Differences in burrow site preferences between Chatham petrels (*Pterodroma axillaris*) and broad-billed prions (*Pachyptila vittata*): investigating techniques to reduce the effects of burrow competition.

A thesis
submitted in partial fulfilment
of the requirement for the degree of
Master of Science

in

Animal Ecology

at

Lincoln University

by

W. J. Sullivan

Lincoln University
2000

Frontispiece

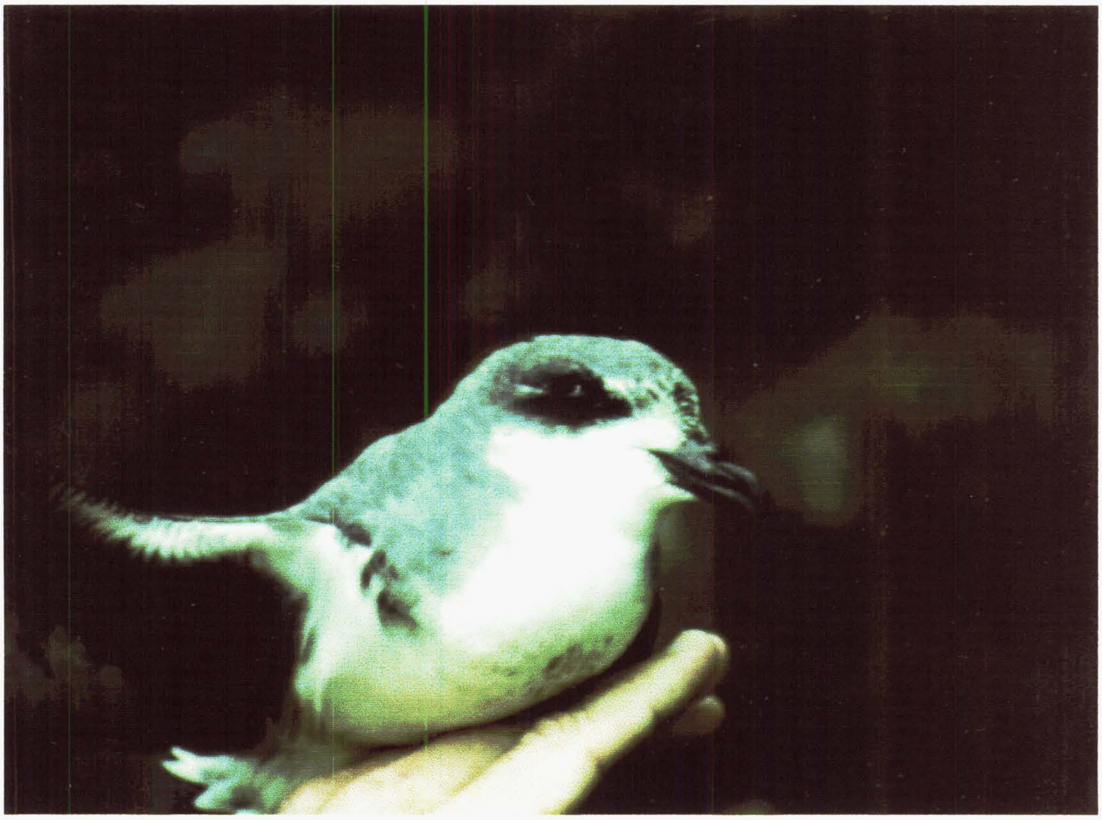

Figure 1. Chatham petrel *(Pterodroma axillaris)*

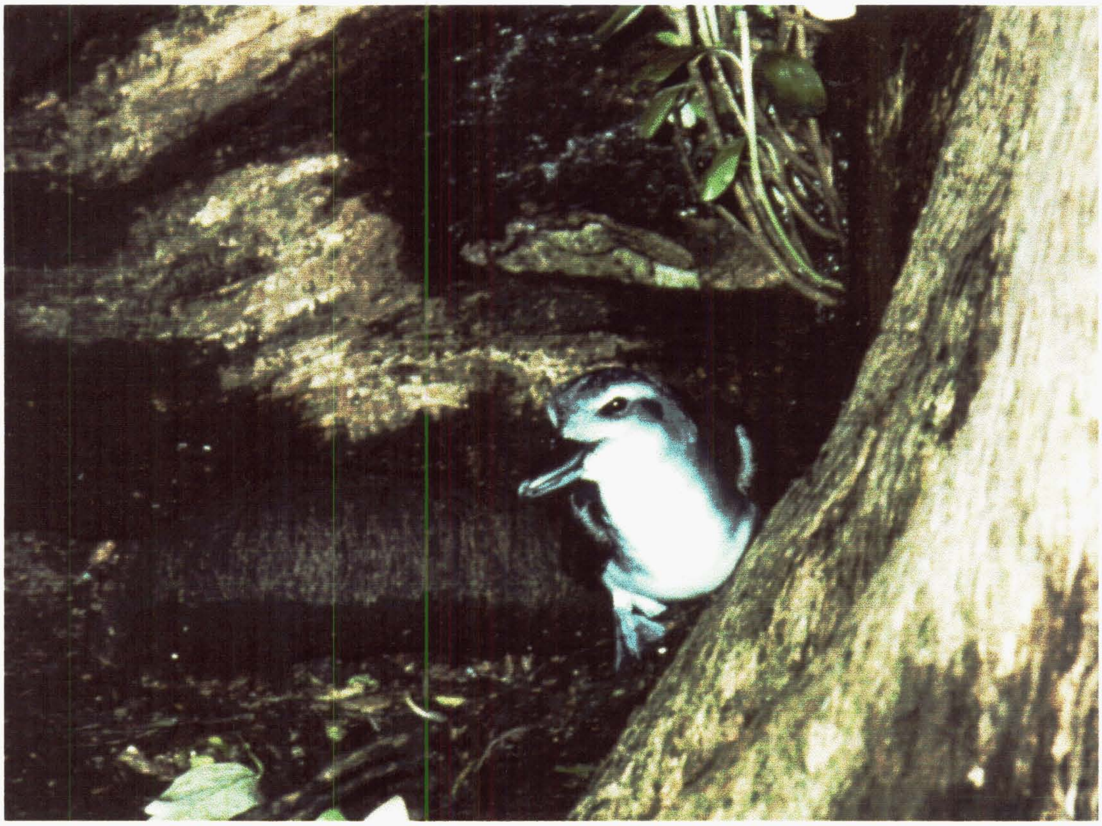

Figure 2. Broad-billed prion *(Pachyptila vittata)*

Abstract of a thesis submitted in partial fulfilment of the requirements for the Degree of M. Sc.

Differences in burrow site preferences between Chatham petrels (*Pterodroma axillaris*) and broad-billed prions (*Pachyptila vittata*): investigating techniques to reduce the effects of burrow competition.

by W. J. Sullivan

The Chatham petrel (*Pterodroma axillaris* Salvin) is an endangered species endemic to the Chatham Islands. It is currently restricted to a population of less than 1000 individuals on South East Island. The key threat to breeding success is interference to chicks by broad-billed prions (*Pachyptila vittata* Forster), when they prospect for burrows for their oncoming breeding season. Management involves patrols around known Chatham petrel burrows and culling broad-billed prions found in the burrows. While relatively successful, these patrols disturb Chatham petrels, are labour and resource intensive, give only short term (hourly) protection and involves killing a native, protected species.

This study investigated alternative methods of protecting the known population of Chatham petrel chicks. Three options were investigated: the possibility of exploitation of different habitat preferences, whether microhabitat features around a Chatham petrel burrow attracted broad-billed prions, and the effectiveness of a burrow entrance flap that allows Chatham petrels to enter their own burrow but discourages broad-billed prions from entering.

Alteration to breeding habitat has contributed to burrow competition. Habitat characteristics for both Chatham petrels and broad-billed prions were quantified and selection ratios compared. Both Chatham petrels and broad-billed prions selected characteristics indicative of mature forest. Chatham petrels are habitat specific and preferred habitat is now limited. Broad-billed prions are generalists and are not limited by habitat availability.

All breeding Chatham petrel burrows have been replaced with artificial burrow chambers and tunnels that assist monitoring and reduce burrow collapse. This study investigated whether artificial boxes, logs and tracks attracted broad-billed prions to Chatham petrel burrows, increasing interference to chicks. Prospecting broad-billed prions were not attracted to Chatham petrel burrows. The presence of logs or tracks did not directly increase chick interference levels, but logs increased the number of broad-billed prions near a burrow.

The burrow entrance flap exploited behavioural differences between the two species. Chatham petrels had a high incentive to push through a flap due to their investment in their burrow and chick, while prospecting broad-billed prions were influenced by the ease in entering potential burrows. This trial found 90% of Chatham petrels entered their burrows through the artificial flap. Flaps acted as barriers to most broad-billed prions, with only 22% entering the burrow through the flap compared to the control burrows.

This study has provided several alternative methods for alleviating the effects of burrow competition between broad-billed prions and Chatham petrels. Habitat preferences should be used to guide searches for unknown Chatham petrel burrows and when establishing a second colony of Chatham petrels. Reducing the presence of logs decreases the number of broad-billed prions around Chatham petrel burrows. While not proven in this study this may potentially decrease interference. Artificial burrow entrance flaps have the potential to provide a low cost, low labour strategy for protecting Chatham petrel chicks.

KEY WORDS Chatham petrel; *Pterodroma axillaris*; broad-billed prion; *Pachyptila vittata*; burrow competition; chick interference; burrow entrance flap; habitat selection; microhabitat; artificial burrow chamber.

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Chapter 1.

Introduction

The Chatham petrel (*Pterodroma axillaris* Salvin) is an endangered marine bird endemic to the Chatham Islands. It has been ranked as a 'Critically Endangered' species by IUCN (1994) and a 'Category A' species by Molloy and Davis (1994). The Chatham petrel breeding population is now restricted to South East (Rangatira) Island (44°20°S and 176°10°W), but was formerly distributed throughout the Chatham archipelago (West, 1994). While never abundant (West, 1994), numbers were unlikely to have been as low as the current population, estimated at 500 to 1000 individuals (Kennedy, 1994). Burrow distribution, low productivity, historical and anecdotal information suggests that the population is declining (Gardner and Wilson, 1999). Currently, breeding success is low due to egg and chick mortality resulting from burrow competition with broad-billed prions (*Pachyptila vittata* Forster) (Kennedy, 1994; West, 1994; Gardner and Wilson, 1999).

In the 1995/96 breeding season, Lincoln University began an ongoing research program investigating the threats to, and management requirements of, Chatham petrels. Gardner and Wilson (1999) determined the impact that burrow competition by broad-billed prions had on Chatham petrel breeding success, while Was (1999) investigated prospecting behaviour of broad-billed prions. This study continues on from their research by identifying differences in burrow site preferences of Chatham petrels and broad-billed prions, and providing techniques in deterring broad-billed prions from interfering with Chatham petrel chicks.

Chatham petrel ecology

Chatham petrels are about 30 cm in length and weigh approximately 200 g (Marchant and Higgins, 1990). They belong to the gadfly group which is comprised of the genera *Lugensa* and *Pterodroma* (Warham, 1990). While they have rarely been recorded at sea (West, 1994), Chatham petrels probably migrate to the North Pacific Ocean in their non-breeding season, as does the closely related black-winged petrel (*Pterodroma nigripennis*). Chatham petrels incubate a single egg from November to February and raises the chick until June. Both sexes contribute to incubation and chick-raising. Like most burrowing petrels, Chatham petrels are nocturnal at their breeding site. The majority of known burrows are situated in open forest (West, 1994).

Subfossil analysis suggests that Chatham petrels previously bred on Chatham, Pitt and Mangere Islands, although in low numbers (Tennyson and Millener, 1994). Archey and Lindsey (1924) recorded Chatham petrels present near the 'Horns' on Chatham Island in 1924, however, West (1994) believes they were referring to taiko (*Pterodroma magentae*). Fleming (1939) described Chatham petrels as 'far from abundant even at the Chatham Islands, and appears to breed only at ... South East Island'. Mammalian predators have occurred on all the islands except South East Island (Tennyson and Millener, 1994), suggesting extinction on these islands is due to predation (K-J. Wilson, pers. comm.). Like most of the smaller *Pterodroma* species, Chatham petrels are likely to be vulnerable to cat and rodent predation (Imber, 1975; Tennyson and Millener, 1994). Loss of forest habitat has possibly contributed to Chatham petrel population decline.

Broad-billed prion ecology

Broad-billed prions are a similar size to Chatham petrels at 28 cm in length with a weight of 170 - 235 g (Marchant and Higgins, 1990). They breed on islands situated near the Subtropical Convergence - on and around Stewart Island, on Snares Island and the Tristan da Cunha group (e.g., Harper, 1980; Warham, 1990). The largest population is on Gough Island where Swales (1965) estimated 10 million pairs. On the Chatham Islands, they are abundant on South East Island, where West and Nilsson (1994) estimated there to be 330,000 pairs, as well as on Mangere and Little Mangere Islands. Midden analysis on Mangere Island by Tennyson and Millener (1994) showed that while abundant on Mangere Island today, broad-billed prions were apparently rare in the past, suggesting that a population increase occurred in the early 1900's. It is possible that the current super-abundance of broad-billed prions on South East Island has been caused indirectly by human activities, such as the introduction of predators throughout the Chatham archipelago, over-fishing of krill-eating fish or whales (Davis, 1999), habitat changes, or a reduction in competitors more vulnerable to predation.

In New Zealand, broad-billed prions stay near the breeding islands all year except for a six week moult at sea (Richdale, 1965; Marchant and Higgins, 1990). The non-breeding season begins in February when they return to the breeding island and prospect for burrows (Richdale, 1965; Was and Wilson, 1998). Nocturnal at their breeding site, broad-billed prions come ashore at irregular intervals, and numbers ashore vary nightly on South East Island (Was and Wilson, 1998). They have high rates of movement between burrows, reflecting the intense competition for burrow space, and often take over burrows of other species (Was and Wilson, 1998). Incubation is from August to October and chicks fledge by January (Richdale, 1965).

Burrow competition between Chatham petrels and broad-billed prions

Warham (1996) stated that shortage of space is usually a population regulator for burrow-nesting seabirds. Competition for burrows on South East Island is intense (Gardner and Wilson, 1999). While Chatham petrels and broad-billed prions presumably co-existed on South East Island historically, burrow competition is probably a symptom of disturbances in the environment, such as the alteration to habitat or perturbations in marine food webs (Kennedy, 1994; Davis, 1999). Burrow competition appears to be the main cause of Chatham petrel breeding failure and, along with the confinement to a single population, could drive Chatham petrels to extinction if left unchecked.

Generally, breeding at different times of the year by two similar species avoids direct burrow competition. Temporal differences may, however, exacerbate competition, where earlier nesting species have not finished breeding before the second species arrives (Coulson and Horobin, 1972; Burger and Gochfield, 1988). Chatham petrel chicks are alone in their burrows when broad-billed prions start prospecting for burrows (Kennedy, 1994; Gardner and Wilson, 1999). Broad-billed prions often oust Chatham petrel chicks from their burrows, usually killing them, to claim 'ownership' of the burrow. Gardner and Wilson (1999) found that 87% of known Chatham petrel burrows were visited by broad-billed prions. Without active management 50 - 70% of breeding failures were attributed to broad-billed prions. Gardner and Wilson (1999) also showed that the majority of broad-billed prions that interfered with Chatham petrel chicks had no prior association with that burrow. Historically, behavioural factors may have evolved to reduce this competition, such as preference for different habitat for burrow sites.

The influence of habitat on burrow competition

Procellariiformes are nidicolous, where they breed in large colonies, do not defend their nests against predators, and their eggs and young are not cryptic. While burrows are safe from aerial predators, they are often restricted to particular habitat types (Lack, 1968). As a result there may be intense intra- and interspecific competition for sites, with some individuals forced to nest in unsuitable habitat and others unable to breed (Lack, 1968; Storey and Lien, 1985; Burger and Gochfield, 1991). High levels of nest site competition may be a result of historically altering breeding habitat that eliminated appropriate sites for nests. Major habitat changes have occurred on South East Island since human settlement over 100 years ago due to grazing stock reducing forest cover by approximately 37% (adapted from Nilsson *et al.*, 1994). Much of the forest on lowland terraces was converted to pasture by browsing and fire (West and Nilsson, 1994) and the large tract of forest (57 ha) in the higher parts of the island was highly modified by browsing (Nilsson *et al.*, 1994). While stock was removed by 1961 after the island was made a nature reserve in the 1950's (Ritchie, 1970), the composition and structure of the regenerating forest has altered, although the effect on Chatham petrels is not yet known.

Current management of Chatham petrels

The current management regime is to cull broad-billed prions found in Chatham petrel burrows. This involves intensive patrolling of the Chatham petrel burrows for up to six hours a night. These patrols disturb Chatham petrels, are labour intensive, provide only short term (hourly) protection, and involve culling a native, protected species. Long term it is impractical and unsustainable to remove broad-billed prions from Chatham petrel burrows manually (Kennedy, 1994).

The short term goal outlined in the Chatham Petrel Recovery Plan (Davis, 1999) is 'to arrest the decline of Chatham petrel breeding pairs and total population numbers, improve productivity on Rangatira and have a new habitat ready for the establishment of a second Chatham petrel breeding population'. To increase productivity, broad-billed prion interference in Chatham petrel burrows needs to decrease. The development of alternative methods of managing this population with minimal management intervention is required. It is also essential that management practices themselves are not having a detrimental effect on Chatham petrel behaviour and possibly productivity. The long term goal is 'to restore sufficient areas of Chatham Island's forest and re-instate Chatham petrel within its traditional breeding range as a number a of self-sustaining populations that will require minimal management' (Davis, 1999). To achieve this goal, knowledge of the habitat requirements of both species is needed.

Research objectives

The aim of this research was to identify and utilise differences in burrow site preferences of Chatham petrels and broad-billed prions, to determine techniques to deter broad-billed prions from interfering with Chatham petrel chicks.

The specific objectives were:

- To investigate habitat selection of both Chatham petrels and broad-billed prions;
- To investigate behaviour of prospecting broad-billed prions in relation to particular burrow and microhabitat features around Chatham petrel burrows which may attract broad-billed prions to Chatham petrel burrows;
- To develop an effective artificial burrow entrance flap that deters broad-billed prions from entering burrows;
- To test the acceptance of breeding Chatham petrels to artificial burrow entrance flaps.

Thesis structure

Physical aspects of the habitat important for nest-site selection by either Chatham petrels or broad-billed prions have not been quantified. Differences may be utilised to either manipulate habitat to support higher numbers of Chatham petrels, or deter broad-billed prions from Chatham petrel burrows by making the habitat unsuitable. Information on habitat requirements is essential when establishing a second population of Chatham petrels. Chapter 2 presents the results of this research, which is prepared as a paper for submission to the *New Zealand Journal of Ecology.*

During preliminary observations, it appeared that broad-billed prions were utilising objects such as logs, rocks and Chatham petrel artificial boxes for orientation and resting. Monitoring Chatham petrel burrows has resulted in an extensive track system around Chatham petrel burrows and it seemed that broad-billed prions used tracks more than the surrounding areas when moving across the ground. These features could make artificial Chatham petrel burrows more attractive to prospecting broad-billed prions and potentially increase interference to Chatham petrel chicks. Broad-billed prion behaviour in relation to these features was observed around Chatham petrel burrows and the results are presented in Chapter 3, submitted to *Emu.*

The effectiveness of burrow entrance flaps, an alternative method of preventing broad-billed prion interference with Chatham petrel chicks was investigated. Burrow entrance flaps exploit differences in the incentive the two species have to enter Chatham petrel burrows. The flap aims to allow Chatham petrels to enter their own burrows but deter prospecting broad-billed prions. The results of the development and testing of burrow entrance flaps are reported in a paper submitted to the *New Zealand Journal of Ecology*, and form Chapter 4 of this thesis.

Based on the results from the previous chapters, Chapter 5 discusses the differences identified in the burrow site preferences between Chatham petrels and broad-billed prions. It then provides options for future management practices for deterring broad-billed prion interference with Chatham petrel chicks and recommendations for further research.

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Chapter 2.

Differences in habitat selection between Chatham petrels (*Pterodroma axillaris*) and broad-billed prions (*Pachyptila vittata*): implications for management of burrow competition.

Abstract: Chatham petrels (*Pterodroma axillaris* Salvin) are an endangered species, restricted to a single population on South East Island. The key threat to their breeding success is interference to chicks by broad-billed prions (*Pachyptila vittata* Forster) when they prospect for burrows for their oncoming breeding season. This burrow competition has resulted from alteration of breeding habitat by humans throughout the Chatham Islands. Understanding habitat preferences may enable managers to manipulate habitat to reduce burrow competition and is essential when establishing Chatham petrels in a proposed second colony. Habitat characteristics surrounding both Chatham petrel and broad-billed prion burrows were quantified and selection ratios compared. Both Chatham petrels and broad-billed prions selected habitat factors associated with mature forest. Chatham petrel habitat use was negatively correlated with availability ($r = -0.38$; $P < 0.001$), and they avoided a large number of habitat characteristics. This suggests that they are habitat specific and their preferred habitat is now limited. Broad-billed prion habitat use is positively correlated with availability ($r = 0.27$; $P < 0.01$) and they were positively associated with a large number of habitat characteristics, which suggests that they are not limited by habitat availability and are not habitat specific. Selection values should be used when deciding on the best location to establish a second Chatham petrel colony and when searching for additional Chatham petrel burrows.

Key words: Chatham petrel; *Ptereodroma axillaris*; broad-billed prion; *Pachyptila vittata*; habitat selection; translocation.

Introduction

The Chatham petrel (*Pterodroma axillaris* Salvin) is an endangered seabird endemic to the Chatham Islands, New Zealand. The species is now restricted to a single breeding population on South East (Rangatira) Island, Chatham Islands, with a total estimated population of less than 1000 individuals (Kennedy, 1994). The immediate threat to Chatham petrel breeding success is chick interference by prospecting broad-billed prions (*Pachyptila vittata* Forster), which compete for their burrows (Kennedy, 1994; Gardner and Wilson, 1999). Broad-billed prions kill or oust chicks when taking over Chatham petrel burrows. The native broad-billed prion is abundant on South East Island with numbers estimated at 300, 000 pairs (West and Nilsson, 1994).

Many seabirds are now confined to islands on which there has not been, or is no longer, human settlement (Ramos *et al.*, 1997). High levels of intra- and interspecific competition for burrows may be a result of human induced alteration of breeding habitat in historical times, eliminating appropriate sites for nests and confining populations to a few, usually predator free, islands. There have been major habitat changes to South East Island since human settlement with approximately 100 years of farming (Nilsson *et al.*, 1994; West and Nilsson, 1994). A considerable proportion of forest on the lowland terraces reverted to pasture while the remaining tract of forest was severely damaged by overgrazing and fire which reduced forest cover and altered forest composition (West and Nilsson, 1994). Stock were removed by 1961 when the island was protected in the 1950's (Richie, 1970; Veitch and Bell, 1990). While burrow competition between the two species is likely to be a natural occurrence, it has probably been exacerbated by a reduction in suitable habitat for both species. Habitat generalists are more likely to adapt to modified or sub-optimal habitat than specialist species.

If the total number of nest sites limits population growth, overlap in nest site requirements between species should result in interspecific competition (Whittam and

Siegal-Causay, 1981; Ramos *et al.*, 1997). To avoid competition, clear separation of site preferences should have evolved (Burger and Gochfield, 1988). This would result in the selection of particular physical features of a habitat (Podolsky and Kress, 1989; Saliva and Burger, 1989; Brandt *et al.*, 1995; Ramos *et al.*, 1997), such as soil type, canopy cover or slope.

Characteristics of, and competition for, nest sites and how these influence breeding success of colonial seabirds, have been described for surface- and ledge-nesters, but not burrow breeders. Such species do not nest randomly with respect to the available habitat but prefer areas with particular features (e.g., Feare *et al.*, 1997; Saliva and Burger, 1989; Spear and Anderson, 1989). There are many examples of habitat segregation between Procellariiformes that reduce inter-specific competition (e.g., Bartle, 1968; Harris, 1974; Harper, 1976; Kennedy, 1978; McCallum, 1981). There is relatively little information, however, on how this segregation behaviour relates to site selection (Ramos *et al.*, 1997).

Physical aspects of the habitat important to nest-site selection by either Chatham petrels or broad-billed prions have not been quantified. It is important to quantify the habitat features that they may be selecting for three reasons:

- If the known Chatham petrel population is aggregated within particular habitat types, it may be possible to manage the habitat to support higher densities of Chatham petrel burrows.
- If broad-billed prions select areas with particular features, habitat could be managed to reduce the attractiveness of habitat surrounding Chatham petrel burrows so that interference decreases.
- Understanding optimal habitat for both Chatham petrels and broad-billed prions could assist in selection or alteration of alternative habitat in the Chatham Islands when establishing a second Chatham petrel population.

Methods

Study site

South East Island is dominated by forest (45% of the island area), with areas of introduced grasses, associations of pohuehue (*Muehlenbeckia australis*), bracken (*Pteridium esculentum*), and ake ake (*Olearia traversii*), scrub and herbfield (Nilsson *et al.*, 1994).

To measure habitat characteristics of broad-billed prion burrows, and habitat availability of South East Island, I sampled habitat throughout different vegetation types (Figure 2.1). Measurements around Chatham petrel burrows predominantly occurred in the Kokopu Creek catchment, as there are very few burrows situated outside this area. Disused burrows, including some in other vegetation types such as bracken, could not be included in this study as their exact location is no longer known. Burrow densities and habitat characteristics were measured between 17 February and 1 April 1999.

Measuring habitat characteristics

A 3 m radius circular quadrat was placed around each Chatham petrel burrow using the entrance as the centre. For each quadrat 14 characteristics were measured (Table 2.1). When measuring broad-billed prion habitat, and habitat availability, I used four-digit random numbers to locate quadrats in a similar methodology to West and Nilsson (1994). Because of the extreme fragility of the forest floor, I positioned quadrats from established tracks and used plywood boards to distribute my weight when positioning and sampling quadrats to prevent collapsing burrows.

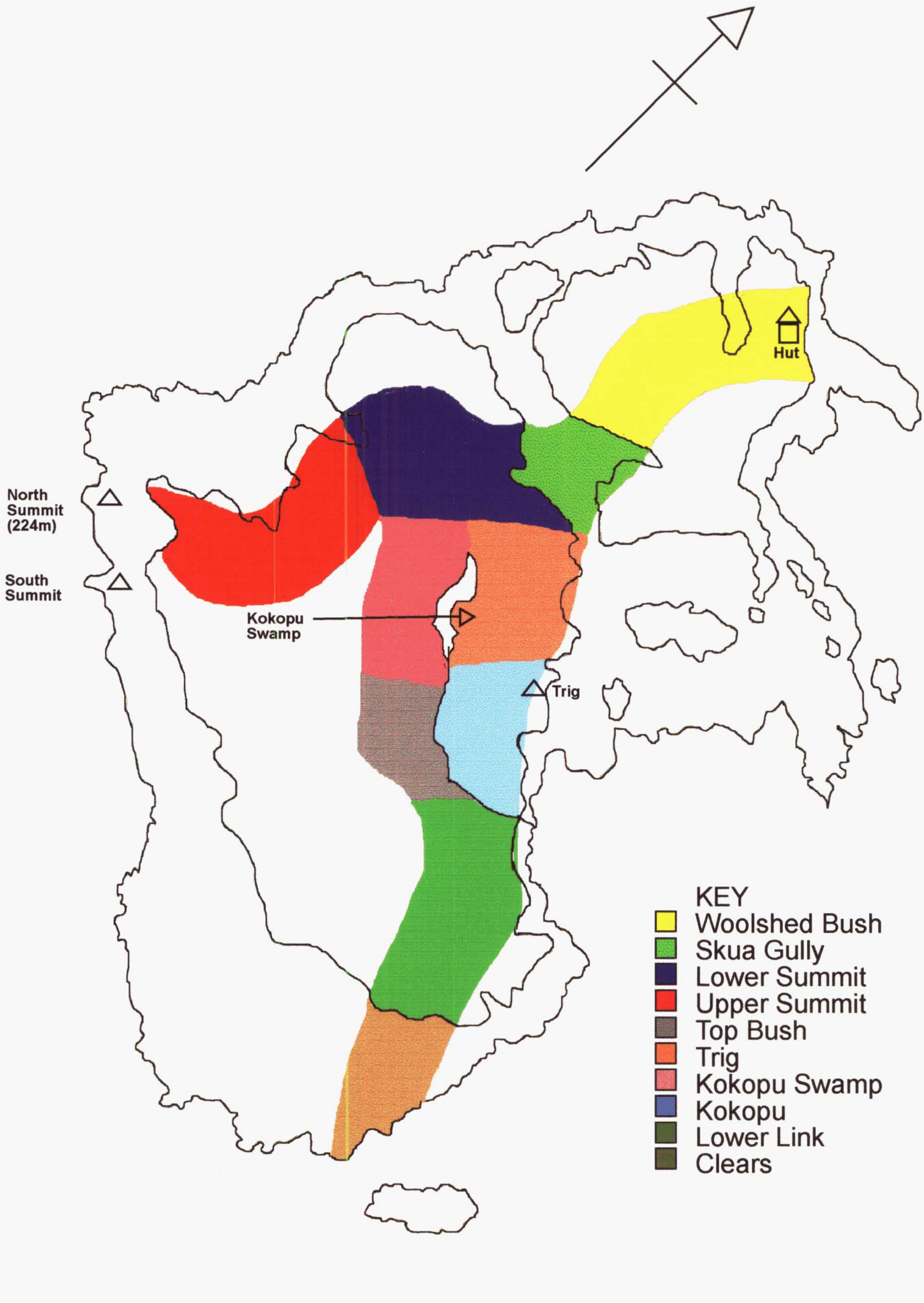

Figure 1. Map of South East (Rangatira) Island, showing locations mentioned in text. Shaded areas indicate area surveyed.

Table 2.1. Habitat characteristics recorded for each 3 m radius quadrat on South East Island.

	Variable	Description
1	number of broad-billed prion (*Pachyptila vittata*) burrows	Burrows with entrances ≈ 130 x 70 mm (West and Nilsson, 1994)
2	slope (°)	estimated angle of ground from the centre of quadrat
3	aspect (°)	compass direction of the slope
4	vegetation height (m)	estimated maximum height of vegetation ± 1 metre
5	canopy cover (%)	estimated cover of vegetation within the quadrat >6 m, ± 5%
6	understory cover (%)	estimated cover of vegetation within the quadrat 0.5 - 6 m, ± 5%
7	number of logs	>50 mm DBH
8	number of stems	all stems > 1 m tall
9	diameter of stems (mm)	>50 mm DBH and 1 m high
10	dominant species	species with the predominant number of stems in quadrat
11	take-off tree (T.O.T) species	tree >50 mm DBH with scratch marks present, ≅ to vegetation height, and nearest to centre of quadrat
12	T.O.T diameter (mm)	DBH
13	T.O.T lean (°)	± 5°
14	soil compaction	hard: could be walked on without collapsing burrows, medium: required boards to prevent collapsing; soft: collapses even with boards (West and Nilsson 1994).

The first two numbers gave the distance in 1m units along the track. The second pair gave the distance at right angles to the track, left if even and right if odd. In impenetrable vegetation, such as regenerating pohuehue or koromiko (*Hebe dieffenbachii*), only the third digit was used reducing this distance to 9 m or less. A total of 124 quadrats were measured, consisting of 44 around Chatham petrel (27 breeding and 17 non-breeding) burrows and 80 random quadrats.

Differences in vegetation types

To test for differences in the habitat characteristics between vegetation types, I divided the quadrats in the sampled area into the broad categories (Figure 2.1) and used One-way ANOVAS for parametric data and Kruskall-Wallis tests or Spearman rank correlations for non-parametric data, using the STATISTICS package.

Habitat selection

Selection describes the use of a resource by an animal in proportion to its availability (Manly *et al.*, 1993). To calculate habitat selection, the percentage use of a habitat characteristic is divided by the availability of that characteristic. Selection ratios for each habitat category of each variable were used to quantify habitat selection for both Chatham petrels and broad-billed prions using the equation:

$$\times_i = o_i/\Xi_i$$

where:

o_i = the proportion of quadrats within habitat characteristics of category i

Ξ_i = the proportion of available habitat characteristics of category i (adapted from Manly *et al.*, 1993).

Because of the small number of Chatham petrel burrows, 'used' (o_i) resources were measured at an individual level, while 'available' or (Ξ_i) resources were considered at a population level (i.e., Design II in Manly *et al.*, 1993). For broad-billed prions, both sets of measurements were made at a population level (Design I; Manly *et al.*, 1993). Overall, the mean density of broad-billed prion burrows was $0.31/m^2$. Based on this, a burrow density of $>0.18/m^2$ (5 burrows/3 m^2) was considered 'used' habitat (o_i), and a density of < 5 burrows/$3m^2$ was considered available or unused (Ξ_I). Standard errors (SE) were determined for the selection indices using the equation:

$$SE = {}_i * \text{square root}(1/n_i - 1/n_t + 1/r_i - 1/r_t)$$

where:

n_i = number of burrow samples of type i

n_t = total number of burrow samples

r_i = number of random samples of type i

r_t = total number of random samples.

To determine if selection occurred for any of the habitat characteristics, I used the equation w_i +/- Z * SE to calculate confidence intervals, which were then used to determine if the selection index was significant at the $P < 0.05$ level. Indices with both lower and upper confidence limits < 1 indicated negative selection, and those with both confidence intervals greater than 1 indicated positive selection. Values for which the lower confidence limit was < 1 and the upper confidence limit >1 indicated that the habitat characteristic was used in proportion to its availability (i.e., no selection).

Results

Chatham petrel and broad-billed prion burrows were largely found in similar habitats (Table 2.3). However, Top Bush (Figure 2.1) contained the majority of Chatham Petrel burrows, while highest proportion of broad-billed prion burrows was in Upper Summit. Chatham petrel burrows were predominantly located in mixed forest with a mean stem density of 0.81 stems/m^2 and a south-eastern aspect, near ribbonwood (*Plagianthus regius*) take-off trees. Broad-billed prion burrows were predominantly in ribbonwood forest with a mean stem density of 0.74 stems/m^2 on a south-western aspect near matipo (*Myrsine chathamica*) take-off trees.

Table 2.2. Location descriptions, South East Island, 17 February to 1 April 1999. All statistical tests are Kruskall-Wallis, except those indicted with [1] which are one-way ANOVAs', or [2] which are Spearman rank correlations. 'Myrs' = *Myrsine chathamica*; 'Cop' = *Coprosma chathamica*; 'Plag' = *Plagianthus regius*; 'Mueh' = *Muehlenbeckia australis*.

Variable	Woolshed Bush	Top Bush	Skua Gully	Lower Summit	Upper Summit	Trig	Kokopu Swamp	Kokopu	Lower Link	Clears	P value
prion burrows (m^2)	0.32	0.50	0.21	0.28	0.53	0.18	0.46	0.32	0.28	0	0.001
slope (°)	5	24	20	10	16	12	15	13	28	0	0.000
aspect	NW	NE	NW	NW	NW	SW	SW	SE	NE	FLAT	0.003
vegetation height (m)	6-10	11-15	0-5	0-5	0-5	0-5	6-10	11-15	6-10	0-5	0.000
understory cover (%)	28	20	75	30	40	45	13	5	5	78	0.000
canopy cover (%)	71	68	48	63	89	78	72	67	65	8	0.000
stems (m^2)	0.46	0.81	0.28	0.99	0.61	1.84	1.13	0.88	0.74	0.14	0.000
stems <50mm (%)	73	70	63	67	66	83	75	56	75	89	0.001
stems 50-100mm (%)	6	14	13	13	16	10	12	19	14	8	0.001
stems >100mm (%)	19	16	19	20	15	6	12	25	11	13	0.046
soil compaction	medium	medium	hard	medium	medium	medium	medium	medium	medium	hard	0.028[1]
dominant species	Myrs	mixed	Mueh	Myrs	Myrs	none	mixed	Plag	Plag	mixed	0.001[2]
T.O.T* species	Cop	Plag	Cop	Myrs	Myrs	Myrs	Cop	Plag	Myrs	none	0.001[2]
T.O.T DBH (mm)	262	415	141	324	282	347	483	263	370	-	0.372
T.O.T lean (°)	28	18	40	27	31	23	22	15	20	-	0.522[1]
n	14	27	2	12	18	6	25	3	7	9	-

Table 2.3. Description of mean habitat characteristics for known Chatham petrel (n = 44) and broad-billed prion (n = 1279) burrows.

Variable	Chatham petrels	Broad-billed prions
Location	Top Bush	Upper Summit
Slope (°)	11-20	11-20
Aspect	SE	SW
Vegetation height (m)	6-10	6-10
Understory cover (%)	0-20	0-20
Canopy cover (%)	80-100	80-100
No. stems/m^2	0.81	0.74
Stems <50 mm (%)	64	65
Stems 50 - 99 mm (%)	16	15
Stems >100 mm (%)	16	18
Take-off tree	ribbonwood	matipo
Soil compaction	medium	medium
Dominant tree sp.	mixed	ribbonwood

Chatham petrel burrow density was significantly influenced by several habitat characteristics (Table 2.4). Chatham petrels selected areas with a vegetation height of 11 - 20 m; canopy cover of 21 - 40%; north-eastern aspects; forest which contained 21 - 30% stems of 50 - 99 mm diametre breast height (DBH). They selected sites near karamu (*Coprosma chathamica*) take-off trees of 16 - 30° lean. They avoided sites at which ake ake predominated, where understory cover was 61 - 80%, vegetation height was 0 - 5 m, areas where there were no stems as well as where the greatest proportion of stems were <50 mm DBH, and 0 - 10% of stems >50 mm DBH; and areas with whitey-wood (*Melicytus chathamica*) take-off trees with a lean of 0 - 15°. Due to the small number of Chatham petrel burrows sampled, the data were highly variable with large standard errors, causing a large number of characteristics with large selection values to be insignificant. Chatham petrel habitat use was negatively correlated with habitat availability (r = -0.38; P < 0.001) and this, along with the large number of variables avoided, suggested relatively high habitat specificity.

Table 2.4. Habitat selection ratios (w_i) for Chatham petrels, with standard errors (SE) and lower and upper confidence limits (LCL; UCL). Significant positive or negative selection ($P < 0.05$) for a category is denoted by + or - respectively. Availability (%) is the number of quadrats category occurs/ total number of quadrats.

Variable	Category	w_i	SE	LCL	UCL	selection	availability
dominant species	*Olearia traversii*	0.78	0.00	0.78	0.78	-	3
	Myrsine chathamica	25.0	44.5	0.00	114		23
	Coprosma chathamica	2.21	2.29	0.00	8.37		2
	Plagianthus regius	3.57	1.75	0.00	8.27		19
	grass	1.85	1.92	0.00	7.02		7
	Melicytus chathamica	16.5	11.25	0.00	46.7		2
	Phormium tenax	16.5	0.00	16.5	16.5	+	2
	Muehlenbeckia australis	1.85	1.90	0.00	6.97		7
	mixed	2.12	0.90	0.15	11.9		25
aspect	ne	1.63	0.23	1.03	2.23	+	30
	se	3.33	1.29	0.00	6.66		12
	sw	2.09	1.18	0.00	5.12		11
	nw	2.27	0.77	0.28	4.26		18
	flat	0.73	0.22	0.17	1.29		30
soil compaction	soft	1.27	0.62	0.00	2.81		7
	medium	0.77	0.13	0.44	1.10		65
	hard	0.71	0.18	0.26	1.16		24
slope (°)	0-10	0.78	0.23	0.16	1.40		30
	11-20	1.35	0.26	0.67	2.03		29
	21-30	3.55	1.45	0.00	7.38		11
	31-40	5.00	2.53	0.00	11.7		12
	40-50	4.18	10.6	0.00	32.0		11
	>50	3.14	2.14	0.00	8.79		7
canopy cover (%)	0-20	1.70	1.16	0.00	4.69		10
	21-40	10.0	3.00	2.28	17.7	+	7
	41-60	2.60	1.52	0.00	6.50		11
	61-80	1.08	1.22	0.00	4.23		40
	81-100	0.72	0.23	0.12	1.32		32
understory cover (%)	0-20	0.86	0.05	0.72	1.00		60
	21-40	1.40	0.65	0.00	3.07		16
	41-60	3.75	2.10	0.00	9.15		8
	61-80	0	0.00	0.00	0.00	-	7
	81-100	1.00	1.02	0.00	3.64		10
vegetation height (m)	0-5	0.25	0.17	0.00	0.68	-	40
	6-10	1.36	0.19	0.88	1.84		32
	11-15	2.36	0.51	1.08	3.64	+	22
	16-20	16.7	0.00	16.7	16.7	+	6
no. logs (3 m radius quadrat)	0	0.61	0.25	0.00	1.26		44
	1	0.97	0.79	0.00	3.00		31
	2	3.86	0.91	1.51	6.21	+	15
	3	10.0	8.52	0.00	32.0		4
	>3	5.00	2.55	0.00	10.1		4
no. stems/m^2	0	0.43	0.02	0.38	0.48	-	79
	1	3.13	1.08	0.29	5.97		16
	2	16.5	49.9	0.00	148		2
	3 or >	0	0.00	0.00	0.00	-	2

stems	0-20	1.25	1.25	0.00	4.46		8
<50 mm	21-40	16.7	35.5	0.00	108		3
(%)	41-60	1.86	0.86	0.00	4.09		21
	61-80	1.00	0.10	0.74	1.26		42
	81-100	0.48	0.13	0.14	0.82	-	26
stems	0-10	0.56	0.11	0.29	0.83	-	48
51-100 mm	11-20	1.46	0.61	0.00	3.04		26
(%)	21-30	3.73	0.95	1.28	6.18	+	15
	31-40	3.00	1.64	0.00	7.22		9
	>40	25.0	13.7	0.00	60.2		3
stems	0-10	0.61	0.14	0.24	0.98	-	38
>100 mm	11-20	1.31	0.15	0.93	1.69		36
(%)	21-30	2.00	0.60	0.46	3.54		18
	31-40	10.0	5.46	0.00	24.1		4
	>40	16.7	16.4	0.00	58.9		4
take-off tree	none	1.15	0.78	0.00	3.26		13
(tot)	*Olearia traversii*	0.76	0.28	0.02	1.50		25
	Myrsine chathamica	3.00	1.22	0.00	6.28		15
	Coprosma chathamica	5.60	1.68	1.09	10.1	+	11
	Plagianthus regius	1.29	0.18	0.80	1.78		33
	dead	1.16	0.54	0.00	2.61		6
	Myoporum laetum	25.0	24.6	0.00	91.1		2
	Melicytus chathamica	0	0.00	0.00	0.00	-	1
tot DBH(mm)	0-200	2.53	0.68	0.78	4.28		19
	201-400	0.97	0.19	0.48	1.46		38
	401-600	1.70	0.28	0.97	2.43		31
	601-800	15.0	8.14	0.00	36.0		5
	>800	3.57	2.42	0.00	9.81		7
tot lean (°)	0-15	0.92	0.02	0.86	0.98	-	55
	16-30	6.10	1.79	1.64	10.6	+	12
	31-45	0.91	0.36	0.00	1.82		24
	>45	4.71	2.55	0.00	11.1		8

Broad-billed prions positively selected a large number of habitat characteristics (Table 2.5). They selected mixed forest or areas in which matipo dominated, where canopy cover was 61 - 80% and understory cover was 21- 40%; areas in which 41- 60% of the stems were <50 mm, 11 -40% stems were 50-99 mm and 11 - 30 % and more than 40% stems were >100 mm DBH; and areas where the take-off trees were predominantly ake ake, matipo, karamu, ngaio (*Myoporum laetum*) and whiteywood that had a DBH of 50 - 200 mm and a lean of >16°. They also selected eastern aspects with slopes of 11 - 40°, soft soils, and logs in the near vicinity of the burrow. Broad-billed prions only avoided sites that were predominantly grass, karamu and flax (*Phormium tenax*), and areas with no take-off trees. Broad-billed prion use was positively correlated with habitat availability ($r = 0.27$; $P < 0.01$), and the wide range of positively selected habitat characteristics indicated that they were not limited by habitat availability and therefore were not habitat specific.

Table 2.5. Habitat selection ratios (w_i) for broad-billed prions, with standard errors (SE) and lower and upper confidence limits (LCL; UCL). Significant positive or negative selection ($P < 0.05$) for a category is denoted by + or - respectively. Availability (%) is the number of quadrats category occurs/ total number of quadrats.

Variable	Category	wi	SE	LCL	UCL	selection	availability
dominant	*Olearia traversii*	12.5	0.00	0.00	0.00	-	3
species	*Myrsine chathamica*	2.96	0.40	1.88	4.04	+	23
	Coprosma chathamica	0	0.00	0.00	0.00	-	2
	Plagianthus regius	4.63	2.92	0.00	12.5		19
	grass	0	0.00	0.00	0.00	-	7
	Melicytus chathamica	33.0	78.55	0.00	244		2
	Phormium tenax	0	0.00	0.00	0.00	-	2
	Muehlenbeckia australis	5.43	3.38	0.00	13.7		7
	mixed	3.08	0.70	1.19	4.97	+	25
aspect	ne	2.80	0.13	2.48	3.12	+	30
	se	5.58	1.43	1.89	9.27	+	12
	sw	2.82	1.31	0.00	6.19		11
	nw	0.78	0.43	0.00	1.89		18
	flat	1.16	0.33	0.31	2.01		30
soil	soft	8.46	1.75	4.10	12.82	+	7
compaction	medium	1.29	0.17	0.86	1.72		65
	hard	0.71	0.29	0.00	1.44		24
slope (°)	0-10	1.17	0.25	0.51	1.83		30
	11-20	2.13	0.34	1.23	3.03	+	29
	21-30	7.73	1.84	2.88	12.58	+	11
	31-40	7.75	2.04	2.36	13.14	+	12
	40-50	5.82	2.14	0.17	11.47		11
	>50	3.14	2.45	0.00	9.61		7
canopy	0-20	0.80	1.16	0.00	3.79		10
cover (%)	21-40	0.75	0.27	0.05	1.45		7
	41-60	3.91	1.33	0.49	7.33		11
	61-80	1.88	0.16	1.47	2.29	+	40
	81-100	2.09	0.49	0.82	3.36		32
understory	0-20	1.22	0.89	0.00	3.50		60
cover (%)	21-40	5.60	1.15	2.64	8.56	+	16
	41-60	6.25	2.54	0.00	12.8		8
	61-80	7.44	3.70	0.00	17.0		7
	81-100	0.80	0.85	0.00	2.98		10
vegetation	0-5	0.98	0.15	0.60	1.36		40
height (m)	6-10	2.13	1.15	0.00	5.01		32
	11-15	4.05	0.34	3.19	4.91	+	22

	16-20	14.3	5.20	1.31	27.29	+	6
no. logs	0	1.27	0.18	0.81	1.73		44
(3 m radius	1	2.03	0.31	1.23	2.83	+	1
quadrat)	2	4.20	0.97	1.69	6.71	+	15
	3	15.0	29.7	0.00	91.5		4
	>3	14.2	0.00	14.2	14.2	+	4
no. stems/m^2	0	0.82	0.12	0.50	1.14		79
	1	2.81	0.91	0.42	5.20		16
	2	16.5	25.13	0.00	82.8		2
	3 or >	0	0.00	0.00	0.00	-	2
stems	0-20	0.25	0.17	0.00	0.69	-	8
<50 mm	21-40	25.0	17.1	0.00	69.0		3
(%)	41-60	3.86	0.45	2.71	5.01	+	21
	61-80	1.14	0.09	0.92	1.36		42
	81-100	1.35	0.21	0.81	1.89		26
stems	0-10	1.06	0.03	0.98	1.14		48
51-100 mm	11-20	2.54	0.29	1.78	3.30	+	26
(%)	21-30	5.20	1.00	2.62	7.78	+	15
	31-40	9.11	2.53	2.60	15.6	+	9
	>40	25.0	13.67	0.00	60.2		3
stems	0-10	1.00	0.15	0.62	1.38		38
>100 mm	11-20	2.22	0.18	1.76	3.30	+	36
(%)	21-30	4.28	0.67	2.55	6.01	+	18
	31-40	13.4	6.22	0.00	29.4		4
	>40	16.7	11.4	0.00	46.06		4
take-off tree	none	0	0.00	0.00	0.00	-	13
(tot)	*Olearia traversii*	2.20	0.34	1.27	3.13	+	25
	Myrsine chathamica	7.70	1.83	2.77	12.6	+	15
	Coprosma chathamica	6.27	1.74	1.59	11.0	+	11
	Plagianthus regius	2.50	0.17	2.03	2.97	+	33
	dead	8.14	3.78	0.00	18.3		6
	Myoporum laetum	50.0	0.00	50.0	50.0	+	2
	Melicytus chathamica	100	0.00	100	100	+	1
tot DBH (mm)	0-200	3.38	0.49	2.11	4.65		19
	201-400	1.90	0.22	1.32	2.48	+	38
	401-600	2.12	0.09	1.89	2.35	+	31
	601-800	16.0	7.24	0.00	34.7		5
	>800	4.75	2.55	0.00	11.32		7
tot lean (°)	0-15	1.16	0.17	0.74	1.58		55
	16-30	7.08	1.38	3.63	10.5	+	12
	31-45	2.30	0.30	1.55	3.05	+	24
	>45	8.67	2.71	1.90	15.4	+	8

Discussion

Availability of suitable burrow sites may be an important factor in limiting the expansion of seabird colonies and breeding success of individuals (Storey and Lien, 1985). As a result, there may be intense inter- and intra-specific competition for sites, with some individuals forced to nest in marginal sites and others unable to breed at all (Lack, 1968; Burger and Gochfield, 1991). Under such circumstances, adaptable species are likely to oust others from particular habitat types (Lack, 1968). Differential resource selection is one of the principal means that permit species to co-exist (Manly *et al.*, 1993)

The habitat that Chatham petrels are currently found in, however, is not necessarily what they prefer, suggesting that the Kokopu Creek catchment has still been modified to the extent of being sub-optimal. Chatham petrel habitat selection was primarily influenced by forest type and structure. Chatham petrels selected vegetation 11 - 20 m in height. The age of ribbonwood on South East Island can be predicted by its diameter (J. Palmer and K-J. Wilson, unpublished data). Diameter increases with height (Spearman's correlation; $r = 0.62$), suggesting that height is an indicator of age. Stem density and understory cover decrease as stands age due to competition, and stem size along with canopy cover increases. Chatham petrels selected areas with moderate canopy cover and avoided dense stands and understory, suggesting that they prefer older forests. The species of take-off tree they selected supports this view. Chatham petrels selected areas in which karamu predominated as take-off trees. Karamu was probably once a dominant species on the island, but is currently only present as remnant trees (Wardle, 1991). They also selected take-off trees that had a lean of 16-30°, avoiding those with leans of 0-15°, as greater leans facilitate climbing. Chatham petrels avoided forest dominated by ake ake, which probably dominated a larger area of the island. Ake ake currently predominates in coastal fringes and on the summits (West and Nilsson, 1994), which may be unsuitable for other reasons such as exposure. Chatham petrels avoided areas with no stems which suggests a need for some cover, for example, for aerial predator avoidance or shelter from adverse conditions (Spear and Anderson, 1989).

Broad-billed prions selected mixed or matipo dominated forests of 11 - 20 m height, dense canopy cover, and moderate understory. They also selected areas which contained logs. This indicates that, like Chatham petrels, they also prefer more mature forests of mixed size classes and avoid areas with high stem density. Broad-billed prions required take-off trees but were adaptable as to the species and lean. Broad-billed prions were present in both pohuehue and bracken, yet few burrows were found in these vegetation types. Broad-billed prions may burrow between the ground and vegetation, or alternatively, only utilise these areas in the non-breeding season.

Topography and physical factors also influenced selection values. Although the majority of Chatham petrel burrows were on slopes with south-eastern aspects, this data suggests that they prefer north-eastern slopes. Steeper slopes were on northern and south-east facing slopes, and the gentler slopes on the south-western aspects (Pearson's correlation; $r = -0.49$; $P < 0.001$). Chatham petrel burrows occurred predominantly on slopes of 11-20°, in contrast to Taylor (1991) who found all Chatham petrel burrows on slopes of 0-10°, however, the number of known burrows at that time was small. While Chatham petrels did not appear to select or avoid particular slopes, the selection values were positive for the steeper slopes but had large standard errors. Therefore, slope should not be disregarded as an influencing factor. Observations of other gadfly petrels show that they generally burrow in relatively steep areas (e.g., Brandt *et al.*, 1995). Broad-billed prions selected eastern aspects and slopes of 11-40°. Advantages of steep terrain over flatter ground may include rapid drainage, reduced burrow collapse and ease of excavation (Stokes and Boersma, 1991; Brandt *et al.*, 1995).

Burrow construction requires substantial excavation and substrate stability and permeability will affect burrow quality. Therefore, substrate characteristics should influence burrow density (Stokes and Boersma, 1991). Many studies have shown burrowing seabirds prefer soft soil (e.g., Harris, 1974; Stokes and Boersma, 1991). There was no correlation between soil compaction and Chatham petrel burrow density but broad-billed prions selected soft soils. Soft soil is a limiting factor on South East Island due to the regenerating forest, as soil gets more compact with increased number of stems. Alternatively, broad-billed prions may make soil soft by intense burrowing.

The negative correlation between Chatham petrel selection values and availability of resources show that they are generally selecting for features which are now limited, suggesting that Chatham petrels are more habitat specific than broad-billed prions. These characteristics, indicative of mature forest, are likely to have been more prominent on South East Island, and throughout the Chatham Islands, before farming began in the mid 1800's. Chatham petrels were originally distributed throughout the Chatham archipelago and, while never abundant (West, 1994), numbers are unlikely to have been as small as the current population. The Chatham petrel colony on South East Island is contracting to occupy only a small area within the Kokopu Creek catchment. It is not known why Chatham petrels remain in the Kokopu Creek catchment. This may be the area where burrow competition in the past was less intense. Social factors can also be important in habitat selection, where individuals will burrow where there is greatest social stimulus (Kharitotonov and Siegal-Causay, 1990). Kharitotonov and Siegal-Causay (1990) and Forbes and Kaiser (1994) stated that species nesting in stable habitats retain strong site tenacity, which suggests that conditions for breeding remain locally favourable. The Kokopu Creek catchment on South East Island was possibly the only area on the island that was not extensively burnt (West and Nilsson, 1994; Nilsson *et al.*, 1994). While survey efforts are concentrated in Kokopu Creek catchment, it seems unlikely that burrow aggregations resembling Kokopu Creek are currently in other areas (Kennedy, 1994). The conclusions from this study are based on the assumption that known distribution reflects actual distribution, and that habitat characteristics selected by the known population represent the population as a whole.

Broad-billed prion selection values on South East Island indicate an extremely large population utilising habitat depending on its availability. Broad-billed prions selected most habitat characteristics, which suggests that they are opportunistic and with an expanding population, they are fully utilising their habitat range. Breeding habitat used by broad-billed prions in other areas is quite different. On North Island in Foveaux Strait, broad-billed prions burrowed in the coastal fringe among *Olearia angustifolia* and *Hebe elliptica* (Kennedy, 1978). Broad-billed prion burrows on Bird Island, Foveaux Strait were mainly confined to the cliffs and bordering scrub (Fineran, 1966). The largest population of broad-billed prions, estimated at 10 million pairs, is on Gough Island, where they predominantly burrowed under large tussocks (Swales, 1965). On Whero Island broad-billed prions were found chiefly in hard banks or under pohuehue (Richdale, 1965). All of these islands were relatively unmodified when these studies took place (Richdale, 1965; Swales, 1965; Fineran, 1966; Kennedy, 1978).

Based on the small numbers of broad-billed prion fossil bones on Mangere Island (Tennyson, 1994), broad-billed prions were likely to be less abundant on the Chatham Islands in the past. Mangere Island was predominantly forested but was cleared when farming began in 1892. Broad-billed prion numbers have since increased (Tennyson, 1994). There is no information on the seabird communities on South East Island before farming, but may have followed the same trend. Nilsson *et al.* (1994) commented that seabirds had "all but disappeared" from South East Island in the 1950's, so it is likely that broad-billed prion numbers have increased since farming ceased. It is impossible to tell from the selection values in this study what broad-billed prion traditional habitat was as they are currently selecting most habitat variables.

Modifying physical features to improve habitat quality may be useful in maximising populations (Stokes and Boersma, 1991). When trying to reduce competition between a rare and an abundant species, it is important that habitat requirements are sufficiently understood to avoid disadvantaging the rare species with any changes (Feare *et al.*, 1996). Habitat manipulation occurred on South East Island in 1990/1991, when a 35m^2 area of bracken and pohuehue was cleared around a Chatham petrel burrow. This was in attempt to encourage Chatham petrels to colonise the area, which they did not (West, 1994). Based on this study, this type of open habitat is unlikely to attract Chatham petrels and instead may be detrimental to the existing pairs. This study found that Chatham petrels prefer old growth, relatively unmodified forest to which little changes should or could be made. Because of broad-billed prions generalist behaviour and their high numbers, there were no differences in habitat selection that could be utilised to disadvantage broad-billed prions, and subsequently discourage them from the vicinity of Chatham petrel burrows.

Chatham petrel selection values should be considered when establishing a second population of Chatham petrels. Protecting areas that have desirable qualities for nesting is fundamental to the successful establishment of new colonies. The establishment of a second population of Chatham petrels is an essential long-term goal (Davis, 1999). Chatham petrel habitat is specialised and may limit colony expansion, therefore for any translocation to be a success this needs to be considered. Generally, a suitable habitat would be tall, open forest, with mixed age and size classes, have north-eastern aspects, moderate canopy cover, areas with a moderate number of logs, or other microhabitat features to assist orientation and locating burrows, have take-off trees with leans of approximately 16 - 30°, and slope of greater than 11°. Currently broad-billed prions are attempting to colonise Pitt Island (Davis, 1999), and have the potential to colonise any new Chatham petrel colony.

Understanding preferred habitat may be used to guide searches for new burrows. Although Chatham petrels are not known along the Kokopu creek, this may be close to typical habitat. However, it must be kept in mind that the conclusions are based on known burrows. Before restricting searches to particular areas, there needs to be a concentrated effort in other habitat types to confirm that the selection values in this study are representative of the whole population.

In summary, it is clear that burrow competition between Chatham petrels and broad-billed prions is due to the recent rapid expansion in the broad-billed prion population. Traditionally, species presumably partitioned available habitat to reduce such competition, and Chatham petrels and broad-billed prions would have selected different habitat characteristics. However, the habitat of South East Island has been considerably modified by human activities. The effect of this change on the seabird community is not known, but has probably altered the ecological balance between the two species. Availability of suitable burrow sites may be an important factor in limiting the expansion and breeding success of the current population of Chatham petrels. Individual birds probably still select burrow sites on the basis of habitat quality, and traditional habitat is likely to be similar to the Kokopu creek catchment in which they currently exist. Broad-billed prions, on the other hand, are generalist in their burrow site choice and have adapted to changes in vegetation on South East Island.

West and Nilsson (1994) state that the species composition over the whole island is likely to have changed, and is still changing, as a result of increasing pressure from broad-billed prions expanding their traditional habitat. However, as broad-billed prions are now starting to colonise Pitt Island, the numbers on South East Island may have peaked. Continual management of the existing population of Chatham petrels, along with translocation, should allow the balance between Chatham petrels and broad-billed prions to eventually stabilise.

Acknowledgments

Many thanks to the Department of Conservation - Wellington Conservancy and Chatham Islands Field centre for funding and support; Rhonda Pearce and Mandy Barron for their assistance in data collection; Kerry-Jayne Wilson and Adrian Paterson for their advice and helpful comments on the draft; to Chris Frampton for his statistical help; and Graham Hickling and James Griffiths for editing a draft of this chapter.

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Chapter 3.

Influence of artificial burrows and microhabitat on burrow competition between Chatham petrels (*Pterodroma axillaris*) and broad-billed prions (*Pachyptila vittata*).

Abstract: The Chatham petrel (*Pterodroma axillaris* Salvin) is an endangered species which breeds only on South East Island, Chatham Islands. The key threat to breeding success is interference to chicks by broad-billed prions (*Pachyptila vittata* Forster), when they prospect for burrows for their on-coming breeding season. Chatham petrel burrows are monitored nightly and broad-billed prions found in the burrows are culled. All known Chatham petrel burrows have been replaced with artificial burrow chambers and tunnels which assist monitoring and reduce burrow collapse. Tracks lead to burrows to facilitate monitoring. This study investigated whether artificial boxes, logs and tracks attracted broad-billed prions to Chatham petrel burrows, thus increasing broad-billed prion interference. I found that prospecting broad-billed prions were not attracted to Chatham petrel burrows. The presence of logs or tracks did not directly increase chick interference levels, but increased the number of broad-billed prions near a burrow. Reducing the presence of logs could decrease the number of broad-billed prions around Chatham petrel burrows, potentially decreasing interference.

Key words: Chatham petrel; *Pterodroma axillaris*; broad-billed prion; *Pachyptila vittata*; artificial burrows; micro-habitat.

Introduction

The Chatham petrel (*Pterodroma axillaris* Salvin) is an endangered species endemic to the Chatham Islands, New Zealand. The species is now restricted to a single breeding population on South East (Rangatira) Island, within the Chatham archipelago. The total estimated population is less than 1000 individuals (Kennedy, 1994). The key threat to breeding success is interference to chicks by the locally abundant broad-billed prion (*Pachyptila vittata* Forster) (Kennedy, 1994; Gardner and Wilson, 1999).

On South East Island, inter- and intraspecific competition for breeding burrows is intense (Was and Wilson, 1998). During their non-breeding season (February to July), broad-billed prions prospect for burrows for their on-coming breeding season (Was and Wilson, 1998). Prospecting coincides with the Chatham petrel chick-rearing period, from mid February to June, and broad-billed prions will evict or kill the chick to claim the burrow (West, 1994; Gardner and Wilson, 1999). Before the current management regime began in 1997, 55% of Chatham petrel breeding attempts failed and Gardner and Wilson (1999) attributed approximately 70% of those failures to interference by broad-billed prions. Since 1997, the Chatham petrel burrows have been intensively patrolled each night and broad-billed prions found in Chatham petrel burrows culled. This has resulted in an extensive track system with major tracks leading to most Chatham petrel burrows.

Artificial burrows have been used successfully in the research and management of several species of burrow nesting seabird, facilitating monitoring and providing access to burrow chambers. This reduces disturbance and the risk of burrow collapse (Warham, 1990; Priddle and Carlisle, 1995). Since the 1992-93 season, all breeding Chatham petrel burrows have been replaced with artificial burrow chambers and tunnels fitted with 100 mm diametre novapipe (Figure 3.1) (Kennedy, 1994). The artificial entrances are larger than natural Chatham petrel burrow entrances, which are approximately 62 mm wide and 96 mm in height (West and Nilsson, 1994).

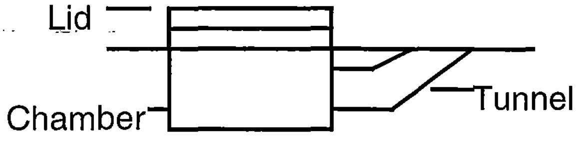

Figure 3.1. Diagram of an artificial Chatham petrel burrow.

Broad-billed prions readily use artificial study burrows. Rohrbaugh and Yahner (1997) suggested that the use of artificial nest boxes by a species indicates a paucity of natural nest sites. This supports Gardner and Wilson's (1999) observations that burrow competition is causing broad-billed prions to take over Chatham petrel burrows. Alternatively, artificial burrows may be more attractive than natural broad-billed prion burrows or claiming existing burrows easier than excavating new burrows.

Artificial nests are presumably selected on the basis of characteristics associated with the nest box and surrounding habitat features (Rohrbaugh and Yahner, 1997). Brandt *et al.* (1995) reported that dark-rumped petrels (*Pterodroma phaeopygia sandwichensis*) situated their burrows under larger than average rocks. There are a number of features of a Chatham petrel nest box which may make it more attractive to broad-billed prions. Broad-billed prion burrow entrances are larger than natural Chatham petrel entrances (West and Nilsson, 1994), and the wider novapipe tunnel of the artificial entrances may attract broad-billed prions. Preliminary observations suggested that broad-billed prions were attracted to raised objects, such as the artificial burrows chamber and surrounding logs for orientation and resting. In chapter 2, I found that there were fewer broad-billed prion burrows in areas with high tree density, presumably as this impedes movement, and preliminary observations suggested they used tracks when moving throughout the colony.

It is essential when managing Chatham petrels not to exacerbate interspecific competition with broad-billed prions. Raised artificial boxes connected by tracks may lead broad-billed prions to Chatham petrel burrows. It may be possible to manipulate habitat characteristics which attract or repel broad-billed prions, such as removing logs from around Chatham petrel burrows. This chapter determines whether the artificial boxes currently used attract broad-billed prions to Chatham petrel burrows. I investigated the effect of logs and tracks on broad-billed prion prospecting behaviour and determined whether these features increased broad-billed prion interference in Chatham petrel burrows.

Methods

Study site:

Observations of broad-billed prions took place around Chatham petrel burrows in the Kokopu Creek catchment (Figure 3.2). The majority of Chatham petrel burrows are located in this area. The Kokopu Creek catchment is the oldest existing tract of forest and is relatively unmodified by past farming activities. It is a mixed species, mixed aged, open forest of 6 - 15 metres in height. This area is moderately sloping with medium soil compaction and north-eastern and south-western aspects. The Kokopu Creek catchment has little understory and moderate canopy cover. This area has a mean of 0.48 broad-billed prion burrows/m^2 (Chapter 2). Active broad-billed prion burrows are on average 1.9 m from Chatham petrel burrows.

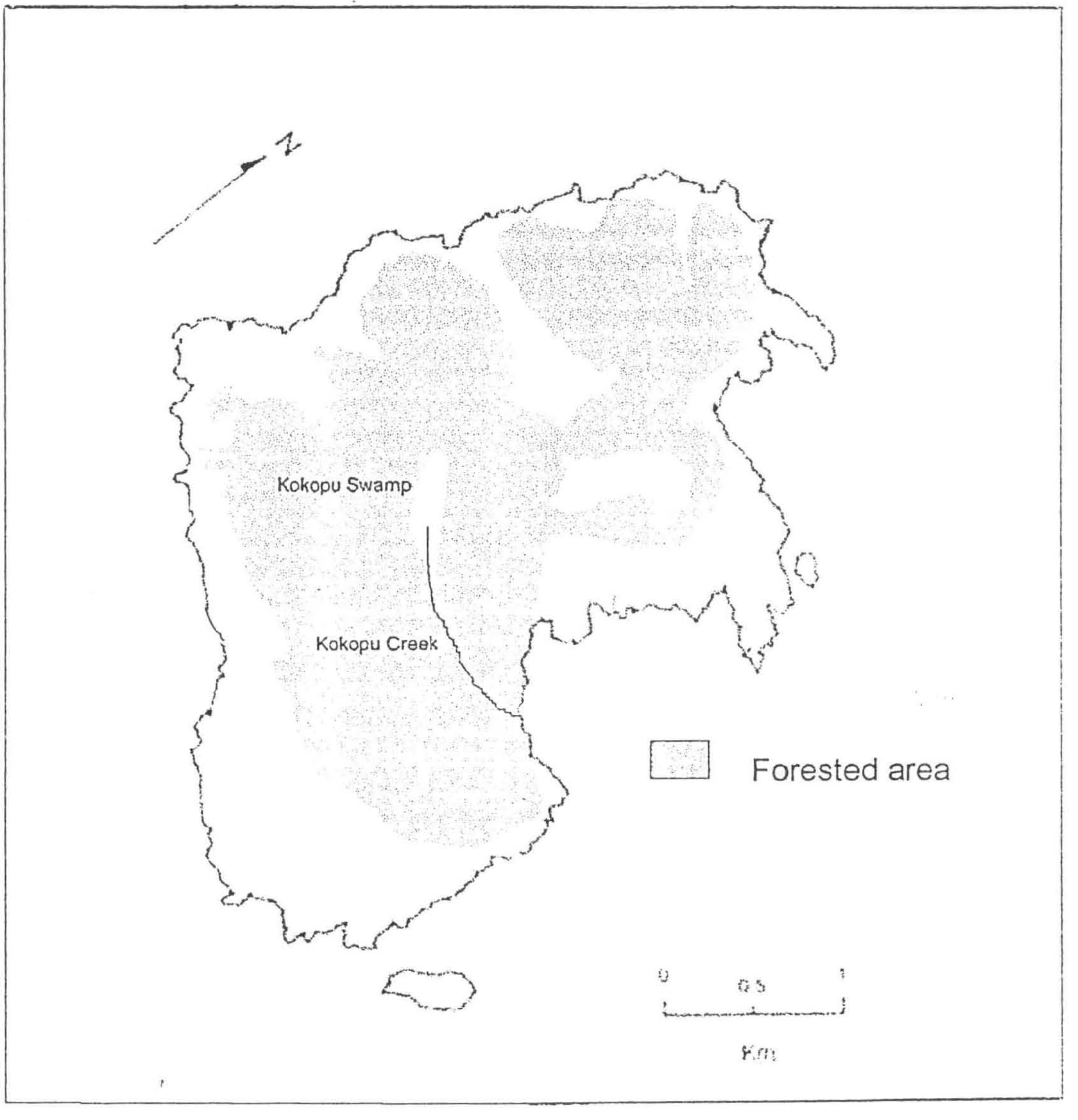

Figure 3.2. Map of South East (Rangatira) Island.

General methods

Preliminary data were collected from 16 April to 5 May 1998 to determine the types of behaviour exhibited by prospecting broad-billed prions (Table 3.1). Information gained from these observations was used to refine the methodology for this study which took place between 15 February and 12 April 1999.

Table 3.1. Descriptions of broad-billed prion behaviour in the vicinity of Chatham petrel burrows.

Behaviour Category	Description
Chatham petrel (CP) burrow interference	Vocalising and/or looking into (within 0.05 m of the entrance), prodding, semi or fully entering CP burrow
Utilising log	Walking on, sitting on, or walking alongside a log (within 0.1 m)
Utilising artificial CP box	Walking on, sitting on, walking alongside (within 0.1 m) or prodding artificial CP burrow chamber
Utilising track	Walking or sitting on track
Interaction	Physical contact between two or more broad-billed prions
Rest	Preening, sleeping or sitting for greater than two minutes
Look	Pausing and looking around
Prospect	Vocalising into, looking into (within 0.05 m of the entrance), prodding, semi or fully entering broad-billed prion burrow; searching ground
Move	Walking or running across ground other than track
React to observer	Cease behaviour and stare at or move away from observer.

To measure the behaviour of broad-billed prions close to Chatham petrel burrows, 21 burrows were selected from the total of 54 known Chatham petrel breeding burrows. A burrow protection trial by the Department of Conservation running simultaneously to this study reduced the number of burrows available and meant burrows could not be selected randomly. A circular quadrat with a 3 m radius was marked around the burrow entrance. Each night an observer watched one burrow three to five hours from dusk, for up to five consecutive nights. The order in which burrows were observed was randomly selected. Observations were simultaneous with those for Chapter 4. Behaviour was observed through a night-vision scope (Zenit NV100 and Apple Nightspy) approximately 3 m from the entrance. Sampling focused on one individual within the quadrat, and continuous recording was used, which gave frequency and duration of behaviours.

Bancroft's (1999) data on the frequency of Chatham petrel burrows entered by broad-billed prions was compared between burrows with logs present or absent in the quadrat and burrows with tracks present or absent in the quadrat.

Data were analysed using STATISTICS. Parametric data was analysed using one-way ANOVA's and Kruskal-Wallis tests were used for non-parametric data.

Results

Broad-billed prion numbers

The number of broad-billed prions in individual quadrats was significantly different (Kruskal-Wallis; H = 33.13; df = 21; $P < 0.05$), and overall, there were 0.45 broad-billed prions entering a quadrat per hour. The number of broad-billed prions ashore during a night had a significant influence on the number of broad-billed prions in a quadrat per hour (Kruskal-Wallis; H = 58.36; df = 33; $P < 0.01$), and this was highly variable. Numbers of broad-billed prions entering the quadrat also varied during a night, with the majority (58%) in the quadrat from 20:00 to 20:59 (Chatham Island standard time). This was approximately one hour after dusk. There was also a large number from 21:00 to 22:59. The mean proportion of time spent on each behaviour did not change during a night.

Changes in broad-billed prion behaviour

Individual broad-billed prions spent a mean of 141 seconds in the quadrat (range: 5 sec - 45 min; SD: 360 sec). The most predominant behaviour was walking (Figure 3.3), and 17% of these broad-billed prions walked through the quadrat engaging in no other behaviour.

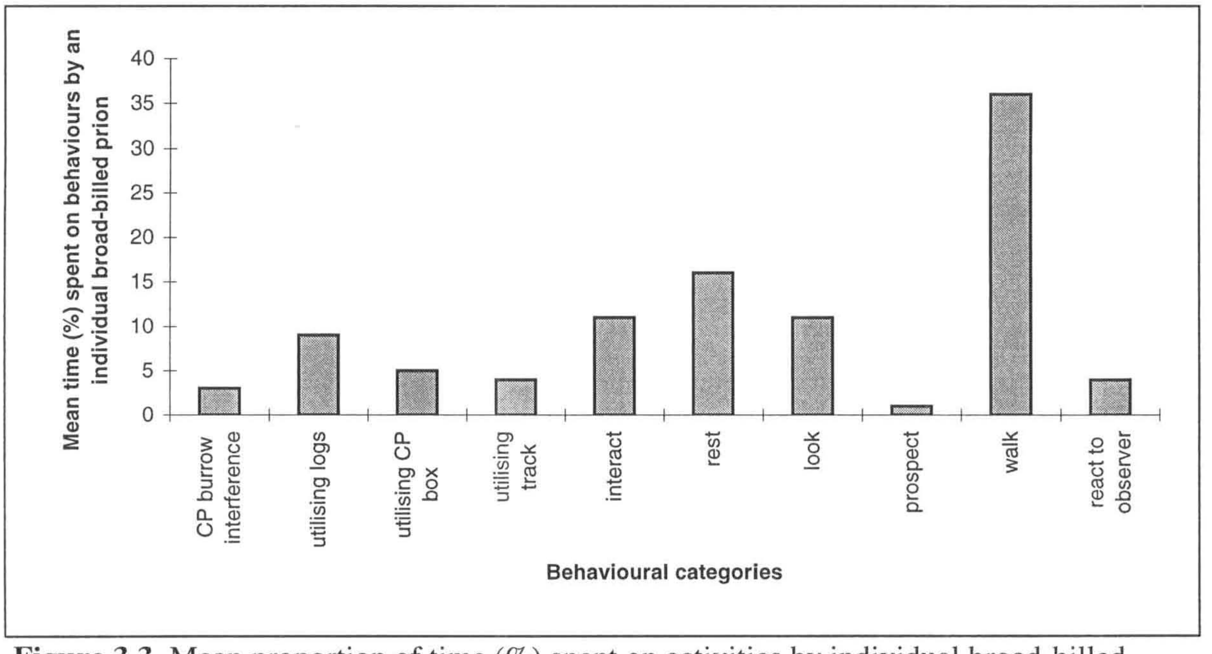

Figure 3.3. Mean proportion of time (%) spent on activities by individual broad-billed prions within a 3 m radius of a Chatham petrel (CP) burrow.

There were significantly more broad-billed prions at Chatham petrel burrows with logs present (Kruskal-Wallis; F = 32.32; df = 148; $P < 0.001$). However, the presence of logs had no significant effect on the total time broad-billed prions spent in the quadrat, or on the time spent on any behaviour (Kruskal-Wallis tests).

There was no significant change in the proportion of time broad-billed prions spent on any behaviour, or the number of broad-billed prions entering the quadrat per hour (Kruskal-Wallis; F = 1.18; df = 1; $P = 0.28$) when a track ran through the quadrat.

Interference with Chatham petrel burrows

Broad-billed prions were no more attracted to Chatham petrels burrows than broad-billed prion burrows. Only 2.7% of broad-billed prions within the quadrat prospected at a Chatham petrel burrow compared to 16% which prospected at an individual broad-billed prion burrow within the quadrat. They spent longer prospecting at broad-billed prion burrows than Chatham petrel burrows (Kruskal-Wallis; H= 25.89; df = 1; $P < 0.001$). The number of broad-billed prions in the vicinity of a Chatham petrel burrow during a night did not influence the level of interference (One-way ANOVA; $F_3 = 0.00$; $P = 0.97$). The number of logs had no effect on the level of interference (One-way ANOVA; $F_{21} = 1.18$; $P = 0.35$), nor did presence or absence of a track within 1 m of the entrance (One-way ANOVA; $F_{21} = 0.01$; $P = 0.91$).

Discussion

Despite 46% of Chatham petrel burrows visited by broad-billed prions in the 1998/1999 breeding season (Bancroft, 1999), broad-billed prion numbers around Chatham petrel burrows were low. Broad-billed prions prospected less often at a Chatham petrel burrow than a broad-billed prion burrow. This suggests that the box and the larger artificial entrance did not attract broad-billed prions to the burrow as predicted. Broad-billed prions spent considerably more time prospecting at broad-billed prion burrows than Chatham petrel burrows, however, the history of these burrows is not known and these birds may have previously bred in these burrows.

The majority of broad-billed prions entered the quadrat one to two hours after dusk. During the observation period, five hours from dusk, the proportion of time they spent on individual behaviours did not change. Was (1999), who observed broad-billed prion behaviour throughout the night, found changes in the types of behaviours exhibited. In her study, more broad-billed prions prospected, moved, and utilised logs in the period 02:30 to dawn than earlier in the night. She suggested that increased surface movement may have been due to the birds preparing to leave the island. The proportion of time spent on behaviours which may increase the chance of chick interference - pausing or looking around, prospecting, sitting and resting, attention to the artificial box and utilising the track, was collectively 47%. Was (1999), who studied broad-billed prions away from Chatham petrel burrows, had similar results. This suggests that broad-billed prions do not change their behaviour when in the vicinity of a Chatham petrel burrow.

The number of broad-billed prions in the vicinity of specific Chatham petrel burrows varied suggesting that some burrows, or surrounding habitat, may attract broad-billed prions. Burrow location by visual means centres on recognition of landmarks in the vicinity of the burrow (Grubb, 1974; Brooke, 1978; James, 1986). Broad-billed prions were attracted to logs which could be used in orientation and location of their burrows during the breeding season. Removing logs around Chatham petrel burrows may reduce the number of broad-billed prions in the immediate area. Chatham petrels also appeared to use landmarks such as logs, tree roots and artificial burrow chambers to locate their burrows. Understanding how Chatham petrels locate their burrows is important before altering the entrance or immediate area to avoid disrupting their location cues. Chatham petrels are breeding at this time, however, and because of their investment in their chicks would have a greater incentive to find their burrows if logs were removed. Vision, audition, olfaction or all three may function in guiding birds to their burrows (Grubb, 1974; Minguez, 1997). Further research into this facet of Chatham petrel ecology is required before any changes are made to the microhabitat and burrow entrance. The frequency of interference to chicks in burrows surrounded by logs was no greater than burrows without logs, nor did behaviour of broad-billed prions change, despite a greater number of broad-billed prions present. Sample size was small, however, and data for chick interference were obtained for only one season. The number of broad-billed prions around a Chatham petrel burrow was influenced by the number of broad-billed prions ashore which was relatively low compared to previous years (Bancroft, 1999).

Broad-billed prion numbers or behaviour did not change with the presence of a major track near a Chatham petrel burrow. There was also no difference in the level of interference to chicks. Broad-billed prions did, however, use tracks more when logs were present and with the increased number around logs, there is a potential that the tracks may lead broad-billed prions to Chatham petrel burrows and increase interference to chicks. Clearing logs around Chatham petrel burrows may reduce this risk.

In summary, this study showed that prospecting broad-billed prions were not notably attracted to the novapipe entrance, chamber lid or burrow markers of the artificial Chatham petrel burrows, compared to natural burrows. Prospecting at Chatham petrel burrows probably results from a shortage of broad-billed prion burrows in that area. The presence of logs or tracks did not directly change behaviour or increase chick interference levels. Broad-billed prions are attracted to logs, however, and used the track more when logs were present. Reducing the presence of logs could decrease the number of broad-billed prions in the vicinity of Chatham petrel burrows and potentially decrease interference.

Acknowledgments

I am grateful for the assistance of Rhonda Pearce and Mandy Barron with field work; Department of Conservation for funding and field support; Kerry-Jayne Wilson and Adrian Paterson for their advice and comments, and Lisa Berndt for editing a draft of this paper.

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Chapter 4.

Use of burrow entrance flaps to minimise interference to Chatham petrel (*Pterodroma axillaris*) chicks by broad-billed prions (*Pachyptila vittata*).

Abstract: The Chatham petrel (*Pterodroma axillaris* Salvin) is an endangered species, restricted to a single population on South East Island, Chatham Islands. The key threat to breeding success is interference to chicks by broad-billed prions (*Pachyptila vittata* Forster), when they prospect for burrows for their oncoming breeding season. The effectiveness in decreasing interference using an artificial burrow entrance flap was investigated. The flap exploits behavioural differences between the species. Chatham petrels have a high incentive to push through a flap due to their investment in their burrow and chick, while prospecting broad-billed prions are influenced by the ease of entering a potential burrow. This trial found 90% of Chatham petrels entered their burrows through the artificial flap. Flaps acted as barriers to most broad-billed prions, where only 22% entered the burrow through the flap ($P < 0.01$) compared to the control burrows. Burrow entrance flaps have the potential to provide a low cost, low labour strategy for protecting known Chatham petrel chicks.

Key words: Chatham petrel; *Pterodroma axillaris*; broad-billed prion; *Pachyptila vittata*; burrow competition; burrow entrance flap.

Introduction

The Chatham petrel (*Pterodroma axillaris* Salvin) is an endangered marine bird endemic to the Chatham Islands, New Zealand. They are now restricted to a single breeding population on South East (Rangatira) Island, Chatham Islands. The total population is estimated at 500 to 1000 individuals (Kennedy, 1994). The key threat to breeding success is interference to chicks by broad-billed prions (*Pachyptila vittata* Forster) (Kennedy, 1994; Gardner and Wilson, 1999). While burrow competition between the two species presumably occurred in the past, it has probably been exacerbated by intense burrow competition due to a reduction in suitable habitat for both species.

Broad-billed prions spend much of the night prospecting for burrows during the non-breeding season (mid February to July) for the on-coming breeding season (Was and Wilson, 1998). This prospecting coincides with the Chatham petrel chick-rearing period. Chatham petrel chicks are left unattended by the adults who generally visit to feed the chick once every 2-3 nights. Broad-billed prions will evict or kill the chick to claim ownership of the burrow (West, 1994; Gardner and Wilson, 1999). Gardner and Wilson (1999) found that without active management, 55% of Chatham petrel breeding attempts failed and they attributed 70% of these failures to interference by broad-billed prions.

To prevent broad-billed prions injuring Chatham petrel chicks and forming an association with their burrows during the breeding season, night patrols occur around the known Chatham petrel burrows. All broad-billed prions found within the entrance or chamber of the burrow are culled. The patrol can visit a burrow up to six times a night depending on the number of broad-billed prions ashore. Breeding success has improved since this intensive management regime was established in 1997, increasing to 78% in 1999 (Bancroft, 1999). This management strategy is not without costs. Patrols disturb Chatham petrels, are labour intensive, provide only short term protection, and involve killing a protected native species. To decrease interference to Chatham petrel burrows, development of alternative methods to manage this population with minimal intervention is needed.

The impacts of burrow competition in seabirds of different sizes have been reduced in the past by artificially reducing the size of the burrow entrance, excluding the larger competitors (Wingate, 1977; Ramos *et al.*, 1997). Reducing the size of the entrance is not an option in this case as broad-billed prions and Chatham petrels are both approximately 200 g (Marchant and Higgins, 1990). Behavioural differences between the two species could be exploited, due to different stages of their lifecycles.

This research trialed artificial 'burrow entrance flaps' attached to the entrance of Chatham petrel burrows, to investigate their effectiveness at deterring broad-billed prions from entering burrows. The flap is attached after the chick had hatched when adults have formed a bond with the burrow, therefore they have a high incentive to push through the flap to reach the chick. Prospecting broad-billed prions may be influenced by the conspicuousness of a burrow's entrance or ease of access, when searching for potential burrows. Gardner and Wilson (1999) suggest that larger, easily accessible burrows may be invaded by broad-billed prions more frequently than burrows with smaller or less conspicuous entrances. If so, they are likely to be deterred by burrow entrance flaps from entering burrows.

Methods

Study site:

Chatham petrel observations took place in the Kokopu Creek catchment where the majority of the known Chatham petrel burrows are situated. The broad-billed prion trials used the artificial broad-billed prion burrows set up by Was and Wilson (1998) in Woolshed Bush. These sites are vegetatively similar and have been described in detail in Chapter 2. The trials were kept separate due to the possibility of inducing interference by broad-billed prions discouraged from entering their own burrows by the flaps.

General

Preliminary data were collected from 16 April to 5 May 1998 using two prototype burrow flaps. This information was used to modify the two flap types. 'Prototype flap A' (Figure

4.1a) was made of 1 mm thick truck tyre with a central X cut. This proved to be unsuitable as Chatham petrels had difficulty pushing through and it did not allow for movement of plant material and soil in and out of the entrance. 'Prototype flap B' was made from 2 mm neoprene, with an inverted T cut, 70 x 70 mm length. This cut was originally 30 mm from the bottom of the entrance (Figure 4.1b) and was lowered to assist Chatham petrel entry (hereafter called 'neoprene flap' Figure 4.2a).

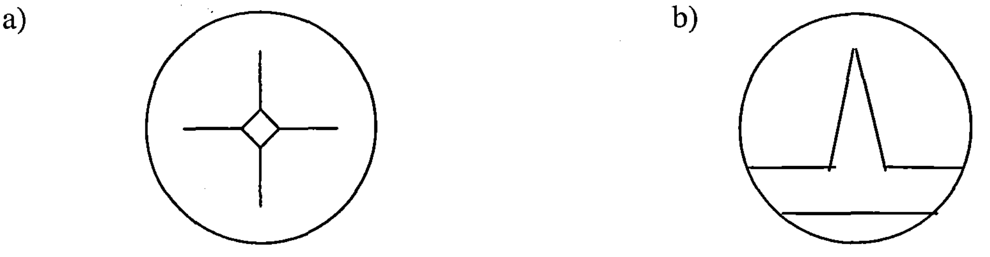

Figure 4.1. Protocol artificial burrow flaps trialed on Chatham petrel, South East Island, 16 April and 5 May 1998; a) 'Prototype flap A', made of 1 mm thick truck tyre with a central X cut; b) 'Prototype flap B', made with 2 mm neoprene with an inverted T cut.

The 'tyre flap' was made with 1 mm thick bike tyre, cut into four 25 mm strips. The two inner strips had a length of 80 mm and the two outer strips 70 mm (Figure 4.2b).

Figure 4.2. Artificial burrow flaps trialed on Cooks petrel (*Pterodroma cookii*), Little Barrier Island, 12 - 27 January 1999 and Chatham petrel and broad-billed prion, South East Island, 15 February - 12 April 1999; a) 'Neoprene flap' made with 2 mm neoprene with an inverted T cut; b) 'Tyre flap' made with 1 mm thick bike tyre cut into four 25 mm strips.

Both designs were fitted to a 30 mm piece of 110 mm Marley drainflo™ novapipe using a 90-114 mm hose clasp. The two new designs were trialed on an analogue species, Cooks petrel (*Pterodroma cookii*) on Little Barrier Island in January 1999. Cooks petrel was used due to their similar body size and burrow entrances. These trials proved the designs to be successful and the information gained was used to refine the methodology for the trials on Chatham petrels and broad-billed prions, which took place on South East Island from 15 February to 12 April 1999.

Chatham petrel trial:

To measure the response of Chatham petrels to the burrow entrance flaps, 21 burrows from a total of 54 known burrows with chicks were selected. A simultaneous Department of Conservation trial on alternative burrow protection methods reduced the number of available burrows and meant that burrows could not be selected randomly. However, treatments were randomly allocated to the 21 study burrows.

A 3 m circular quadrat was marked out around the burrow entrance at 1 m intervals. Each observer watched one burrow per night, for three to five hours beginning at dusk. Behaviour was observed through a night-vision scope (Zenit NV100 and Apple Nightspy) approximately 3 m from the burrow entrance.

A pre-treatment phase was completed on 10 Chatham petrels to determine the mean time, from 1 m away, to enter its burrow using a digital timer. The mean number of attempts was also recorded for each bird, which was defined as when a Chatham petrel looked into the burrow entrance within approximately 0.05 m. These values assisted the observers in determining how disturbed the bird was by the flap during the treatment stage.

During the treatment stage, burrows were watched to observe three visits by the same Chatham petrel, which would determine the extent of habituation. This gave an indication to whether their tolerance changed with increased familiarity to the flaps. Observations ceased after five nights if the bird did not visit the burrow during the observation period. The lid of the artificial burrow was raised to identify the Chatham petrel 20 minutes after it had entered to allow time for the chick to be fed without disturbance. The bird was identified using low intensity torch light and members of the pair were distinguished by a coloured paint stripe on their head. If the Chatham petrel appeared to be distressed and refused to enter the burrow after approximately 6 minutes, which was the longest typical time determined from the pre-treatment stage, the flap was gently pulled away using an attached string. The flaps were only in place while observers were present.

Observations on a control burrow occurred simultaneously with a treatment burrow. This procedure compared the time and attempt values before and during the treatment, and between the treatment and control. The data were analysed using One-way ANOVA's and Fishers Least Significant Difference tests in SYSTAT.

Broad-billed prion trial:

To measure the effectiveness of flaps in preventing broad-billed prions from entering burrows, 47 artificial broad-billed prion burrows were used. These burrows were used and described by Was and Wilson (1998).

A pre-treatment phase of 20 days established the natural visitation rates to burrows. For the treatment phase, 20 burrows had the flap attached (10 of each design) with the remainder as control burrows. To monitor movement into the burrow and therefore the effectiveness of the flap, a 'fence' made of sticks was placed inside the entrance and if displaced indicated that the burrow had been entered. This technique is often used (eg Bartle, 1968) for monitoring burrows as it is time effective and avoids unnecessary disturbance. It does not prevent birds from entering the burrows. The fences were checked and if necessary replaced at approximately 01.00 to 02.00 and again after dawn. Any unbanded broad-billed prion found within a burrow was banded. The broad-billed prion was returned to the burrow via the tunnel as this is considered less stressful (Gardner and Wilson, 1999), unless a flap was attached in which case it was returned via the burrow lid to avoid induced habituation. The treatments were randomly allocated and swapped every 12 days as some burrows were already occupied. This meant that those birds would have greater incentive to push through and would have a faster rate of habituation to the flaps than broad-billed prions prospecting at Chatham petrel burrows.

Birds found within the burrows were categorised as occupiers or prospectors. Occupiers were broad-billed prions that had been found in that burrow two or more times. Data from Was and Wilson (1998) gave the occupancy history of individual burrows for four years. The frequency of broad-billed prions to enter burrows was compared between treatment and control burrows and data were analysed using One-way ANOVA on SYSTAT.

Results

Chatham petrel trial

Both burrow entrance flap designs significantly increased the time it took for Chatham petrels to enter their burrow (Fisher's LSD test, $P < 0.01$) compared to the control burrows. The flap did not cause the number of attempts to significantly differ (One-way ANOVA, $F_3 = 1.69$, $P = 0.18$), and 90% of Chatham petrels went through the flap compared to 100% through the control burrows (Table 4.1). We were not able to test whether the three petrels that did not enter would have entered in subsequent visits. The response of Chatham petrels to the neoprene and tyre designs were not significantly different (Fisher's LSD test, P = 0.81).

Table 4.1: Response of Chatham petrels to burrow entrance flaps, South East Island, 15 February to 12 April 1999.

	mean time[1] (min)	**mean number of attempts[2]**	**% entered**	**n**
Control	0.52	3	100	12
Flap				
'neoprene'	2.05**	4^{NS}	88	16
'tyre'	2.21**	2^{NS}	93	15

[1] time taken from 1 m to enter burrow

[2] number of times bird looks down at entrance within 0.05 m

Significance: NS = $P > 0.05$; * = $P < 0.05$; ** = $P < 0.01$

Natural behaviour of a Chatham petrel around its burrow entrance without the flap attached was highly variable. The time it took to enter the control burrows ranged from 11 seconds to 5.20 minutes, and the number of attempts to enter ranged from 1 to 12. There were no significant correlations between the age of chicks and time to enter (Pearson correlations matrix, P = 0.43) and the age of chicks and number of attempts (Pearson correlations matrix, P = 0.38).

Broad-billed prion trial

There was a highly significant decrease in the frequency of prion entry between treatment and control burrows (One-way ANOVA, $F_3 = 24.27$, $P < 0.01$), with a reduction of 80% for the neoprene design and 73% for the tyre design (Table 4.2).

Table 4.2: Effect of burrow entrance flaps on frequency of burrows entered by broad-billed prions, South East Island, 15 February to 12 April 1999.

	burrows entered (% decrease)	**occupier[1] (%)**	**prospector[2] (%)**	**unknown[3] (%)**
Control	271	30.0	7.8	60.5
Flap				
'neoprene'	11 (80)	63.6	18.2	18.2
'tyre'	35 (73)	37.1	8.6	54.3

[1] 2 known visits over 4 seasons in one burrow (data also from Was & Wilson 1998)
[2] Broad-billed prion found in a burrow in which it has never been recorded
[3] Burrow had been entered but no broad-billed prion found

The majority of prions found in the burrows with the neoprene flaps attached were 'occupiers'. Within the control burrows and those with the tyre flap attached, the majority of the birds that entered were not found in the burrows, thus the status of these birds was unknown.

Discussion

Response of Chatham petrels to burrow entrance flaps

Behavioural differences between two species of seabird have never been used to minimise the effects of burrow competition. This research shows that manipulating behavioural differences has the potential to be an effective management tool.

Burrow entrance flaps do not prevent adult Chatham petrels from entering their own burrows. Chatham petrels were affected by the flap, shown by the increased time it took to enter the burrow. However, this does not appear to be detrimental as the number of attempts to enter the burrow did not change, and the majority of petrels still entered. Of the 19 petrels trialed, three did not enter through the flap. Of these, one petrel pulled off the flap which not secured probably and entered, and one petrel refused to enter after previously entering the burrow through the flap. Due to time and permit restrictions, we were not able to test whether these petrels would have refused to enter with subsequent visits or if tolerance to the flap would increase. Natural burrows are replaced with artificial nests boxes and novapipe tunnels once the chicks are 10 days old (Bancroft, 1999). Based on observations of Chatham petrel behaviour towards the artificial nest box, a relatively greater disturbance than the flap, I would predict an increase in tolerance. I observed the initial response of one Chatham petrel to an artificial box and tunnel, without the flap attached. This has not previously been observed with Chatham petrels. Over an hour the bird returned three times, and made a total of 12 attempts to enter. The bird did not fully enter during this hour and I assumed that it would not enter the chamber through the novapipe tunnel which it encountered half-way into the tunnel. It was unlikely that the chick was fed. We observed the same bird entering the burrow nine nights later with little hesitation and the chick fledged (Bancroft, 1999).

Currently, the plan is to attach the flap after the egg has hatched and remove before the chick first leaves the burrow. The stage in the breeding cycle in which the flap is attached may have a significant influence on subsequent behaviour by Chatham petrels. Nest-site tenacity is generally high in Procellariiformes (Thibault, 1994). Petrels tend to return to the same nest during successive breeding seasons which provides a focal point for partners to meet (Warham, 1990). The following questions need to be answered. Would the incentive lessen if the flap was attached before the breeding season? If the flap had been on for the majority of the previous season, would the Chatham petrel recognise its own burrow the following season if the flaps are not attached until after incubation? Severe disturbances to nest sites may cause shifts to new nest sites. Such shifts could result in the break-up of pairs and consequently lower reproductive success (Morse and Kress, 1984; Warham, 1990). Long term monitoring is important to ensure that the flap does not disrupt mate and burrow fidelity, and cause burrow swapping in succeeding seasons. Ideally, the flap should be in place all year round to prevent problems in burrow recognition, minimising the likelihood of induced burrow shifts. It would also reduce the number of broad-billed prions breeding in burrows during the Chatham petrel non-breeding season, alleviating the need for other management practices.

Chicks of many petrel species leave the burrow at night some time before fledging to exercise and orientate with their surroundings (Manuwal, 1976; Harper, 1976; Warham, 1990). The timing of this behaviour varies with species. For example, fairy prion (*Pachyptila turtur*) chicks first leave the burrow about 52 hours before departure (Harper, 1976), and black petrel (*Procellaria parkinsoni*) chicks 10 nights prior to fledging (Imber, 1987). Incidental observations suggest Chatham petrel fledglings start leaving the burrow at approximately 15 days prior to fledging (P. Gardner, pers. comm.). The flap may prevent the chick leaving, disrupting exploratory behaviour, or prevent the chick from returning to the chamber, causing it to leave the burrow prematurely. Petrel chicks explore the immediate confines of the burrow from an early age (Manuwal, 1976; Minguez, 1997) and the development of a cognitive ability that allows chicks to return to their nest during the nestling period (Minguez, 1997) may mean that the chick will perceive the flap to be a normal part of its burrow. Alternatively, chicks may be more likely to recover from broad-billed prion attack at an older age and the flaps could be removed before this exploratory stage.

Another aspect that needs to be investigated is the potential changes in the microclimate of the chamber. Flaps may reduce airflow, increasing humidity, temperature, ammonia and carbon dioxide, which could have detrimental impacts on chick respiration and growth. Many petrel species have deep chambers (Manuwal, 1976), however, and petrels often block their entrances with leaf material while the adult is in occupancy (Warham 1990), consequently airflow may be naturally limited. Chatham petrels cover their entrances with leaf material when they leave although I have not observed them blocking the entrances while in the burrow. Chicks develop thermoregulation at an early age (Manuwal, 1976), and should be able to adjust to moderate increases in temperature.

Because Chatham petrels are an endangered species, the sample size for the trial was small, and was exacerbated by their unpredictable behaviour. Like most petrel chicks (Richdale, 1945; Harper, 1976; Imber, 1987), Chatham petrel chicks are generally fed every 2-3 nights. The feeding rhythm in petrels from hatching to fledging is irregular (Richdale, 1945; Warham, 1990), and there is no set pattern to parental attendance (Imber, 1987). As with all other Procellariiformes (Warham, 1990), both members of the Chatham petrel pair feed the chick and visits are independent of one another. This made it difficult to observe behaviour for three consecutive visits, in order to measure changes in tolerance levels.

Response of broad-billed prions to burrow entrance flaps

Because the artificial broad-billed prion burrows used have been utilised by birds for up to four seasons, a number of 'occupiers' continued to enter the burrow through the flap. Like

Chatham petrels, the longer a pair of broad-billed prions have bred together, the higher the chance of birds retaining their burrow despite disturbance, such as the attachment of a flap. As no broad-billed prion establishes an association with a Chatham petrel burrow with the current management regime in place, it is more important to look at the response of 'prospectors'.

Attaching a burrow entrance flap to a burrow effectively deterred prospecting broad-billed prions from entering. Of the two treatments, the 'neoprene' design was the most effective. This design requires the neoprene to be fitted taunt over novapipe, however, not all burrow entrances have the novapipe entrance, such as entrances situated under logs. The reduction in the frequency at which broad-billed prions entered burrows through the tyre flap is still high, and this design could be used for these burrows.

Most non-breeding petrels visit their burrows infrequently and irregularly during the non-breeding season (Bartle, 1968; Warham, 1990). The number of broad-billed prion numbers ashore each night varied and overall numbers are considered lower than average this season (Bancroft, 1999). Years when greater broad-billed prion numbers are ashore may increase pressure to find burrows and the flaps may become less effective.

Bartle (1968) stated that dead leaves placed in their entrances by Pycroft's petrel (*Ptrerodroma pycrofti*) burrows gave them a disused appearance, disguising the burrows from predators such as tuatara (*Sphenodon punctatus*) which prefer large, open burrows. This behaviour is not unusual in petrels. Chatham petrels, broad-billed prions and white-faced storm petrels (*Pelagodroma marina*) were all observed to cover their entrances with leaves and sticks. This attempt to camouflage burrows perhaps reflects that conspecifics and other species are attracted to large, open entrances. The flap, however, appears to make Chatham petrel burrows more conspicuous to broad-billed prions, with the number of broad-billed prions recorded within 1 m of a Chatham petrel burrow looking at or investigating the entrance increasing from 3% with no flap to 15% with a flap attached.

Despite this no broad-billed prion entered Chatham petrel burrows through the flap. Broad-billed prions are curious, often investigating new objects such as artificial boxes. It is impossible to tell whether they perceived there to be an entrance behind the flap or were just looking at this new object.

Conclusions

While more detailed research on an analogue species is required before burrow entrance flaps can be included in the current management regime (G. Taylor, pers. comm.), this research provides a potential alternative method for alleviating the effects of burrow competition between broad-billed prions and Chatham petrels. This could be at least or more effective as current management but less disturbing to Chatham petrels. It would also be less labour intensive due to the reduced number of broad-billed prions likely to enter burrows, therefore the intensity of night patrols could decrease and the number of broad-billed prions culled reduced.

Acknowledgments

Thanks to the Department of Conservation, both Chatham Field Centre and Wellington Conservancy, for funding and field support, particularly Graeme Taylor for encouragement and advice; to Rhonda Pearce and Mandy Barron for their field assistance, and Chris Frampton for his statistical help. Many thanks to Kerry-Jayne Wilson and Adrian Paterson for their advice and comments on drafts of this chapter. I would also like to thank the Auckland Conservancy for permission for the trials on Little Barrier Island.

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Chapter 5.

General Discussion

Introduction

In undisturbed conditions, the natural partitioning of breeding habitat by burrowing petrels may result in different spatial niches being occupied by particular species (Warham, 1996). Burrowing petrels tend to reduce interspecific competition by having different nesting requirements, such as take-off points, or substrate preferences (Warham, 1996). Behaviour leading to and associated with burrow competition between Chatham petrels and broad-billed prions is strongly influenced by habitat and microhabitat preferences due to historical changes to the vegetation of the Chatham Islands.

Current management of burrow competition between Chatham petrels and broad-billed prions involves nightly patrols around known Chatham petrel burrows with any broad-billed prion found within the burrow culled. While this is relatively successful, it has large costs. The patrols disturb Chatham petrels, are labour and resource intensive, provides only short term (hourly) protection and involves killing a protected native species. This study investigated alternative methods of protecting the known population of Chatham petrel chicks. Three options were investigated: exploitation of differences in habitat preferences by Chatham petrels and broad-billed prions; whether microhabitat features surrounding a Chatham petrel burrow attracted broad-billed prions; and the effectiveness of a burrow entrance flap that allows Chatham petrels to enter their own burrows but discourages broad-billed prions from entering.

Differences in habitat preferences

Research Implications

Considerable literature exists on nest site characteristics for burrowing Procellariiformes, but there is little information on habitat selection which distinguishes between preferred habitat and sub-optimal habitat utilised because of availability. Two exceptions to this are studies by Brandt *et al.* (1995) who found that the dark-rumped petrel (*Pterodroma phaeopygia sandwichensis*) on Maui Island in Hawaii specifically selected sites located on steep slopes in the vicinity of shrub cover. Burger and Gochfield (1991) showed that the Herald petrel (*P. arminjoniana*), a cavity nester on Round Island in the Indian Ocean, preferred deep cavities surrounded by vegetation cover.

Chapter 2 showed that forest age and topography of the immediate area influenced Chatham petrel habitat selection. The habitat characteristics Chatham petrels both selected and avoided suggested that they prefer mature forest with north-eastern aspects. While Chatham petrels did not select or avoid particular slopes, the selection values were positive for slopes of >11° but had large standard errors. Slope should not be disregarded as an influencing factor. The negative correlation between Chatham petrel selection values and availability of resources show that they generally selected features that are now limited on South East Island, such as tall forests. This suggests that Chatham petrels are habitat specific and have not adapted to changes in the vegetation. However, caution is needed with this theory, as there are a number of disused burrows situated in grass swards, and two breeding burrows situated in open areas, though on the forest edge. As well as Chatham petrel distribution throughout the Chatham Islands diminishing, their range on South East Island has also contracted within, at least, the last 10 years that Chatham petrels have been monitored. Pohuehue (*Muehlenbeckia australis*) is currently spreading into bush fragments, and along with exotic grass swards and bracken (*Pteridium esculentum*), and is impeding non-forested areas from regenerating. Chatham petrel distribution may, therefore, continue to constrict and be prevented from expanding on South East Island. Mature forest was likely to have been more prominent throughout South East Island, and on other islands in the Chatham archipelago, before farming began in the mid 1800's. Chatham petrels were probably distributed throughout the Chatham archipelago, based on fossil bones found on Chatham, Pitt, Mangere and South East Islands, and while never abundant (West, 1994) numbers are unlikely to have as small as the current population.

Like Chatham petrels, broad-billed prions selected mature forests with mixed size classes, as well as eastern aspects and slopes of >11°. They avoided areas with high stem density indicative of a young regenerating forest. Broad-billed prions selected a wide range of habitat characteristics, suggesting that they are opportunistic, possibly reflecting an expanding population. Selection values were positively correlated with habitat availability, indicating an extremely large population utilising habitat proportionate to its availability. This shows that they are not habitat specific and are adaptable to change. This does not appear to be the case for other broad-billed prion populations. On North Island in Foveaux Strait, broad-billed prions burrowed in the coastal fringe among *Olearia angustifolia* and *Hebe elliptica* (Kennedy, 1978). Broad-billed prion burrows on Bird Island, Foveaux Strait were mainly confined to the cliffs and bordering scrub (Fineran, 1966). The largest population of broad-billed prions, estimated at 10 million pairs, is on Gough Island, where they predominantly burrowed under large tussocks (Swales, 1965). On Whero Island broad-billed prions formed the smallest petrel population, probably due to restricted suitable habitat (Richdale, 1965). They were found chiefly in hard banks or under pohuehue. All of these islands were relatively unmodified when these studies took place (Richdale, 1965; Swales, 1965; Fineran, 1966; Kennedy, 1978).

The link between the present burrow sites and habitat features may be co-incidental and caused by human modification to the Chatham Islands. Vegetation modification can take place on islands in a relatively short time period, particularly where the vegetation has evolved in the absence of grazing herbivores as on South East Island. Petrel species are long lived and tend to exhibit strong site tenacity (Warham, 1990), and a site initially selected by a breeding pair as optimal in terms of habitat requirements may change over time. There are disused Chatham petrel burrows situated in what is now grass. Unfortunately the history of these burrows is not known, and original vegetation may have been different. The original vegetation type of South East Island is largely unknown and descriptions are anecdotal. The composition and structure of the regenerating forest is presumably different to the original forest.

Selection of a suitable burrow site may be more complex and involve density-dependent factors. A species may be attracted to a site because of social stimulus and not by its habitat features (Kharitotonov and Siegal-Causey, 1990). Warham (1996) stated that gadfly petrels do most of their aerial displays over the nesting site. Social stimulus is a plausible explanation for Chatham petrel site selection, where a lot of the courtship displays appear to occur in the Kokopu Creek catchment.

The habitat that Chatham petrels are currently found in, however, is not necessarily what they are selecting, suggesting that the Kokopu Creek catchment has still been modified to the extent of being sub-optimal. While the Kokopu Creek catchment may not be Chatham petrel's traditional habitat, it is the area where they have persisted and therefore must have characteristics which, if not preferred, are tolerated. Until information is available on original habitat types and past distribution of Chatham petrels, then the above information should be utilised in assisting future management practices.

Management recommendations

Understanding differences in habitat preferences can be useful in managing burrow competition. When trying to reduce competition between rare and abundant species, it is important that habitat requirements are sufficiently understood to avoid disadvantaging the rare species (Feare *et al.*, 1996). Modifying physical features to improve habitat quality has been used to maximise populations by increasing the availability of preferred habitats. Feare *et al.* (1996) discussed the clearance of a number of aggressive weeds to increase nest density of sooty terns (*Sterna fuscata*) in the Seychelles. Priddel and Carlile (1997) found that the removal of *Pisonia* lessened the mortality of the endangered Gould's petrel (*Pterodroma leucoptera leucoptera*) by reducing the rate of entanglement. This study found that Chatham petrels selected old growth forest, to which little change should or can be made. Because of the generalist behaviour of broad-billed prions and their high population numbers, there were no differences in habitat selection that could be utilised to discourage them from Chatham petrel burrows. Intense management practices have the potential to be highly disrupting to all wildlife in the area with little benefit to Chatham petrel productivity.

This thesis recommends that habitat preference is utilised in the following practices:

- Protecting areas that have desirable qualities for burrow sites is fundamental in establishing new colonies. The establishment of a second population of Chatham petrels is an essential long-term goal (Davis, 1999). Chatham petrel habitat appears specialised and may limit colony expansion. The following habitat preferences are likely to have some importance to Chatham petrel distribution and should be considered in translocation:

1. north-eastern aspects
2. moderate canopy cover (approx. 20 - 40%)
3. vegetation height greater than 10 m
4. areas with a moderate number of logs, or other microhabitat features to assist orientation and location of burrows
5. open forest, mixed age and size classes

6. available take-off trees, with leans of approximately 16 - 30°
7. slope >11°.

While broad-billed prions selected many of these characteristics, by translocating Chatham petrels to an area with no or few broad-billed prions, eliminating or controlling birds that colonise the area should be feasible.

Areas that should be avoided are those that have dense understory; vegetation height of less than 5 m; stands that either have no stems, >3 stems/m^2, even aged or no large stems; and take-off trees that have leans of < 15°. Areas that are dominated by ake ake (*Olearia traversii*) are avoided on South East Island. This may be because ake ake is now restricted to exposed areas along the coast and on the summits.

- Understanding preferred habitat can be used to guide searches for new Chatham petrel burrows. Although Chatham petrel burrows have not been found along the Kokopu Creek, this area contains many of the characteristics that Chatham petrels prefer. However, it must be kept in mind that the conclusions are based on known burrows and searches have previously been concentrated in one area. Before limiting searches, other habitat types need to be searched to confirm that the selection values in this study are representative of the whole population.

Future research

This research on habitat selection between Chatham petrels and broad-billed prions has raised a number of gaps in the current understanding of the past and present population dynamics between Chatham petrels and broad-billed prions:

- The influence of social stimuli of both Chatham petrels and broad-billed prions when locating an initial burrow site needs to be fully understood and taken into account when translocating a second colony of Chatham petrels;

- Research on past vegetation type and extent, and regeneration processes, is required to determine how changes in the past have influenced the current population dynamics of Chatham petrels and broad-billed prions;
- The historic breeding range and habitat of both Chatham petrels and broad-billed prions needs to be determined to relate these to present habitat change and population numbers;
- A comparative study of habitat type and social dynamics between broad-billed prion populations, in particular those that breed in relatively unmodified habitat, is required to understand what has caused the imbalance within the seabird community on South East Island;
- Whether pohuehue can be removed to facilitate regeneration and prevent smothering of forest fragments, and therefore improve existing Chatham petrel habitat should be determined.

Attractiveness of microhabitat features

Research implications

Microhabitat features may make certain burrows more attractive to prospecting birds than others. Jouventin *et al.* (1985) found this with six species of burrowing Procellariiformes but did not state what these features were. Brandt *et al.* (1995) reported that dark-rumped petrels situated their burrows where large rocks were common. These rocks were consistently larger than the average rock size in the general habitat.

After taking the disproportionate number of Chatham petrel burrows to broad-billed prion burrows into account, Chapter 3 demonstrated that broad-billed prions prospected less frequently, and spent less time, at Chatham petrel burrows than broad-billed prion burrows. This suggests that the box and the larger artificial entrance did not attract broad-billed prions to artificial Chatham petrel burrows as predicted. The proportion of time spent on behaviours near Chatham petrel burrows that may increase the chance of chick interference - pausing or looking around, prospecting, sitting and resting, attention to the artificial box and utilising the track, was collectively 47% of total time on the ground surface. Was (1999), who studied broad-billed prions away from Chatham petrel burrows, had similar results. This suggests that overall, broad-billed prions do not change their behaviour around a Chatham petrel burrow. This supports the previous statement that broad-billed prions are not unduly attracted to Chatham petrel burrows.

The number of broad-billed prions in the vicinity of different Chatham petrel burrows varied. While this could result from a small sample size, it could also suggest that some burrows, or their surrounding habitat, attracted broad-billed prions. Burrow location by visual means centres on recognition of landmarks around the burrow (Grubb, 1974; Brooke, 1978; James, 1986; Minguez, 1997). Broad-billed prions were attracted to logs that could be used in orientation and location of their burrows during the breeding season. The frequency at which broad-billed prions entered Chatham petrel burrows surrounded by logs was not greater than burrows without logs, despite logs attracting broad-billed prions to the area.

The number of broad-billed prions or their behaviour was not influenced by tracks near Chatham petrel burrows. There was also no difference in the number of broad-billed prions entering Chatham petrel burrows near tracks. Broad-billed prions did, however, use tracks more when logs were present. While logs and tracks did not appear to influence the number of broad-billed prions entering Chatham petrel burrows, the sample size was small and broad-billed prion numbers ashore this season was comparatively low (Bancroft, 1999). Potentially, logs and tracks near Chatham petrel burrows could increase interference to chicks due to the greater number of broad-billed prions near logs.

Concerns about the novapipe entrance increasing the attractiveness of the burrows to broad-billed prions is unproven and the advantage of preventing tunnel collapse outweighs any subtle attraction.

Management recommendations

Based on the above findings, I recommend that:

- logs within 3 m of a Chatham petrel burrow are removed to reduce the number of broad-billed prions in the immediate area. Chatham petrels were also found to use landmarks such as logs, tree roots and artificial burrow chambers to locate their burrow. However, because of the investment in their chicks, Chatham petrels have a greater incentive to find their burrows if logs were removed and should not be detrimentally affected by changes to the microhabitat.

Future research

- Further research into how Chatham petrels locate their burrows is required before any changes are made to the microhabitat. I recommend that this study be complemented with experimental trials.
- Correlations between microhabitat features and the number of broad-billed prions entering Chatham petrel burrows used only one year of data and may not have detected subtle differences. Broad-billed prion numbers on the island at the time were relatively low compared to previous years (Bancroft, 1999), and behaviour may change with increased numbers as the pressure to find a burrow increases.

Effectiveness of burrow entrance flaps

Research implications

Behavioural differences between two species of seabird have never been used as a method to minimise the effects of burrow competition. This research showed that manipulating behavioural differences has the potential to be an effective management tool. The results of the burrow entrance flap trials (Chapter 4) found that the flaps do not prevent adult

Chatham petrels from entering their own burrows. While they took longer to enter the burrow through the flap, this reaction does not appear to be detrimental as the number of attempts to enter the burrow did not change, and the majority of Chatham petrels still entered. Of the 19 Chatham petrels trialed, three did not enter through the flap. Of these, one Chatham petrel pulled off the flap which was not secured properly and entered, and one Chatham petrel refused to enter after doing so the previous visit. Due to time and permit restrictions, I was not able to test whether these Chatham petrels would have refused to enter with subsequent visits or if tolerance to the flap would increase with familiarity. As disturbance to the Chatham petrels was kept to a minimum during these trials, none of the Chatham petrels were caught and identified. There is a possibility that the birds that did not enter were prospectors rather than occupants of the burrow and therefore did not have as high an incentive to enter.

Attaching a burrow entrance flap to a burrow effectively deterred prospecting broad-billed prions from entering. Of the two designs trialed, the 'neoprene' flap was the most effective. This design requires the neoprene to be fitted taut over novapipe and not all burrow entrances have the novapipe entrance, such as entrances situated under logs. The tyre design still reduced the frequency at which broad-billed prions entered a burrow, and could be used for these burrows.

Management recommendations

A major problem in this study was that data collection was time consuming, reducing sample size. More intensive trials are required on an analogue species before the burrow entrance flap should be included in the management program of Chatham petrels.

- Long term trials are required to ensure that the flap does not disrupt mate and burrow fidelity, and cause burrow swapping in succeeding seasons. Ideally, the flap should be in place all year round to prevent problems in burrow recognition, minimising the likelihood of induced burrow shifts. It would also reduce the number of broad-billed prions breeding in burrows during the Chatham petrel non-breeding season, alleviating the need for other management practices.

Future research

There is a number of potential effects that the burrow entrance flap may have on Chatham petrel behaviour:

- Currently, the plan for using the burrow entrance flap is to attach it to the burrow after hatching and remove it before the Chatham petrel chicks first leave the burrow. Chicks of many petrel species leave the burrow at night some time before fledging to exercise and orientate with their surroundings (Manuwal, 1976; Harper, 1976; Warham, 1990). Incidental observations suggest Chatham petrel fledglings start leaving the burrow approximately 15 days prior to fledging (P. Gardner, pers. comm.). The stage in the breeding cycle that the flap is attached may influence subsequent behaviour by Chatham petrels. The following questions need to be answered:

1. Does the flap disrupt exploratory behaviour, or prevent the chick returning to the chamber causing it to leave the burrow prematurely.
2. Would Chatham petrel's incentive to enter through the flap lessen if the flap was attached before the breeding season?
3. If the flap had been on for the majority of the previous season, would the Chatham petrel recognise its own burrow the following season if the flaps are not attached until after incubation?

Severe disturbances to burrows may cause burrow shifts. Such shifts could result in the break-up of pairs and consequently lower reproductive success (Morse and Kress, 1984; Warham, 1990). Long term monitoring is important to ensure that the flap does not cause greater disruptions to mate and burrow fidelity, and cause burrow swapping in succeeding seasons, than the current intensive management regime.

- Flaps may reduce airflow, increasing humidity, temperature, ammonia and carbon dioxide levels, which could have detrimental impacts on chick respiration and growth.

Conclusions

Where behaviourally similar species are sympatric (overlap in space), there are often strong ecological interactions, which can result in the extinction of one species. To survive, a species needs to become specialised and diverge morphologically, ecologically, and behaviourally (McLean *et al.*, 1994). Traditionally, Chatham petrels and broad-billed prions may have partitioned habitat to avoid competition. However, the habitat on the Chatham Islands has been considerably modified by human activities. The effect of this change on the seabird community is not known, but has probably altered the balance between the two species. Availability of suitable burrow sites may now be an important factor in limiting the expansion and breeding success of the current population of Chatham petrels.

Chatham petrels are habitat specialists and probably still select burrow sites based on habitat quality. Broad-billed prions, on the other hand, are relatively generalist in their burrow site choice and have adapted to changes in the vegetation on South East Island. This confirms anecdotal evidence where broad-billed prions have been observed to burrow in hollow trees and under old beams. Breeding habitat used by broad-billed prions in other areas is quite different, which suggests that broad-billed prion's generalist behaviour is a result from their superabundance on South East Island.

Based on the small quantities of broad-billed prion fossil bones on Mangere Island (Tennyson, 1994), broad-billed prions were probably less abundant on the Chatham Islands in the past. Mangere Island was predominantly covered in forest but was largely cleared when farming began in 1892. Broad-billed prion numbers have since increased (Tennyson and Millener, 1994). There is no information on the seabird communities of South East Island before farming began, but they may have followed the same trend. Nilsson *et al.* (1994) commented that seabirds had "all but disappeared" from South East Island in the 1950's, so it is likely that broad-billed prion numbers have greatly increased since farming ceased in 1961. It is impossible to tell from the selection values in this study what traditional broad-billed prion habitat was as they are currently selecting most habitat variables.

There are several options available to managers for modifying the surrounding habitat directly around a Chatham petrel burrow and altering Chatham petrel burrows to reduce the attractiveness of burrows to broad-billed prions. These options would potentially decrease interference with Chatham petrel chicks. The habitat preferences of both species showed that little can be done to the habitat throughout the Chatham petrel colony. A greater understanding of the two species habitat preferences can, however, be used to guide future ground searches and assist selection or alteration of habitat in the Chatham Islands for the development of a second population of Chatham petrels.

Broad-billed prions prospecting at Chatham petrel burrows probably results from a shortage of broad-billed prion burrows in that area. Prospecting broad-billed prions were not especially attracted to artificial Chatham petrel burrows. The presence of logs or tracks did not appear to change behaviour or increase the number of broad-billed prions entering Chatham petrel burrows. This study did suggest that because broad-billed prions are attracted to logs and used tracks more often when logs were present, reducing the presence of logs could decrease the number of broad-billed prions in the vicinity of Chatham petrel burrows and potentially decrease interference.

While more detailed research on an analogue species is required before burrow entrance flaps can be used, this research provides a potential method of protecting the known population of Chatham petrel chicks. This could be at least or more effective as current management but less disturbing to Chatham petrels than culling prions. A reduction in the number of broad-billed prions entering burrows would allow the labour intensive night patrols to decrease.

It is hoped that the studies described in this thesis will contribute to the understanding of the causes of burrow competition between Chatham petrels and broad-billed prions and provide managers with alternative options to the current management regime.

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Acknowledgments

Special thanks to my two field assistants Rhonda Pearce and Mandy Barron for their hard work, support and fishing excursions; no one else would of sat outside a hole in the ground for six hours a night for a month without complaining, or bush-bashed through head high *Muehlenbeckia* every day when surveying the vegetation with such grace.

Many thanks to my supervisors, Kerry-Jayne Wilson for her advice, editing and the lively discussions, particularly during field work; and Adrian Paterson for providing advice and well needed grammar corrections.

Thanks to Chris Frampton for his equations, advice and enthusiasm during the most difficult part of my thesis, where without his statistical help I would still be staring mournfully at my spreadsheets.

Thanks to the Department of Conservation, both Chatham Field Centre and Wellington Conservancy, for both funding and supporting this research, in particular Graeme Taylor for his encouragement and advice; thanks also to the Auckland Conservancy for permission for the trials on Little Barrier Island.

Many thanks to Rhonda Pearce, Graham Hickling, James Griffith and Lisa Berndt for editing drafts of my chapters, and to Jenny Sullivan for creating the frontispiece amd Figure 2.1.

Thanks to my friends both within and outside the department, my family and all the 'South East Islanders' for their friendship and support over the past two years, especially through my stressed, 'difficult' periods.

My final thanks go to Kerry-Jayne, who gave me the opportunity to work in paradise.

Appendix 1: Location[1] of Chatham petrel burrows used in chapter 2.

Burrow number	Location	Burrow number	Location
1	lower summit	89	kokopu swamp
5	upper summit	90	top bush
11	kokopu swamp	92	woolshed
20	lower summit	94	top bush
29	top bush	96	top bush
31	lower summit	97	top bush
41	kokopu swamp	98	kokopu swamp
54	kokopu swamp	106	top bush
60	kokopu swamp	107	top bush
61	kokopu swamp	109	top bush
62	upper summit	112	kokopu swamp
63	lower summit	113	top bush
64	kokopu swamp	114	top bush
68	top bush	117	top bush
67	upper summit	121	top bush
74	top bush	123	top bush
76	upper summit	125	kokopu swamp
78	upper summit	126	top bush
81	top bush	127	top bush
84	top bush	128	top bush
87	kokopu swamp	131	kokopu swamp
88	top bush	133	top bush

[1] Positions of 'locations' are shown in Figure 2.1 and their habitat characteristics are described in Table 2.3.

Appendix 2. Location and quadrat co-ordinates used to situate the random quadrats for vegetation surveys for chapter 2.

quadrat	location[1]	quadrat co-ordinates[2]	quadrat	location	quadrat co-ordinates
1	woolshed	10/48 20m from hut	41	trig	51/79
2	woolshed	15/1	42	trig	24/83
3	woolshed	1/53	43	trig	4/93
4	woolshed	18/16	44	kokopu swamp	?
5	woolshed	47/91	45	kokopu swamp	40/32
6	woolshed	47/66	46	kokopu swamp	6/80
7	woolshed	91/70	47	kokopu swamp	19/34
8	woolshed	14/19	48	kokopu swamp	56/55
9	woolshed	46/25	49	kokopu swamp	48/58
10	woolshed	90/36	50	kokopu swamp	62/94
11	woolshed	20/72	51	kokopu swamp	21/67
12	woolshed	9/6	52	top bush	95/9
13	skua gully	99/5	53	top bush	30/62
14	skua gully	100/43	54	top bush	43/61
15	lower summit	70/2	55	top bush	68/0
16	lower summit	23/68	56	top bush	78/56
17	lower summit	46/57	57	kokopu swamp	16/37
18	lower summit	32/55	58	kokopu swamp	63/94
19	lower summit	95/85	59	kokopu swamp	40/53
20	lower summit	39/33	60	kokopu swamp	53/77
21	lower summit	9/95	61	kokopu	13/41
22	lower summit	89/19	62	kokopu	57/00
23	upper summit	82/70	63	kokopu	40/8
24	upper summit	82/39	64	lower link	49/74
25	upper summit	40/29	65	lower link	91/17
26	upper summit	39/65	66	lower link	97/75
27	upper summit	34/9	67	lower link	71/63
28	upper summit	55/26	68	lower link	79/32
29	upper summit	66/19	69	lower link	89/75
30	upper summit	17/43	70	lower link	81/83
31	upper summit	96/15	71	clears	71/41
32	upper summit	99/50	72	clears	56/6
33	upper summit	52/41	73	clears	12/1
34	upper summit	30/48	74	clears	17/3
35	upper summit	36/2	75	clears	60/1
36	upper summit	25/2	76	clears	88/15
37	upper summit	97/26	77	clears	14/11
38	trig	57/63	78	clears	63/54
39	trig	93/64	79	clears	61/37
40	trig	80/91	80	woolshed	20/10 below hut

[1] Positions of 'locations' are shown in Figure 2.1 and their habitat characteristics are described in Table 2.3.

[2] Quadrat co-ordinates determined using four digit random numbers - first two numbers gave the distance (1 m) along track, second two gave the distance at right angles to track, left if even and right if odd.