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Population trends, timing of breeding and survival of Salvin's albatrosses (*Thalassarche salvini*) at Proclamation Island, Bounty Islands, New Zealand

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Abstract We used data from 3 sources to examine the population size and trend of Salvin's albatrosses (*Thalassarche salvini*) breeding on Proclamation Island, Bounty Islands, New Zealand. Island-wide counts of breeding birds during incubation resulted in totals that declined 14%, from 3065 in 1997 to 2634 in 2004. A count of breeding albatrosses over part of the island in 2011 indicated a further decline of 13% between 2004 and 2011, and an overall decline of 30% between 1997 and 2011. Additional counts on part of Depot Island indicated a decline of 10% in the numbers of breeding pairs between 2004 and 2011. Daily observations of 70 nests showed that hatching spanned the period from 5 to 21 November 1997, with a median of 15 November, apart from 5 eggs that had not yet hatched by the end of the study period. Based on the banding and recapture of chicks banded in March 1985 annual survival was estimated at 0.926. The scale of the decline estimated in this population has resulted in the conservation status of Salvin's albatross being upgraded from nationally vulnerable to nationally critical.

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Keywords Salvin's albatross; *Thalassarche salvini*; population trend; breeding season; annual survival; Bounty Islands

INTRODUCTION

Salvin's albatross (*Thalassarche salvini*) is endemic to New Zealand with estimated annual breeding populations of 76,352 pairs in 1978 at the Bounty Islands (Robertson & van Tets 1982) and 1100-1200 pairs during 2008-2010 at the Snares Western Chain (Sagar *et al.* 2011). These population estimates make this the second-most abundant albatross species breeding in New Zealand, after the estimated 100,000 pairs of white-capped albatrosses (*T. cauta steadi*) breeding at the Auckland Islands (Gales 1998). Despite their abundance Salvin's albatrosses are one of the least known albatross species, primarily because breeding is restricted to 2 isolated archipelagos which are difficult to access due to their exposure to severe sea conditions. However, in recent years they have been recorded in sufficiently high numbers in the bycatch of New Zealand trawl fisheries that they have been

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Fig. 1. Bounty Islands, showing Proclamation, Depot and Funnel Islands Photo: J.L. Sagar

identified as at potential risk from the impacts of commercial fisheries (Richard *et al.* 2011), and so there has been a greater concerted effort to obtain information about the species.

Commercial fishing operations were recognised as the major factor in the decline of albatross populations from the late 1980s (Bartle 1991; Brothers 1991; Croxall & Gales 1998; Gales 1998) and this led to several albatross population studies being established. However, because of their remote and difficult to access breeding sites, population monitoring of Salvin's albatrosses was not initiated until 1997-98. The first expedition was planned, funded and implemented by the late Gerry Clark and had the primary aims of establishing population monitoring of the breeding populations of Salvin's albatross, erect-crested penguin (*Eudyptes sclateri*), fulmar prion (*Pachyptila crassirostris*) and Bounty Island shag (*Leucocarbo ranfurlyi*) (Clark *et al.* 1998). The Bounty Islands were visited again in 2004 (de Roy & Amey 2005) and 2011(Hiscock & Amey 2012) to repeat the 1997 surveys. Here, we report the results of the estimates of the numbers of breeding pairs of Salvin's albatrosses from the 3 expeditions between 1997 and 2011. We used information from these surveys to assess any changes in population size during this period. In addition, we use observations on the timing of hatching in October-November 1997 and recapture data from birds banded as chicks in March 1985, respectively to estimate timing of breeding and annual survival. Overall, these results provide important new information on the size and trend of the population of Salvin's albatrosses at the Bounty Islands. We also report the first estimates of the timing of the breeding season and annual survival of birds of known-age.

METHODS

The Bounty Islands (47° 45'S, 179° 03'E; Fig. 1) are 760 km east of mainland New Zealand and comprise 22 bare granite outcrops with a total area of 135 ha. The islands form 3 groups, spread over 4.5 km of ocean (Taylor 2006). The largest is Depot Island which is 800 m long and 50 m high; the highest point in the archipelago is on Funnel Island at 73 m above sea level (Taylor 2006). The islands are the major breeding location of Salvin's albatross, erect-crested penguin, and fulmar prion and the only breeding location of the Bounty Island shag. Salvin's albatrosses and erect-crested penguins nest in mixed colonies covering most areas above wave height on 8 islands in the group. Fulmar prions breed in rock crevices and the Bounty Island shags nest on small ledges on steep cliffs above the sea. Snares cape petrels (*Daption capense australe*), Antarctic terns (*Sterna vittata*) and southern black-backed gull (*Larus dominicanus*) also nest on the islands (Robertson & van Tets 1982). In addition, the islands are a major breeding ground of New Zealand fur seals (*Arctocephalus forsteri*) (Taylor 2006).

Counts

Counts of incubating birds were made during the periods 31 October-17 November 1997, 12-17 November 2004, and 11-14 November 2011. During each of these visits Proclamation Island was divided into the same 8 blocks based on geographic features, with the boundaries marked with stock markers for the duration of each visit; these 8 blocks encompassed the entire area of the island occupied by breeding albatrosses. Within each of these blocks all Salvin's albatrosses that were incubating an egg were counted. The sum from each block gave an estimate of the numbers breeding on the entire island at that time. In 1997 the boundary between blocks 7 and 8 was in a different position to that of 2004 and 2011. Therefore, it was not appropriate to compare counts of these blocks in 2004 and 2011 with that in 1997 unless the totals were summed. In 2011 block 8 was not counted because deteriorating weather reduced the time available for counting.

The census method on all islands was for 2 people to search each block systematically. One person counted Salvin's albatross nests where an albatross (with or without an attendant partner) was incubating an egg or brooding a chick. No nests with an abandoned egg or chick were recorded. In most cases the egg or chick was seen as the albatross repositioned itself in response to the approach of the counter, otherwise the stance of the albatross indicated that it had an egg or a chick (*i.e.*, most birds not incubating sit with their wings folded higher on their back than do incubating birds, and they are more likely to stand up completely when approached). When the breeding status of a bird was unclear from these indicators the bird was gently lifted to confirm if an egg or a chick was present. After being counted each nest mound was sprayed with a spot of stock marker on the ground close-by.

After each block was covered by the first person, the second person walked at a 90° angle to the direction of the first person and checked about 25-120 occupied nests to record the numbers of nests missed or double counted, identified respectively by the absence of spray or presence of 2 sets of spray. The estimated proportion of missed and/or double counted nests was then applied to total number of occupied nests recorded by the first person to derive an adjusted count for each block.

In 2004 additional counting blocks were established on Depot and Funnel Islands. On both islands a discrete area, clearly defined by natural features, was marked out with stock marker and the incubating birds were counted using the same methods as on Proclamation Island. Depot Island was revisited in 2011 and breeding birds within the same area were counted. There was insufficient time to repeat the count on Funnel Island during 2011.

Nest failure and timing of hatching

On 29 October 1997 a study area measuring 10 m by 20 m was established on Proclamation Island. All 86 nests with an egg within the study area were marked and 70 of these were monitored daily from 31 October to 17 November to record pipping (*i.e.*, when the eggshell was starred or had a small hole broken, the first sign that a chick was hatching), chick hatching dates (the first day that a chick was completely free of the eggshell), and the rate of nest failure.

Survival analysis

During March 1985 CJRR banded 590 and 400 well-grown Salvin's albatross chicks on Proclamation and Depot Islands, respectively. Therefore, as well as counting the number of birds on an egg or chick, the majority of birds were also checked for a leg band. All band numbers were recorded, if possible, and the bird sprayed with a spot of stock marker so that it was not recaptured during the same visit. In addition to the expeditions in 1997, 2004 and 2011, recaptures were made (by PMS) on Proclamation Island 16-17 October 2012 and 21-23 October 2013. All these recapture data were used in the following analysis of survival.

As we had a small sample of recoveries we used the joint recapture/recovery model of Burnham (1993) to estimate survival probabilities. This model is parameterised with 4 different probabilities; S_i: the probability that a banded individual survives from year i to year $i + 1$ (here referred to as survival probability), F_i: the probability that a banded individual does not emigrate permanently from the study area from year i to year i+ 1 (here defined as fidelity probability), p_i: the probability that a banded individual that is alive and in the study area at i is seen at $i + 1$ (the resighting probability), r_i: the probability that a banded individual that has died between year i and $i + 1$ is found and its band reported to the Banding Office (the recovery probability). The most general model included separate survival (S), fidelity (F) and recovery (r) parameters for each year (t); for the 1985 cohort of chicks separate resighting (p) parameters were calculated for each year of recapture effort (t).

To make inferences from the data we *a priori* formulated different models, each representing a hypothesis about survival and other mathematically necessary but biologically unimportant parameters (nuisance parameters). These models were fitted using Program MARK 7.1 (White & Burnham 1999). To evaluate the fit of our set of models to the data we used a parametric bootstrap Goodness-of-Fit (GOF) test on the most general model (*i.e.*, the model with the most parameters). If the structure of the general model adequately fit the data, then subsequent models that are constraints of the general model can be derived (White *et al.*2001). These bootstrap simulations also provide an estimate of the dispersion parameter ($\hat{c}$), calculated as the observed deviance divided by the average of the simulated deviances ($\hat{c}$ =1) if the model fits perfectly. The models were ranked according to the small sample-size adjusted Akaike's information criterion (AICc; Burnham & Anderson 1998). To reduce the list of reasonable models, we conducted modelling in 2 steps (Lebreton *et al*. 1992). First, we looked for a model that minimised the influence of the nuisance parameters (F, p, r) in the most parsimonious way. The survival part of the model

Table 1. Counts of Salvin's albatrosses on Proclamation Island, 12-16 November 1997. Total nests are all nests containing an egg or chick. Unmarked nests are nests that had been overlooked during the ground count; a negative number indicates that the nest had been counted twice.

Ground count block number	Transect count		Total	
	Total nests	Unmarked	Marked	Adjusted nest total
1	344	0	120	344
2	150	1	99	151
3	413	0	98	413
4	406	1	100	410
5	332	1	100	335
6	289	1	100	292
7	697	1	103	704
8	420	-1	107	416
Total (blocks 1-8)	3051	4	827	3065

Table 2. Counts of Salvin's albatrosses on Proclamation Island, 15-23 November 2004. Total nests, all nests containing an egg or chick. Unmarked nest, a nest that had been overlooked during the ground count; a negative number indicates that the nest had been counted twice.

Ground count Proclamation Island block	Transect count		Total	
	Total nests	Un-marked	Marked	Adjusted nest total
1	262	1	120	265
2	99	0	28	99
3	414	1	82	419
4	312	2	100	318
5	253	1	100	256
6	216	0	100	216
7	400	-1	103	396
8	665	0	107	665
Total (blocks 1-8)	2622	4	827	2634

was kept as the most complex structure in this step. Second, we assessed different models for survival while always retaining the most parsimonious structure of the nuisance parameters. It was not possible to estimate the survival of birds banded as chicks (in March 1985) due to limited recovery data for this cohort in the first few years after banding. For this reason the recapture/recovery data for the chick cohort were modelled using the simple Cormack-Jolly-Seber (C-J-S) model in Program MARK 7.1.

RESULTS

Counts

Proclamation Island

The results of the transect counts in all years showed that few nests were missed or double-counted, and so the adjusted totals are within 1% of the total number recorded within each block in all years (Tables 1-3). These estimated adjusted totals indicated that the numbers of breeding pairs within all 8 blocks on Proclamation Island decreased by 14%, from 3,065 in 1997 to 2,634 in 2004 (Table 4). Likewise, the estimated adjusted totals of breeding pairs in blocks 1-7 decreased by 13% from 1969 in 2004 to 1721 in 2011 (Table 4). Because different boundaries were used between blocks 7 and 8 in 1997 from those used in 2004 and 2011 only the adjusted totals for blocks 1-6 could be used to estimate changes across the entire period from 1997-2011. These showed that estimates of the adjusted total numbers of breeding pairs in blocks 1-6 decreased by 30%, from 1945 in 1997 to 1368 in 2011 (Table 4). Declines occurred between all 3 years

Table 3. Counts of Salvin's albatrosses on Proclamation Island, 14 November 2011. Total nests, all nests containing an egg or chick. Unmarked nest, a nest that had been overlooked during the ground count; a negative number indicates that the nest had been counted twice.

Ground count Proclamation Island block	Transect count		Total	
	Total nests	Un-marked	Marked	Adjusted nest total
1	285	0	38	285
2	84	1	25	87
3	311	1	39	319
4	295	0	52	295
5	235	0	48	235
6	147	0	100	147
7	336	3	59	352
Total (blocks 1-7)	1693	5	361	1720

Table 4. Comparison of adjusted totals of ground counts of Salvin's albatrosses on Proclamation Island, November 1997, 2004 and 2011.*, different block boundaries were used in 1997 and 2004, therefore blocks 7 & 8 combined for comparisons.

Block	1997 Adjusted total	2004 Adjusted total	2011 Adjusted total	Difference between adjusted totals 1997 & 2004		Difference between adjusted totals 2004 & 2011		Difference between adjusted totals 1997 & 2011	
				n	%	n	%	n	%
1	344	265	285	-79	-23	20	8	-59	-17
2	151	99	87	-52	-34	-12	-12	-64	-42
3	413	419	319	6	1	-100	-24	-94	-23
4	410	318	295	-92	-22	-23	-7	-115	-28
5	335	256	235	-79	-24	-21	-8	-100	-30
6	292	216	147	-76	-26	-69	-32	-145	-50
7*	704	396	353	-59	-5	-43	-11	-	-
8*	416	665	-	-	-	-	-	-	-
Adjusted total blocks 1-6	1945	1573	1368	-372	-19	-205	-13	-577	-30
Adjusted total blocks 1-7	-	1969	1721	-	-	-248	-13	-	-
Adjusted total blocks 1-8	3065	2634	-	-431	-14	-	-	-	-

in all blocks, with the exception of block 3 where the numbers of breeding pairs counted increased about 1% between 1997 and 2004 (Table 4).

Depot & Funnel Islands
Transect counts on Depot and Funnel Islands showed that no nests were missed or counted twice in 2004, whilst a minimal number were missed on Depot Island in 2011 (Table 5). The estimated adjusted count of breeding pairs in the block on Depot Island decreased 10%, from 720 in 2004 to 648 in 2011 (Table 5).

Nest failure and timing of hatching
Of the 70 Salvin's albatross nests monitored daily from 31 October to 17 November 1997, 24 (34.3%) failed, 28 (40.0%) hatched, and 13 (18.6%) had pipped. The hatch dates of the pipped eggs were estimated using a mean pipping period of 4 days (SD 0.92, range 1-5 days) estimated from the 28 chicks that had hatched. The estimated median hatching date of these 41 chicks was 15 November (range 5-21 November; Figure 2). The remaining 5 (7.1%) eggs were candled and all were viable and close to pipping.

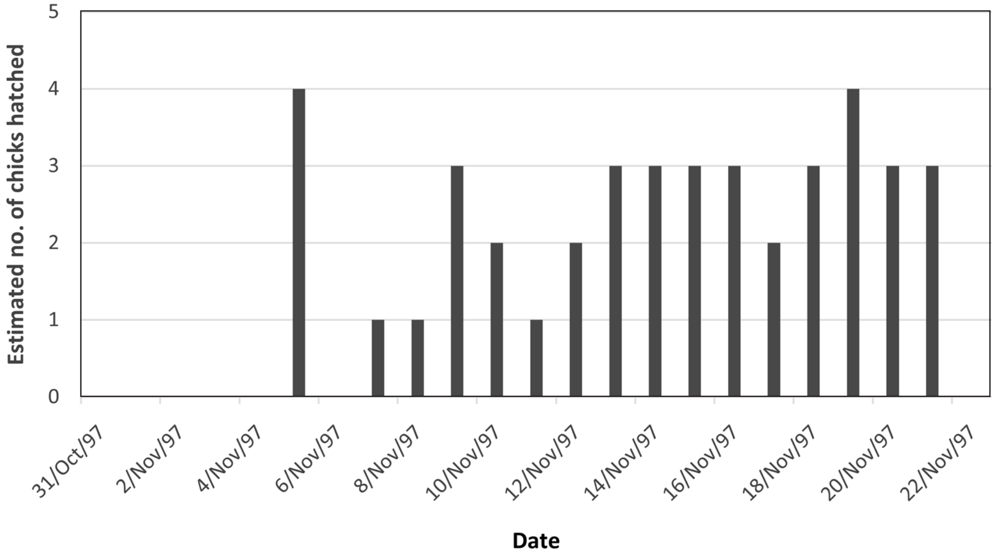

Fig. 2. Hatching dates of Salvin's albatross chicks on Proclamation Island, Bounty Islands, November 1997. $N = 41$, comprising 28 observed hatching dates and 13 estimated from pipping eggs when observations ended on 17 November 1997.

Table 5. Counts of Salvin's albatrosses on Funnel Island, 22 November 2004 and on Depot Island 21 November 2004 and 11 November 2011. Total nests, all nests containing an egg or chick. Unmarked nest, a nest that had been overlooked during the ground count.

	Ground count total nests	Transect count		Adjusted nest total
		Un-marked	Marked	
Funnel Island – November 2004	1206	0	107	1206
Depot Island – November 2004	720	0	100	720
Depot Island – November 2011	641	2	194	648

Survival

Of the 590 chicks banded on Proclamation Island in March 1985, 40 were recaptured during 1997, 23 during 2004, 17 in 2011, 4 in 2012 and 5 in 2013. One of the 17 bands recorded in 2011 was on a long-dead carcass. No birds were recorded away from the banding island. The bootstrap goodness of fit estimates a $\hat{c}$ of 1.22, indicating that the most general model had an adequate fit to the data. Results indicate that the apparent survival of the 1985 cohort of chicks (Φ) was 0.926 (SE = 0.062, 95% CI = 0.677-0.987). Probabilities of recapture, recovery and fidelity are given in Table 6. There were insufficient recaptures of the chicks banded on Depot Island for an analysis of survival.

DISCUSSION

Our results provide the first estimates of population trend and survival of Salvin's albatrosses at the Bounty Islands, while providing further information about the timing of breeding.

Population trend

Overall, on Proclamation Island the numbers of breeding Salvin's albatrosses declined by an estimated 30% over the 14 years between 1997 and 2011. Similarly, on Depot Island there was an estimated decrease of 10% in the numbers of breeding pairs in the 7 years between 2004 and 2011.The main potential errors associated with these counts include missing or double counting of nests with eggs, and including non-breeding birds in the count. However, we accounted missed or double counting by a different observer undertaking transect counts after the initial survey. By identifying the contents of each nest as either an egg or a chick, we also confirmed only breeding birds were counted in our study.

Another potential error could arise from different rates of breeding failure before the count of occupied nests. Rates of nest loss prior to all our counts are unknown. However, if we assume that all empty nests counted in the study area in 1997 and

Table 6. Probability of live recapture, reporting of dead recovery and fidelity for the S(g) p(t) r(.) F(.) Burnham model and the C-J-S model of the 1985 Salvin's albatross chick cohort, at Proclamation Island, Bounty Islands. SE, 1 standard error; LCI, lower 95% confidence interval; UCI, upper 95% confidence interval.

Parameter	Estimate	SE	LCI	UCI
Probability of recapture in 1997	0.286	0.051	0.198	0.395
Probability of recapture in 2004	0.283	0.068	0.169	0.432
Probability of recapture in 2011	0.435	0.129	0.216	0.682
Probability of recapture in 2012	0.129	0.069	0.043	0.329
Probability of recapture in 2013	0.181	0.088	0.065	0.416
Probability that a bird remains on the study area and is available for live recapture given that it is alive (fidelity)	0.961	0.066	0.442	0.999

2011 represented failed breeding attempts and that the failure rate was constant between 14 September (estimated end of egg laying (see below) and 14 November (count date), then the failure rate in 1997 (0.62% nests/day) was almost twice that of 2011 (0.34% nests/day). Therefore, application of these failure rates to back-calculate the total numbers of breeding pairs at the end of laying would indicate even higher rates of estimated population decline. However, because the estimated failure rates were not verified it is not appropriate to make this comparison.

The number of empty nests could also be affected by the proportion of pairs that attempt to breed in any given year. In colonies of other albatross species there is a proportion of nests in which no eggs are laid in any given season (*e.g.*, Buller's albatross *T. bulleri* Sagar & Warham 1998). On the Bounty Islands some empty nest pedestals are dismantled to refurbish the pedestals of neighbouring pairs (J. Amey, *pers. obs.*). Such complexity in population parameters has been recorded in other albatross species both within and between sites through intensive study over many years (*e.g.*, Prince *et al.* 1994; Sagar *et al*. 1999), but given the remoteness and inhospitable conditions such studies have not yet been undertaken on the Bounty Islands. However, the establishment of additional monitoring sites on Depot and Funnel Islands in 2004 was an attempt to account for the variability in population parameters between sites. Unfortunately, the Funnel Island site could not be visited in 2011, but the Depot Island site showed 10% fewer Salvin's albatrosses breeding there in 2011 than in 2004, thus supporting the trend estimated for Proclamation Island.

During November 1978 the density of Salvin's albatross nests on Proclamation Island was estimated from a number of quadrats, sited in areas of variable nest density, at 0.5 pairs/m^2 and when multiplied by the estimated area occupied by breeding birds resulted in an estimate of 8,656 breeding pairs (Robertson & van Tets 1982). In November 1997 there were an estimated 3,065 breeding pairson Proclamation Island (Clark *et al.* 1998; this study). Unfortunately, the methods of estimating density in 1978 are insufficiently known to allow them to be replicated (Taylor 2000). Therefore, because two methods (scaling up in 1978 and whole-island counts subsequently) were used to estimate the numbers of breeding pairs, comparison of the 1978 with subsequent estimates cannot be supported, although it does suggest a long-term decline.

Several factors may have contributed to the estimated decline in the numbers of Salvin's albatrosses breeding on Proclamation Island 1997–2011. No introduced plants or animals occur on the Bounty Islands, and so the apparent population decrease is unlikely to be due to these land-based factors (Taylor 2000). However, the numbers of New Zealand fur seals coming ashore at the Bounty Islands have increased since they were almost extirpated by exploitation in the early 19th century (Taylor 2006) and their activity may contribute to breeding failure if nesting albatrosses are disturbed or an expansion of fur seal loafing areas results in a reduction of the area available for nesting albatrosses.There have been no studies of such interactions at the Bounty Islands, and so any surmise is speculative. At-sea factors, such as, commercial fishing operations that result in bycatch or competition for the same resource and climate variability that changes the distribution or abundance of the preferred prey of albatrosses may also affect demographic parameters, and so contribute to population change. Consequently, studies are needed that integrate environmental factors, trophic levels, foraging behaviour, climate and fisheries interactions (Barbraud *et al.* 2012), if the underlying reason for population trends in seabirds are to be disentangled. Meanwhile, the apparent decrease in the numbers breeding at the Bounty Islands has resulted in the conservation status of Salvin's albatross being upgraded from nationally vulnerable to nationally critical (Robertson *et al.* 2013).

Timing of breeding

Salvin's albatrosses are annual breeders (Sagar *et al.* 2011) and the average length of the incubation period in *Thalassarche* species is 68-73 days (Tickell 2000). The only published study of the laying and incubation period within the shy albatross group (comprising Salvin's albatross, shy albatross *T. cauta*, white-capped albatross *T. steadi*, and Chatham albatross *T. eremita*) are for shy albatrosses, which has a mean incubation period of 73 days (Hedd & Gales 2005). Therefore, assuming an incubation period of 73 days for Salvin's albatrosses mean egg-laying on the Bounty Islands would be 2 September with most eggs laid 24 August – 14 September.

Our information on hatching dates indicates an earlier start to the breeding season in 1997 than in 1978. In 1997, we observed the first chicks on 5 November and estimated a median hatching date of 15 November. During their 1978 visit, Robertson & van Tets (1982) recorded that 4 of their sample of 35 nests had chicks "…almost completely hatched…" on 9 November, with 52% of their chicks hatched and 25% pipping by 19 November. Assuming that the incubation period was the same in both years, this indicates that laying was about 4 days earlier in 1997 than in 1978. On the Western Chain, The Snares, Sagar (1977), found 9 eggs, 122 live chicks and 13 dead chicks on Rima Islet on 21 November 1976. On this information, Robertson & van Tets (1982) considered that breeding on the Bounty Islands was probably 7-10 days behind that of the Western Chain. Subsequently, Clark (1996) estimated that hatching occurred from 29 October to 19 November in 1995 on Toru Islet of the Western Chain, and with the information from our study this indicates that breeding on the Bounty Islands is probably 5-10 days later than on the Western Chain, a similar estimate to that made by Robertson & van Tets (1982).

Survival

The estimated survival probability of 0.926 for the cohort of chicks banded in 1985 is less than the 0.939 estimated for the 1986 cohort of chicks banded on the Western Chain (Sagar *et al.* 2011). However, in both cases there was a long interval between banding and first recapture effort (Bounty Islands – banded 1985, first recapture effort 1997, Clark *et al.* 1998; Western Chain – banding 1986, first recapture effort 1995, Clark 1996), and so there are no estimates of mortality in these first 10-12 years of their life. Various factors may have contributed to the lower estimated survival rate of birds recaptured at the Bounty Islands compared to those from the Western Chain. These include differences in oceanographic conditions affecting levels of prey availability at fledging, leading to differential mortality shortly after fledging and, in subsequent years, differences in the degree to which the foraging range of these populations overlaps with trawl fisheries. This could lead to different levels of exposure to trawl fisheries, and so the potential for bycatch.

Breeding albatrosses are highly faithful to their nesting colony year after year (Warham 1990), and this is reflected in the estimated fidelity of 0.961.

The results presented here indicate a rapid decline in the numbers of Salvin's albatrosses breeding on Proclamation Island, Bounty Islands. Consequently, further research is warranted to determine whether this is representative of the numbers breeding on the Bounty Islands as a wholeand, if so, what factors are contributing to such a decline.

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