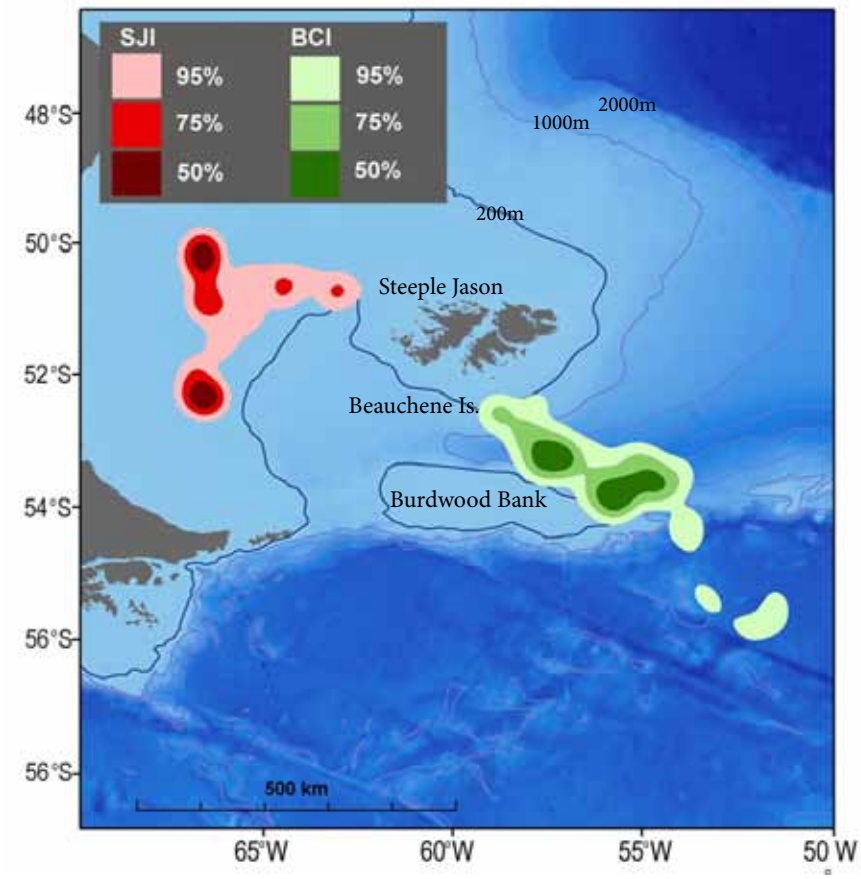


Figure 6. Kernel Density Estimation (area utilized) of male Rockhopper penguins during the incubation period at Steeple Jason in November 2009 (red) and Beauchêne in November 2010 (green). The 50 % zones show the areas where the probability of occurrence is the highest.

Location	No. of birds	Period	Maximum distance from colony km (Mean ± SD)	Minimum Convex Polygons /Area (km²) (Mean ± SD)	Total Minimum Convex Polygons /Area (km²) for all birds	*Absolute minimum trip duration (days)
BCI	4	Nov 2010	338 ± 166	20,296 ± 16803	58,324	12 ± 3
SJ	3	Nov 2009	327 ± 32	17,316 ± 4736	42,858	9 ± 2

Figure 7. Distance and durations of male foraging Rockhopper penguins during the incubation period at Steeple Jason and Beauchêne *Island. * Reflects the duration of the battery life of the trackers from the male departing the colony to the last locational fix and not necessarily the completed journey.*

Dive characteristics - incubation period - male foraging characteristics

Diving activities were lowest during the hours of darkness and during morning and evening twilight periods (Fig. 8) at Steeple Jason. However, birds at Beauchêne exhibited more activity during the twilight periods and less during the middle of the day.

The number of dives below 5 m per day for each bird varied between 300 and 465 dives. Steeple Jason males on average, were submerged under water for longer periods during individual dives and displayed deeper dives than the Beauchêne males (Fig. 9). The deepest dives were recorded for birds from Beauchêne.

Male Rockhopper penguins from Steeple Jason displayed higher diving efficiency (DE) than Beauchêne birds and DE in both groups decreased with depths greater than 25 m (Fig. 10). The most frequent foraging dive depths was between 5 - 30 m for birds at Steeple Jason and notably shallower at 5 - 15 m for male Rockhopper penguins from Beauchêne (Fig. 11a & b).

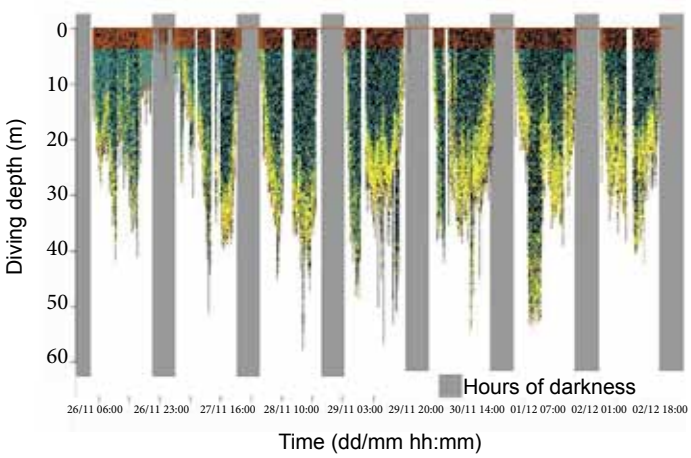


Figure 8. Diving depth profile of a male Rockhopper penguin during the incubation forage from Steeple Jason in Nov 2009.

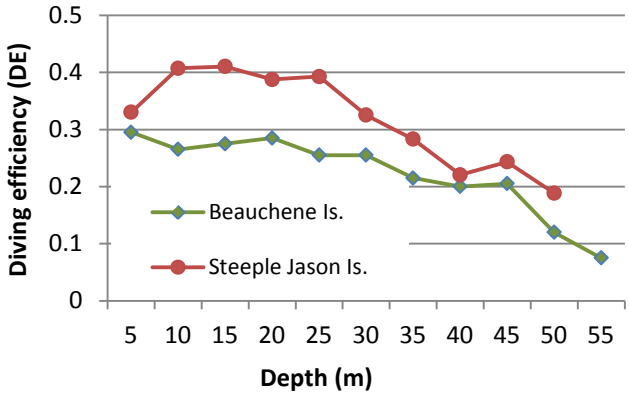


Figure 10. Diving efficiency in relation to depth for male penguins during incubation forage.

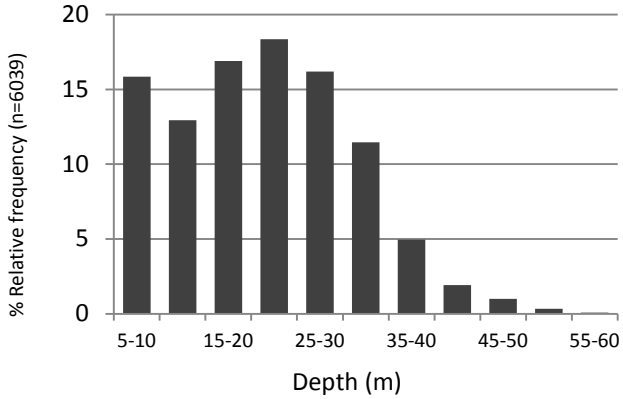


Figure 11a. Diving depth frequency in males at Steeple Jason.

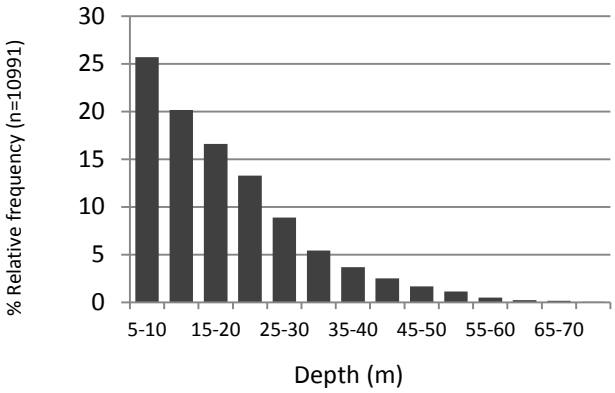


Figure 11b. Diving depth frequency in males at Beauchêne.

	Steeple Jason Nov 2009		Beauchêne Nov 2010	
BIRD	a	b	c	d
Days recorded	9	7	15	13
No dives >5m per day	301	475	385	401
Mean bottom time (sec)	39 ± 17	39 ± 18	19 ± 13	19 ± 10
Maximum bottom time (sec)	100	90	85	110
Mean dive duration (sec)	83 ± 22	83 ± 24	67 ± 22	70 ± 26
Maximum dive duration	145	140	135	135
Mean bottom depth (m)	21 ± 10	21 ± 9	19 ± 12	17 ± 11
Maximum depth (m)	23 ± 11	24 ± 10	20 ± 12	19 ± 11
Deepest dive (m)	56	58	74	63
Mean time spent between dives (sec)	30 ± 15	21± 9	22 ± 13	24 ± 15
Diving efficiency	0.35	0.38	0.23	0.30

Figure 9. Diving parameters in 4 male breeding Rockhopper penguins during the incubation forage from Steeple Jason (2009) and Beauchêne (2010). (Mean ± SD)

Chick-rearing period – female foraging characteristics

Fig. 12 shows the foraging tracks of female breeding penguins at Beauchêne between 05 -17 December 2010 during the brood period. The majority of birds travelled in a northerly direction towards the mainland Falklands. A few individuals travelled south and foraged in the vicinity of the 200 m shelf contour. One bird travelled further towards the Burdwood Bank (the track stops due to battery expiring, rather than the penguin!) and into water depths greater than 1000 m. On average the females foraged a maximum distance of 40 km from the colony.

Fig. 13 shows female Rockhopper penguins foraging at Steeple Jason during the brood period in December 2010. The birds travelled mainly in a west and south-westerly direction from the colony. All birds foraged in depths of less than 200 m. Females travelled on average a maximum of 33 km from the colony.

Birds at Steeple Jason during the crèche period in January 2011 (Fig. 14) travelled in a similar direction to those in the previous December. Several individuals undertook longer trips and foraged in depths greater than 200 m. Females on average foraged 5 km farther from the colony than in December.

Birds at Steeple Jason during the brood period in 2011 were tracked from the northernmost colony and travelled in a northerly direction. Females travelled less distance, with an average of 26 km from the colony than birds from the western colonies the previous year (Fig. 15).

Females at Beauchêne, in addition to travelling farther from the colony than at Steeple Jason, also used a larger area at sea for travelling and foraging (Fig. 16).

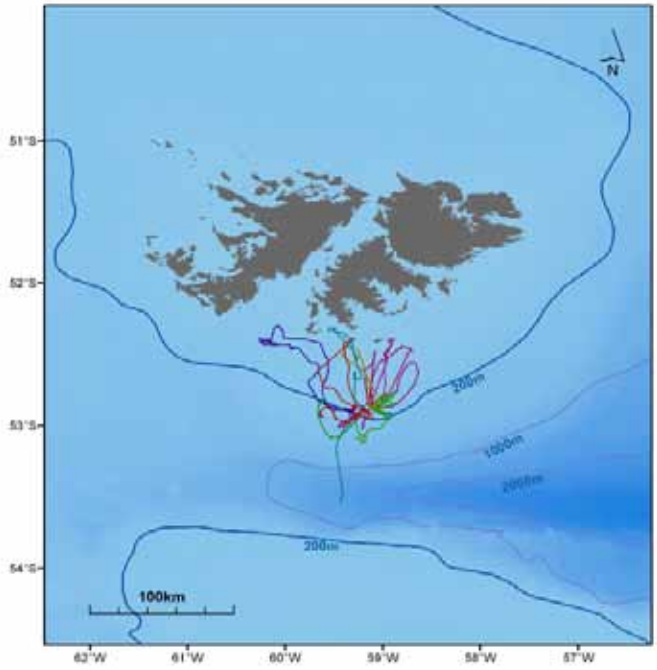


Figure 12. Female foraging trips from Beauchêne - Dec 2010 (n= 13 birds).

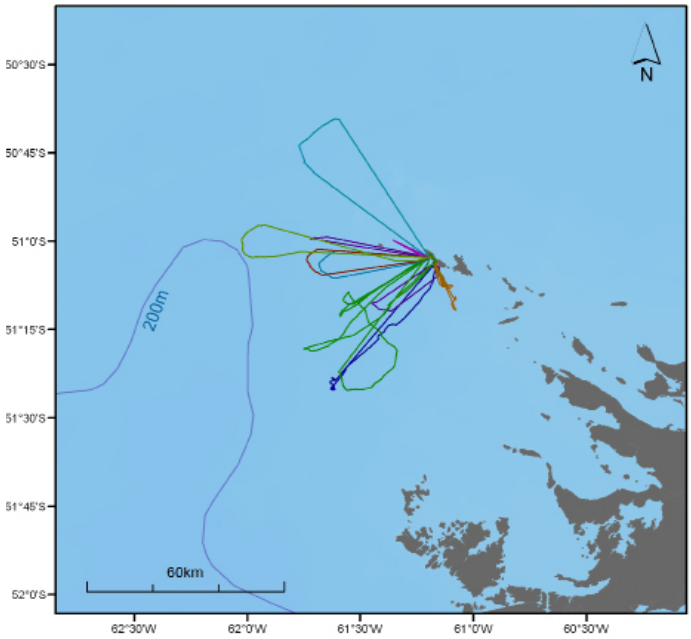


Figure 13. Female foraging trips from Steeple Jason - Dec 2010 (n= 14 birds).

Study site	No. of foraging trips	Period in the breeding season	Maximum distance from colony (km) (Means ± SD)	Minimum Convex Polygons (Area) km² for individual birds (Means ± SD)	Total Minimum Convex Polygons (Area) km² for all birds
BCI	13	Dec 2010 Brood	40 ± 19	486 ±432	5349
SJ	16	Dec 2010 Brood	33 ± 21	125 ± 141	1623
SJ	19	Jan 2011 Early crèche	38 ± 26	251 ± 240	3257
SJ	23	Dec- Jan 2012 Brood	26 ± 14	196 ± 253	3335

Figure 16. Distance and area of female Rockhopper penguins foraging during the chick-rearing period at Steeple Jason and Beauchêne Island

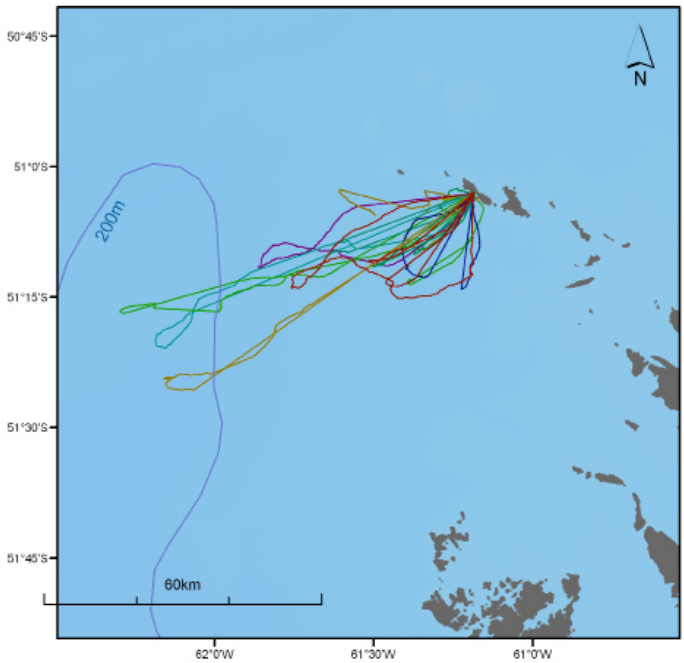


Figure 14. Female foraging trips from Steeple Jason - Jan 2011 (n=13 birds).

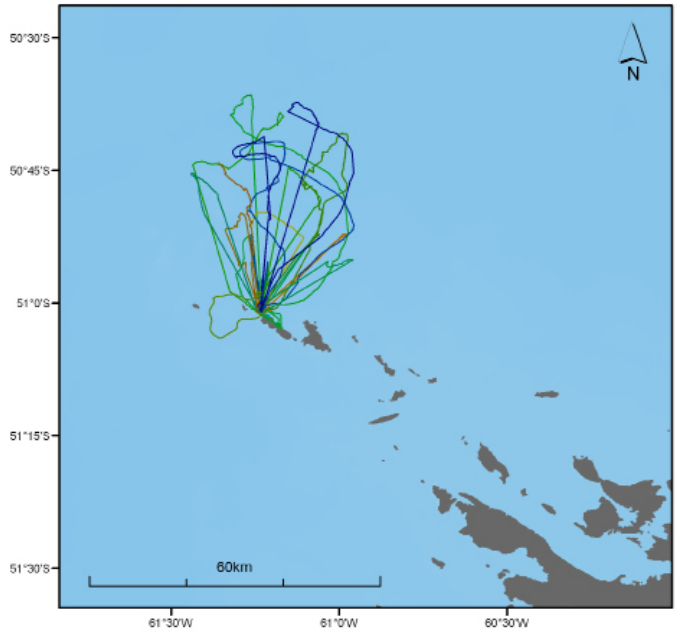


Figure 15. Female foraging trips from Steeple Jason - Dec 2011 and Jan 2012 (n=17 birds).

Foraging times and durations

For female penguins at Beauchêne the average foraging duration was 28 h and the maximum duration 70 h. Birds at Steeple Jason displayed similar patterns during the brood and crèche in 2010 and brood in 2011 with an average foraging duration of 17 h and maximum of 37 h. (Fig. 17). Females commenced foraging bouts between 06:00 and 07:20 in all groups.

The Beauchêne females began foraging on average 1 h after the birds at Steeple Jason. The time birds ended their foraging dives before travelling back to the colony varied and some depended on whether the bird spent an overnight period at sea or not (Fig. 18). Generally, birds ceased foraging from the late afternoon to early evening. Direct observations at the colonies recorded the majority of birds arriving after 16:00 and up until dusk (21:00-22:00). Birds that overnighted at sea began foraging earlier by 2 h and 20 min than those leaving the colony (Fig. 18). If they overnighted at sea birds also continued foraging later in the day for, on average, 4 h 30 min longer compared with those that returned to the colony the same day.

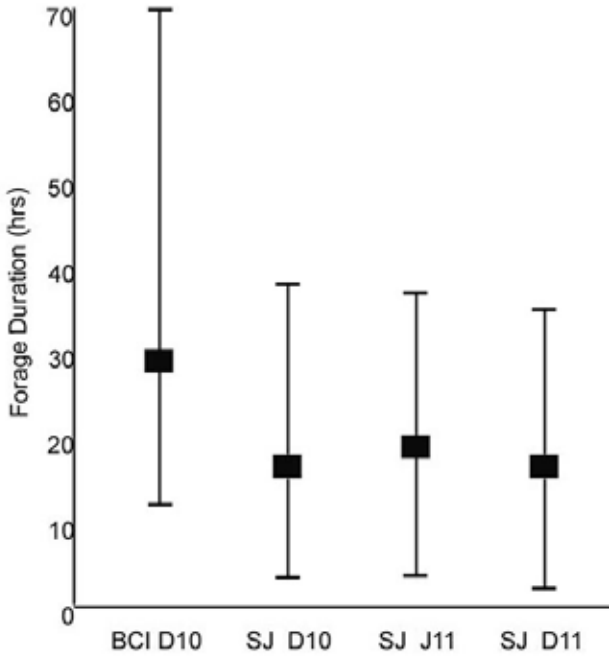


Figure 17. Forage duration of female Rockhopper penguins during the brood and crèche period. (means indicated by square and minimum and maximum by lines).

	Forage start from colony	Forage start from sea	Forage end at colony	Forage end at sea
BCI D10	07:21	03:46	15:02	21:35
SJ D10	06:26	03:30	16:17	22:16
SJ J11	06:36	05:14	18:21	23:59
SJ D12	06:01	04:18	15:55	20:13

Figure 18. Mean start and end times of individual foraging durations in female Rockhopper penguins during the brood and crèche period.

Diving characteristics of females during the chick-rearing period

Diving characteristics of penguins depend on the foraging grounds in question and the prey being targeted. In general the deeper the penguin dives, the more dive duration (time spent under water) increases. Deeper dives are also more energetically costly as they require more time to descend and ascend and require longer time at the surface to recover for the next dive.

Brood 2010 - Beauchêne and Steeple Jason

Female birds foraging in the brood period at Beauchêne on average dived to 32 m, some 7 m deeper and 16 s longer than female birds at Steeple Jason during the same period (Fig. 19). Diving efficiency was higher in the Beauchêne birds, possibly because they spent less time on the surface between consecutive dives. Differences between the frequency distribution of dives were apparent between the two groups. The relative frequency of dives decreased with depth; however birds at Beauchêne exhibited greater dive depth frequencies with 75% of all dives at depths between 5 - 40 m (Fig 20). Steeple Jason birds displayed higher frequency of dives between 5 - 20 m and rapidly decreasing frequency of dive depths thereafter (Fig 21.). The deepest dive of all birds at Beauchêne Island was 92 m with a mean maximum depth of 75 m. At Steeple Jason this compared to a maximum depth of 84 m and a mean maximum depth of 66 m (Fig. 19).

Brood and crèche 2010 - Steeple Jason

Birds during the brood and crèche period at Steeple Jason in the summer 2010/11 showed similarities in dive characteristics. The average dive duration (time spent underwater) was similar at 69 s and 70 s, respectively (Fig. 19). The average bottom depth of dives in the brood period was 25 m compared to 22 m in the crèche period. Birds during the brood period spent on average 6 s longer between consecutive dives than in the crèche period. This possibly accounts for the lower value of diving efficiency for this period at 0.24 compared to 0.30 in the crèche period. Birds in both periods exhibited similar diving depth frequencies with the highest number of dives less than 20m (Fig. 21 & 22).

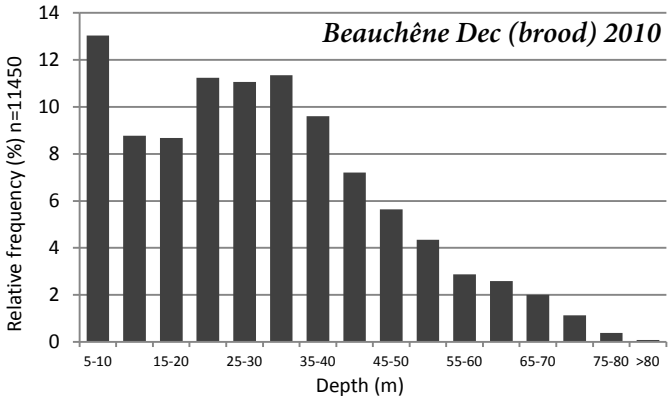


Figure 20. Frequency distribution of dive depths for foraging females.

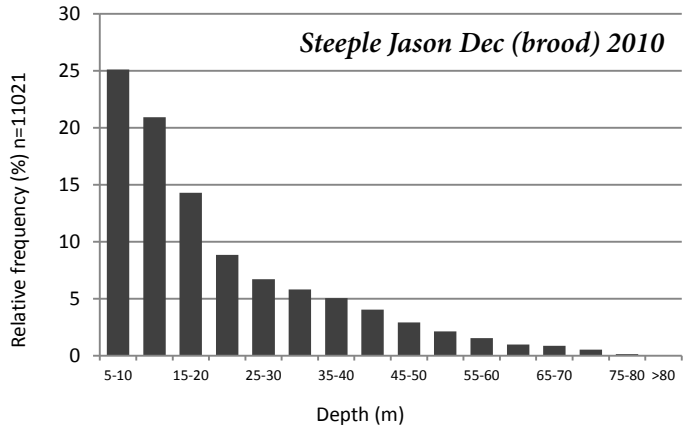


Figure 21. Frequency distribution of dive depths for foraging females.

	BCI DEC 2010	SJ DEC 2010	SJ JAN 2011	SJ DEC 2011
Number of birds	14	15	13	17
Number of individual trips	13	16	19	23
Number of dives >3m	12,273	12,360	8,761	9,252
Number of dives >5m (foraging dives)	11,450	11,021	7,972	8,473
Mean bottom time (s)	33 ± 6	23 ± 6	27 ± 9	26 ± 9
Maximum bottom time (s)	85 ± 13	73 ± 14	76 ± 10	76 ± 18
Mean dive duration (s)	85 ± 11	69 ± 10	70 ± 11	68 ± 13
Maximum dive duration (s)	136 ±10	121 ±14	131 ± 17	131 ± 17
Longest dive duration (s)	155	139	164	171
Mean bottom depth (m)	32 ± 5	25 ± 5	22 ± 5	22 ± 6
Maximum depth (m)	75 ± 11	66 ± 10	67 ± 13	73 ± 18
Deepest dive (m)	92	84	92	96
Mean time spent between dives (s)	33 ± 7	36 ± 6	30 ± 5	36 ± 14
Diving efficiency	0.30 ±0.06	0.24 ±0.05	0.30 ±0.09	0.28 ±0.08

Figure 19. Dive characteristics of female Rockhopper penguins foraging in the chick-rearing period. (Mean ± SD)

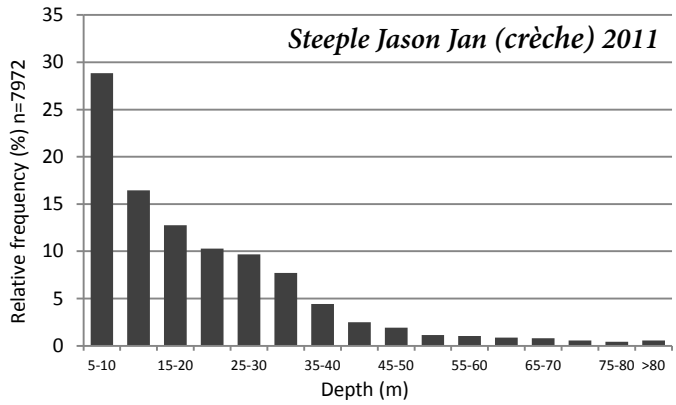


Figure 22. Frequency distribution of dive depths for foraging females.

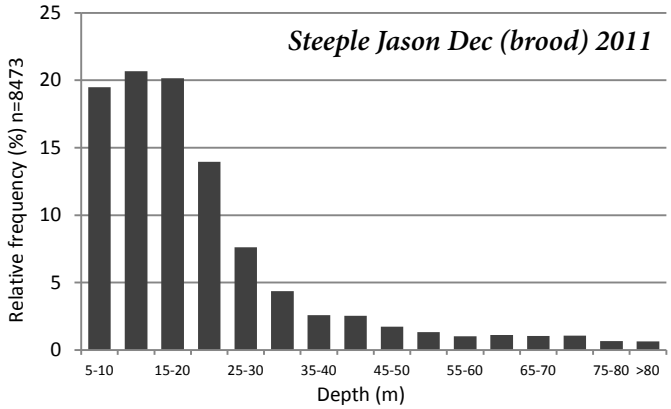


Figure 23. Frequency distribution of dive depths for foraging females.

Brood period 2010 and 2011 - Steeple Jason

The average dive durations were similar between the two years at 69 s and 68 s, as were the mean bottom depths of foraging dives at 25 m and 22 m for 2010 and 2011, respectively (Fig. 19). Diving efficiency was only slightly higher in the 2011 brood period and the average time spent between dives on the surface for both groups were similar.

The location of foraging greatly influences the diving behaviour, and although analyses are incomplete, the data indicate greater differences exist between the female foraging penguins at Beauchêne Island and Steeple Jason than between the different groups at Steeple Jason.

Differences in foraging durations, overnight periods at sea, and dive characteristics between the Beauchêne and Steeple Jason birds reflect the differences in habitats and prey availability encountered. Both sites hold significant populations of Rockhopper penguins and thus intra-specific competition may also influence their strategies, as well as competition with other surface diving seabird species in the vicinity.

Female Rockhopper penguin diet during chick-rearing period

Previous studies in the Falkland Islands (Croxall et al. 1985; Pütz et al. 2001; Clausen et al. 2002) found that Rockhopper penguins generally preyed on crustaceans and smaller proportions of fish and squid – that varied with the location, time of season and year.

Crustaceans were found to be the most dominant prey item in terms of mass and numbers at Beauchêne in December 2010. Fish, in particular *Sprattus fuegensis* (sprat) dominated the diet at Steeple Jason during the same period (Fig. 24) but there was a shift from fish to crustaceans during the crèche period. In the 2011 brood period at Steeple Jason the diet was more evenly divided between crustacean and fish and with smaller proportions of squid.

The most numerous crustacean taken was *Euphausia vallentini* - a large species of krill. The most frequent sizes taken were 20 – 22 mm (standard length) (Fig. 26). The amphipod *Themisto gaudichaudii* and the small euphausiid *Thysanoessa* sp. were generally present in lower numbers and with an average length (SL) of 15 mm.

Cephalopods were the least important prey item, in terms of mass, for both sites and all periods. Squid present in diet samples tended to be juveniles (e.g. *Gonatus antarcticus* and *Kondakovia longimana*). Estimated mantle length of *G.antarcticus* from beaks recovered showed that the majority of individuals ranged from 20 - 36 mm.

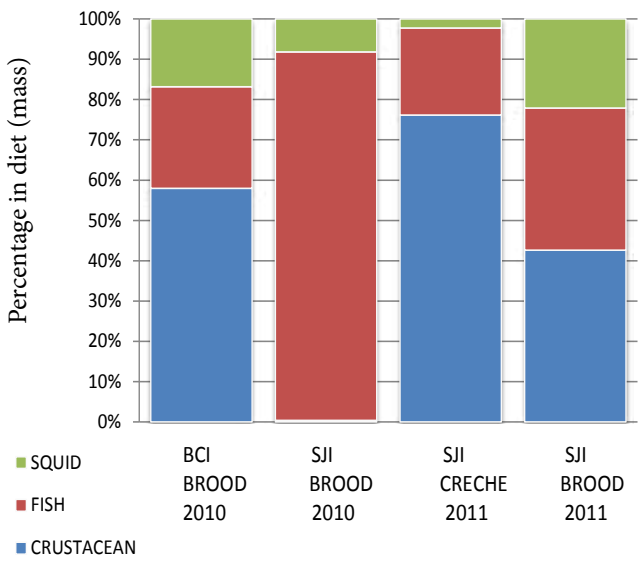


Figure 24. Reconstituted mass of prey type in diet of female Rockhopper penguins at Steeple Jason and Beauchêne.

Low numbers of the commercial squid species *Loligo gahi* were taken by the Rockhopper penguins and individuals measured an average of 7-8 cm (ML). No squid found in the diet were of any significant size or value to the commercial fishing industries in Falklands' waters.

The largest prey item taken was *S. fuegensis*. Regression calculations from fresh otoliths in the diet gave a maximum length of 21 cm (TL). Other species of fish found in the diet, but in much lower numbers, were Nototheniidae (rockcod). However, due to difficulty in identifying otoliths the exact species were unknown; most otoliths were too eroded to estimate overall length. Rockhopper penguins also preyed upon juvenile fish species, including icefish, *Champsocephalus gunnari,* and *Agonopsis chiloensis.* Whole intact (mainly 19 - 21 mm TL) individuals of *A.chiloensis* were found in several diet samples. Other otoliths were also found for unidentified fish species. It is thought these were most likely juveniles and identification is on-going. All prey items found in the diet are common species abundant within Falklands' waters; most found in shallow pelagic waters.

The only previous Rockhopper penguin diet study at Beauchêne in 1982 (Croxall et al. 1985) found crustaceans made up 79 % by numbers or 45 % by weight and juvenile squid 21 % by numbers and 53 % by mass. The diet from 2010 at Beauchêne found the most frequent prey item was crustaceans accounting for 96 % of diet by numbers or 58 % by mass. Squid accounted for 17 % by mass or 3 % by numbers and fish, which was absent in the diet in 1982, accounted for 25 % by mass. Given the lack of diet data in-between the years, the evidence suggests that some combination of inter-annual variation and opportunistic foraging is seen at both Beauchêne and Steeple Jason.

Stable isotopes

Stable isotope analysis is useful in inferring diet trends in seabirds, especially during phases of extended foraging such as the pre-winter and incubation trips. Fig. 25 show preliminary results of carbon and nitrogen ratios in blood taken from females, reflecting the diet during the chick-rearing period, and indicates some segregation amongst the locations and years. Analysis of the stable isotope data is on-going.

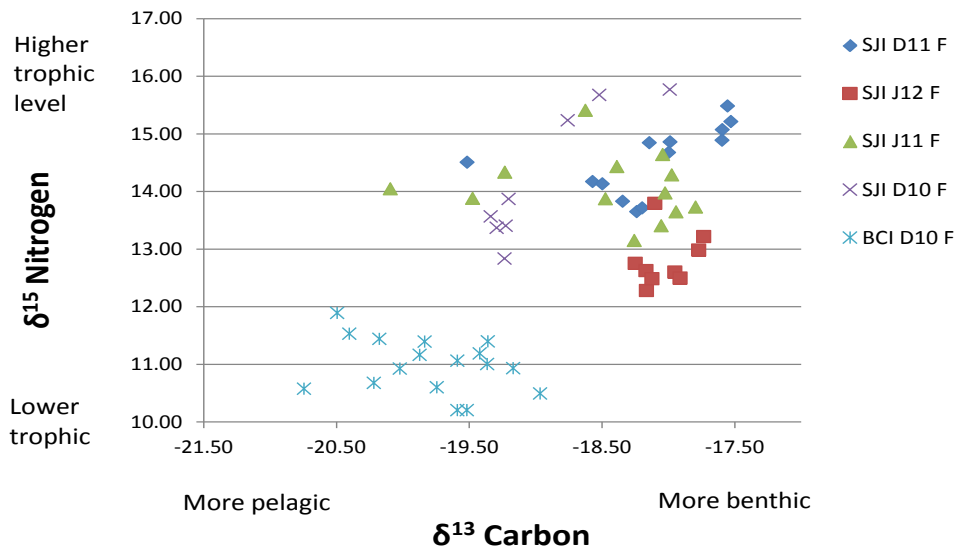
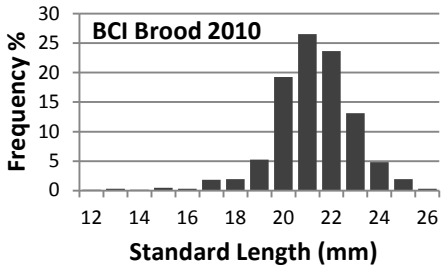
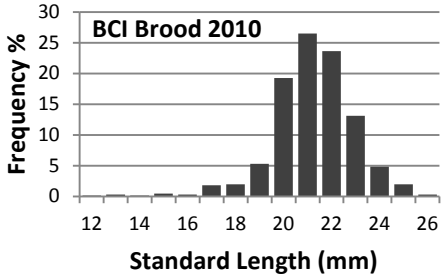


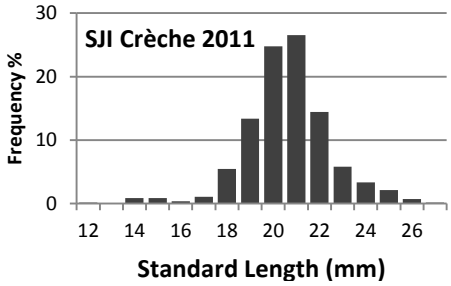
Figure 25. Stable isotopic ratios of carbon and nitrogen in blood reflecting the diet of female Rockhopper penguins during the chick-rearing periods at Steeple Jason and Beauchêne.

Figure 26: Length frequency graphs of prey items taken by female Rockhopper penguins during the chick-rearing period at Beauchêne (brood period 2010) and Steeple Jason (brood and crèche period 2010/11 and brood period in 2011).

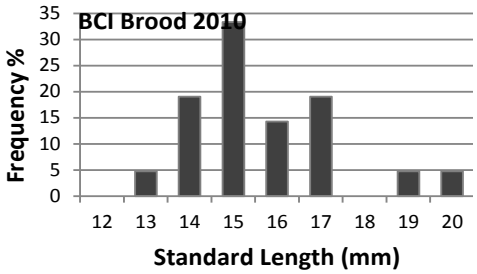
Euphausia vallentini

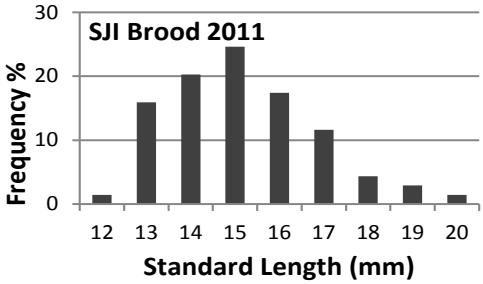






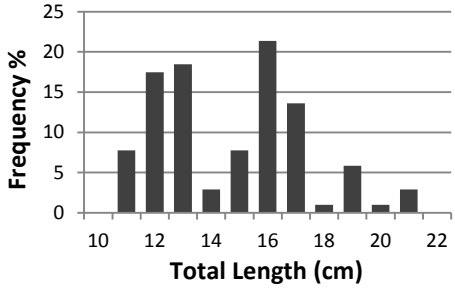
Thermisto gaudichaudii



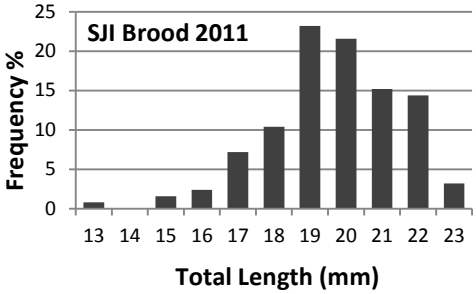


Euphausia sp.

Sprattus fuegenisus (all locations)

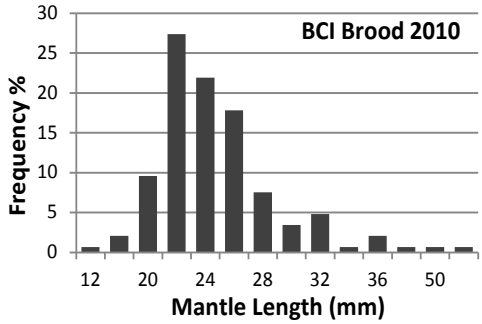


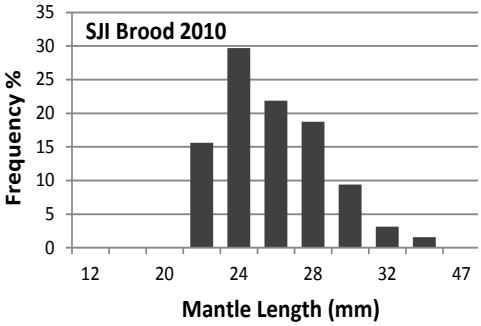
Agonopsis chiloensis

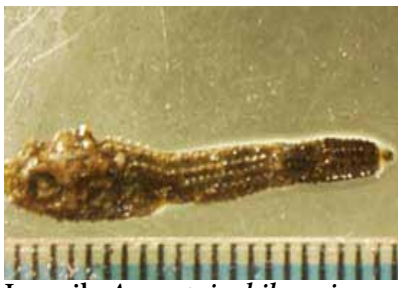


Thermisto gaudichaudii

Juvenile squid spp. (*G.antarcticus* & others)

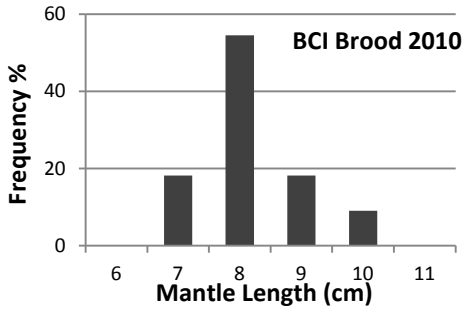


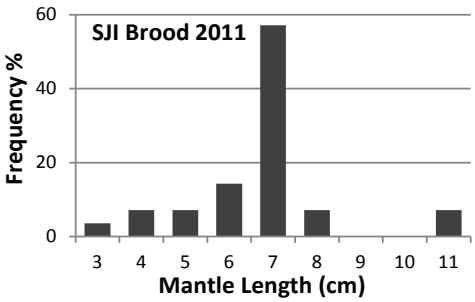




Juvenile *Agonopsis chiloensis*

Loligo gahi squid





Juvenile *Gonatus antarcticus*

Winter migration

At the end of the breeding season, with the onset of winter, food supplies become substantially reduced and Rockhopper penguins need to disperse or migrate further afield to find adequate food to maintain energy reserves over the winter. Following the adult moult in March and April Rockhopper penguins migrate away from the Falkland Islands and return again the following September - October. During these 5-6 months at sea, the penguins are capable of travelling thousands of kilometres in search of food.

The longest tracking duration was 138 days from devices on birds at Steeple Jason. The shortest periods were 16 and 29 days, both on trackers deployed at Beauchêne (Fig. 27). It is unknown why the trackers stopped working after this relatively short time as it is unlikely that the trackers fell off, or at worst that both birds succumbed to predation. The Argos service was terminated on the 09 Aug 2011 which accounts for the last 3 remaining transmitting tags being disabled at the same time. The tags that stopped transmitting before this date were due to exhausted batteries.

Tag ID	Transmitter Start	Transmitter End	Transmitter Period (days)
78022	25.03.11	09.08.11	138
78023	25.03.11	09.08.11	138
78024	21.03.11	05.04.11	16
78025	16.03.11	13.05.11	29
78026	25.03.11	09.08.11	138
78027	19.03.11	20.07.11	124
78028	25.03.11	08.07.11	106
102026	18.03.11	21.07.11	126

Figure 27. Satellite transmission dates of 8 devices attached to Rockhopper penguins.

Winter foraging areas and distances

Wintering birds from Steeple Jason travelled in a westerly direction towards the coast of South America and continued northerly on the Patagonian Shelf. Birds mainly foraged on shelf waters in 200 m or less depths and to a lesser extent on the shelf-slopes in waters over 1000 m in depths. The furthest distance from the colony was 1,250 km or latitude 39.7°S.

Birds from Beauchêne travelled in a south-easterly direction onto the Burdwood Bank. Birds either journeyed in a northerly direction meeting up with the Patagonian shelf-slope or, in the case of one bird, travelled west through the Drake Passage and below the tip of South America.

Tag ID	Study site	Maximum distance from colony (km)	Minimum Convex Polygon /Area ((km^2)	Dominant habitat
78022	SJ	950	250-300,000	Shelf
78023	SJ	630	200-250,000	Shelf
78024	BCI	400	23- 33,000	Shelf – slope
78025	BCI	890	230 -330,000	Slope
78026	SJ	1,250	380- 480,000	Shelf – slope
78027	BCI	1,400	730 - 830,000	Slope
78028	SJ	670	100 -150,000	Shelf
102026	BCI	1,400	330 - 430,000	Oceanic

Figure 28. Distance and area parameters of individual tracked Rockhopper penguins during the winter migration.

The majority of birds from Beauchêne foraged on the shelf-slope waters or deep oceanic waters. The furthest distance from the colony was 1,400 km (Fig. 28.). The combined ocean area utilised between March and August by the four wintering Rockhopper penguins from Beauchêne was approximately 1,000,000 km^2. The four Steeple Jason wintering birds utilised an ocean area approximately 675,000 km^2 over the same time period.

Individual winter foraging strategies

Several different foraging strategies were displayed by the birds (Fig. 29) from Steeple Jason (Fig. 30 a & b) and Beauchêne (Fig. 30 c & d). However, the total number of birds tracked at each location was relatively small and these maps will not represent all potential areas exploited by Rockhopper penguins during the winter migration. Additionally, foraging strategies may vary inter-annually and are likely to be influenced by the availability of resources at the time.

Winter dispersal

Foraging tracks from Steeple Jason Rockhopper penguins highlight the importance of the Patagonian Shelf, in particular around the coast of South America in the early winter periods (Fig. 31 b & c) and later farther north on the continental shelf (Fig. 31 d-f).

For Beauchêne birds, the area around the Burdwood Bank, a shallow region some 200 km south of the Falklands was highly utilised in the early winter migration (Fig. 31a). Birds dispersed through the winter months along areas of shelf-slopes and deeper oceanic waters associated with cold water currents and nutrient up-welling (Fig. 31b & c), either to the north of the Falklands, or in oceanic waters off the southern tip of Chile.

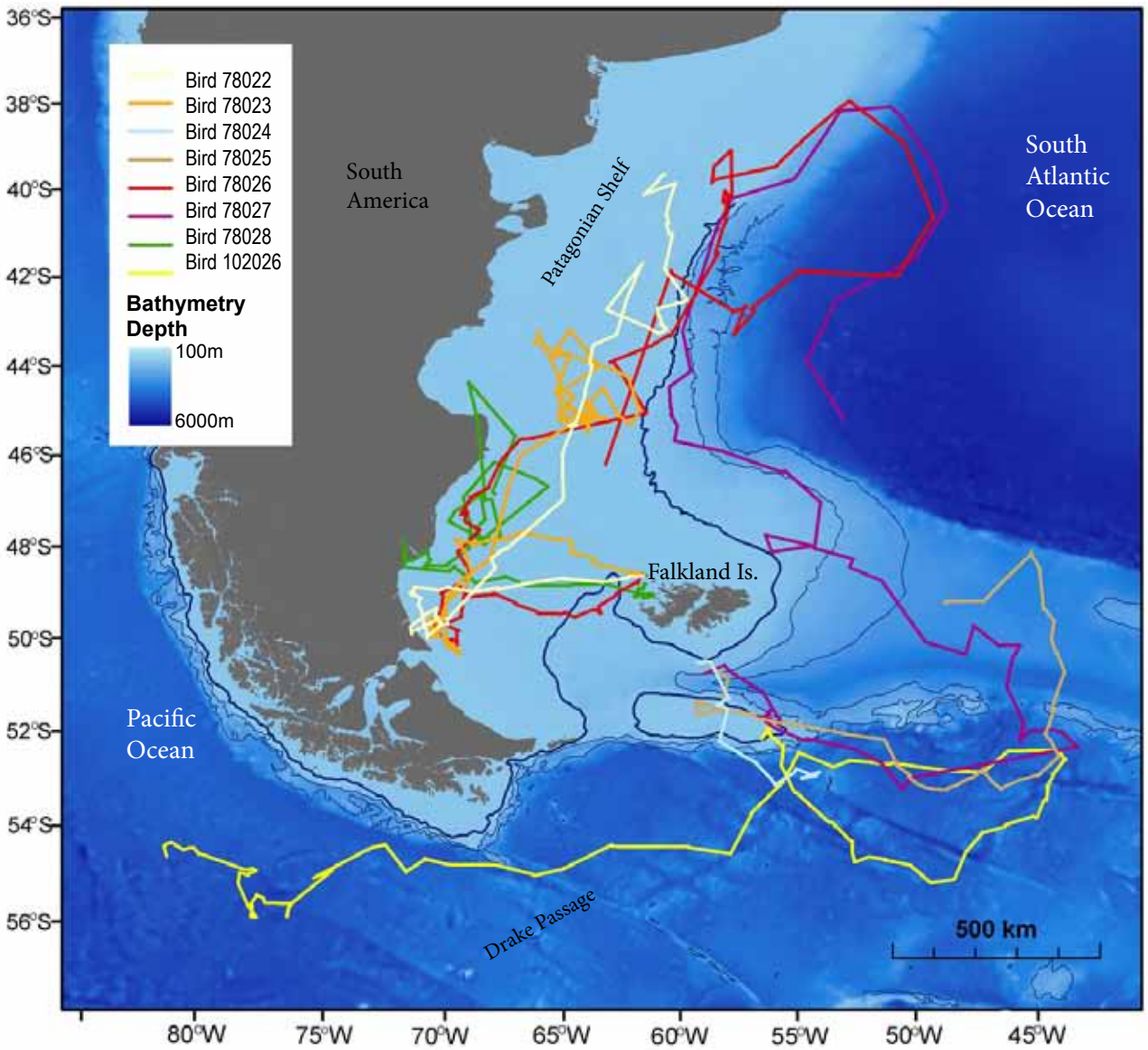
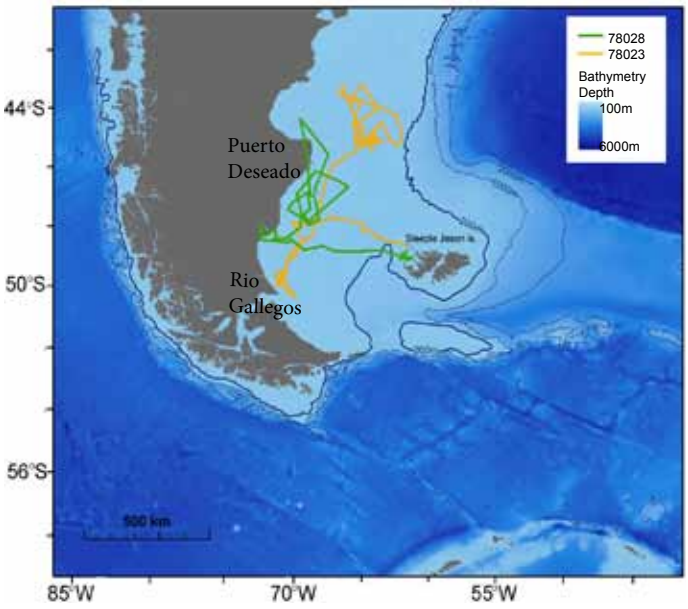


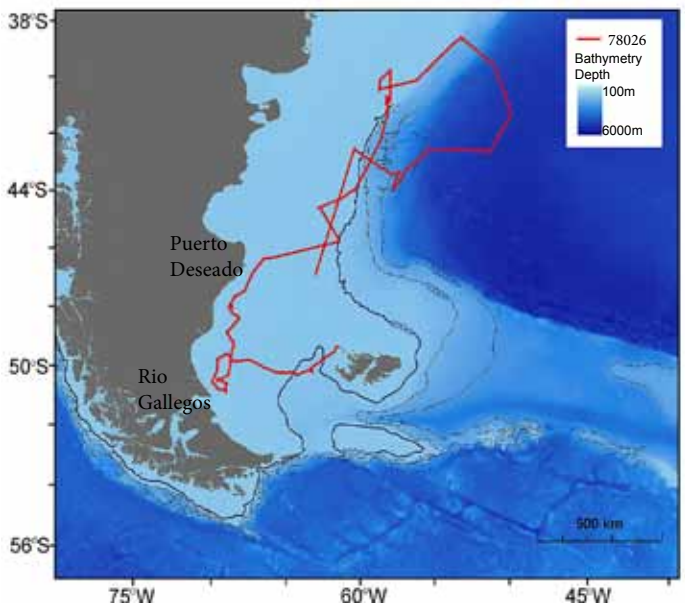
Figure 29. Individual winter migration (March - August 2011) satellite tracks of Rockhopper penguins from Steeple Jason and Beauchêne islands.

Figures 30 a - d. Individual foraging strategies of Rockhopper penguins during the winter migration.



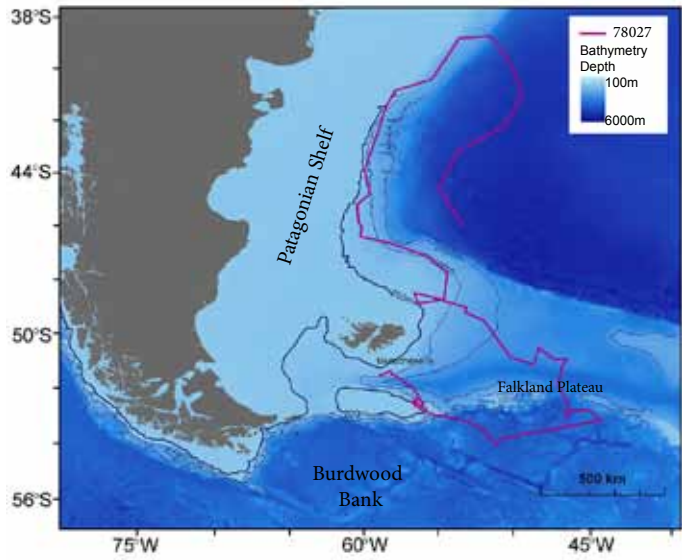
30a Steeple Jason birds - Strategy 1.

Concentrated periods along the coast between Rio Gallegos and Puerto Deseado, Argentina, with birds either remaining predominately in this region or journeying further offshore but remaining on the Patagonian Shelf. Majority of time spent on shelf waters < 200 m depth.



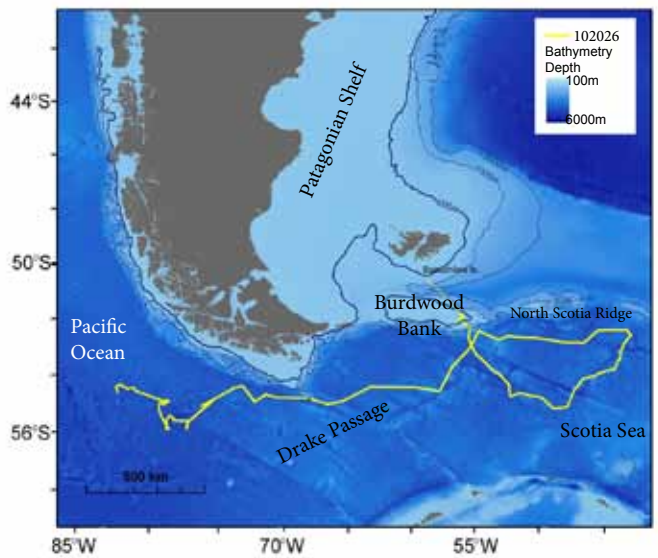
30b Steeple Jason bird - Strategy 2.

Concentrated periods along the coast of South America, travelling northwards following the coast to Puerto Deseado region, and journeying on over the Patagonian Shelf and shelf-slope to latitudes of 40 °S. Time spent on the shelf in water depths < 200 m and to a lesser extent over shelf-slope and oceanic waters > 2000 m depths.



30c Beauchêne bird - Strategy 1.

Initial concentrated period on the east Burdwood Bank travelling in an anti-clockwise loop over the Falkland Plateau to join with the Patagonian shelf-slope north of the Falklands, and following the Falkland Current northerly to latitudes of 40 °S. Majority of time spent on shelf -slopes in water depths > 200 m.



30d Beauchêne bird - Strategy 2.

Initial concentration of time on the east of Burdwood Bank, an anti-clockwise loop over oceanic waters of the Scotia Sea following the North Scotia Ridge in a westerly direction and continuing through the Drake Passage and into the Pacific region of Southern Chile. Majority of time spent in oceanic waters > 2000 m depths.

The maps below show the combined Kernel Density Estimations (KDE) of all the eight tracked birds from Steeple Jason (red) and Beauchêne (green) during consecutive months over the winter migration. Little overlap of the two populations occurred. Potentially, Beauchêne and Steeple Jason birds have more overlap with their South American counterparts, than each other.

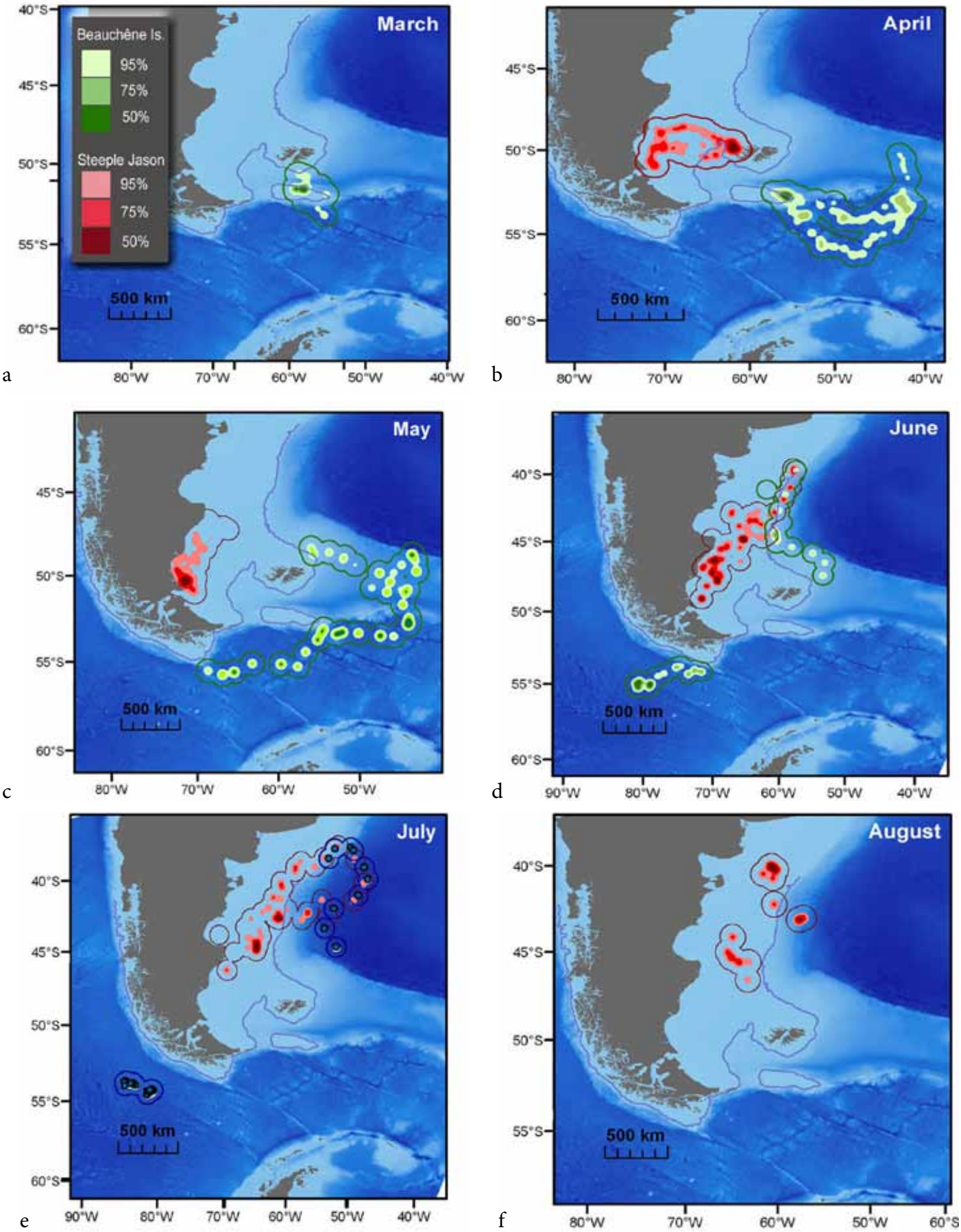


Figure 31. Kernel Density Estimations by month of wintering Rockhopper penguins.

4. Management conservation

Survival at sea in all seasons and the success of raising chicks is influenced by food availability but can also be impacted by anthropogenic activities.

The potential for seabirds to become oiled due to surface pollution is influenced by the species involved and its foraging ecology, distribution and behaviour at sea. Penguins tend to be particularly vulnerable to oiling given the amount of time they spend at the sea surface (White et al. 2001).

Tracking information from this study shows Rockhopper penguins travel over vast areas during winter migrations and are likely to encounter more numerous and diverse threats than on foraging trips during the breeding period. Fishery and hydrocarbon activities are both extensive in the south west Atlantic region and this work will help give a better idea of where potential overlaps may exist and when the most vulnerable periods for Rockhopper penguins are, as well as highlight differences in the exposure to potential threats between Steeple Jason and Beauchêne birds.

Fig. 32 indicates wintering birds from Beauchêne and Steeple Jason spend large portions of their time outside Falklands' waters and travel through other South American countries' Economic Exclusion Zones (EEZs), as well as travelling and foraging through international waters.

Fig. 33 shows the potential overlap of Rockhopper penguins with the current licenced offshore exploration areas for hydrocarbons in Falklands' waters. The results from the tracked penguins in this study indicate more potential overlap between Beauchêne birds and the southern deep water exploration areas.

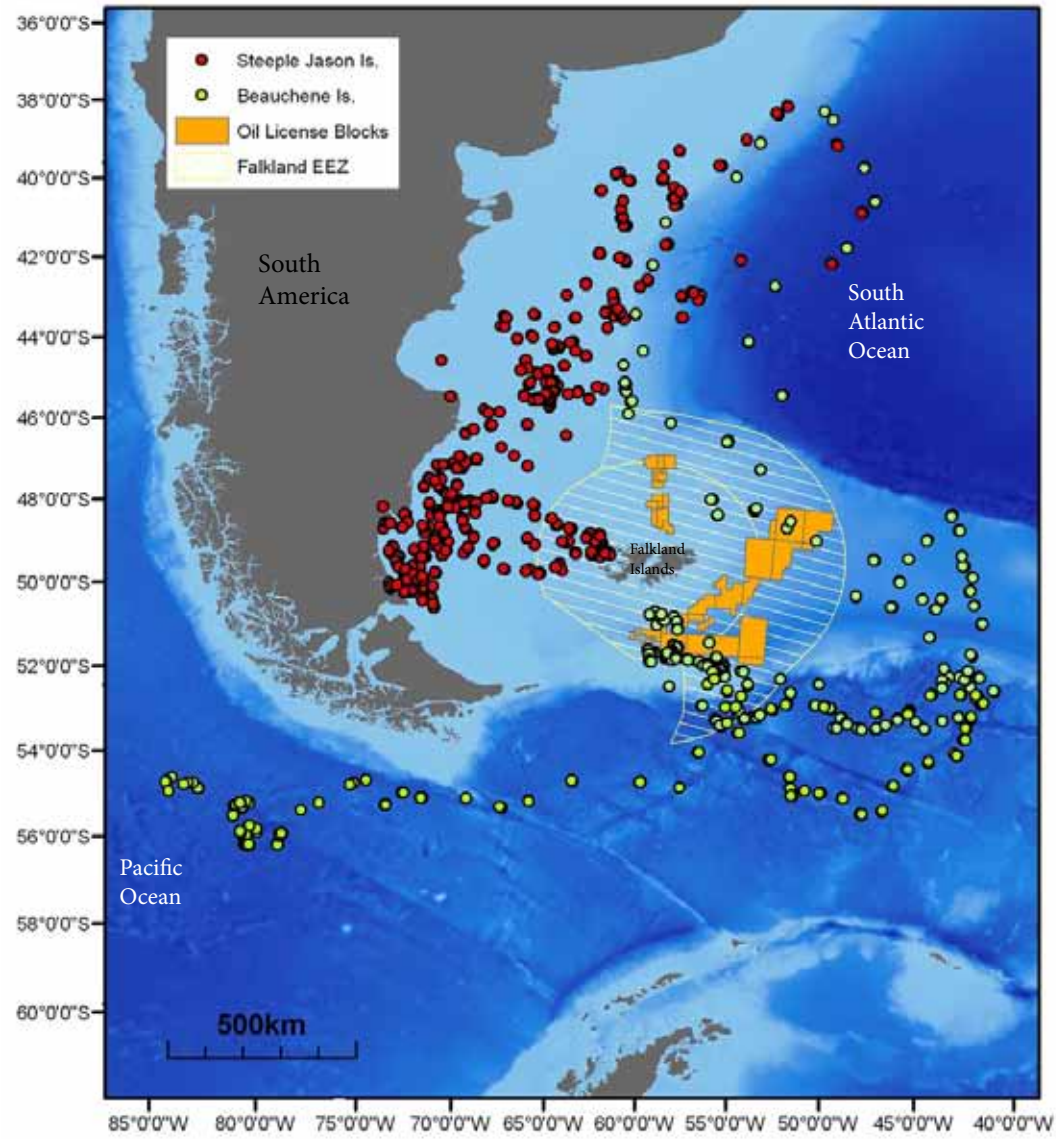
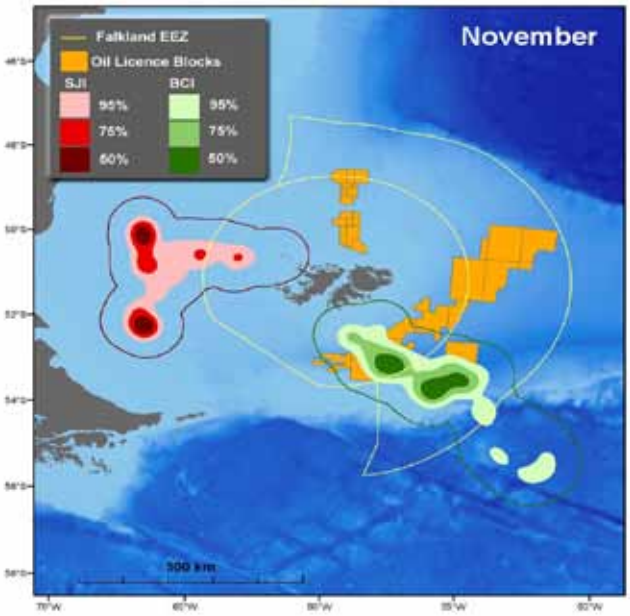
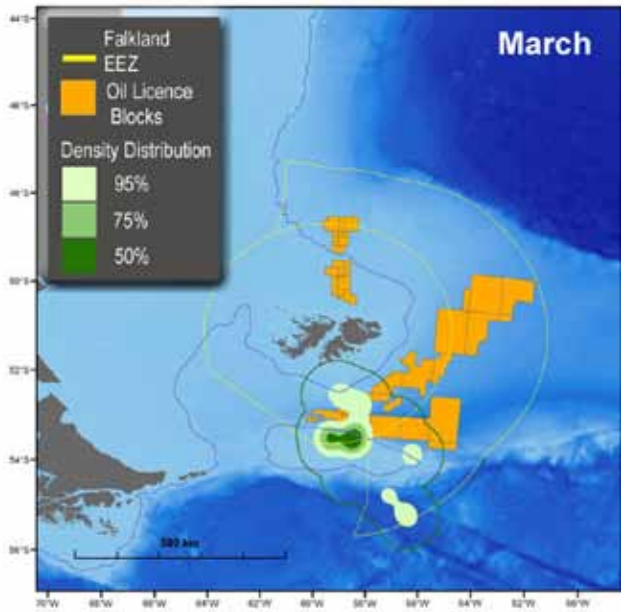


Figure 32. Locational positions of wintering Rockhopper penguins from Steeple Jason (red dots) and Beauchêne (green dots) and overlap with current licenced oil exploratory blocks in Falkland's waters.

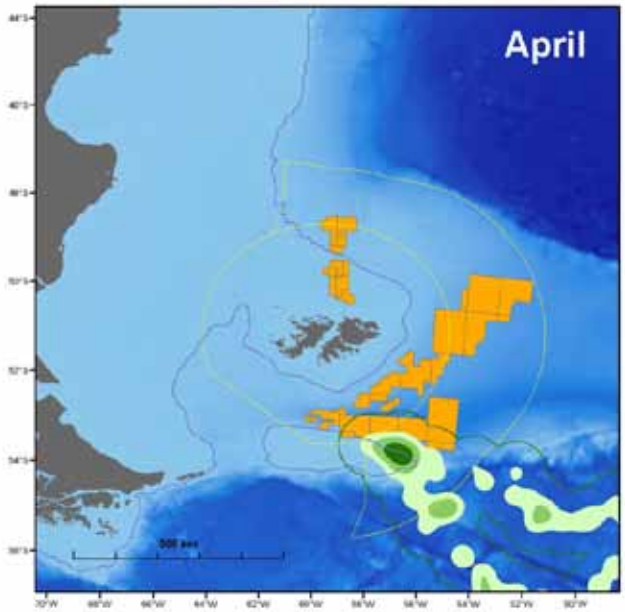
Figure 33 a - e. Kernel Density Estimations of Rockhopper penguins over (a) male incubation forage and (b - e) winter migration (both sexes) and overlap with current licenced oil exploratory areas in the Falkland's waters.



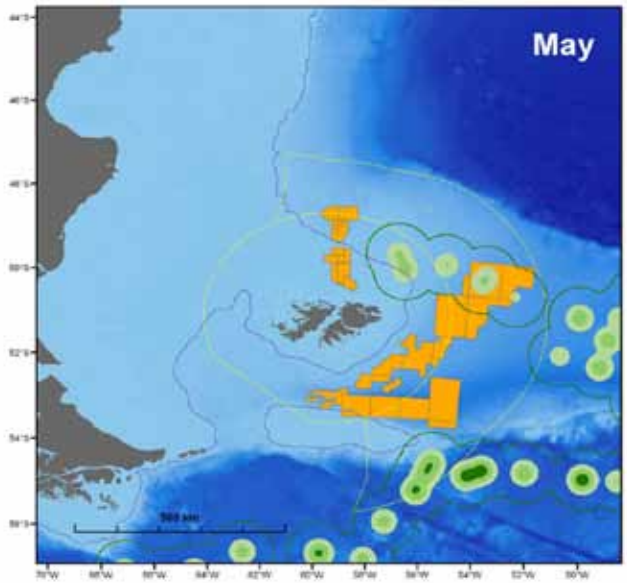
a.



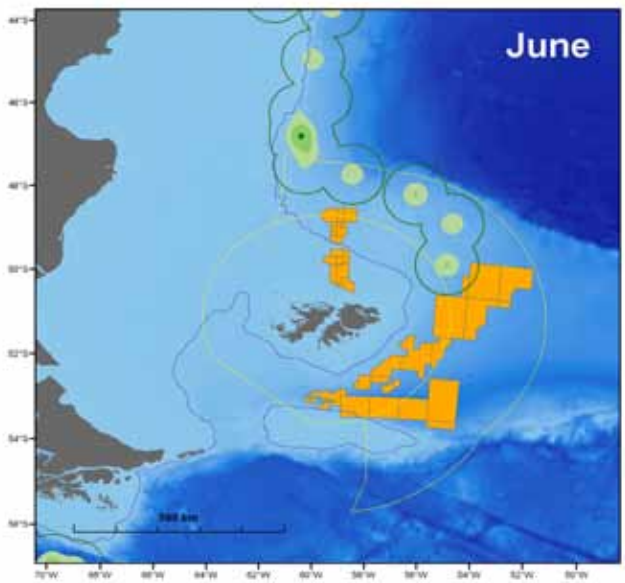
b



c



d



e

The birds tracked from Steeple Jason in this study showed little or no overlap with exploration areas in the northern Falkland waters. The months when most overlap occurred between individuals tracked at Beauchêne and exploration areas was November during the male incubation foraging period and, for both sexes, March-April during the early part of the winter migration.

Caution should be applied when interpreting this information as it is based only on a handful of individual birds and over a relatively short time frame. It does not necessarily represent the movement and distribution of the whole population from Steeple Jason or Beauchêne or the potential extent of overlap. However, it does provide data which otherwise was unknown and forms a foundation for developing improved guidance for relevant management decisions.

Part of the Rockhopper project was to involve the community of the Falkland Islands. We held presentations and discussions at the local Farmers' Week in Stanley, with British Forces Military Conservation Group and local FC members. The Infant & Junior School raised money towards a satellite device and learnt how they worked and where the Rockhopper penguins carrying them were going in the winter. The FC junior Watch Group members raised money through a sponsored walk for Rockhopper penguins and participated in activities about "what penguins eat and where they go".

The project could not have been completed without the many volunteers, boat skippers and field assistants. In addition, we had great support and help from sea-bird experts - all to whom we are extremely grateful. Photos clockwise from top left: Dr Anton Wolfaardt and his wife Leigh-Anne gave their time to help at Beauchêne in Dec 2010. Dr Mark Bolton and Andy Stanbury (RSPB) helped out at Steeple Jason in 2009. Leif Poncet, skipper of Peregrine, sailing us through choppy waters to Beauchêne. Dr James Robinson (head of RPSB Northern Island) and his wife Lorraine Chivers assisted during their sabbatical in Dec 2011 at Steeple Jason. Dr Alastair Baylis of FC was pivotal to the project and Dr Norman Ratcliffe from British Antarctic Survey, who has given his time to help and advise on data analysis, with Sarah at Beauchêne in March 2011; and finally the penguins themselves for their un-obliging co-operation.

N. Ratcliffe

Roy Smith

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Photos: All photos in the report belong to Sarah Crofts unless otherwise noted.

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