2010 ARCHIPELAGO-WIDE CENSUS

GENTOO AND ROCKHOPPER PENGUINS

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Contents

EXECUTIVE SUMMARY

Gentoo Penguin

- The number of Gentoo Penguin breeding pairs doubled when compared with the number counted during the last archipelago-wide census in 2005.
- The Falkland Islands population is now estimated to be 132,321 breeding pairs, the largest number reported since the first estimate was generated in 1933. The Falkland Islands is likely to be the largest component of the global population.
- Gentoo Penguin populations typically show substantial inter-annual variation in breeding numbers. Inter-annual variability probably reflects adult birds skipping a breeding season, deferred breeding and lower recruitment related to years of reduced food availability or other environmental perturbations. This makes detecting systematic changes in population numbers difficult.

Rockhopper Penguin

- The number of Rockhopper Penguin breeding pairs increased by 50.6% when compared with the number counted during the last archipelago-wide census in 2005.
- The Falkland Islands population is now estimated to be is 319,163 ± 18,503breeding pairs. With this revised population estimate, the global population of the subspecies *E. c. chrysocome* is now closer to 870,000 breeding pairs of which the Falklands population accounts for approximately 36 % (second largest population after Chile).
- The Falkland Islands population appears to be stable rather than in further decline. However there is still no evidence of recovery to 1930's levels.

GENERAL INTRODUCTION

A number of Falkland Islands seabird populations are of global importance both numerically, and in terms of conservation status. For example, the Falklands are home to 70 % of the world's population of Black-browed albatross (approx 400,000 breeding pairs and listed as 'Endangered' under the IUCN Red List), and approximately 29 % of the world's population of southern Rockhopper Penguins (approx 211,000 breeding pairs and listed as 'Vulnerable' under the IUCN Red List). Accordingly, fluctuations in local populations impact the global conservation status of these species.

In light of resource development, Falklands Conservation initiated the Falkland Islands Seabird Monitoring Programme (FISMP) in 1989/90. The FISMP involves the annual census of selected seabird breeding colonies but also includes an archipelago-wide census conducted at 5-yearly intervals since 1995 (i.e. 1995, 2000, 2005). The purpose of the FISMP is to understand the population trends of key seabird species breeding at the Falkland Islands in order to support informed conservation initiatives and guide policy. The purpose of the archipelago-wide census is to ensure fluctuations at selected annually monitored breeding colonies are representative of changes for the Falkland Islands population as a whole. The FISMP and archipelago-wide census also aim to engage, educate and involve the local community. Regular monitoring of Falklands seabird populations has contributed to the identification of regional and global conservation priorities and provides information necessary for IUCN listing.

This report details the findings of the fourth archipelago-wide census. Specifically, we review the 2010 population estimates for Gentoo and Rockhopper Penguins breeding at the Falklands Islands.

GENTOO PENGUINS

Baylis, A.M.M, Crofts, S. & Wolfaardt, A.C. (in press) The world's largest Gentoo Penguin population? The current status of the population breeding at the Falkland Islands. *Marine Ornithology*

SUMMARY

- It was estimated that 132,321 ± 2,015 pairs of Gentoo Penguins were incubating eggs in 2010, the largest reported estimate since the first survey in 1933.
- Based on the 2010 census of the Falkland Islands' population, the estimated size of the global Gentoo Penguin population is about 384,000 breeding pairs, of which the Falkland Islands accounts for 34%, probably the largest component of the global population.
- In the Falkland Islands, annually monitored breeding colonies (20 % of the total breeding population) proved to be a reliable proxy for archipelago-wide changes in the number of breeding pairs.
- Inter-annual trends at annually monitored breeding colonies and archipelago-wide results suggest that the Falkland Islands breeding population has increased in the last decade. However annual monitoring data also revealed large inter-annual variability in the number of breeding pairs at the Falkland Islands which compounds the difficulty in assessing systematic population changes from five-yearly archipelago-wide censuses.

INTRODUCTION

Gentoo Penguins are one of the most widely distributed penguin species, ranging from 46 - 65° S (Woehler 1993). The global population has been conservatively estimated to be about 317,000 breeding pairs, two-thirds of which breed on the sub-Antarctic islands of South Georgia, Kerguelen and the temperate Falkland Islands (Woehler 1993, Ellis *et al.* 1998). The remainder is confined to the Antarctic Peninsula and associated islands (Woehler 1993). Although populations in the Antarctic are increasing (e.g. Lynch *et al.* 2008) some populations in the sub-Antarctic have declined, though short term population fluctuations make it difficult to assess accurately population trends (Jouventin & Weimerskirch 1990, Woehler & Croxall 1997, Woehler *et al.* 2001, Crawford *et al.* 2003, Lescroël and Bost 2006). Because some of the largest Gentoo Penguin breeding populations have apparently declined, the species is currently listed as 'Near Threatened' on the IUCN Red List (BirdLife International, 2011). Long term monitoring, particularly at the largest breeding populations, is therefore an important conservation action because changes in the largest breeding populations will influence the global conservation status of the species.

The Falkland Islands supports one of the largest Gentoo Penguin populations in the world (Huin 2006, Pistorius *et al.* 2010). Since 1990 annual counts at selected breeding colonies have been undertaken to monitor trends in the number of breeding pairs and breeding success. In addition to annual monitoring, since 1995 archipelago-wide censuses have been undertaken at five-yearly intervals (i.e. 1995, 2000, 2005). The aim of the archipelago-wide censuses is to assess whether fluctuations at the annually monitored breeding colonies are representative of changes for the Falkland Islands population as a whole. In this paper we present the results of the 2010 Falkland Islands archipelago-wide census. We assess (i) the current status of the Falkland Islands population of Gentoo Penguins and (ii) whether archipelago-wide patterns in population trends reflect trends at annually monitored breeding colonies.

METHODS

The Falkland Islands are located approximately 600 km east of mainland South America, in the southwest region of the Atlantic Ocean between 51 - 53°S and 57 - 62°W (Fig. 1). In 2010, the fourth archipelago-wide census was conducted from the 24 October to 8 December 2010. Gentoo Penguins have a high degree of breeding synchronicity (Williams 1990) and egg laying at the Falkland Islands is usually completed by late October (Otley *et al.* 2005). The census is timed to take place during the incubation period.

Due to logistical constraints, the census was conducted over an extended period and it is probable that some breeding pairs had failed prior to counting. Although correction factors are not available for the Falkland Islands, Croxall and Rothery (1995) report an average of 4% of breeding pairs failed before egg laying was completed at South Georgia. Overall, therefore, our count may underestimate true values by a small amount; however, the earlier archipelago-wide censuses were conducted over similar time spans (e.g. 24 October – 15 December 1995 and 2 November – 30 November 2005) so the 2010 results should be consistent with previous results

Consistent with methods used in the previous three censuses, the number of breeding pairs at each colony was counted with the aid of a tally counter while scanning from outside the colonies. At least three direct counts of nests occupied by adults were made by a minimum of two observers. In some cases large colonies were photographed from vantage points, and breeding pairs subsequently counted electronically. Counts were repeated if they varied by more than 5% and were averaged once within this range (Thompson and Riddy 1993). Trends in the number of breeding pairs (i.e. the breeding population) are regarded as an index of Gentoo Penguin population size and are the only practical means available to estimate patterns of relative population abundance.

The significance of population changes between archipelago-wide censuses was tested using the equation:

$$d = \frac{\mathrm{N1} - \mathrm{N2}}{\sqrt{\mathrm{V[N1]} + \mathrm{V[N2]}}}$$

Where N = total number of Penguin breeding pairs for year x and V = total variance for year x. $P = 0.05$ when $d = 1.96$.

Annual monitoring at selected breeding colonies followed the same methods as those used to count breeding colonies during the archipelago-wide census. From 1990 - 2010 between two and 17 Gentoo Penguin breeding colonies have been monitored each year, with a total of 18 different colonies monitored. The selection of annually monitored breeding colonies reflects a compromise between accessibility, size and the spatial distribution of breeding colonies. Since 2003, annual counts have been undertaken at the same 15 colonies (Fig. 1). To explore the non-linear population trends at annually monitored breeding colonies (2003 – 2010) we used a Generalized Additive Model (GAM) with a Poisson error structure and log link function (Fewster *et al.* 2000, Delord *et al.* 2004) implemented using the mgcv package in R (v2.13.1, R Development Core Team 2011). These 15 annually monitored breeding colonies account for 16.8 % of the estimate of 65,860 breeding pairs at the time of the last archipelago-wide census in 2005 (Huin 2006).

To assess how accurately changes in annually monitored breeding colonies reflected total archipelago-wide changes, the percent change in the number of Gentoo Penguin breeding pairs between each archipelago-wide census were calculated and then compared with the percentage change in breeding pairs from the 15 annually monitored breeding colonies for the same years (1995, 2000, 2005 and 2010). Normality was tested using Kolmogorov–Smirnov Tests and subsequently non-parametric Mann–Whitney-U-tests were used due to non-normal distributions. If variances were unequal, data was first ranked and significance tested using the unequal variance *t*-test (Ruxton 2006). Significance was assumed at $P < 0.05$. All values are presented as ± 95 % CI unless otherwise stated.

RESULTS

A total of 126,367 ± 1,995 breeding pairs were counted at 79 colonies in the 2010 archipelago-wide census. We were unable to access five Gentoo Penguin breeding colonies. In 2005, there were 5,954 ± 298 breeding pairs estimated at these five breeding colonies. Assuming that the five missed breeding colonies remained stable (or increased) between 2005 – 2010m the conservative estimate for the Falkland Islands population is 132,321 ± 2,015 breeding pairs. This is not an unreasonable assumption given the minimum increase across annually monitored breeding colonies was 32 % between 2005 – 2010 and the average increase across all breeding colonies (including annually monitored breeding colonies) was 107 ± 84 %. If the five missed breeding colonies increased by an average of 107 %, then the estimate for the missed breeding colonies would be 12,325 breeding pairs, or a total population of 138,692 breeding pairs. Due to large variability in the extent and direction of population changes between breeding colonies at five-year intervals (Table 1), and the associated inaccuracy of interpolating from the 2005 figures, we use the conservative population estimate of 132,321 breeding pairs for further analyses.

The conservative 2010 population estimate represents an increase of 101% when compared with the number of Gentoo Penguin breeding pairs counted during the 2005 archipelago-wide census (65,860 ± 1,052, annual intrinsic growth rate of 6.1 %). Similarly, the 2010 population estimate was 105% larger than the 1995 population estimate (64,430 ± 923) (Fig. 2) and 16.5% larger than the 2000 estimate (113,570 ± 1,578 breeding pairs; $d = 58.7$, $P < 0.01$; Fig.1). The increase in breeding numbers over the last decade, and especially over the last five years, is consistent with the results of the GAM that revealed a positive trend across annually monitored breeding colonies between 2003 – 2010 (proportion of deviance explain was 93.9 %, $R^2 = 0.64$, $df = 6$, $P < 0.01$) (Fig. 3). The number of breeding pairs counted at annually monitored colonies were however highly variable between years (Fig. 2). For example breeding pairs declined by 30 % between 2008 – 2009, followed by a 67 % increase between 2009 and 2010 (Fig. 2).

In 2010, annually monitored breeding colonies accounted for 20 % of the total Gentoo Penguin population at the Falkland Islands. Trends in annually monitored breeding colonies broadly reflected archipelago-wide population changes (Fig. 2, Table 2). However, estimates of population change differed by as much as 39 percentage points when comparing the change in total number of breeding pairs between annually monitored breeding colonies and the archipelago-wide census (Table 2).

DISCUSSION

The conservative 2010 estimate of Gentoo Penguins breeding at the Falkland Islands is 132,321 breeding pairs. The 2010 results equate to the largest breeding population estimate on record, surpassing the estimate of 116,000 breeding pairs in 1932 (Bennett 1933). In 2005, the Falkland Islands Gentoo Penguin population was estimated to account for about 21% of the world population (Pistorius *et al.* 2010). Based on the 2010 archipelago-wide census the conservative global population is now about 384,000 breeding pairs. The Falkland Islands accounts for 34 % of the global population estimate and is probably the largest population of Gentoo Penguins in the world, followed by South Georgia with 105,000 breeding pairs (Clarke *et al.* in press) and Iles Kerguelen with about 35,000 breeding pairs (Woehler 1993).

Our study confirms that the current subset of annually monitored breeding colonies provides a good proxy for archipelago-wide population changes (also see Pistorius *et al.* 2010), despite the geographical bias in the location of annually monitored breeding colonies (only one West Falklands breeding colony currently monitored annually). Importantly, monitoring breeding colonies annually also provides the capacity to detect and better understand Gentoo Penguin population variability over both short and long time-scales and thus affords a more informed assessment of population trends over time (e.g. Baylis *et al.* 2011). Trends from annually monitored breeding colonies between 2003 and 2010 were consistent with archipelago-wide results and indicate the Falkland Islands Gentoo Penguin breeding population has increased over the past decade. However results from annually monitored breeding colonies reveal large inter-annual fluctuations in the number of breeding pairs, as is evident across many breeding locations (e.g. South Georgia) (Croxall et al. 1988, Croxall & Williams 1991, Woehler and Croxall 1997). Short term population fluctuations complicate the detection of long term population trends and therefore the degree of the population increase remains unclear.

Indeed substantial temporal variability in the number of Gentoo Penguin breeding pairs at the Falkland Islands has resulted in a wide range of population estimates and uncertainty regarding population trajectories (Bingham 1998; Pütz *et al.* 2001; Clausen and Huin 2003; Pistorius *et al.* 2010). Similarly we report a doubling in the number of breeding pairs between the 2005 and 2010 archipelago-wide censuses. However, our results are unlikely to represent a doubling of the Falkland Islands breeding population because the proportion of the population counted between censuses is unlikely to have been the same (Link and Sauer 1998). While large population changes over short temporal scales have been reported in other penguin species (e.g. Woehler *et al.* 2001), the large inter-annual changes in the number of Gentoo Penguins breeding at the Falkland Islands highlights that the archipelago-wide population estimate could vary by over 60 % from one year to the next (e.g. 30% decline at annually monitored breeding colonies between 2008 and 2009 followed by a 67 % increase between 2009 and 2010). Although the primary purpose of the archipelago-wide census at the Falkland Islands is to validate whether annually monitored breeding colonies are a good representation of archipelago-wide population changes, differences in the number of Gentoo Penguin breeding pairs between consecutive archipelago-wide censuses can be misinterpreted as population changes. Our results highlight that estimates of the breeding population derived from the five-yearly archipelago censuses alone are misleading, and highlight the importance of implementing a long-term Gentoo Penguin monitoring programme on an annual basis.

A number of factors have been suggested to influence the temporal variability in the number of breeding pairs at the Falkland Islands. These include egg collection, competition with commercial fisheries and disease (i.e. factors related to penguin survival, a key demographic parameter that contributes to population change) (Woods and Woods 1997, Bingham 1998, Pütz *et al.* 2001). Most recently, the 2005 decline in the number of Gentoo Penguin breeding pairs counted during the archipelago-wide census was attributed to adult mortality associated with a 2002 harmful algal bloom event (Pistorius *et al.* 2010). However the limited data available suggests that only selected breeding colonies were affected by the harmful algal bloom (Uhart *et al.* 2004), implying other factors should also be considered when assessing archipelago-wide population trends. In particular, the proportion of the breeding population abstaining from breeding in particular year is thought to contribute to inter-annual variability in the number of Gentoo Penguins breeding at South Georgia, mediated at least in-part by environmental variability acting on prey availability (Croxall et al. 1988, Croxall & Williams 1991, Croxall and Rothery 1995, Trathan *et al.* 2006). For example, Williams (1990) reported significant inter-annual variation over a four year study in the number of marked Gentoo Penguins returning to breed in subsequent years (range 20 – 80 %). Croxall and Rothery (1995) demonstrated that adult penguins skipping one or more breeding seasons in combination with immigration could account for much of the variability in the number of Gentoo Penguins breeding during their study period (1978 – 1992). Therefore large inter-annual variation in the number of breeding pairs at the Falkland Islands may also reflect adult birds skipping one or more breeding seasons, immigration, pulses in recruitment, or a combination of these factors (in addition to the factors highlighted above). To test this hypothesis we would need to account for the proportion of the total adult Gentoo Penguin population that breeds in a particular year. Although this would provide a more accurate measure of population change, this ratio is not known for the Falkland Islands.

Ideally a demographic study that assesses breeding frequency and recruitment should be integrated into future population studies as this will aid in the interpretation of changes in the breeding population. While the use of flipper bands may not be appropriate (Saraux *et al.* 2011), transponders (e.g. Gendner *et al.* 2005) may be feasible at selected breeding colonies where Gentoo Penguins travel along a defined pathway to access the breeding colony. Future population studies could also address the geographic bias in the location of annually monitored breeding colonies by including additional breeding colonies on West Falklands.

Table 1: The number of Gentoo Penguin breeding pairs counted at breeding colonies around the Falkland Islands during the 1995 – 2010 archipelago-wide censuses.

Total Gentoo Penguin breeding pairs		**132,321** ± 2,015	**65,857** ± 953	**113,571** ± 1,578	**64,426** ± 1,052
	% change	**2010**	**2005**	**2000**	**1995**
Islands					
Barren Island	251	1925	548	1353	326
Beauchêne Island	75	681	390	749	490
Beaver Island	107	1025	495	2842	892
Bleaker Island	70	2025	1189	1265	875
Carcass Island	376	571	120	610	180
Fourth Passage Island		3190	*300*	*300*	*300*
Grand Jason Island	226	5334	1636	5226	2196
Great Island	83	586	320	451	490
Keppel Island	198	2429	816	1248	560
Lively Island	12	475	424	652	490
New Island	171	4431	1637	6668	5100
Pebble Island	191	6996	2408	1669	754
Saunders Island	94	10358	5327	6679	3510
Sea Lion Island	125	3827	1701	2813	1484
Speedwell Island	150	5513	2209	2335	2229
Steeple Jason Island	151	5812	2319	7079	3923
Weddell Island	266	2802	765	2300	1220
East Falklands					
Ajax Bay	15	129	112	1	14
Bertha'sBeach	150	568	227	216	310
Bluff Cove	51	1390	921	959	850
Brazo del Mar	174	2174	792	495	357
Bull Point	118	3815	1750	4784	2794
Cape Dolphin	93	2583	1338	1447	1148
Concordia	115	2497	1162	1274	701
Cow Bay	152	1599	634	277	117
Egg Harbour	234	274	82	0	7
Elephant Beach (little creek)	158	451	175	261	304
Fanning Harbour	32	252	191	102	160
Fox Point	38	569	412	226	378
Kidney Cove	44	1227	850	1625	1730
Salthouse	16	185	159	65	110
Lion Point + limpet creek	148	4132	1664	1182	585
Long Island	68	146	87	137	176
Lorenzo Pond	90	1368	721	723	0
LowBay	48	592	400	456	330
Moffit Harbour	161	167	64	47	130
Moss Side	221	1420	442	443	379
Motley Point	172	2121	780	743	800

Murdos Cave	118	286	131	110	137
New Haven	59	824	518	472	400
Paloma Beach	113	1221	572	540	601
Pleasant Roads	64	69	42	54	123
Port King	44	758	527	354	208
Rookery Point	44	280	195	73	300
Rookery Sands	143	1589	654	325	249
Sand Hills	-100	0	203	249	330
Swan Pond	126	332	147	170	0
Toggle Point	55	65	42	52	44
Volunteer Point	142	3529	1458	1091	970
West Falklands					
Albemarle	-78	171	763	4002	2626
Big Seal Rookery		245	0	3137	716
Cape Orford	0	0	0	2157	311
Dunnose Head	48	211	143	87	0
Fox Bay East	-100	0	80	2574	534
Fox Bay West	48	1107	748	1435	855
Fox Point	140	800	334	1566	751
Gladstone Valley	38	534	386	317	410
Gladys Cove		0	74	0	0
Grave Cove	59	7029	4422	4640	1434
Hope/Bramble Point	91	1119	585	1110	654
Hoste Inlet	0	0	0	0	66
Leopard Bay	52	1190	784	46	270
Little Mountain	30	614	473	278	375
Long Point	24	497	402	279	52
Lucas peninsula	317	1160	278	2390	1457
Narrows	51	1848	1220	1906	1257
North Beach (in Narrows)			*75*	*153*	*103*
Port Edgar	0	0	0	1830	1408
Port North	-1	676	683	1291	705
Port Richards	19	793	664	1246	830
Queen Point	45	645	445	1001	832
Rodeo Point	294	945	240	743	120
Shag Cove	103	343	169	65	16
Stephens Peak	219	6011	1885	1659	894
Stevelly Bay	60	2745	1721	1614	1071
Ten Shilling Bay	-27	102	140	2432	342
Town Point (in Narrows)			*737*	*701*	*416*
Whaler bay	-8	2962	3207	2431	1000
Not counted			**2005**	**2000**	**1995**
Shallow Bluff			1705	2268	1737
Carcass Bay			1357	4219	2039
Hill Gap			315	1387	728
Swan pond (seal bay)			1627	1519	875
Sparrow Cove (minefield)			950	750	300

Table 2. Percentage change in Gentoo Penguin breeding numbers between1995 - 2010. Values were calculated for five-yearly archipelago-wide censuses and for a subset of 15 annually monitored breeding colonies (for corresponding years only). Results are presented as percent change in the total number of breeding pairs and percent change calculated from the average number of breeding pairs (values are ± standard deviation).

	Five year change (%): total number of breeding pairs		**Five year change (%): average number of breeding pairs**		
Year	Archipelago-wide	Annually monitored breeding colonies	Archipelago-wide *(excluding annually monitored breeding colonies)*	Annually monitored breeding colonies	Significance (unequal variances *t*-test and Mann–Whitney-U-tests)
1995-2000	76.3	50.4	101 ± 150	36 ± 67	$t = -1.7$, $df = 23.7$, $P = 0.08$
2000-2005	-42.0	-42.3	8 ± 212	15 ± 63	$U = 371$, $Z = -1.6$, $P = 0.10$
2005-2010	100.9	140.1	111 ± 87	124 ± 58	$U = 341$, $Z = -1.0$, $P = 0.30$

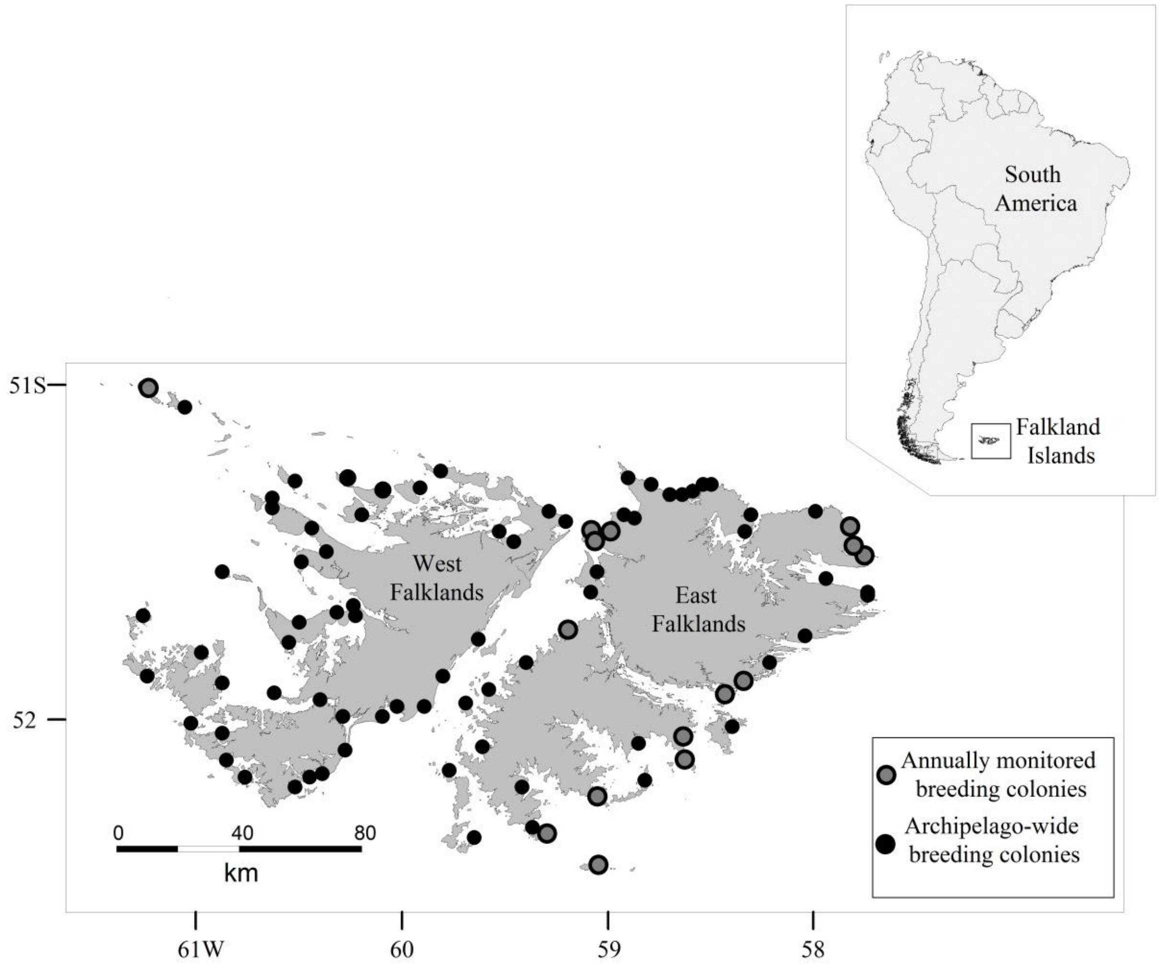

Fig. 1. Location of Gentoo Penguin breeding colonies at the Falkland Islands, including breeding colonies that are currently monitored annually.

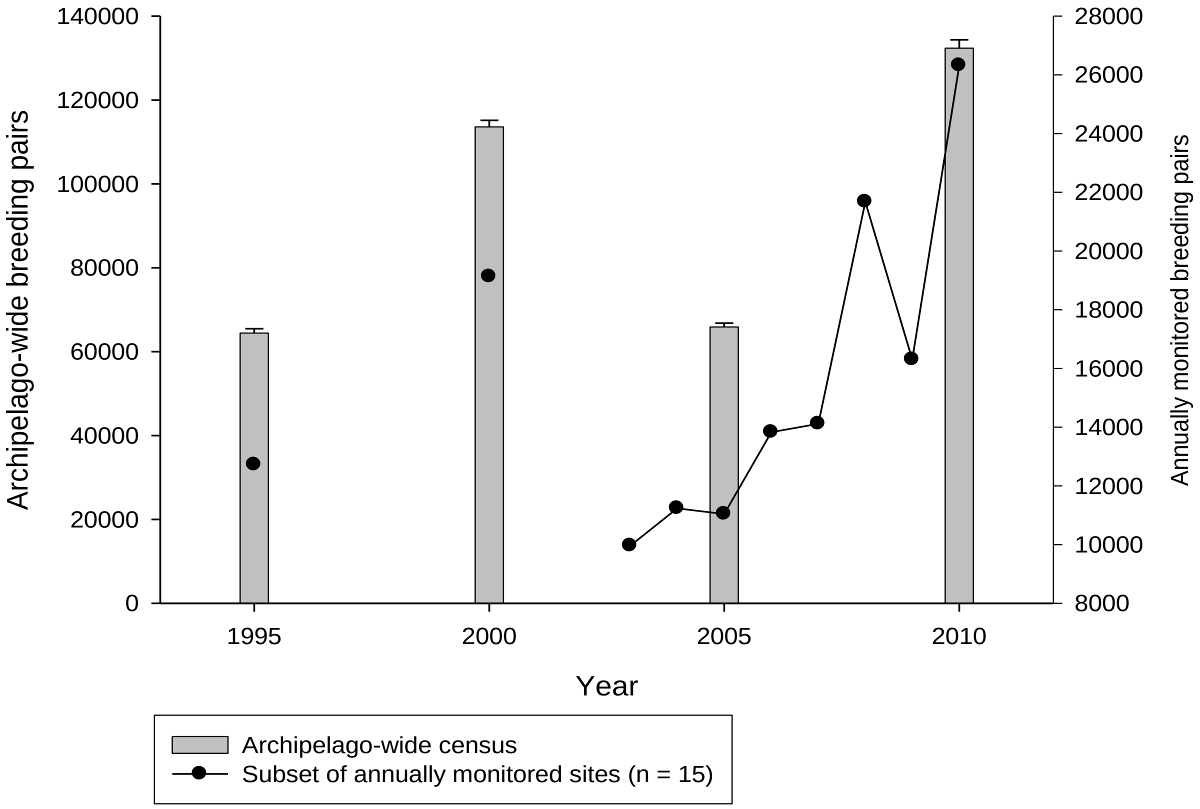

Fig. 2. Estimates of the number of Gentoo Penguin breeding pairs at the Falkland Islands. Presented are archipelago-wide census results (bar), and census results for a subset of 15 annually monitored breeding colonies (line).

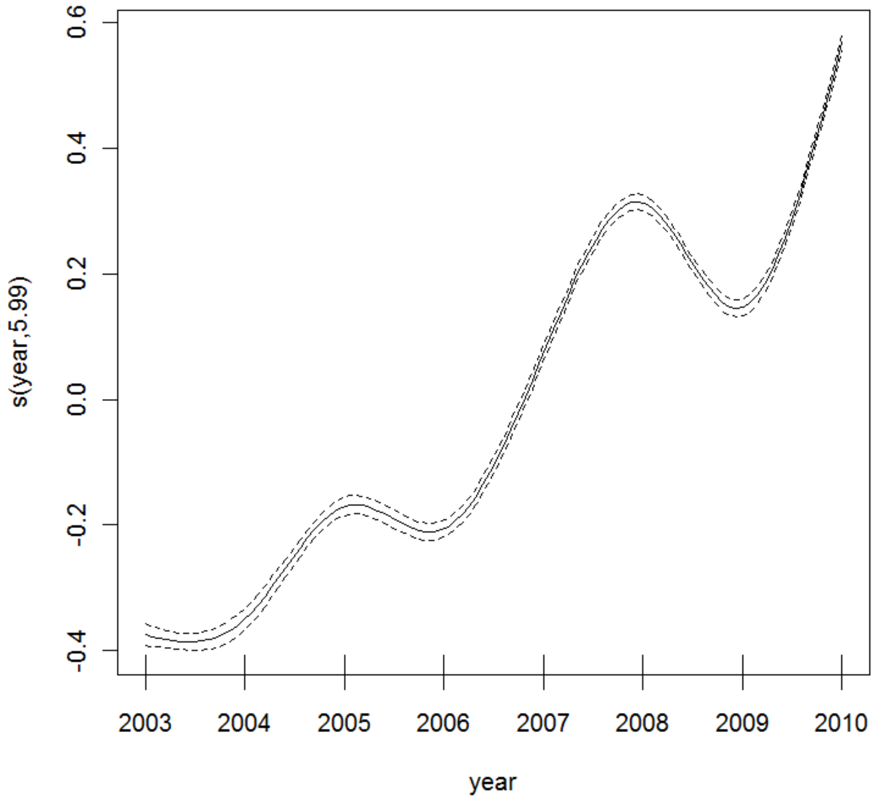

Fig. 3. Results from a Generalized Additive Model depicting a positive trend in the number of breeding pairs counted at annually monitored breeding colonies between 2003 – 2010 (proportion of deviance explain was 93.9 %, R^2 = 0.64, *df = 6*, *P < 0.01*).

ROCKHOPPER PENGUINS

SUMMARY

- The number of Rockhopper Penguin breeding pairs increased by 50.6% when compared with the number counted during the last archipelago-wide census in 2005.
- The Falkland Islands population is now estimated to be is 319,163 ± 18,503breeding pairs. With this revised population estimate, the global population of the subspecies *E. c. chrysocome* is now closer to 870,000 breeding pairs of which the Falklands population accounts for approximately 36 % (second largest population after Chile).
- The Falkland Islands population appears to be stable rather than in further decline. However there is still no evidence of recovery to 1930's levels.

INTRODUCTION

There are two subspecies of Southern Rockhopper penguins (*Eudyptes chrysocome*). *E. c. chrysocome* breeds at the Falkland Islands and a number of offshore islands in southern Chile and Argentina. The subspecies *E. c. filholi* breeds on the sub-Antarctic Islands of Prince Edward and Marion Islands, Crozet Islands, Kerguelen Islands, Heard Island, Macquarie Island and Campbell, Auckland and Antipodes Islands. The global population of the subspecies *E. c. chrysocome* (herein referred to as Rockhopper Penguin) is estimated to be 761,500 breeding pairs (Huin 2006, Oehler *et al.* 2008, IUCN 2011). Based on the 2005 Falkland Islands population estimate (210,000 breeding pairs; Huin 2006), the Falkland Islands account for 26% of the global population of this subspecies.

In 1932 the Falkland Islands Rockhopper Penguin population was estimated to be 1.5 million breeding pairs (Bennet 1933 and re-assessed by Pütz *et al.* 2003). Between the 1930's – 1990's the Falkland Islands population of Rockhopper Penguins declined by over 86 % (1.18% per annum over a 73-year period between 1932 - 2005) (Huin 2006). There are no population data for Rockhopper Penguins between the 1930's – 1980's and therefore it is unclear whether the decline at the Falkland Islands was gradual, stepwise or sudden. However, a mass mortality event in 1986 (attributed to the starvation of adult birds during moult) resulted in further population declines between the late 80's and early 90's (Keymer 1988, Ellis *et al.* 1998).

The decline of the Falkland Islands population of Rockhopper Penguins mirrors severe population declines at other key Rockhopper Penguin populations and implies that broad-scale ecosystem changes are likely to be involved (e.g. ecosystem-scale at-sea factors such as shifts in the availability and distribution of prey linked to changes in sea surface temperature and/or ecosystem structure) (Moor 1986, Hilton *et al.* 2006). Egg collection at the Falkland Islands in the early to mid 1900's (estimated as tens of thousands of eggs collected per year) has also been suggested as a factor contributing to early population declines (Woods and Woods 1997).

The most recent data indicates that Rockhopper Penguin populations are now increasing in Chile and Argentina, although the absence of long-term population data at these sites (particularly breeding sites in Chile) make assessing population trends difficult (Schiavini 2000, Oehler *et al.* 2008). The most recent population estimates for the Falkland Islands indicate that Rockhopper Penguins declined by ca. 90,000 pairs between 2000 and 2005. This decline was thought to be largely a result of the 2002 Harmful Algal Bloom (HAB) event (Uhart *et al.* 2004; Huin 2006).

This report assesses (i) the current status of Rockhopper Penguins breeding at the Falkland Islands and (ii) whether archipelago-wide patterns in population trends reflect trends at annually monitored breeding colonies.

METHODS

(i) Timing of census

Rockhopper Penguins lay their first 'A' egg between the 27 October – 10 November. It is estimated that 95 % of Rockhopper Penguins breeding at selected study sites at New Island lay the 'A' egg by 5 November, with the second 'B' egg laid ca. 4 days later (Poisbleau *et al.* 2008). Operational constraints dictated that the timing of the census was not optimal for Rockhopper Penguins. Specifically, the archipelago-wide census was timed to take place after Black-browed Albatross peak egg laying, which also coincides with Gentoo Penguin incubation. The archipelago-wide census typically starts in late October (23 October in 2010), and therefore many Rockhopper Penguin pairs are yet to lay their first 'A' egg. This means we actually measure 'potential' breeders at sites visited prior to egg laying. There are no data available to assess error due to misclassification of breeders/non breeders. Although it would be prudent for future studies to validate what proportion of potential breeders (i.e. pairs) actually breed, given the pre-laying attendance patterns of Rockhopper Penguins there is no inherent reason why a census just prior to the mean date of laying of A-egg should be automatically unsuitable. However, we acknowledge the timing of the census does add an unknown degree of error to our estimates, although unavoidable due to logistic/resource limitations.

(ii) Census techniques

Consistent with the methods used in the previous three censuses, we used direct counts, photography and transects to count Rockhopper Penguins. Table 1 provides an overview of sites visited and methods used.

Direct counts

Rockhopper Penguins breeding at selected sites were direct counted with the aid of a tally counter (Table 1). Three direct counts of nests occupied by adults were made by a minimum of two observers. Counts were repeated if they differed by more than 5% and were averaged once within this range (Thompson and Riddy 1993). Due to limited time on offshore Islands, large Rockhopper Penguin colonies that were direct counted (e.g. North Island) were counted by a single observer. We cannot provide estimates of error for these counts. Consistent with previous censuses, these counts were attributed a 5% error (Huin 2006).

Photographs

Rockhopper breeding pairs at several sites were photographed and then counted electronically (Table 1). Consistent with previous censuses, these counts were attributed a 5% error (Huin 2006).

Transects

The transect method employed by Falklands Conservation was developed by Huin and Reid (2006) for Black-browed Albatross. Huin and Reid (2006) provide a thorough review of the method and its refinement between the 2000 and 2005 censuses that will not be repeated here. Transects were used to estimate the number of Rockhopper Penguins breeding at Steeple Jason and Beauchêne Island. At these sites Rockhopper Penguins are patchily distributed within large Black-browed Albatross (*Diomedea melanophris*) colonies.

In summary, the transect method involves three steps:

(i) Mapping colony perimeter using a handheld GPS (Garmin GPS 72) to generate an estimate of colony area. The colony perimeter being measured relates explicitly to Black-browed Albatross breeding colonies rather than Rockhopper Penguin colonies. For consistency the error attributed to the GPS measurement of colony area was 1% (Huin and Reid 2006).

(ii) Conducting line transects to estimate the densities of nests within colonies (Croxall and Prince 1979; Huin 2006). The number of transects was dependent on the size and configuration of the colony and variability in nest density. Each transect line was five metres wide and was divided into a succession of adjacent five metre squares (individual area of 25 m^2). For each individual colony, transect counts were averaged to produce an overall estimate of the breeding density.

(iii) Combining these measures to extrapolate total breeding pairs.

Assumptions of the transect method are:

- Changes in colony area reflect actual changes in colony size, rather than differences in routes walked by counters.
- Measurements of the density of nesting birds from transects are representative of the overall variation of density within the colony area being measured.

Calculation of variance

We use the calculations presented in Thompson and Rothery (1991) and modified by Huin and Reid (2006) to estimate the variance (V) of the estimated number of nests (N) for each colony:

$$V[\mathrm{N_i}] = (\mathrm{A_i^2} \times \frac{\mathrm{S_i^2}}{\mathrm{n_i}}) + (\mathrm{S_{ai}^2} \times (\mathrm{x_i^2} + \frac{\mathrm{S_i^2}}{\mathrm{n_i}})/1)$$

Where N_i is the number of quadrats; x^i and S_i^2 are the sample mean and variance of the density of nests; A_i and S_{ai}^2 are the estimated mean and variance of the colony area. The first term in the equation is the variation of nest density between quadrats and the second term is due to the variance arising from multiple estimates of the colony area.

Variances for each site were added together to provide the 95% confidence interval (CI) for the entire Falklands population. This was achieved by transforming variance to a coefficient of variation (CV).

$$CV = \frac{\sqrt{V[N_i]}}{N_i} \times 100$$

And then to a 95% CI:

$$95\%\ CI = N_i \times \frac{CV}{100} \times 1.96$$

The significance of population changes between archipelago-wide census was estimated using the equation below, where V = total variance, and Y = total number of Penguins for year *x*. $P = 0.05$ when $d = 1.96$.

$$d = \frac{Y1 - Y2}{\sqrt{V[Year\ 1]} + V[Year\ 2]}$$

(iii) Annual monitoring vs archipelago-wide census

To assess how accurately changes in the annually monitored sites reflect total population changes, the percent change in the number of Rockhopper Penguin breeding pairs between each archipelago-wide census was calculated and then compared with the percentage change in breeding pairs from annually monitored sites for years in which both counts were available (2005 and 2010). All values are presented as ± 95 % CI.

Over the course of the FISMP some annually monitored breeding colonies have been discontinued and, to compensate, additional breeding colonies included. The most recent subset of annually monitored Rockhopper Penguin breeding colonies was started in 2003 (and includes sub-colonies at Steeple Jason Island which in previous archipelago-wide censuses were not differentiated). Therefore we present comparisons for the 2005 and 2010 archipelago-wide census.

RESULTS

During the 2010 census 286,826 ± 18,442 Rockhopper Penguin breeding pairs were counted at 31 breeding sites between the 23 October and the 22 November 2010 (Fig.1, Table 1). In 2010, we were unable to assess seven Rockhopper Penguin colonies. These were Campa

Menta, Carcass Point, Grand Jason, McBride Head, New Island, Seal Bay and White Rock. In 2005, a total of 31,416 ± 1,136 breeding pairs were estimated at these colonies. Therefore the conservative Falklands population estimate is 319,163 ± 18,503 breeding pairs (note 95% CI based on the addition of variances from all sites, rather than the addition of 95% CI). This estimate assumes that the missed breeding colonies remained stable or increased between 2005 – 2010. This is not an unreasonable assumption given the average increase across all breeding colonies was 59 ± 107 %. Assuming the missed breeding colonies increased by an average of 59 %, then the estimate for the missed breeding colonies would be 49,951 breeding pairs, or a total population of 336,777 breeding pairs. We use the conservative population estimate of 319,163 breeding pairs for analysis because breeding colonies exhibited large variability when comparing the extent and direction of population change at five-yearly intervals and interpolating population changes are therefore unlikely to be accurate (Table 1).

The 2010 population estimate represents an increase of 50.6% when compared with the number counted during the last archipelago-wide census in 2005 (210,418 ± 13,584; $d = 9.3$, $P < 0.01$), but similar to the 2000 and 1995 censuses when taking into account 95% confidence intervals (Fig. 2, Table 1). Based on the difference between the largest population estimates, 2000 and 2010 the Falklands' population of Rockhopper Penguins has remained relatively stable between the 10 year period (2000 archipelago-wide census reporting 298,496 – 317,472 breeding pairs and the 2010 census 300,659 – 337,666 breeding pairs; $d = 1.5$, $P > 0.05$).

Steeple Jason Island and Beauchêne Island accounted for 73 % of the 2010 Falkland Islands Rockhopper population estimate (Table 1). The Steeple Jason Island population estimate increased from 59,033 ± 10,838 to 121,396 ± 13,191 ($d = 7.2$, $P < 0.01$). The increase at Steeple Jason Island reflects higher nest density in 2010 (average of 0.43 ± 0.1) than that reported in 2005 (0.21 ± 0.1) (although surprisingly not significant; Paired-T test: $t = 2.963$, $df = 2$, $P = 0.097$) (Table 3).

At Beauchêne Island, the estimated number of breeding Rockhopper Penguins increased by 48% from 71,343 ± 8,038 breeding pairs in 2005 to 105,778 ± 12,752 in 2010 ($d = 4.5$, $P < 0.01$). The increase was largely due to a higher nest density and larger total area calculated for Area A, the largest colony on Beauchêne Island (Table 2 and Table 3).

Colony area (Table 3) relates to Black-browed Albatross colonies and does not explicitly relate to Rockhopper Penguin colonies. This is because Rockhopper Penguins are patchily distributed within Black-browed albatross colonies. This patchy distribution resulted in large variability in average nest density, irrespective of the number of quadrats measured (Fig. 3). The total colony area calculated increased at both Islands, although the degree of change varied substantially between areas at both Steeple Jason Island (average 4.5 ± 24.0 %) and Beauchêne Island (average 3.2 ± 7.3 %) (Table 3).

Based on the most recent 2010 archipelago-wide census, Rockhopper Penguin annually monitored sites represent only 1.7% of the Falklands population. Surprisingly trends in annually monitored sites broadly reflected total population changes (51 % increased based on the archipelago-wide census total population estimate, compared to 73 % increase based on annually monitored sites) (Fig. 2). The degree of population change between annually monitored sites was however large (- 34% - 200%).

DISCUSSION

We report is 319,163 ± 18,503 Rockhopper Penguin breeding pairs representing a 50.6% increase in the number of breeding pairs between the 2005 and 2010 archipelago-wide census. With this revised population estimate, the global population of *E. c. chrysocome* is now closer to 870,000 breeding pairs of which the Falklands population accounts for approximately 36 %. Chile (Isla Noir, Isla Ildefonso, Isla Diego Ramirez) remains the largest Rockhopper Penguin population with an estimated 377,000 pairs (43 % of global population) (Schiavini 2000, Oehler *et al.* 2008, IUCN 2011). Two colonies account for the majority of the Falkland Islands population of Rockhopper Penguins, these being Steeple Jason Island and Beauchêne Island (38 % and 33 % of the 2010 Falkland Islands population estimate respectively).

The Falkland Islands Rockhopper Penguin population declined by ca. 90,000 pairs between 2000 and 2005 (Fig 2). This decline was thought to reflect mortality associated with a 2002 Harmful Algal Bloom (HAB) (Uhart *et al.* 2004; Huin 2006). The 2010 archipelago-wide census results (increase of ~109,000 breeding pairs) therefore suggest the recovery of Rockhopper Penguins from the 2002 HAB event (Uhart *et al.* 2004). Recovery may have been facilitated by the comparatively high breeding success at the Falkland Islands when compared to other populations of Northern (*E. Moseleyi)* and Southern Rockhopper Penguins breeding in the Indian and Pacific Oceans (Williams 1995, Pütz *et al.* 2001). The increase in the number of breeding pairs may also reflect higher survival and higher recruitment of juveniles into the breeding population over the last five years. Further, immigration and/or variation in the ratio of adult birds skipping breeding seasons may have also contributed to variability in the number of Rockhopper Penguin breeding pairs between the 2005 and 2010 archipelago-wide censuses (as predicted for Gentoo Penguins). For example, a three year study on the sub-Antarctic Macquarie Island revealed that only 3 % of males and 8 % of females bred in all seasons (Hull *et al.* 2004). Alternatively, Reya Rey et al. (2007) reported a return rate of 72 % and 63 % in two successive seasons at Isla de los Estados. Little is known regarding recruitment, survival or adult breeding deferral in Rockhopper Penguins at the Falkland Islands, although a recently established demographic study of Rockhopper Penguins at New Island (New Island Conservation Trust) will address some of these key knowledge gaps.

The current Falkland Islands population trend is best regarded as stable. However, the population remains at less than 20% of the 1930's estimate of ca. 1.5 million pairs (Pütz *et al.* 2003). Intuitively, if the decline of the Falkland Islands Rockhopper Penguin population was associated with a regional ecosystem-scale shift that affected productivity or preferred prey abundance/distribution, then a recovery to 1930's levels may be limited by regional carrying capacity (Weimerskirch *et al.* 2003, Hilton *et al.* 2006). Therefore, although it is desirable that the Falkland Islands population of Rockhopper Penguins recovers to previous levels, historical population size may not be an appropriate conservation objective.

Throughout their range, Rockhopper Penguins face growing threats that include pollution, disease, commercial fishing and climate changes (Pütz *et al.* 2002). For example, Rockhopper Penguins breeding at the Falkland Islands have experienced several anomalous mass mortality events, such as those reported in 1986 and in 2002 (HAB) (Keymer *et al.* 2001; Uhart *et al.* 2004). Such events may increase in frequency as a result of climate changes and highlights the vulnerability of the Falkland Islands Rockhopper Penguin population to an increasingly stochastic environment. Conservation efforts should continue to monitor populations (i.e. detect adverse changes), assess significance of changes and where possible identify the cause of population change in order to mitigate against threats that result in further population declines (Croxall and Rothery 1991).

Limitations of the Rockhopper Penguin archipelago-wide census

Steeple Jason Island and Beauchêne Island accounted for 73 % of the 2010 Falkland Islands Rockhopper population estimate. Therefore population changes at these sites ultimately influence total population estimates – the accuracy of which are dependent on the methods used. Given the transect method is used to estimate breeding numbers for these sites, it is important that readers are aware of the limitations of this method.

Estimates of colony area varied by as much as 29 % between the 2010 and 2005 census. Changes in area however, do not relate to changes in the size of Rockhopper Penguin colonies because the area measured is the size of Black-browed Albatross colonies and not the size of Rockhopper Penguin colonies. Huin and Reid (2006) highlights the patchy distribution of Rockhopper Penguins within albatross colonies at Steeple Jason Island and Beauchêne Island that results in substantial variability in average nest density between quadrats – regardless of sampling effort (i.e. number of quadrats sampled). This was also the case in 2010 (Fig. 3). Therefore in practice, we cannot meet the first assumption of the transect method *'Measurements of density are representative of the overall variation'*. Population numbers generated for Rockhopper Penguins using the transect method are probably overestimated because Rockhopper Penguins are patchily distributed within the areas measured.

Sites that were direct counted increased by an average of 58% which lends some degree of confidence to the estimates generated from the transect method. Nevertheless, results derived from the transect method should be interpreted with caution and total population estimates be considered as 'best estimates' rather than absolute values. Methods to accurately count Rockhopper Penguins at Steeple Jason Island and Beauchêne Island remain elusive. Rockhopper Penguins are not suited to aerial photography and direct counting large colonies is not practical.

Finally, annually monitored sites accounted for less than 2% of the Falklands population of Rockhopper Penguins. Although this study indicates these sites broadly reflect total population changes, there was also significant variability when comparing population changes between sites (-34% - 200%). The inclusion of additional sites to bolster the proportion of the Falkland Islands population that is monitored annually should be considered, although the inclusion of additional sites is dependent on attaining further funding.

Table 1: Rockhopper Penguin population counts and changes at breeding sites around the Falkland Islands for the 1995 – 2010 archipelago-wide censuses.

	Change (%) 2005-2010	2010	2005	2000	1995	Method
	Average **59** ± 107	**319,163** ± 18,503	**210,418** ± 13,584	**298,496** ± 18,976	**287,799**	
Islands						
Arch Island	41	650	462	698	411	D
Beauchêne Island	48	105,778	71,343	62,218	69,227	D-T-P
Bird Island	39	10,254	7,365	7,858	10,600	D
Bleaker Island	-30	536	766	746	700	D
Clump Island	5	225	214	209	83	D
Cochon Island	44	552	384	264	515	D
Elephant Jason	59	1,363	859	844	100	D
Hummock Island	530	460	73	871	540	D
Keppel Island	34	1,404	1,047	782	1,168	D
Kidney Island	17	297	253	257	100	D
North Island	44	4,763	3,314	3,462	3,472	D
Passage islands	64	446	272	456	392	D
Pebble Island	-1	8,513	8,583	6,778	6,702	D-P
Rabbit Island	183	853	301	793	600	D
Saunders Island	16	10,560	9,126	6,912	5,781	D
Sea Lion Island	11	401	360	484	504	D
South Jason	187	1,301	453	889	300	P
Steeple Jason[1]	106	121,396	59,033	108,954	111,171	D-T-P
West Point Island	8	2,249	2,085	5,004	4,042	D-P
East Falklands						
Fanning Head[2]	-36	837	1,317	1,273	1,071	D
			386	727	1,071	
Cape Bougainville	7	1,487	1,385	1,723	1,943	D
Berkeley Sound South	47	2,131	1,445	2,455	1,910	D
Diamond Cove	13	167	148	152	155	D
Berkeley Sound North	39	2,648	1,909	2,334	2,460	D
West Falklands						
Stephens Peak	135	2,933	1,250	2,574	2,504	D
Tamar Point	37	3,141	2,300	1,988	2,566	D
Penguin Point	32	288	219	242	93	D
Hope Harbour	-23	2,114	2,736	2,778	2,243	D
Sites missed 2010						
Carcass Point			2,896	3,300	3,783	
Grand Jason			10,496	48,404	34,000	
McBride Head			3,073	4,868	4,146	
Seal Bay			8,734	9,931	8,487	
New Island			5,667	7,413	5,500	
White Rock			100	100	150	

Campa Menta	450	482	380

D = Direct count, P = Photo count, T = Transect

[1] Worksheets from 2005 suggests Steeple Jason values should be 60,661 ± 10,838.
[2] Fanning Head values for 1995 - 2000 presented in Huin 2006 and for consistency are presented here. These values do not match annual monitoring records (annually monitored values presented below, but not included in analysis).

Table 2. Changes in the average nest density at Steeple Jason Island and Beauchêne Island between the 2000, 2005 and 2010 archipelago-wide censuses.

		Nest density ($5m^2$)		
Site	**Area**	**2010**	**2005**	**2000**
Steeple Jason Island	S1	0.40	0.23	0.23
	S2+S3	0.37	0.25	0.33
	S5	0.51	0.15	0.45
	Average	0.43 ± 0.1	0.21 ± 0.1	0.34 ± 0.1
Beauchêne Island	Area A	0.52	0.35	0.71
	Area C1	0.31	0.33	0.23
	Area C2	0.48	0.48	0.37
	Area E	0.51	0.48	0.46
	Average	0.46 ± 0.1	0.41 ± 0.1	0.44 ± 0.2

Table 3. Changes in the size of specific areas at Steeple Jason Island and Beauchêne Island between the 2000, 2005 and 2010 archipeligo-wide censuses.

		% change	Area (m^2)		
Site	**Area**	**2005-2010**	**2010***	**2005***	**2000†**
Steeple Jason Island	S1	29.4	81,481	57,536	57,956
	S2+S3	-18.4	102,184	120,986	98,410
	S5	2.5	87,337	85,154	87,278
	TOTAL	2.7	271,001	263,676	243,644
			2010*	**2005†**	**2000†**
Beauchêne Island	A	10.9	151,254	134,790	108,361
	C1	-12.7	27,657	31,164	26,243
	C2	10.3	7,983	7,157	9,169
	E	5.7	10,820	10,204	10,782
	TOTAL	7.3	197,714	183,315	154,556

†Area estimated using colony spinning method (Huin and Reid 2006).

**Area estimated using hand held GPS*

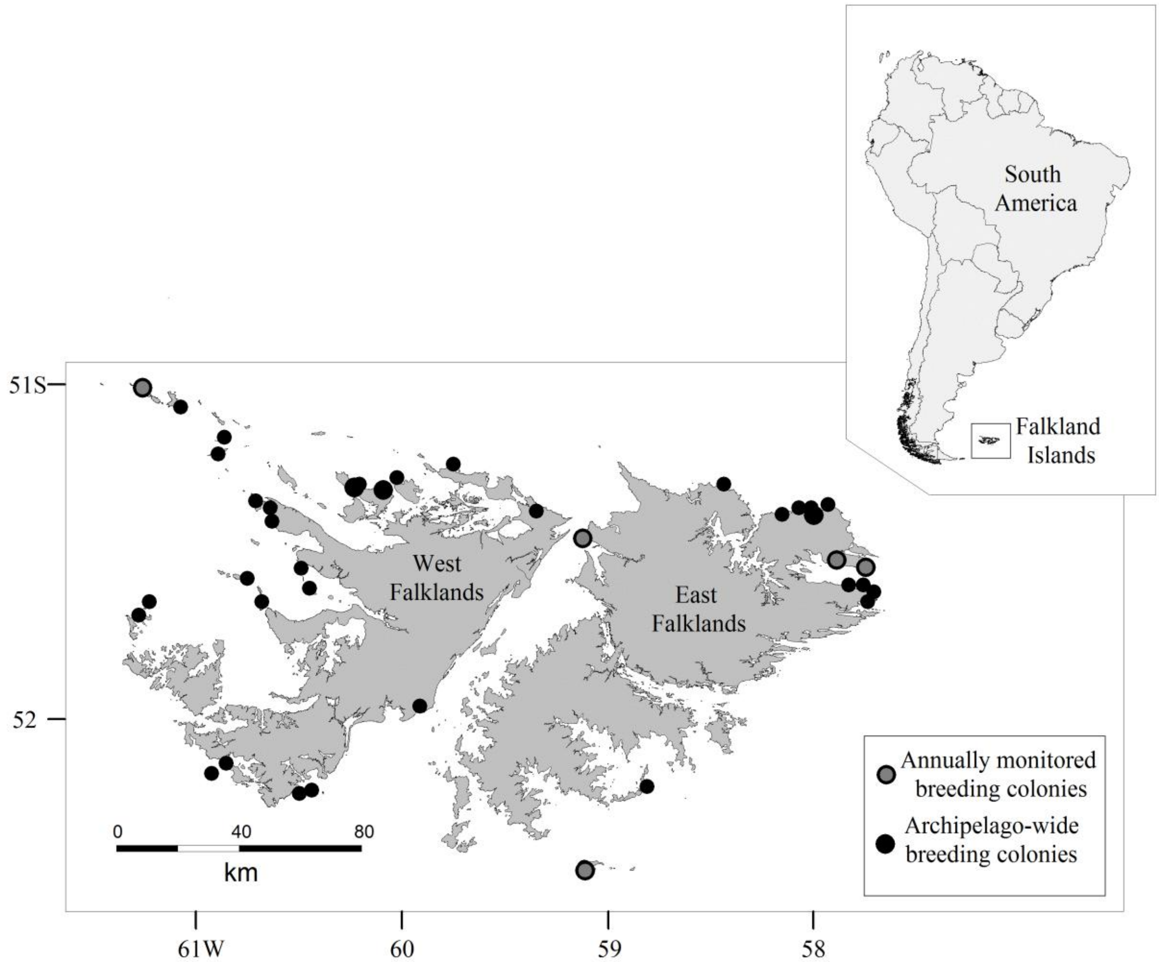

Fig. 1: Location of Rockhopper Penguin breeding colonies at the Falkland Islands, including breeding colonies that are currently monitored annually.

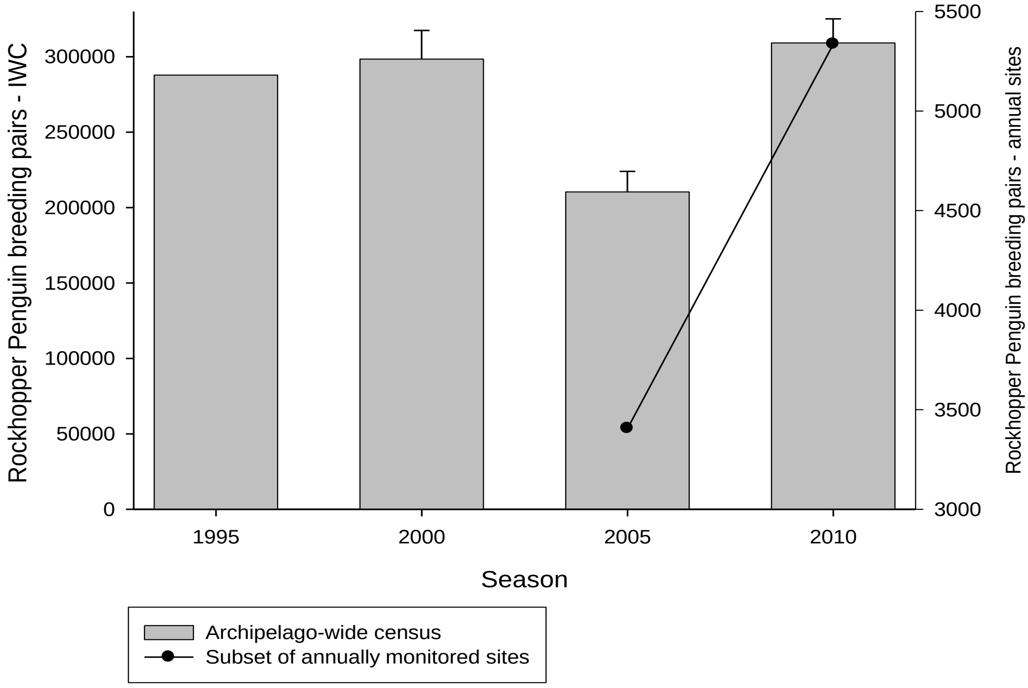

Fig. 2: Estimates of the number of Rockhopper Penguin breeding pairs at the Falkland Islands. Presented are archipelago-wide census results (bar), and census results for a sub-set of annually monitored sites (line).

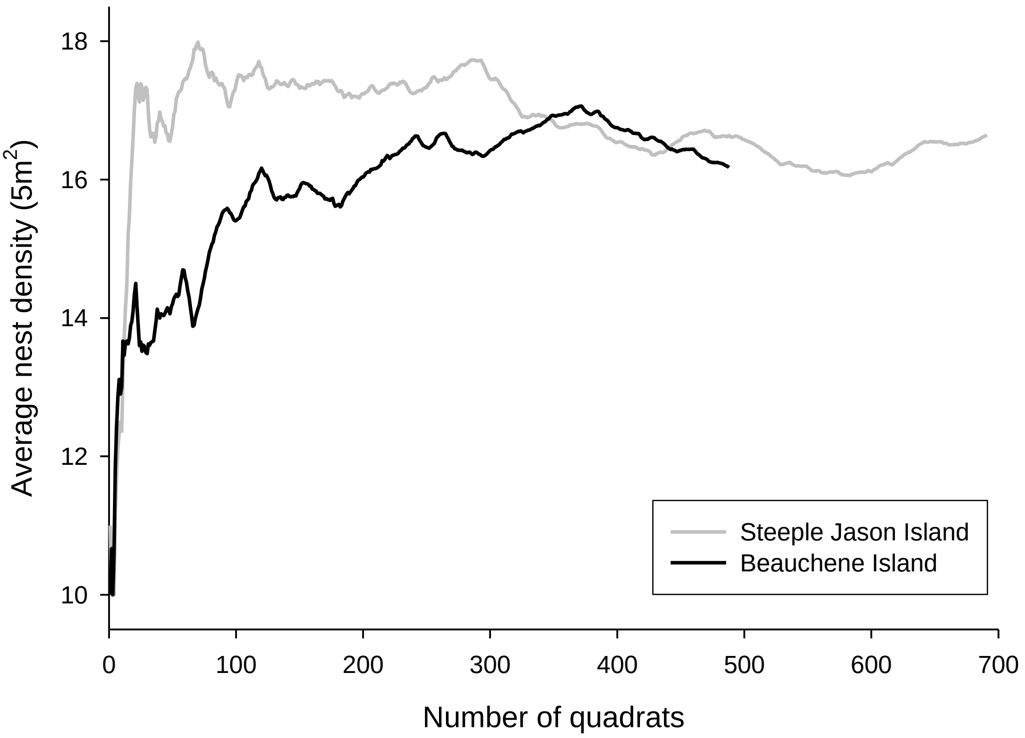

Fig. 3: The average nest density calculated for 2010 in relation to the number of quadrats measured. Rockhopper Penguins are patchily distributed within Black-browed albatross colonies. Despite almost 700 quadrats at Steeple Jason Island and 500 at Beauchêne Island, nest density was still irregular, highlighting that Rockhopper Penguin population estimates generated from area/density measurements must be interpreted with caution.

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