10 year assessment on the status and conservation of Hutton's shearwaters

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10 year assessment on the status and conservation of Hutton's shearwaters

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ABSTRACT

Monitoring of breeding success in 2006/07 and 2007/08, and visits in December 2007 to assess levels of stoat predation and burrow densities were undertaken in order to assess the status and conservation of Hutton's shearwaters 10 years after an intensive study. Long-term (20 year) estimates of burrow density within the Kowhai Valley show an increase in five out of seven monitored sub-colonies, and an increase in overall density within this colony. Along with the discovery of a new area of burrowed ground within the Kowhai these results suggest the population of Hutton's shearwaters has increased in this colony over the last 20 years, at an estimated average rate of increase of 1.7% a year. Burrow density data for Shearwater Stream is less robust, but does not appear to show a decline. Measures of predation rates in the Kowhai colony show no major differences in the numbers of adult shearwaters found on transects in comparison with the late 1990s and the recovery of shearwater carcasses from down burrows in the two recent seasons also does not differ from the late 1990s. Burrow occupancy levels in both colonies in 2006/07 (53-57%, or 66-70% if a correction factor is applied) are similar to the earlier study. In marked contrast, breeding success in both the Kowhai Valley and Shearwater Stream was unprecedentedly low in the 2006/07 breeding season and low (although within the previously recorded range for the Kowhai) in 2007/08. In both years Shearwater Stream suffered consistently lower (12-22%) breeding success than the Kowhai, a pattern also reported from 1987. Continued monitoring of breeding parameters is recommended, along with predator control within Shearwater Stream. Modelling of at-sea factors, colony size and predation rates may help to understand differences between the two colonies and inter-annual variation in breeding parameters.

1. Introduction

1.1 HISTORICAL RANGE

Hutton's shearwaters *Puffinus huttoni* are a globally endangered seabird (Molloy and Davis Category B; Taylor 2000) that breed at just two sites in the Seaward Kaikoura mountains. Their breeding range was formerly more widespread with historical records from the late 19th to the mid 20th centuries indicating more than 10 colonies in both the Seaward and Inland Kaikoura Ranges (Harrow 1976; Sherley 1992). Sub-fossil remains from North Canterbury indicate that Hutton's shearwater was apparently always restricted to the Marlborough and North Canterbury areas of South Island (Worthy and Holdaway 1995). The contraction in breeding range of Hutton's shearwater has left this species within two remaining colonies: the Kowhai Valley and smaller Shearwater Stream. Both of these sites are in rugged mountainous country at altitudes of 1200-1800m. The first of these breeding colonies was only discovered in 1964 (Harrow 1965), some 50 years after the species was described (Matthews 1912).

1.2 EARLY STUDIES OF HUTTON'S SHEARWATER

The late discovery and inaccessible breeding range of Hutton's shearwater has meant that until relatively recently knowledge of the species' breeding ecology and conservation has been restricted to information gleaned from short-visits to the breeding colonies. Following over 10 years of visits, Harrow (1965, 1976) provided the first scientific description of the breeding biology of Hutton's shearwater, detailing information on their breeding colonies, the timing of breeding, egg-laying and incubation, fledgling dispersal, activities at-sea and historical records of the species range. Evans (1973) hypothesised that Hutton's shearwaters were responsible for the large-scale erosion and the destruction of their own habitat: a hypothesis that can be rejected given the continued existence of both extant colonies 40-years after Evans' (1973) visit. Tarburton (1981) and West (1985) provided information on measurements and feeding ecology, indicating a diet mainly of krill (euphausid species) and small fish (cupeid species). Observations also indicate Hutton's shearwaters feed upon whitebait (*Galaxias* species) when this is in season (Harrow 1976). Other early studies provide some evidence for a circular migration route around Australia (Warham 1981; Marchant & Higgins 1990), and the relationship of Hutton's shearwaters to other *Puffinus* species within New Zealand (Wragg 1985).

Sherley (1992) provided the first quantitative assessment of the size of the breeding population at both the Kowhai Valley and Shearwater Stream colonies. The population size (estimated at 134,000 breeding pairs) was based upon estimates of colony area, burrow density and occupancy, although a more robust estimate of burrow occupancy re-calculated the population size to be closer to 106,000 pairs (Cuthbert & Davis 2002b). The work of Sherley (1992) also provided a baseline for the long-term monitoring of Hutton's shearwaters. Following Sherley's work, monitoring of breeding success, banding of adults and chicks, and limited predator control in two seasons was undertaken by Department of Conservation staff in three sub-colonies of the Kowhai Valley colony from 1989-90 until 1995-96 (A.Davis and B. Paton 1996).

1.3 ECOLOGICAL RESEARCH 1996-97 TO 1998-99

The installation of a research hut in the Kowhai Valley enabled a large-scale study of the species breeding ecology to be undertaken over three full breeding seasons, from 1996/97 until 1998/1999 and was carried out by R. Cuthbert and E. Sommer. As well as describing the behaviour and breeding ecology of Hutton's shearwaters in more detail, the major objective of this research was to assess the impact of predation by introduced stoats *Mustela erminea* and to provide guidance for the conservation and management of the species (Cuthbert 1999; Cuthbert 2001). The results of this three-year study, which also utilised breeding and banding data from A. Davis and B. Paton revealed new aspects on the health of the Kowhai Valley colony of Hutton's shearwaters (where >90% of the population is located). However, breeding, survival and predation estimates for Shearwater Stream remained unknown. The key results from this study and relevant published references are listed below:

1. A sensitivity analysis of Hutton's shearwaters indicated that the modelled population growth rate was most influenced by adult survival, recruitment and between-year variation in adult survival, while the population growth rate was relatively robust to variation in mean and between-year variation in breeding parameters (Cuthbert *et al.* 2001).

2. Burrow density within the Kowhai Valley is high in comparison to similar sized *Puffinus* species and the distribution of burrows within all areas of suitable habitat, and the high degree of competition for burrows (Cuthbert 1999) suggests the availability of habitat may be limited (Cuthbert and Davis 2002a).

3. Over 10 years of study, annual adult survival, breeding success and burrow occupancy averaged 93.1%, 46.5% and 70.5% respectively, a range of values very similar to demographic data for other *Puffinus* species breeding in environments free from introduced predators (Cuthbert and Davis 2002b).

4. Stoats are present in the colony year-round and shearwater remains were found in 99.6% of 788 stoat scats examined, along with remains of invertebrates (7.9%), skinks (7.6%), mice (1.5%) and hares (0.9%). Shearwater egg fragments were found in only 6.2% of scats and at low frequencies throughout the year, in contrast there was a

marked prey-switch at the time of chick hatching with stoats almost exclusively (>90%) feeding on chicks rather than adults (Cuthbert *et al.* 2000).

5. Radio-tracking data from 11 stoats indicated small home range sizes during summer (males 16.0 ha, females 9.4 ha) and that both sexes were defending intrasexual territories. This territorial behaviour is likely to limit the stoat population to around 20-30 adults within the Kowhai Valley (Cuthbert and Sommer 2002).

6. Estimates of predation based upon shearwaters found on transects through colonies (3 seasons), down study burrows (10 seasons), within intensively monitored burrows (2 seasons), radio-tracking (2 seasons) and identification of predators from kill and feeding sign (Cuthbert 2003) estimated that stoats were on average killing 0.25% of breeding adults and 12% of chicks in each season. A population model suggests the impact of this predation is a reduction in the potential yearly growth rate of 0.86%, however the overall average growth rate of the model at 0.44% a year was still positive (Cuthbert and Davis 2002c).

7. Comparison of breeding and predation rates of varying sized colonies of Hutton's and sooty shearwaters (*P. griseus*) indicate predation is inversely density dependent, with the 20-30 adult stoats present only able to take a small proportion of the 106,000 pairs of shearwaters within the Kowhai Valley (Cuthbert 2002).

8. Visits to eight extinct colonies of Hutton's shearwaters indicated that the only factors that differed to the extant colonies was the relative accessibility of the extinct sites and the presence of feral pigs (*Sus scrofa*). This evidence, along with the presence of pigs adjacent to the relatively inaccessible boundaries of the two remaining colonies, strongly suggests that predation and habitat destruction by pigs may have been the major factor in the past range contraction of Hutton's shearwater.

Following the results of this study the Department of Conservation decided that: 1) stoat control within the shearwater's breeding colonies was not a priority due to the estimated minimal impact of predation and healthy figures for breeding success and adult survival 2) long-term monitoring of the population should remain in place to assess population trends as well detect a change in predation levels if it were to occur, and 3) the establishment of a new breeding colony should be a priority as with just two extant colonies the species will remain at high risk should anything happen in these areas. Efforts to establish a third breeding colony on the Kaikoura Peninsula are now well underway with three seasons of chick translocations occurring from 2006 to 2008.

1.4 RESEARCH OBJECTIVES IN 2007

The purpose of this report is to summarize our current knowledge of the population trends and population health of Hutton's shearwaters 10 years on from the three-year study of Cuthbert (1999; 2001), and in light of unprecedented poor breeding success in 2006/07 breeding season (M. Bell 2007) assess the extent and impact of stoat predation at both the Kowhai Valley and Shearwater Stream colonies.

2. Methods and materials

2.1 TIMING OF FIELD WORK & LOGISTIC SUPPORT

Support for this project was provided by the Department of Conservation with logistical support from the DOC Kaikoura Field Centre. Transport into both colonies was provided by Kaikoura Helicopters. Fieldwork in the Kowhai Valley was carried out from 7-10 December 2007. A trip to the Shearwater Stream colony was planned, but persistent high winds and low cloud over the five-day period set aside for the work, prevented safe access to the colony. Other information on breeding success is utilised from both 2006/07 and 2007/08 following visits led by Mike Bell with support from the Department of Conservation.

2.2 FIELD METHODS

2.2.1 Burrow density estimates

Burrow density was estimated in 2007 through 105 4x4 metre quadrats, with 15 quadrats randomly distributed every 5-15 metres on a route traversing through seven sub-colonies of the Kowhai Valley. Density estimates followed the same methods as in 1998/99, when burrow density was measured in 297 quadrats within eight sub-colonies. Within each quadrat all burrow entrances exceeding 0.4 metres in length (ca. a forearm's length) were counted, apart from entrances that obviously joined the same burrow which were recorded as a single entrance. Burrows on the boundary of the quadrat that were adjudged to be more than 50% outside the boundary line were not recorded. A fuller description of these methods is provided in Appendix 2 of Cuthbert (2001). No attempt was made to assign burrows as "used" or "unused" on the basis of sign at the burrow entrance (c.f. Sherley 1992), as comparisons between 8 independent observers found this method was on average only accurate in 63.5% of cases for burrows of known occupancy and that there were also large differences between observers (Cuthbert and Davis 2002b). Earlier sources of burrow-density data following the same methods (randomly distributed 4x4 metre quadrats) are available from the 1997/98 breeding season (50 quadrats randomly distributed across the whole Kowhai Valley; Table 1), 1998/99 season (296 quadrats in 8 monitored sub-colonies), and the 2004/05 season (175 quadrats in 7 sub-colonies).

Burrow density estimates for the Kowhai Valley and Shearwater Stream are also available from Sherley (1992), and Smale and Sherley (1997). This work was based upon counts within fixed 10x10 metre quadrats, along with estimates of burrow occupancy assigned from sign at the entrance. A sub-sample of these quadrats (because of the loss of marker-poles) was resurveyed in 1997/98 within the Kowhai Valley. No fixed quadrats could be found within Shearwater Stream in 1997/98 or 1998/99. Because of evidence over the accuracy of estimating occupancy on the basis of sign (see above), trends using Sherley's data are based upon the total number of burrow entrances within quadrats.

The final source of burrow density estimates comes from Shearwater Stream in 2007, where M. Bell counted burrow entrances in 31 randomly distributed circular quadrats with an area of 20 m2, within 4 separate sub-colonies.

The methods used in all these studies, area covered and sub-colonies monitored are recorded in Table 1.

TABLE 1: DENSITY QUADRATS IN KOWHAI VALLEY AND SHEARWATER STREAM.

AREA	YEAR	QUADRATS	QUADRAT AREA (HA)	% OF COLONY AREA*	NUMBER OF SUB-COLONIES	METHODS USED
KV	1987	17	0.17	0.7	14[A]	Fixed 100 m^2 quadrats
KV	1991	15	0.15	0.6	11[B]	Fixed 100 m^2 quadrats
KV	1997	50	0.08	0.3	Random over valley	Random 16 m^2 quadrats
KV	1998	296	0.47	1.9	8[C]	Random 16 m^2 quadrats
KV	1998	10	0.10	0.4	8[D]	Fixed 100 m^2 quadrats
KV	2004	175	0.28	1.2	7[E]	Random 16 m^2 quadrats
KV	2007	105	0.17	0.7	7[F]	Random 16 m^2 quadrats
SS	1988	7	0.07	2.6	5[G]	Fixed 100 m^2 quadrats
SS	1993	5	0.05	1.9	4[H]	Fixed 100 m^2 quadrats
SS	2007	31	0.06	2.3	4[I]	Random 20 m^2 quadrats

* Area calculated by Sherley 1992

[A] Sub-colonies 1, 4, 5, 6, 7, 8, 9, 21, 14, 15, 16/17, 18, 24, 29

[B] Sub-colonies 1, 4, 5, 6, 7, 8, 9, 15, 16/17, 18, 29

[C] Sub-colonies 1, 4, 5, 9, 15, 30, 31, 32

[D] Sub-colonies 1, 4, 5, 9, 15, 30, 32

[E] Sub-colonies 1, 4, 5, 9, 15, 30, 32

[F] Sub-colonies 1, 4, 5, 9, 18, 30, 33

[G] Sub-colonies 1, 2, 3, 4, 5

[H] Sub-colonies 1, 2, 4, 5

[I] Sub-colonies unknown, but assumed to be the four main sub-colonies

2.2.2 Colony area and habitat

Within the Kowhai Valley colony as many sub-colonies as possible were visited by RJC and ESS in the 2007 to assess if there have been reductions in the areas of breeding colonies. Time constraints prevented a more robust approach (such as using GPS to map sub-colony boundaries), although we feel this qualitative approach would be good enough to pick up major changes. In addition, we also looked for any overall changes in the colony between 2007 and the late 1990s, such as erosion, deer browse, presence of stoat-scats and stoat-caches.

2.2.3 Estimating predation rates from transects

During the three-year study of Cuthbert (1999), transects totalling between 2.6 to 3.9 km in length (depending on the year) were established in order to determine causes of mortality and estimate predation rates of adult birds within the colony. Between 7 and 9 areas of the Kowhai Valley were monitored within sub-colonies 4, 5, 9, 15, 18, 30 and 32 in all three years, as well in sub-colonies 7 and 19 in year 1. Transects were fixed and marked, and traversed upwards from one side to the other of each sub-colony following a “zig-zag” route. Transects were walked at a slow and careful pace, stopping every 2-3 steps to scan in all directions for the presence of shearwater bodies. All carcasses were then collected and examined to determine the cause of death. These transects were walked twice a month during all three 6-month seasons of Cuthbert (1999) and provided two separates estimates of mortality rates:

1. The average number of adult shearwater carcasses found per distance of transect walked.
2. The estimated density of adult shearwater carcasses within sub-colonies, based upon the perpendicular distance of each carcass from the transect line and distance-sampling analysis (program DISTANCE; Laake *et al.* 1993).

During December 2007 transects were repeated in 13 sub-colonies, with an estimated total distance of 7.5 km of transects walked (measured by GPS or through counting paces). There were not enough carcasses recovered to estimate the density of bodies using distance-sampling, therefore comparison between the late 1990s and 2007 were based on the number of carcasses found per unit distance walked. All carcasses found were autopsied and classified by carcass age based on the same signs as used in the late 1990s. Of most interest was to classify carcasses into <2 and >2 weeks of age; during the three seasons of intensive study transects were repeated twice a month and all birds were removed, thus all birds we were collecting were generally <2 weeks in age.

2.2.4 Estimating predation rates from burrows

The numbers of dead adults and chicks found down study burrows or down burrow-scoped burrows was used to estimate predation rates of birds within burrows (Cuthbert and Davis 2002c) and the continued monitoring of carcasses down burrows was recommended as a means of determining changes in predation. Over the 10 seasons from 1989/90 to

1998/99 numbers the number of adults found down burrows was very low with just 6 dead adults from a total of 1,538 burrows checked, an overall pooled mean of 0.39%. Numbers of chicks down burrows was higher with 26 dead chicks from 1,465 over nine seasons (fledging data was not collected in 1995/96), with an overall pooled average of 1.77%.

New estimates of predation rates down burrows are available from the 2006/07 and 2007/08 breeding seasons, following visits to burrowscope sub-colonies within both the Kowhai Valley and Shearwater Stream colonies (M. Bell 2007 and pers.comm.). While visits and checks of burrows in these two seasons were less frequent (burrowscoping was undertaken in the early incubation and late chick-rearing periods, versus early incubation, hatching and late chick-rearing in the earlier study) carcasses of adults and large chicks usually persist within burrows (RJC own observations), enabling comparisons to be made.

2.2.5 Burrow occupancy and breeding success

New estimates of burrow occupancy and breeding success are available from the 2006/07 and 2007/08 breeding seasons, following visits to both the Kowhai Valley and Shearwater Stream colonies (M. Bell 2007 and pers. comm.) to burrowscope burrows during the incubation and chick-rearing periods. Concerns have been raised over the accuracy and precision of burrowscopes and within the Kowhai Valley they have been shown to be unable to classify a burrow's contents in 9% of occasions (due to burrows being too tight or twisted) and furthermore to incorrectly classify a further 10% of burrows where the contents were adjudged to be determined (Cuthbert and Davis 2002b). However, for burrows that were classified as occupied during the first check of the breeding season (a bird incubating an egg) burrowscopes were likely to be accurate in measuring breeding success during subsequent checks of the same burrow (Cuthbert and Davis 2002b).

These concerns over the accuracy of burrowscopes suggest all estimates derived from this equipment needs to be treated with some caution, especially burrow occupancy. It is recommended that in future years of monitoring any use of burrowscopes should be augmented with study burrows, where the occupancy status and outcome is without doubt and additional data (such as chick age and banding of adults) can be gathered. Cuthbert and Davis (2002b, see Table 3) report that overall burrowscopes underestimated burrow occupancy by 12% in comparison to burrows checked through study hatches. Consequently, burrow occupancy estimates from 2006/07 are examined with and without a correction factor of 12%.

In addition, the methods deployed in 2006/07 and 2007/08 also differed in the definition of burrow occupancy during the incubation period with all burrows containing a shearwater classified as occupied (with the assumption that all birds were incubating eggs), whereas during 1989/90 to 1998/99 burrows were classified as occupied only if it is was certain they contained a bird incubating an egg. From personal experience (RJC and ES), during incubation in the Kowhai Valley some burrows contain non-incubating birds. Burrowscoping data from 1997/98 found that for 306 burrows checked 16 (5.2%) of these contained birds but no eggs. Consequently estimates of breeding success from 2006/07 and 2007/08 may slightly underestimate the true figure. Lastly, because the objective of burrowscoping in 2007 was to find as many incubating adults as possible to allow breeding success to be estimated, information on the total number of burrows checked was not kept, and thus burrow occupancy (the proportion of total burrows containing an incubating pair) cannot be calculated for this year.

3. Results

3.1 BURROW DENSITY

Comparison of burrow density within the Kowhai Valley based upon randomly distributed 4x4 metre quadrats indicate significant differences in the density of burrows within individual sub-colonies and within the whole valley. Increases are apparent when comparing all available sub-colonies monitored (8 in 1997/98, 7 in 2004/05 and 7 in 2007/08), or comparing the same 6 sub-colonies that were monitored in all three years. Comparison of individual sub-colonies suggests increases have occurred in five out of seven sub-colonies (Table 2). Changes in burrow density for the two sub-colonies with negative slopes (based on the fitted regression line through all three years of survey) were not significant at $P < 0.05$ (singe-factor ANOVA).

There is less power to detect overall trends with the more limited number of fixed 10x10 metre quadrats established by Sherley (1992), and a single-factor ANOVA for the Kowhai Valley using all three years of measurements (1987, 1993, 1998) was non significant ($F_{2,39} = 0.78$, $P = 0.47$). Comparing burrow numbers between the same fixed quadrats indicated significant positive correlations for all three pairs of correlations (1987 & 1993, $R^2 = 0.81$, $n = 15$ quadrats, $P < 0.001$; 1993 & 1998, $R^2 = 0.80$, $n = 8$, $P < 0.005$; 1987 & 1998, $R^2 = 0.69$, $n = 10$, $P < 0.01$), although (unsurprisingly) the strength of the correlation between burrows numbers is weaker for the longer time interval between the 1987 & 1998 estimates. Paired T-tests, comparing differences between matched pairs of quadrats provides more power to test for differences, and these indicate no significant difference in burrow densities between 1987 & 1993 ($t = 1.45$, $n = 15$, $P = 0.17$), but significant increases between 1993 & 1998 ($t = 2.89$, $n = 8$, $P < 0.05$) and 1987 & 1998 ($t = 2.97$, $n = 10$, $P < 0.02$). Fixed quadrats within Shearwater Stream show no significant correlation between burrow numbers ($R_2 = -0.06$, $n = 5$, N.S.) and no significant difference in burrow densities with a paired t-test comparing 1988 & 1993 ($t = 0.72$, $n = 5$, $P = 0.51$), although the number of repeat measurements is very low.

Using all available density estimates and comparing over time provides further evidence that there has been no decrease in burrow density within the Kowhai Valley colony (Figure 1), and the positive slope of the line approaches significance (*P* = 0.07).

Table 2 shows results from burrow density estimates for the Kowhai Valley colony from 1997/98, 2004/05 and 2007/08 breeding season following the same survey methodology (randomly distributed 4x4 metre quadrats), indicating the total number of quadrats within the valley or each sub-colony, mean burrow density (burrows/ha), *P* values for single-factor ANOVA (and t-test for colony 15) for testing for significant differences in burrow density between the three years, and the fitted slope of the regression line over the ten-years (estimated change in burrows/year).

TABLE 2

SUB-COLONY	1997-1998 DENSITY	N	2004-2005 DENSITY	N	2007-2008 DENSITY	N	P	SLOPE
All data	6383	(296)	5843	(175)	7411	(105)	<0.001	85.0
Same 6	5925	(229)	4950	(150)	6938	(90)	<0.001	73.2
1 (Camp)	4831	(37)	3775	(25)	4292	(15)	n.s.	-76.5
4	3849	(38)	4450	(25)	7667	(15)	<0.001	377.9
5	5223	(28)	4425	(25)	5625	(15)	n.s.	19.2
9 (Top)	7452	(52)	6375	(25)	9417	(15)	<0.01	161.5
15	9010	(48)	11200	(25)	-	-	<0.001*	364.9
30 (Col)	6750	(20)	4900	(25)	8042	(15)	<0.005	79
33 (New)	6722	(44)	5775	(25)	6583	(15)	n.s.	-35.7
32 (Woody)	5263	(19)	-	-	-	-	-	-
18	-	-	-	-	10250	(15)	-	-

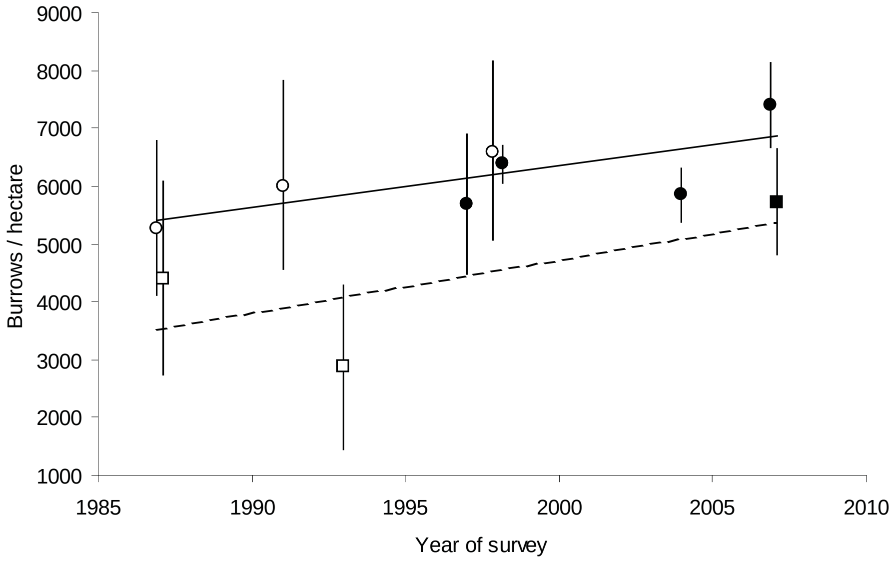


Figure 1: Average burrow density estimates and fitted regression lines for the Kowhai Valley (circles and un-dashed line) and Shearwater Stream (squares and dashed line). Unfilled circles and squares are data from repeated burrow counts at fixed 10x10 metre quadrats. Filled circles are from randomly distributed 4x4 metre quadrats within the Kowhai Valley and filled squares are randomly distributed 20m2 circular quadrats within Shearwater Stream. Error bars are 95% confidence intervals around the mean, calculated from a t-distribution for random quadrats (where data were normally distributed) and from boot-strapping for fixed quadrats.

Within the Kowhai Valley overall burrow density is estimated to have increased by 40% for the 20-year period from 1987 to 2007: an annual rate of increase of 1.7% a year. Estimated increases for the periods 1988 to 1998 and 1997 to 2007 (i.e. increases estimated using the same survey methods: fixed and random quadrats) indicate annual increases for these two 10-year periods of 2.5% and 1.5%, respectively. With only three measurements, analysis of the data for Shearwater Stream is less robust and the regression is non-significant (R^2 = 0.43, n = 3, P = N.S.; $F_{1,2}$ = 0.76, P = 0.54). However, the slope of the line is very similar for both Shearwater Stream and the Kowhai Valley (Figure 1).

3.2 COLONY AREA AND HABITAT

Our visit to the Kowhai Valley colony gave no clear indication that there had been major changes in the area of sub-colonies or habitat within the valley. Searches along the main valley floor were made to look for stoat dens and caches of shearwaters. While the presence of stoats was confirmed (with scats recovered from many typical sites and shearwater carcasses with characteristic kill and feeding sign) there was no indication from searches for caches that there had been a step-change in predation rates.

One obvious difference between 2007 and the late 1990s was the presence of considerable deer-sign. In the late 1990s chamois were the only ungulate routinely seen in the valley; red deer were only seen within the valley on a few occasions in the three years. The degree of browse and prominence of well-worn paths suggests that deer numbers (and possibly goat numbers) have increased in the valley in the last 10 years. The presence of a well-worn deer path in to the valley from the “one” access point above the waterfall blocking the southern extremes of the colony is of major concern, as this is close to the areas where feral pigs have previously been seen, and thus may make it easier for pigs to enter the colony. Reports from Shearwater Stream (M. Bell pers.comm.) also indicate considerable numbers of deer and goats within the colony, with some evidence of damage to burrows and certainly to vegetation.

Whilst localised erosion is occurring in some sub-colonies (especially the lowest section of sub-colony 6 which is undercut by the Kowhai river) visits to more than 10 sub-colonies and scanning other sub-colonies with binoculars indicated no major change in the extent of their area in comparison to the late 1990s. The one major difference was the discovery of a new and heavily burrowed area of ground in the southeast corner of the valley where upwards of 500 burrows are occurring in two patches (Figure 2). This area was not marked or mapped as an area of burrowed ground by Sherley (1992), nor was it marked or mapped in the late 1990s study period (Figure 3).

This site is across a steep gut and was explored and visited in both 1997/98 and 1998/99 and was classified then as an old remnant colony, with a few old burrows and evidence (from the size and shape of the tussocks and earth) that it had once been more extensively burrowed. The density and extent of burrowing in 2007 is new. Dave Walford (DOC Kaikoura) independently recognised this new area and spoke to us about it after the December 2007 visit, as he had hunted through this area in the November 2007 burrowscope trip and remembered from previous hunting trips that there had not formerly been burrows here.

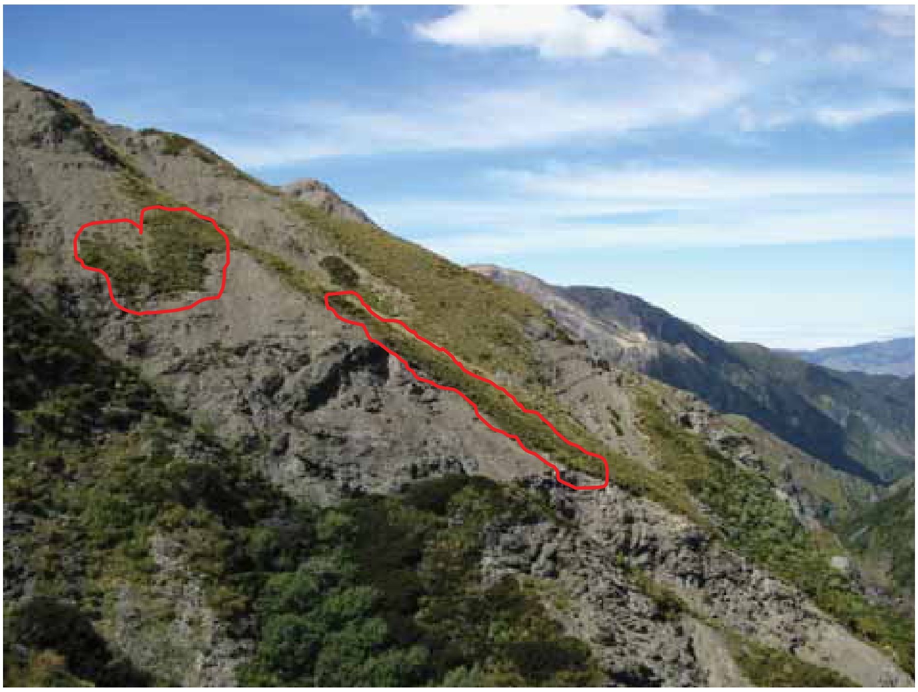
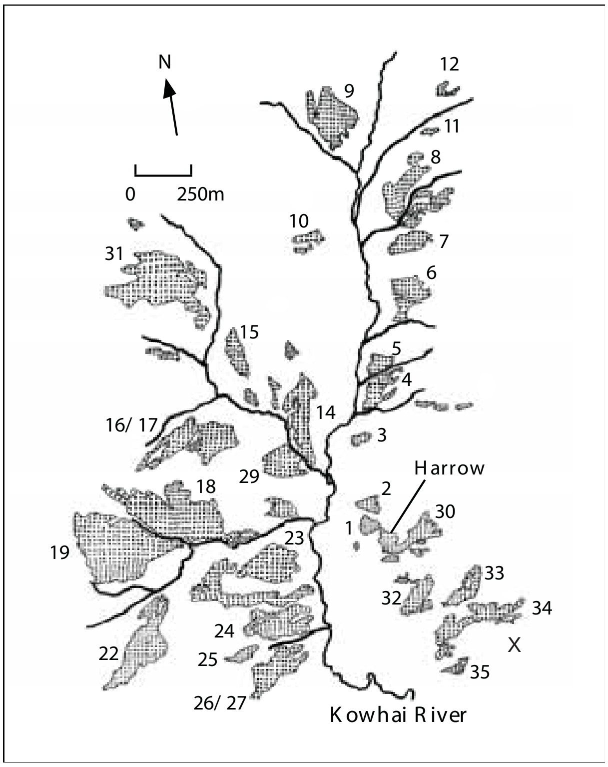


Figure 2: New areas of colony within the Kowhai Valley demarcated with a red outline. The photo was taken looking south from the top of sub-colony 33.

Figure 3: Map of the Kowhai valley colony. Numbering of sub-colonies follows figure 2 of Sherley (1992), with the exceptions of areas 18 and 19, which were formerly labeled as 18b and 18a respectively, and sub-colonies 32, 33, 34 and 35 that were not clearly demarcated by Sherley (1992). The approximate position of the newly discovered colony is indicated by “X” in the southeast corner of the map.



3.3 PREDATION RATES FROM TRANSECTS

Transects totalling 7.5 km in length were walked by RJC, ES, P. Gaze and P. Bradfield during December 2007. A total of 20 adult shearwater carcasses were recovered. Necropsy and inspection indicated that one of these was from a previous year and that 6 were likely to be >2 weeks in age. The final figures are 19 carcasses from the current 2007/2008 season, with 13 carcasses two weeks in age, giving overall estimates of 2.5 and 1.7 birds/km of transect walked, respectively. Comparison of these rates with data for adult carcasses on transects from the late 1990s indicate no major difference in the numbers of birds found (Figure 4). For the three field-seasons in the late 1990s there was no significant seasonal trend in mortality (one-way ANOVA $F_{6,10}$ = 0.67, N.S.) for the 7 half-monthly periods from early October to early January (when adult birds were recovered, before the arrival of chicks as the predominant item in the diet of stoats). The overall average number of adults found during October to early January in 17 sessions over the three seasons was 2.0 adults/km (an overall pooled total of 99 birds found over 48.8km of transect walked during October to January in these three years). T-tests indicate no significant difference in the recovery of carcasses in 2007 in comparison to the 17 sessions from the study in the late 1990s.

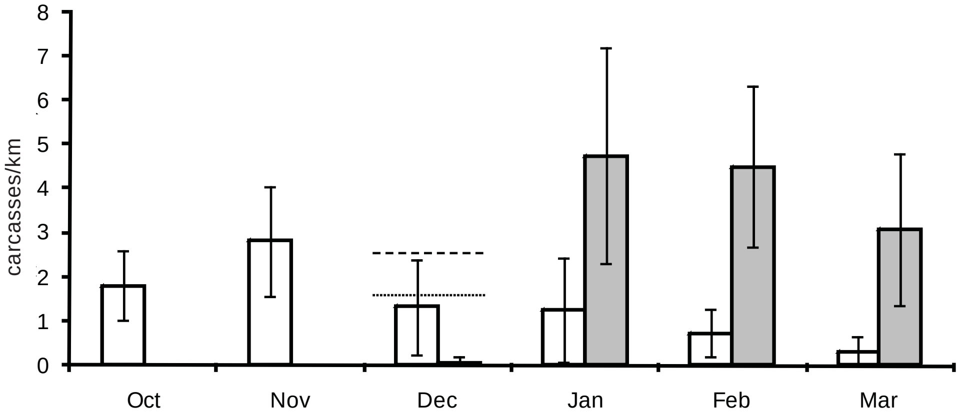


Figure 4: Mean number of adult carcasses (unfilled bars ± 1 SD) and chick carcasses (filled bars) found per kilometre of transect walked during the three intensive seasons in the late 1990s and the number of adults found per km during December 2007 (dashed horizontal lines). The lower dashed line includes all 19 birds found on the transect (regardless of age), whereas the upper dashed line represent the number of birds estimated to be <2 weeks in age. For clarity monthly averages are presented, although transects were walked twice a month.

3.4 PREDATION RATES FROM BURROWS

Checks of both Shearwater Stream and the Kowhai Valley in the 2006/07 and 2007/08 breeding seasons found no dead adults down burrows during the burrowscoping sessions, however there were a total 5 dead chicks from the Kowhai Valley and 2 from Shearwater Stream (Table 3). The overall pooled average for Shearwater Stream and the Kowhai Valley in these two seasons was 1.1% and 2.3%, respectively. Both of these estimates are within the pooled 95% confidence intervals for the number of dead adults recovered during the 10 years of study in the Kowhai Valley (Table 4), indicating no major change in numbers of dead birds down burrows.

TABLE 3: NUMBERS OF BURROWS CHECKED AND NUMBERS OF ADULT AND CHICK CARCASSES RECOVERED DOWN BURROWS IN THE KOWHAI VALLEY AND SHEARWATER STREAM COLONIES IN 2006/07 AND 2007/08, ALONG WITH THE POOLED MEAN OVER BOTH YEARS.

	KOWHAI VALLEY				SHEARWATER STREAM			
YEAR	2006	2007	TOTAL	POOLED MEAN	2006	2007	TOTAL	POOLED MEAN
Burrows	187	166	353		119	>124	>243	
Dead adults	0	0	0	0.0%	0	0	0	0.0%
Burrows	80	139	219		57	124	181	
Dead chicks	0	5	5	2.3%	1	1	2	1.1%

TABLE 4: NUMBERS OF BURROWS AND NUMBER OF ADULT AND CHICK CARCASSES RECOVERED DOWN BURROWS FROM 1989/90 TO 1998/99 WITH POOLED MEAN FOR THE 10 YEARS AND 95% C.I.

YEAR	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	TOTAL	POOLED MEAN	LOWER CL	UPPER CL
Burrows	50	55	83	90	87	84	73	350	386	280	1538			
Dead adults	0	0	0	0	4	0	0	2	0	0	6	0.39%	0.14%	0.85%
Burrows	50	55	83	90	87	84	*	350	386	280	1465			
Dead chicks	1	0	1	3	4	4	*	5	7	1	26	1.77%	1.16%	2.59%

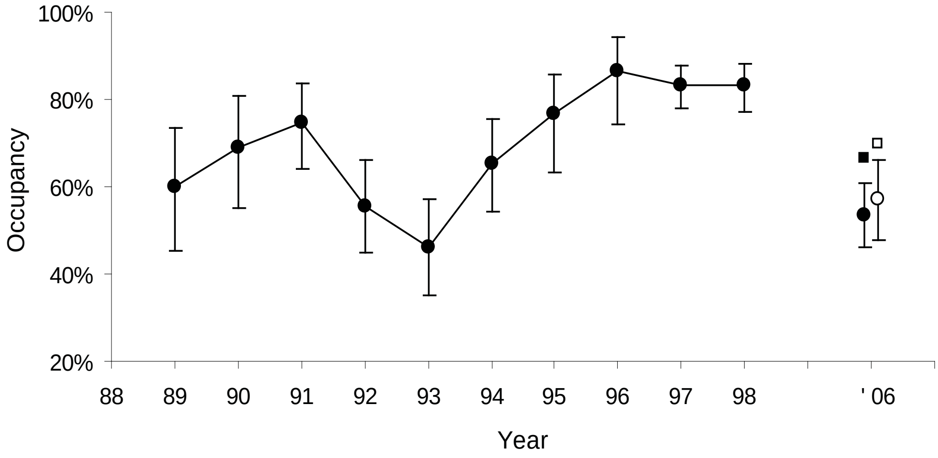
*There was no visit to the colony at the late chick stage in this season.

3.5 BREEDING SUCCESS AND BURROW OCCUPANCY

Burrow occupancy was estimated with the burrowscope in 2006/07 with occupancy values of 53.5% within the Kowhai Valley (*n* = 187 burrows checked) and 57.1% in Shearwater Stream (*n* = 119 burrows) (M. Bell 2007). If a correction factor of 12% is introduced to account for underestimating occupied burrows with the burrowscope, then occupancy may have been around 65.5% and 69% respectively. Estimates of breeding success in 2006/07 were very low for both colonies, with Bell (2007) locating just 16.3% and 3.5% of rechecked burrows contained chicks in the Kowhai Valley and Shearwater Stream, respectively. Even if ca. 5% of the original burrows checked during incubation contained non-incubating birds then estimated breeding success was still very low (17.1% and 3.7%). In the 2007/08 “breeding success” was again very low in Shearwater Stream with only 9 chicks found from 124 burrows that were rechecked, a productivity figure of around 7%. The Kowhai Valley recorded better values with 40 chicks found from 139 burrows, an overall breeding success of 29%. However there were strong differences between different areas of the Kowhai Valley with Camp sub-colony recording chicks in 22% of burrows (14 chicks from 91 burrows), whereas Opposite-Top sub-colony had chicks in 57% of burrows (26 from 48 burrows). The recovery of “6-7” dead chicks in Camp colony strongly suggests high rates of stoat predation within this sub-colony in 2007/08.

This monitoring indicates that (regardless of some uncertainty due to methodology) breeding success has been poor in both 2006/07 and 2007/08 seasons, and especially so for Shearwater Stream. However, burrow occupancy levels at both sites appear similar in 2006/07 to those recorded in the 10 years from 1989/90 (Figure 5). Breeding success in 2006/07 is very low for both colonies and unprecedentedly low for the Kowhai in comparison to previous years (Figure 5). However, in 2007/08 whilst breeding success is still poor (29%) it is nonetheless similar to other years within the Kowhai Valley (Figure 5). These two years (1992/93 and 1993/94) were when stoat control was undertaken within the colony.

While there are only two seasons of data, the values of breeding success for Shearwater Stream are very poor in both years (3.5% and 7%) and appear consistently lower than the Kowhai Valley (12.5% lower in 2006/07 and 22% in 2007/08). Interestingly, Sherley (1992) found a similar difference between the Kowhai Valley and Shearwater Stream for an indirect estimate of productivity (the proportion of burrows containing chicks and feather-down divided by the total number of burrows assigned as “used” based on sign at the entrance), with estimates of 31% and 16% respectively. While there is some considerable uncertainty in the accuracy of this, the difference of around 15% between the two colonies, is consistent with the results from 2006/07 and 2007/08. Stoat control has also been undertaken in Shearwater Stream in both these two poor breeding seasons, with more than 100 traps present, although there is little information on the number of animals trapped and killed.



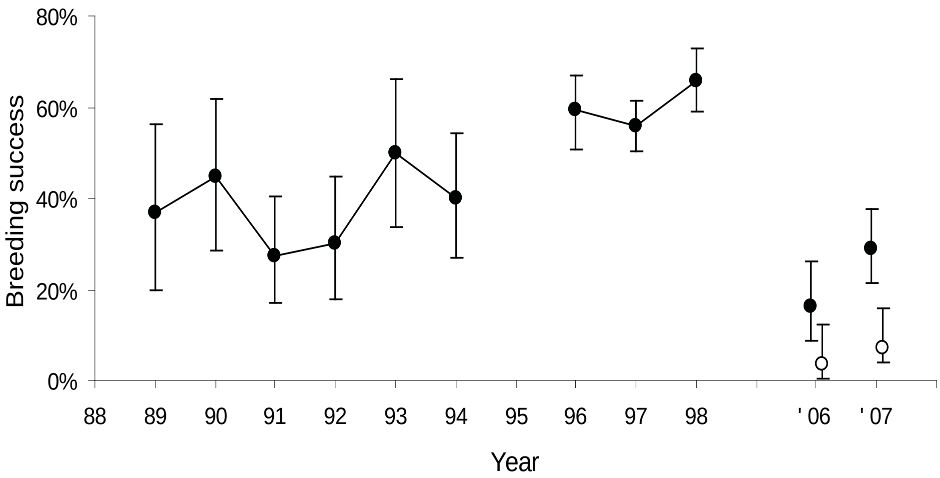


Figure 5: Colony estimates of burrow occupancy and breeding success for the Kowhai Valley (filled circles) from 1989/90 to 1998/99, and from the Kowhai Valley and Shearwater Stream (unfilled circles) in 2006/07 and 2007/08. For burrow occupancy in 2006/07 square values represent the estimate with a correction factor of 13%. Error bars represent 95% confidence intervals. Stoat trapping was undertaken in the Kowhai in 1991/92 and 1993/94.

4. Discussion

The results of this study ten-years on from the intensive study of Hutton's shearwaters in the late 1990s show some contrasting results.

1. Long-term (20 year) estimates of burrow density within the Kowhai Valley that have been measured by different observers and with varying methods show an increase in burrow density in 5 out of 7 sub-colonies that have been repeated, and an overall increase in burrow density within the overall colony. Along with the discovery of a new area of burrowed ground within the Kowhai these results suggest the population of Hutton's shearwaters has increased in this colony over the last 20 years. Burrow density data for Shearwater Stream is less robust, but does not appear to show a decline.
2. Indirect measures of predation rates show no major differences in the numbers of adult shearwaters found on transects during 2007 in comparison with the late 1990s, with numbers found in 2007 (1.7 to 2.5 carcasses/km) very similar to the three-year average from 1997/97 to 1998/99 (2.0 carcasses/km).
3. The recovery of shearwater carcasses from burrows also show no major differences during 2006/07 and 2007/08 breeding seasons in comparison to the late 1990s. No adults were found down burrows in the two recent years of study, and the percentage of chicks found (2.3% in the Kowhai and 1.1% at Shearwater Stream) is within the range recovered from 1989/90 to 1998/99 (an average of 1.77%).
4. In marked contrast, breeding success in both the Kowhai Valley and Shearwater Stream was unprecedentedly low in the 2006/07 breeding season and low (although within the previously recorded range for the Kowhai) in 2007/08. In both years Shearwater Stream suffered consistently lower breeding success than the Kowhai. Poor breeding success at Shearwater Stream has occurred despite the presence of some stoat control in the last two seasons. While breeding success is very low, burrow occupancy levels in both colonies in 2006/07 (53-57%, or 65-69% if a correction factor is applied) are similar to 1989/90 to 1998/99.

These contrasting results present an interesting picture of the conservation status and health of both remaining colonies. For the Kowhai Valley the evidence suggests a long-term increase in the population (a result consistent with population modeling; Cuthbert and Davis 2002c) at an annual rate of around 1.7% since quadrats were first undertaken in 1987. The validity of the conclusion that the population has increased within the Kowhai Valley depends on suitability of just using burrow density to indicate population trends. This approach was recommended by Cuthbert (2001) due to the natural high rates of turnover in burrow entrances in the often soft and friable soil within the sub-colonies. During the study in the late 1990s, of 109 and 156 burrow entrances marked in the 1996/97 and 1997/98 seasons respectively, 6 and 9 burrow entrances were filled in with soil/collapsed in the following breeding season (an average loss of 5.7% of burrows from one season to the next). Consequently, in order to maintain a constant number of burrows from year to year, new burrows will need to be dug by birds at an annual rate of ca. 5%; therefore if numbers of breeding birds were really declining this should be closely followed by a decline in burrow numbers. The evidence from the Kowhai Valley also suggests no major change in adult mortality from adult carcasses on transects and down burrows, nor any major change in rates of chick mortality down burrows, but two poor seasons of breeding success. If this evidence is correct is has important implications because the sensitivity analysis of Hutton's shearwaters indicated that the population growth rate was most influenced by rates of adult survival, and relatively robust to variation in mean and between-year variation in breeding parameters (Cuthbert *et al.* 2001): populations of a long-lived seabird like Hutton's shearwater can withstand some very poor years of breeding success.

Because of the estimated low impact of stoat predation within the Kowhai Valley colony and the fact that breeding success was lowest within the valley during two years of stoat control (1991/92 and 1992/93), it was concluded that between-year variation in breeding success is more likely to be influenced by environmental factors rather than predation (Cuthbert 2002). The key environmental variable likely to be most affecting Hutton's shearwater is the availability of food and feeding conditions at-sea, although heavy winter snowfalls do cause local effects within the colony through preventing birds from accessing their burrows (Harrow 1976; RJC unpublished). A recent paper by Mills *et al.* (2008) explores the role of euphausid availability and various measures of at-sea conditions in a long-term study (41 years) of red-billed gulls *Larus novaehollandiae scopulinus* on the Kaikoura Peninsula. This study indicated significant positive relationships between the availability of euphausids and various measures of gull breeding performance and also found that inter-annual availability of euphausiids was influenced by various measures of at-sea environmental conditions including the Southern Oscillation Index (SOI) and frequency of certain winter and weather types. Exploring whether these, or other environmental factors, have a similar relationship with breeding parameters of Hutton's shearwater would be of interest in trying to understand the observed inter-annual variation in breeding success and especially if this can explain the two recent very poor years of breeding.

Stoats are certainly still present and predation of shearwaters is still occurring within the Kowhai Valley, and measures of breeding success (and numbers of dead chicks) indicate some sub-colony differences in predation rates. Potentially some differences in the variability of sub-colony breeding success (and possibly the reliability of the overall estimates of breeding success) are due to the sampling design in 2006/07 and 2007/08. For speed and ease of re-finding, burrows for checking breeding success were clumped closely together in these two years. Intensive monitoring of burrows and radio tracking of stoats in 1997/98 and 1998/99 indicated that stoat predation is also clumped, with an animal frequently returning to the same patch and removing all (or nearly all) chicks from this area. Monitoring of breeding success in the late 1990s was carried out at more sub-colonies (eight), and within each sub-colony burrows for checking were distributed at 5 to 10m intervals along transects that traversed through the area. The effect of this sampling design will be to reduce the likelihood of sampling burrows from a single stoat predated area (or an area untouched by stoats) and in combination with a larger number of sub-colonies visited should provide a better and less variable estimate of breeding success within the whole colony.

For Shearwater Stream our conclusions are less robust due to the reduced scale of work that has occurred there. Monitoring of burrow density is inconclusive, although there is no evidence for a major decline in burrow numbers from 1987 to 2007. The habitat and soils within Shearwater Stream are very similar to the Kowhai Valley, and again burrow density should be a relatively sensitive indicator of population change. Measures of burrow occupancy and predation rates from burrows also indicate comparable values with the Kowhai Valley study from the 1990s. Breeding success within Shearwater Stream is very poor and if the values recorded in 2006/07 and 2007/08 (3.5% and 7%) are close to the real long-term average for the colony then these values of breeding success are clearly not sustainable for the population. Values of breeding success also appear to be consistently 12-22% lower at Shearwater Stream in comparison to the Kowhai. The most likely explanation for these differences between the two colonies is a land-based threat and in particular differential impact in stoat predation at Shearwater Stream.

One of the main conclusions of the study in the Kowhai Valley was that inverse density-dependent predation was occurring whereby the “safety in numbers” of shearwaters meant that the stoats could only kill a small proportion of adults, eggs and chicks. Shearwater Stream is more than an order of magnitude smaller than the Kowhai colony (ca. 8,000 versus 106,000 pairs) and hence the proportional impact of stoats in Shearwater Stream may be greater (however the Taiaroa Head colony of sooty shearwaters on the Otago Peninsula with ca 2,100 pairs appears large enough to benefit from inverse density-dependent predation, although this colony may also directly benefit from predator control at the nearby Northern Royal Albatross breeding colony). Shearwater Stream (with fewer breeding pairs) is also more likely to see reduced protection from safety in numbers in seasons with naturally occurring poor breeding success (e.g. influenced by at-sea conditions) and the magnitude of any poor season could be increased by stoats predating a greater proportion of chicks in these years. Modeling the number of stoats, natural fluctuations in occupancy and hatching success and chick predation may help determine if the 12-22% difference between the two colonies is consistent with the small size of the Shearwater Stream colony.

Of interest and concern is that the two very poor seasons of breeding success in Shearwater Stream have occurred in years where trapping and stoat control has taken place. Similar results from the Kowhai Valley (where stoat trapping occurred in 1992/93 and 1993/94) led to the conclusion that (for the Kowhai colony) other environmental factors had a greater influence on breeding success than stoat predation (Cuthbert 2002). The impact of stoat predation may well be of greater importance in the smaller Shearwater Stream colony and what is of concern is that despite two years of trapping, breeding success was still lower than in the Kowhai: suggesting that the efficacy of stoat control at protecting shearwaters is low. Trapping in both years at Shearwater Stream was done by the landowner. In the first year most traps were set outside of the colony and these, as well as those in the colony, were checked infrequently. The number of animals caught is unknown. As the population of birds at both colonies should be influenced by the same at-sea factors, the Shearwater Stream and Kowhai Valley colonies can act as controls for one another, and stopping stoat control at Shearwater Stream during one season could test the efficacy of trapping and/or the differential impact of stoats. Trapping and burrowscoping in Shearwater Stream on its own, without gathering comparable occupancy and breeding data from the Kowhai Valley, will limit the ability to determine if any changes in breeding success are a consequence of trapping or environmental factors that are occurring at-sea.

5. Research and management recommendations

In light of the results of this study we make the following research recommendations:

1. Monitoring of breeding success and burrow occupancy should continue in both Shearwater Stream and the Kowhai Valley for a minimum of three more breeding seasons to provide a better assessment of average breeding success and occupancy, and determine if differences between the two colonies are consistent. Monitoring both colonies will also provide a more robust estimate of the efficacy of stoat trapping versus environmental variability at influencing breeding success.
2. To provide more reliable estimates of breeding success for each colony and to reduce sampling error, burrows should be monitored from at least four sub-colonies and burrows should be spread through each sub-colony rather than clumped.
3. Detailed records should be kept of the total number of burrows fully checked during the incubation period and their contents (empty, bird on egg, bird and unknown contents, or unknown contents) so that burrow occupancy can be measured and results fully compared with previous years.
4. Ideally, measures of breeding success and occupancy measured with a burrowscope should be augmented with a sample of dug study burrows in which checks occur during the incubation, early chick

and late chick periods. This will provide a much more reliable estimate of burrow occupancy and information on the timing of breeding failures.

5. Transects of known length should be walked through sub-colonies to search for shearwater carcasses to assess rates of stoat predation. As a priority this should be undertaken in Shearwater Stream during the incubation period to quantify dead adults. However, transects in both colonies and during the incubation and chick-rearing periods will provide more information to compare between colonies and between the current period and the late 1990s.

6. Exploratory analysis of environmental variables and modeling of colony size should be undertaken to see if annual fluctuations in breeding success and colony differences can be explained by these factors.

7. Management within both colonies should prioritize reducing the numbers of browsing animals (deer, goats, chamois) and if hunting takes place during late summer or the autumn/winter ensure that carcasses are removed. Areas close to the boundaries of both colonies (particularly for the more accessible Kowhai Valley) should also be hunted to reduce and remove pigs from the colonies.

8. Stoat trapping should continue throughout the year within the Shearwater Stream colony, with good records kept on trapping effort and numbers of stoats killed. Future consideration should be given to experimentally ceasing trapping to estimate the efficacy of stoat control and their impact in the absence of trapping.

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Appendix 1: Transect data for Kowhai Valley

YEAR	TOTAL TRANSECT DISTANCE (KM)	MONTH	NO. DEAD ADULTS	NO. DEAD CHICKS
1996/97	1.467	early Nov	5	0
1996/97	3.069	late Nov	13	0
1996/97	3.897	early Dec	6	0
1996/97	3.247	late Dec	10	0
1996/97	3.897	early Jan	13	6
1996/97	3.597	late Jan	2	12
1996/97	3.247	early Feb	4	8
1996/97	3.597	late Feb	2	15
1996/97	3.597	early March	1	18
1997/98	2.647	early Oct	5	0
1997/98	2.647	late Oct	2	0
1997/98	2.647	early Nov	9	0
1997/98	2.647	late Nov	3	0
1997/98	2.647	early Dec	1	0
1997/98	3.031	late Dec	3	0
1997/98	3.031	early Jan	6	14
1997/98	3.031	late Jan	2	27
1997/98	3.031	early Feb	1	22
1997/98	3.031	late Feb	3	9
1997/98	3.031	early March	0	5
1998/99	3.031	early Oct	6	0
1998/99	3.031	late Oct	8	0
1998/99	3.031	early Nov	6	0
1998/99	3.031	late Dec	2	1
1998/99	1.795	early Jan	1	9
1998/99	2.323	late Jan	1	12
1998/99	3.031	early Feb	4	18
1998/99	2.323	late Feb	0	10
1998/99	3.031	early March	2	8
2007/08	7.541	early Dec	13*	0

*20 birds found on transects; one was previous season’s, six were >2 weeks old

Appendix 2: Quadrat data for Kowhai Valley

YEAR	SUB-COLONY	NO. QUADRATS ($16 M^2$)	AVERAGE NO. BURROWS PER QUADRAT	BURROWS/M^2
1997/98	across valley	50	9.1	0.57
1998/99	1	37	7.7	0.48
1998/99	4	38	6.2	0.38
1998/99	5	28	8.4	0.52
1998/99	9	52	11.9	0.75
1998/99	15	48	14.4	0.90
1998/99	30	25	10.8	0.68
1998/99	32	19	8.4	0.53
1998/99	33	49	10.8	0.67
2004/05	1	25	6.0	0.38
2004/05	9	25	10.2	0.64
2004/05	4	25	7.1	0.45
2004/05	5	25	7.1	0.44
2004/05	15	25	17.9	1.12
2004/05	30	25	7.8	0.49
2004/05	33	25	9.2	0.58
2007/08	4	15	12.3	0.77
2007/08	5	15	9.0	0.56
2007/08	9	15	15.1	0.94
2007/08	18	15	16.4	1.03
2007/08	30	15	12.9	0.80
2007/08	33	15	10.5	0.66