Burrow competition between broad-billed prions (*Pachyptila vittata*) and the endangered Chatham petrel (*Pterodroma axillaris*)

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ABSTRACT

The endangered Chatham petrel (*Pterodroma axillaris*) competes for nesting burrows with the locally abundant broad-billed prion (*Pachyptila vittata*) at its only breeding site on South East Island, Chatham Islands. Prions are the most serious threat to Chatham petrels and if left unmanaged cause over half of all breeding failures. This report discusses burrow occupancy and prospecting habits of the prions, habitat preferences of both species, and the development of a burrow entrance flap that discourages prions from entering Chatham petrel burrows.

Most prions banded in study burrows were never recaptured. Of those recaptured, most were either in, or within 5 m of the burrow they were banded in. A few were found in study burrows up to 100 m from their banding point. Up to six different prions regularly visited study burrows within a non-breeding season, and up to four within a breeding season.

During their non-breeding season prions spent 12% of their time prospecting. Prospecting was most common between 0230 hours and first light. A few prions investigated up to six burrow entrances during a 25-minute observation period. No correlation was found between nights with little or no prospecting and weather or lunar patterns.

Habitat characteristics for both Chatham petrels and prions were quantified. Chatham petrels exhibited greater habitat specificity and their preferred habitat is now limited. Prions were generalists and were not limited by habitat availability.

The burrow entrance flap exploited behavioural differences between the two species. The petrels with a chick inside the burrow had a high incentive to push through a rubber flap, whereas prospecting prions were deterred by the flap. 90% of Chatham petrels entered their burrows through the flap. Only 22% of prions that entered control burrows entered burrows while a flap was in place.

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1. Introduction

Historically, burrow-breeding seabirds have bred on mainland sites in many parts of New Zealand. However, the introduction of predators such as rats (*Rattus rattus*, *R. norvegicus* and *R. exulans*), cats (*Felis catus*) and mustelids (Mustelidae) have removed seabirds from many of the larger islands, thus resulting in increased densities of burrow-breeding species on predator-free islands (Segonzac 1972; Imber 1975). These remaining predator-free islands are mostly small, with inadequate breeding space for all the birds supported by the surrounding ocean (Ramos *et al.* 1997). As a result, intra- and inter-specific competition for nest sites can be intense. Some individuals are forced to nest in sub-optimal sites, and in many instances breeding populations have been reduced.

Intra- and inter-specific competition for burrow nesting sites occurs on South East Island (44°S,176°30'W), Chatham Islands, New Zealand. Intra-specific burrow competition occurs among broad-billed prions (*Pachyptila vittata*), and inter-specific competition between the prions and white-faced storm petrels (*Pelegodroma marina*), Chatham petrels (*Pterodroma axillaris*) and diving petrels (*Pelecanoides urinatrix*) (Taylor 1991; Kennedy 1994; Gardner & Wilson 1999). Even the larger, aggressive, blue penguins (*Eudyptula minor*) and sooty shearwaters (*Puffinus griseus*), that also nest on the island, are affected by the prions.

Of immediate concern is the competition between prions and the endangered Chatham petrels. Prions are their most serious threat. Chatham petrels breed only on South East Island and there are possibly fewer than 2000 individuals. It appears that a combination of high prion numbers, their prospecting behaviours, and their sedentary behaviour conflicts with the breeding cycle of the Chatham petrel (Kennedy 1994; Gardner & Wilson 1999). The locally abundant prions return to South East Island during their non-breeding season and prospect for burrows at the time Chatham petrels leave their chicks unattended. Prions can oust Chatham petrel chicks from their burrows, or kill chicks, to claim ownership of these burrows (Gardner & Wilson 1999). About 130 burrows are known to have been used by Chatham petrels in recent years, but only about 40–50 of these were used by breeding pairs of Chatham petrels at the time of this study. Without intensive management their fledging rates are low, probably contributing to a population decline.

1.1 AIMS

The aim of the research reported here was to develop management strategies to minimise the impact broad-billed prions have on Chatham petrels. It resulted in two Masters theses (Was 1999 and Sullivan 2000); the present report synthesises from those theses information that will:

- Help the Chatham petrel recovery group decide on future management strategies.
- Assist Department of Conservation managers on the Chatham Islands to carry out such management.

1.2 STUDY OBJECTIVES

This report presents information on the following objectives:

1. To explore methods of deterring prions from using Chatham petrel burrows.
2. To describe the burrow-prospecting behaviours of the prions.
3. To determine whether prions return to breeding burrows used in previous years, or if they prospect for a vacant or occupied burrow in their non-breeding occupancy period.
4. To compare habitat preferences of prions and Chatham petrels with the aim of manipulating habitat features to the advantage of the Chatham petrels.

1.3 STUDY SITE

Field work took place on South East Island (218 ha), in the Chatham Island group (44° S, 176° 30'W) (Fig. 1).

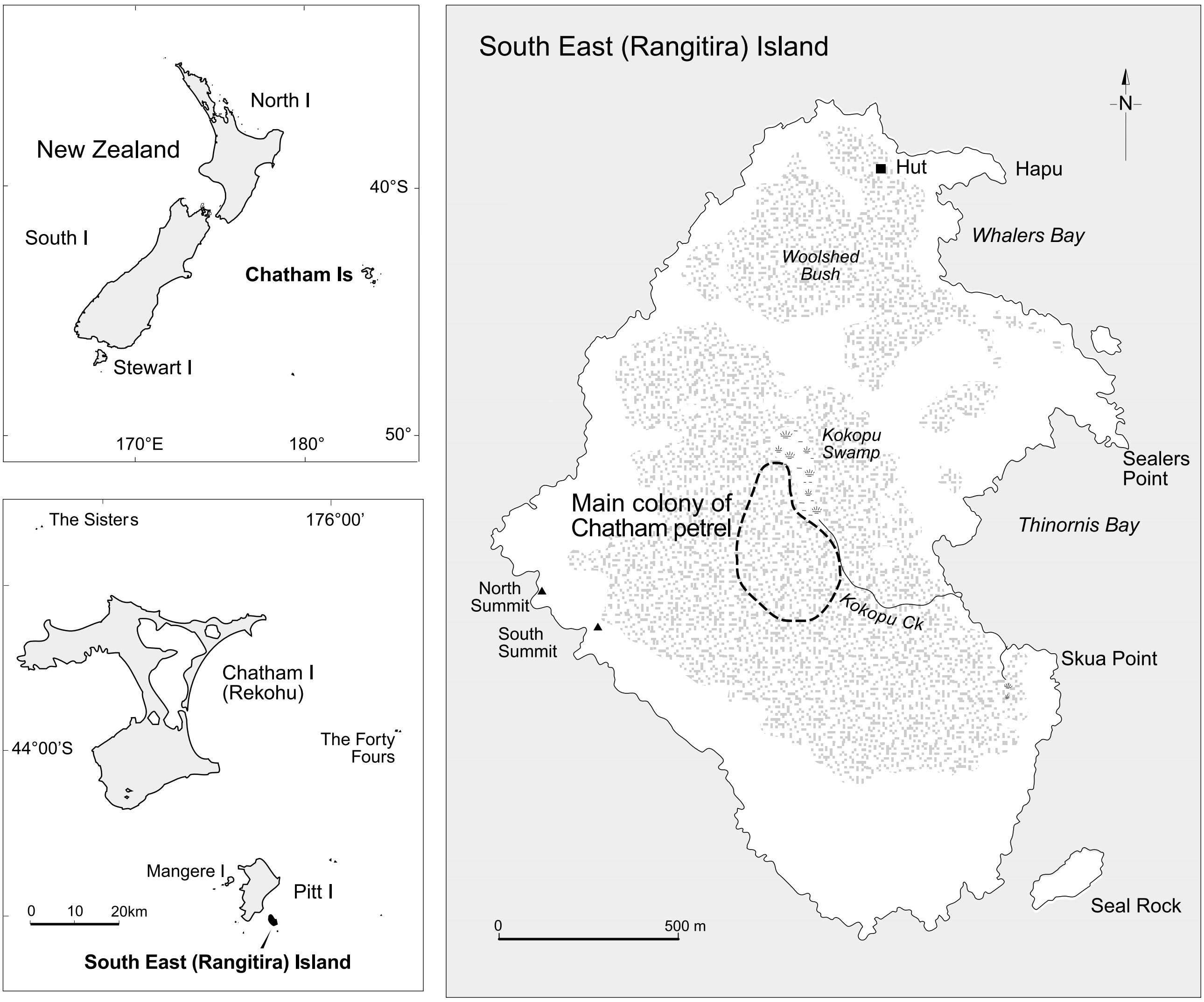


Figure 1. Map of South East (Rangatira) Island, its location within the Chatham Islands group, and Chatham Islands in relation to mainland New Zealand.

The research took place during seven visits to South East Island between 1996 and 1998 (Table 1).

TABLE 1. VISITS MADE TO SOUTH EAST ISLAND.

DATE	SEASON
06 February–01 March 1996	NB
04 December–18 December 1996	BR
14 February–14 April 1997	NB
01 October–05 October 1997	BR
26 October–11 December 1997	BR
13 March–01 May 1998	NB
17 February–01 April 1999	NB

NB: non-breeding season for broad-billed prions
BR: breeding season for broad-billed prions.

Part 1. Burrow occupancy and prospecting behaviours of broad-billed prions

2. Burrow occupancy

2.1 INTRODUCTION

The aim of this part of our study was to determine the patterns of burrow use by the prions. The specific objectives were to determine:

1. The recapture rate of prions in study burrows both within and between seasons.
2. The number of individual prions that prospected at study burrows.
3. Burrow use by resident (burrow owner) and non-resident prions.
4. The number of individuals found using more than one study burrow.
5. The distances moved by those prions found in more than one study burrow.
6. The likelihood of prions returning to breeding burrows which they had been prevented from using in the previous season.

2.2 METHODS

The large number of prions on South East Island (at least 330,000 breeding pairs: West & Nilsson 1994) permitted us to choose four easily accessible study sites. Three of these were located in the coastal forest, alongside frequently used tracks close to the hut. The fourth site, near Kokopu swamp, was within the main concentration of Chatham petrels.

2.2.1 Burrow occupancy

During the 1996 non-breeding season, adult prions from 34 burrows in the three study sites near the hut were banded. In the 1996 breeding season 76 burrows containing a chick were selected for further study; these included most of the 34 original burrows. Study burrows were restricted to those with a tunnel short enough for field workers' hands to touch the back of the breeding chamber. All adult prions caught in these burrows were banded.

We fitted 64 of these burrows with artificial nest chambers, consisting of a 10-litre plastic bucket fitted with a 105 mm diameter Novapipe tunnel. An inverted plastic plant saucer placed over the bucket lip served as a burrow lid, allowing identification of birds with minimal disturbance. Artificial burrows were not installed until the chick stage of the breeding cycle, to minimise the chance of desertion by adults. The remaining 12 study burrows were kept as controls. Due to the friable nature of the soil on South East Island and the continual modifications made by prions to their burrows, each of these control burrows collapsed during the next non-breeding season.

Study burrows were monitored nightly to determine their occupancy: any unbanded prion found was banded, and band numbers of all prions in study burrows were recorded.

2.2.2 Blockading of broad-billed prion burrows

Fourteen of the artificial prion study burrows were blockaded by Department of Conservation staff in May 1997 at the same time and using the same method used to protect Chatham petrel burrows from prions (see Gardner & Wilson 1999). We assumed that if birds were excluded from their burrow, they would attempt to claim ownership of a new burrow nearby. We therefore selected burrows close to other study burrows to maximise the chance of recapturing banded birds. Burrows in the Kokopu study site were not blockaded, to avoid interference with the nearby Chatham petrel burrows. Blockades were removed from prion and Chatham petrel burrows in November 1997.

2.3 RESULTS

2.3.1 Recapture rate by season

Up to 79% of banded adult prions were not recaptured in any study burrow (Table 2). Of the 84 birds recaptured, fewer revisited their burrow, in the non-breeding season (12% and 29%) than in the breeding season (22% and 43%). Approximately 10% of banded birds were recaptured either in a different study burrow, or in several study burrows. Only during non-breeding seasons did we capture prions in more than two study burrows.

TABLE 2. PERCENTAGE OF ADULT BROAD-BILLED PRIONS BANDED IN STUDY BURROWS AND SUBSEQUENTLY RECAPTURED IN A LATER SEASON. NON-BREEDING SEASON (NB); BREEDING SEASON (BR). (1997 AND 1998 DATA COMBINED).

SEASON	NOT RECAPTURED (%)	SAME BURROW (%)	DIFFERENT BURROW (%)	MULTIPLE BURROWS (%)	*N*
NB-NB	79	12	5.8	3.2	105
NB-BR	68	29	3.3	0.0	151
BR-BR	73	22	4.7	0.0	85
BR-NB	47	43	4.4	6.0	74

TABLE 3. NUMBER OF DIFFERENT BROAD-BILLED PRIONS CAPTURED IN STUDY BURROWS IN THE NON-BREEDING (NB) AND BREEDING (BR) SEASONS.

NO. OF BIRDS	1	2	3	4	5	6	7	8	9	10
NB season 1997	5	14	12	17	9	1	3	6	2	1
NB season 1998	3	21	7	5	2	1	0	0	0	0
BR season 1996	17	26	21	3	0	0	0	0	0	0
BR season 1997	19	16	5	0	0	0	0	0	0	0

2.3.2 Number of prions that visited study burrows

During the 1997 and 1998 non-breeding seasons, more than two different prions were recorded in 73% (1997) and 38% (1998) of the study burrows (Table 3). Ten separate birds visited one burrow. Even during the breeding season, 36% (1996) and 12.5% (1997) of study burrows were visited by more than two prions.

Most non-resident prospecting prions (those who visited less frequently than the individuals presumed to be the burrow owners) were recorded in a burrow only once (72%). However, some burrows were entered up to ten times by individuals that were not the principal users of the burrow.

2.3.3 Visitation of multiple burrows by broad-billed prions

We captured 57 prions in more than one study burrow; some were found in up to four different study burrows. Of these 57 prions, 23 had bred the previous season, whereas 34 had no known breeding history. Most burrow shifts took place within the non-breeding season (60%), the remainder between the breeding and non-breeding season.

Recaptured birds were found at varying distances, ranging from less than 2 m up to 100 m from where they were initially captured (Fig. 2).

Figure 2. Number of adult broad-billed prions found in more than one burrow, and the distance between these burrows.

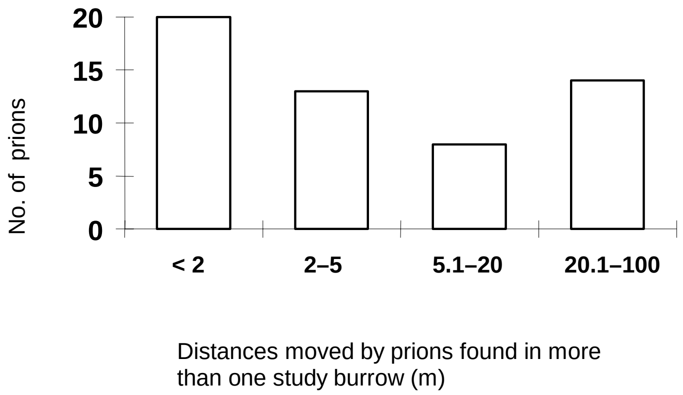


TABLE 4. PERCENTAGE OF BLOCKADED BROAD-BILLED PRION BURROWS USED IN THE NON-BREEDING SEASON (AFTER REMOVAL OF BLOCKADE) COMPARED TO THOSE NOT BLOCKADED.

	BLOCKADED (%)	*N*	NOT BLOCKADED (%)	*N*
Burrow used	36	5	61	39
Burrow not used	64	9	38	24

2.3.4 Burrow use after blockading

Blockading burrows during the breeding season appeared to discourage the return of prions to the burrow they had previously bred in, during the non-breeding season following removal of the blockades (Table 4).

2.4 DISCUSSION

The majority of adult prions banded in study burrows were never recaptured, suggesting that most only visit a burrow once. Some prions did visit the burrow in which they had previously bred, after their post-breeding moult. Prions were more likely to return to a burrow they occupied in a previous breeding season, but that tendency to return diminished with each new season. This suggests these prions display site, rather than burrow, tenacity. Like many seabird islands, the soil on South East Island is very fragile and burrow collapse is common (Richdale 1965; West & Nilsson 1994). This suggests that a broad-billed prion might select a site with certain characteristics and return to this area, including the burrow within it, rather than bond to a less permanent burrow.

The likelihood of catching a banded prion in a burrow other than the one in which it was banded was small: only 401 birds were banded out of an estimated 330,000 breeding pairs. Yet, 14 % of the banded birds were found in two or more study burrows; slightly over half (n=32) of these we found in burrows less than 5 m from the burrow in which they were banded. Previous prion studies found that new mates tended to be neighbours (Richdale 1965). This may explain the high frequency of visitation to neighbouring burrows we observed. All 23 other prions found in more than one burrow, were found in study burrows 5–100 m from their original banding burrow. The two individuals found approximately 100 m away were with their partner of the previous season. Hence, for these birds at least, the pair bond was stronger than site tenacity. Using West & Nilsson's (1994) estimate of one prion burrow for every 1.3 m^2, there are 24,166 broad-billed prion burrows in a 100-m radius of each study burrow. With such a high number of natural burrows, the likelihood of birds randomly selecting two study burrows 100 m apart is very low. Consequently, it seems plausible that the prions in this study have cued in on either the artificial burrow, or the easily observed and accessible Novapipe tunnel entrance. This suggests they may be more likely to enter artificial burrows than natural burrows. Gardner & Wilson (1999) suggested that the conspicuous Novapipe tunnel fitted to almost all known Chatham petrel burrows may attract prions.

Our study indicates that most prions that visit Chatham petrel burrows are prospecting birds, most of whom will visit the burrow only once. 79% of interferences recorded in Chatham petrel burrows cause no measurable harm to the chick (Gardner & Wilson 1999). Prions only appear to attack Chatham petrel chicks after they have previously entered the burrows, presumably in an attempt to establish themselves in that burrow. Gardner & Wilson (1999) estimate that 14% of prion interferences in Chatham petrel burrows result in injury to the chick. Chatham petrel chicks are quiet (pers. obs.), possibly misleading a prospecting prion into assuming the burrow is unoccupied. As Chatham petrel burrows are interspersed between broad-billed prion burrows and have a similar burrow entrance (West & Nilsson 1994), they seem equally likely to be visited as any unoccupied prion burrow.

Burrow blockading has been used in an attempt to exclude prions from Chatham petrel burrows during the prion breeding season (Gardner & Wilson 1999). Our study showed that burrow blockading during the breeding season appeared to discourage prions that previously bred in that burrow, from returning to their burrow in the subsequent non-breeding season. However, the sample size was small (n=14). Gardner & Wilson (1999) found that blockading Chatham petrel burrows prevented prions from breeding in the burrow; this ensured that the burrow was available for Chatham petrels at the beginning of their breeding season. However, blockading had no effect on burrow interferences during the prion non-breeding season, when prions prospect most intensely for burrows.

Any measures taken to protect Chatham petrel burrows from prospecting prions have to include all prions rather than focusing on a particular sector within the population. Unless prions can be excluded from Chatham petrel burrows in the prions' non-breeding season, management of Chatham petrel chicks will have to continue to take place on a night-by-night basis to ensure the impact of prions in Chatham petrel burrows is minimised as much as possible.

3. Burrow prospecting behaviour of broad-billed prions during the non-breeding season

3.1 INTRODUCTION

In this section we report on the prospecting behaviours of broad-billed prions. While there have been many studies on the breeding biology of petrels, surface behaviours are poorly described (Warham 1990, 1996). No behavioural studies appear to have specifically studied burrow prospecting.

The key questions addressed are:

1. What proportion of their time do prions dedicate to burrow prospecting ?
2. What proportion of the prions ashore on South East Island on any given night are prospecting for burrows?
3. Are there any nights when little or no prospecting behaviour is apparent and, if so, do these correlate with meteorological or lunar phenomena?
4. What proportion of time is spent prospecting at burrow entrances and how many different burrow entrances do prions investigate?
5. How far do individual prions move on the ground surface at night?
6. Does the frequency of behaviours change during the course of a night?

3.2 METHODS

The surface behaviours (taking place on the ground rather than in the birds' burrows) of prions were studied using 13 behavioural categories, these 13 were then grouped into four larger categories. These groupings were; *prospecting related behaviours*: prospect, excavate, half in burrow; *resting behaviours*: sit on surface, sit in burrow entrance, sit on log, sleep, preen, stand; *movement behaviours*: move; and *social behaviours*: vocalise, mutual preen and interact. Observations were made either by torchlight or with a night-vision telescope, and recorded using a hand-held dictaphone. Three observational methods were used: continual focal observations; instantaneous circular plot sample; and a fixed-line transect survey. The instantaneous circular plot sample results are not included in this report as they were found to replicate those of the fixed-line transect survey (Was 1999).

3.2.1 Continual focal observations

Continual focal observations were made on 45 nights in 1997 and 23 nights in 1998. This method provided information on the duration of each particular behaviour. A prion was observed for 25 min or until it moved out of sight or entered a burrow. Durations of each activity were recorded and these times were pooled, giving total time spent in each activity for each prion.

3.2.2 Fixed-line transect survey

Fixed-line transect surveys were carried out on 19 nights in 1997 and 31 nights in 1998. Once each night at about 2230 hours an observer walked a section of the Lower Summit Bush Track (approximately 400 m in length) and recorded the behaviours of prions on both sides of the track. Observations were made using torchlight, thus maximising number of birds seen. The behaviour of each prion was recorded at the instant the birds were seen.

3.2.3 Statistical analysis

Fixed-line transect survey data and instantaneous circular plot sample data are presented as percentage of individuals engaged in each behaviour category ± standard error (SE).

Continual focal observation data were calculated as a proportion of the time which individuals spent engaged in each behaviour category. To determine if behaviours varied during the night, data were broken into three time periods (period 1: 1630–0000 hours; period 2: 0001–0230 hours; period 3: 0230–first light). These data were analysed using Fisher's least-significance difference test.

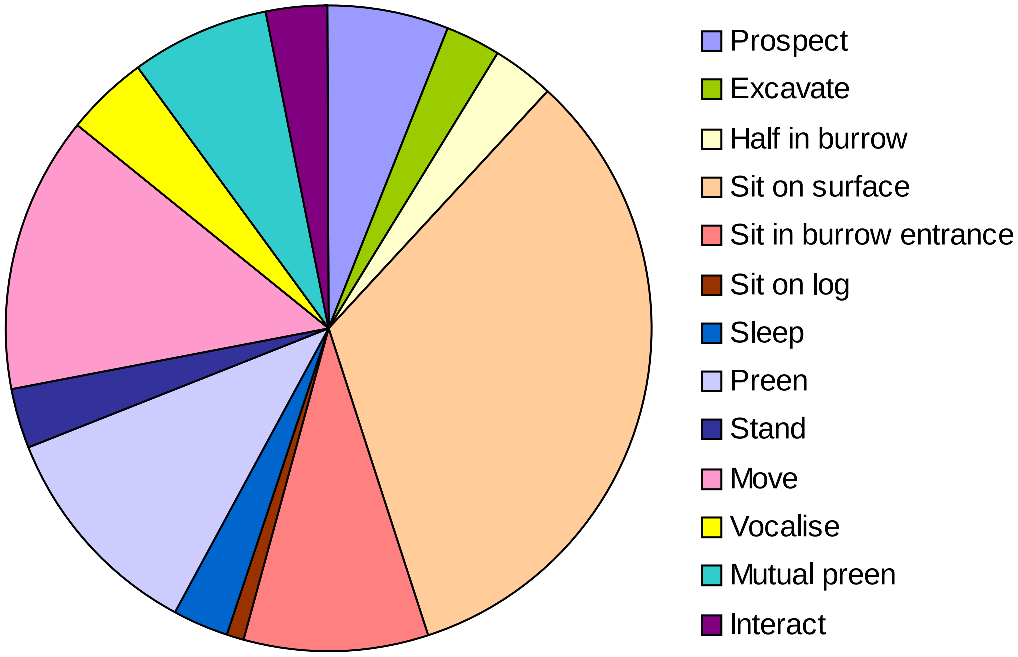
3.3 RESULTS

Most prions observed during a 25-min period displayed prospecting behaviour at least once. A small number were observed prospecting up to six times. Over half of prions observed prospecting did so at only one burrow entrance during the 25-min observation period. However, a small number were observed prospecting at up to six different burrow entrances (Fig. 3). Prions displayed prospecting related behaviour at some point during 56% (n=203) of 25-min observation periods. They spent 12% ± 0.4 of their time during these observations prospecting at burrow entrances (Fig. 4). Results from the fixed-line transect surveys were similar with 17% of prions recorded prospecting (Fig. 5).

Of the total of 68 study nights, there were only four nights (6%) when no broad-billed prions were observed prospecting; on five nights (7.4%) only one prion was observed prospecting. No correlation was apparent between weather or lunar phase and nights where one or fewer prions prospected (Was 1999).

Figure 3. Number of burrow entrances prospected at by broad-billed prions during 25 minute observation periods. Continual focal observations; 1997/1998 data combined.

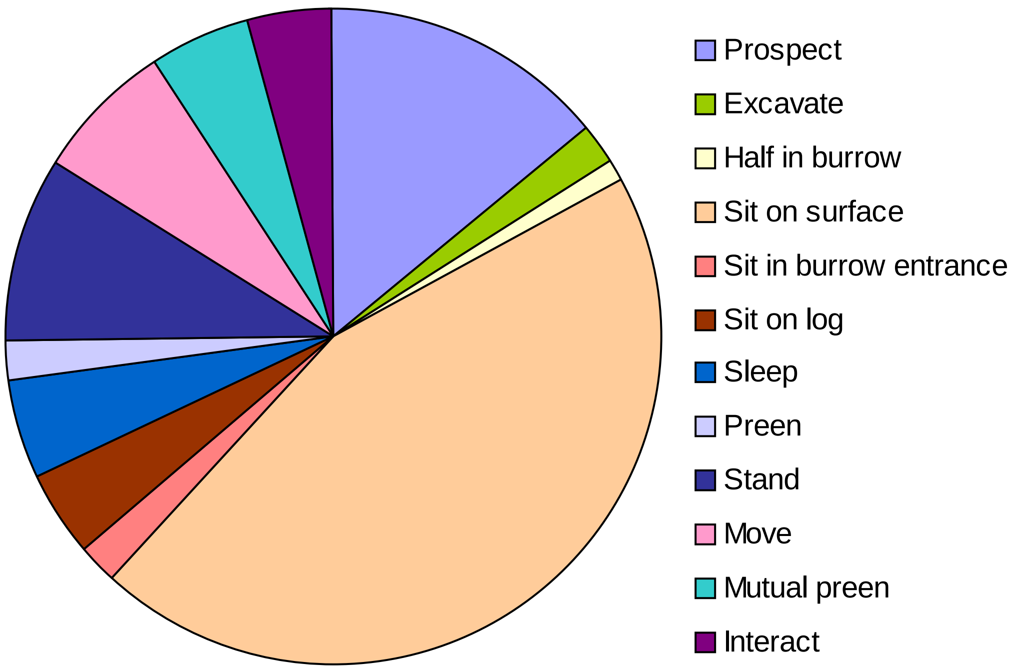
Figure 4. Percentage of time prions spent in specified behaviours during 25-minute observation periods. Tot for the four behaviour groupings were: prospec 12%; rest 60%; move 14% social 14%. 1997/1998 da combined.



Prions were observed moving up to 16 m during a 25-min observation period. This was the maximum distance prions could be followed in this study. Movements of less than 5 m were common (± 70%) while movements greater than 10 m were less common (± 9%).

Prions displayed some behaviours more frequently at certain times of night. More prions prospected between 0230 hours and first light; more aggressive interactions took place between 1630 hours and midnight; and more prions moved across the ground between 0230 hours and first light than any other time of night.

Figure 5. Percentage of prions that displayed specified behaviours du fixed-line transect surve Totals for the four behaviour groupings we prospect 17%; rest 66%; move 7%; social 9%. 199 1998 data combined.



3.4 DISCUSSION

There were few nights during this study where broad-billed prions were present on the island but no prospecting behaviour was detected. At any time of night about 12% of prions ashore are likely to be engaged in behaviours that could result in burrow interference. As there are probably over 660,000 prions on South East Island (West & Nilsson 1994), at least 80,000 prions may thus be prospecting for burrows at any given time. These individuals could possibly visit up to six burrow entrances within any 25-min period. During prospecting, prions vocalise into a burrow entrance and if there is no response they are likely to enter. As Chatham petrel chicks are silent, prions could assume the burrow was empty. This coupled with the fact that Chatham petrel burrows are interspersed among prion burrows, it is likely that from time to time a prion will investigate a Chatham petrel burrow.

Some prions moved at least 16 m during a 25-min observation period. It was impractical to follow birds on the fragile terrain, so the distance moved may be greater. As prions were taking off and landing throughout most nights, the majority of movement observed would have been related to their arrival or departure on the island. Culling of prions found on the surface close to Chatham petrel burrows (within 5 m or even 20 m) has been suggested. Our results show that most birds killed in any surface cull would not have posed any threat to Chatham petrels. The majority of prions that pass within a few metres of a Chatham petrel burrow do not investigate that burrow. As prions are very mobile, management of burrow competition will have to either be on an impractically large scale or focus specifically on protecting known Chatham petrel burrow entrances.

Prion interference at Chatham petrel burrows peaks at two times throughout the night. The first peak is between 2200 hours and midnight when broad-billed prions displayed aggressive interactions most frequently. The second peak is between 0200 hours and first light, when the highest numbers of prions were recorded prospecting. This suggests that management of prions would be more effective if targeted during those periods. Management currently involves patrolling Chatham petrel burrows and culling any broad-billed prions found within petrel burrows. This study suggests that patrols around Chatham petrel burrows should be more frequent on first arrival of prions and in the 2 hours before first light. It also suggests that with the high numbers of prions that may be prospecting at any time, alternative management techniques are needed. Part 2 of this report investigates techniques that can reduce burrow competition between Chatham petrels and broad-billed prions.

Part 2. Reduction of burrow competition between Chatham petrels and broad-billed prions

In undisturbed conditions, the natural partitioning of breeding habitat by burrowing petrels may result in different habitats being occupied by each 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). To some extent burrow competition between Chatham petrels and broad-billed prions is probably influenced by the birds' (micro)habitat preferences, and by historical changes to the vegetation of the Chatham Islands.

While current intensive management is relatively successful, it is costly. The night patrols disturb Chatham petrels, are labour- and resource-intensive, provide only short-term (hourly) protection and involve killing prions which are a protected native species. The aim of our research was to identify and utilise differences in burrow site preferences of Chatham petrels and prions, to determine means of deterring prions from entering Chatham petrel burrows.

The specific objectives were:

1. To investigate habitat selection of both Chatham petrels and prions.
2. To investigate if burrow features and microhabitat features around Chatham petrel burrows influence prospecting prions.
3. To develop an artificial burrow entrance flap that deters prions from entering burrows.
4. To test the acceptance of burrow entrance flaps by breeding Chatham petrels.

4. Differences in habitat preferences

4.1 INTRODUCTION

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, eliminating suitable nesting sites thus confining populations to a few predator-free, islands. Thus, while burrow competition between Chatham petrels and prions is likely to be natural, it has probably been exacerbated as both species became confined to small predator-free islands, and further by modification of remaining habitats.

To avoid competition entirely, clear separation of site preferences should have evolved (Burger & Gochfield 1991). Physical aspects of the habitat that are important to nest-site selection by either Chatham petrels or broad-billed prions have not been quantified. Doing so is important for three reasons:

1. It may be possible to manage the habitat to support higher densities of Chatham petrel burrows.
2. If prions select areas with particular habitat features, habitat could be managed to reduce the attractiveness to prions of the area surrounding Chatham petrel burrows.
3. Understanding optimal habitat for both Chatham petrels and prions could assist in selecting and managing alternative habitats when trying to establish Chatham petrel populations on other islands.

4.2 METHODS

To measure habitat characteristics of prion burrows, and habitat availability on South East Island, we randomly sampled habitat throughout different vegetation types. Quadrats were placed around every Chatham petrel burrow using the entrance as the centre. For each quadrat 14 characteristics were measured. A more detailed methodology is described in Sullivan (2000) and will be published elsewhere.

4.3 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. We used selection ratios for each habitat category of 14 variables to quantify habitat selection for both Chatham petrels and prions. The equations used are described in Sullivan (2000). Indices with both lower and upper confidence limits < 1 indicated negative selection; those with both confidence limits 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).

4.4 RESULTS

4.4.1 Chatham petrel habitat preferences

Chatham petrel burrow density was significantly influenced by several habitat characteristics (Appendix 1). 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 diameter breast height (DBH). They showed preference for sites near karamu (*Coprosma chathamica*) take-off trees with a 16–30° lean. They showed lack of preference for sites at which akeake (*Olearia traversii*) predominated, where understorey cover was 61–80%, vegetation height was 0–5 m, areas where there were no stems as well as areas where the greatest proportion of stems were <50 mm DBH, areas where 0–10% of stems were >50 mm DBH and areas with mahoe (*Melicytus chathamica*) take-off trees with leans of 0–15°. As the number of Chatham petrel burrows sampled was small, the data were highly variable with large standard errors. Therefore a number of characteristics with large selection values gave insignificant results. 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.

4.4.2 Broad-billed prion habitat preferences

Prions positively selected a large number of habitat characteristics (Appendix 2). They selected mixed forest or areas in which matipo (*Myrsine chatamica*) dominated, where canopy cover was 61–80% and understorey cover was 21–40%; areas in which 41–60% of the stems were <50 mm, 11–40% stems were 50–99 mm, more than 40% stems were >100 mm DBH; and areas where the take-off trees were predominantly akeake, matipo, karamu, ngaio (*Myoporum laetum*) and mahoe that had a DBH of 200–600 mm and a lean of >16°. They also selected eastern aspects with slopes of 11–40°, and soft soils. Most burrows had logs nearby. Prions avoided sites that were predominantly grass, karamu and flax (*Phormium tenax*), and areas with no take-off trees. Prion habitat was positively correlated with habitat availability ($r = 0.27$; $P < 0.01$). The wide range of positively selected habitat characteristics indicated that prions were not limited by habitat availability and therefore were not habitat-specific.

4.5 DISCUSSION

Forest age and topography influenced Chatham petrel habitat selection. The habitat characteristics both selected and avoided by Chatham petrels suggested that they prefer mature forest with north-eastern aspects. Chatham petrels did not appear to select or avoid particular slope steepness but this factor should not be disregarded: the selection values were positive for slopes of >11°, but standard errors were large. The negative correlation between Chatham petrel selection values and availability of resources shows that they generally selected features such as tall forests that are now limited on South East Island. Hence Chatham petrels appear to be habitat-specific and not to have adapted to changes in the vegetation. A number of disused burrows situated in grass swards, and two breeding burrows situated in open areas (though close to the forest edge) show that our results may not indicate the full extent of habitats they could use. On South East Island, Chatham petrel distribution has contracted during the last 10 years. Pohuehue (*Muehlenbeckia australis*) is currently spreading into bush fragments, and along with exotic grass swards and bracken (*Pteridium esculentum*) is impeding non-forested areas from regenerating. This may further reduce areas suitable for Chatham petrels. Mature forest was likely to have been more prominent on South East Island, and on other islands in the Chatham archipelago, before farming began in the mid 1800s. Sub-fossil bones of Chatham petrels have been found on Chatham, Pitt and Mangere Islands, and while apparently never abundant (West 1994) numbers are unlikely to have been as small as the current population.

Like Chatham petrels, broad-billed prions selected mature forests with mixed size classes, and avoided areas with high stem density typical of young regenerating forests. Prions selected eastern aspects and slopes >11°. Prion selection values were positively correlated with habitat availability, indicating an extremely large population, utilising habitat proportionate to its availability. They selected a wide range of habitat characteristics, suggesting that they are opportunistic, possibly reflecting a still expanding population. Prions are not habitat-specific and are adaptable to change.

The location of present burrow sites in relation to habitat features may be influenced by human modification of the Chatham Islands. Vegetation modification can occur over a relatively short time period. Petrel species are long-lived and tend to exhibit strong site tenacity (Warham 1990); habitat at a site initially selected by a breeding pair may change over time. The original vegetation type of South East Island is largely unknown and descriptions of recent changes are anecdotal. The composition and structure of the regenerating forest are presumed to differ from the original forest.

Selection of a suitable burrow site may involve more than just habitat features. For example, a species may be attracted to a site because of social stimulus (Kharitonov & Siegel-Causey 1990). Warham (1996) stated that gadfly petrels do most of their aerial displays over the nesting site. As most courtship displays occur over Kokopu Creek, this could greatly influence the current distribution of Chatham petrels on South East Island.

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 original vegetation types and past distribution of Chatham petrels are known, our information is the best available guide to assisting managers in selecting translocation sites.

5. Attractiveness of microhabitat features

5.1 INTRODUCTION

Artificial burrows have been used successfully in the research and management of several species of burrow-nesting seabird. They provide easy access to burrow chambers, thus reducing disturbance and the risk of burrow collapse (Warham 1990; Priddle & Carlisle 1997). Since 1992, all Chatham petrel breeding burrows have been replaced with artificial burrow chambers and the tunnels fitted with 100 mm diameter Novapipe (Kennedy 1994). The artificial entrances are larger than natural Chatham petrel burrow entrances.

Prions readily use the artificial Chatham petrel burrows and artificial burrows may be more attractive to them than natural broad-billed prion burrows (Gardner & Wilson 1999). Several features of a Chatham petrel nest box may make it attractive to prions. Prion burrow entrances tend to be larger than natural Chatham petrel entrances (West & Nilsson 1994), and the wider Novapipe tunnel of the artificial entrances may attract prions. Preliminary observations suggested that prions use raised objects, such as the artificial burrow lids and logs for orientation and resting. Our preliminary observations found fewer prion burrows in areas with high tree density, presumably as this impedes movement; and suggested that prions used tracks when moving through the colony. 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 prions, such as removing logs from around Chatham petrel burrows. Our research investigated whether the artificial boxes attracted prions.

In this section we investigate the effect logs and tracks have on prion prospecting behaviour, and determine whether these features exacerbate interspecific competition for burrows.

5.2 METHODS

We observed the behaviour of prions close to Chatham petrel burrows in the Kokopu Creek catchment. Behavioural categories exhibited by prospecting prions are described in Sullivan (2000). This part of our study took place between 15 February and 12 April 1999. Twenty-one of the 54 known Chatham petrel breeding burrows were selected for study. Another trial running simultaneously meant burrows could not be selected randomly. A circular quadrat with a 3 m radius was marked around the burrow entrance. Each night beginning at dusk, an observer watched one burrow for 3 to 5 hours for up to five consecutive nights. The order in which burrows were observed was randomly selected. 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, with continuous recording of frequency and duration of behaviours.

Bancroft's (1999) data, on the frequency at which Chatham petrel burrows were entered by prions, was used to compare the frequency of prion interference between burrows where logs were present or absent and burrows close to or distant from tracks.

Data were analysed using STATISTICS one-way ANOVA for parametric data and Kruskal-Wallis tests for non-parametric data.

5.3 RESULTS

5.3.1 Broad-billed prion numbers

There were significant differences in the number of prions around Chatham petrel burrows (Kruskal-Wallis: $H = 33.13$; df = 21; $P < 0.05$). Overall, there were on average 0.45 prions entering a quadrat per hour. The majority of prions (58%) entered the quadrat between 2000 and 2059 hours (Chatham Island standard time), approximately 1 hour after dusk; 30–33% entered from 2100 to 2259 hours.

5.3.2 Changes in prion behaviour

There were significantly more 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 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 prions spent on any behaviour, or the number of prions entering the quadrat per hour (Kruskal-Wallis: $F = 1.18$; df = 1; $P = 0.28$) when a track ran through the quadrat.

5.3.3 Interference with Chatham petrel burrows

Prions were no more attracted to Chatham petrel burrows than prion burrows. Only 2.7% of prions within the quadrat prospected at a single Chatham petrel burrow compared to 16% that investigated any single prion burrow also within the quadrat. They spent longer prospecting at prion burrows than Chatham petrel burrows (Kruskal-Wallis: $H = 25.89$; df = 1; $P < 0.001$). The number of prions in the vicinity of a Chatham petrel burrow during a night did not influence the level of interference (One-way ANOVA: $F = 0.00$; df = 3; $P = 0.97$). The number of logs had no effect on the level of interference (One-way ANOVA: $F = 1.18$; df = 21; $P = 0.35$), nor did presence or absence of a track within 1 m of the entrance (One-way ANOVA: $F = 0.01$; df = 21; $P = 0.91$).

5.4 DISCUSSION

Microhabitat features may make certain burrows more attractive to prospecting prions than others. Our research suggested that prions prospected less frequently, and spent less time, at Chatham petrel burrows than prion burrows.

This suggests that the box and the larger artificial entrance did not attract prions to artificial Chatham petrel burrows as predicted.

The number of 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 prions more than others. Vision, audition, olfaction or a combination of all three may help guide birds to their burrows and burrow location by visual means centres on recognition of landmarks around the burrow (Grubb 1974; Brooke 1978; James 1986; Minguez 1997). Our observations suggested that Chatham petrels used landmarks such as logs, tree roots and artificial burrow chambers to locate their burrow. Although prions were attracted to logs, the frequency at which prions entered Chatham petrel burrows with logs nearby was no greater than the rate they entered burrows without logs.

Neither the number of prions nor their behaviour was influenced by tracks. There was no difference in the number of prions entering Chatham petrel burrows near tracks compared to those without tracks nearby. Prions did, however, use tracks more when logs were present. While logs and tracks did not appear to influence the number of prions entering Chatham petrel burrows, the sample size was small and prion numbers ashore during 1999 were low compared with previous years (Bancroft 1999).

Concerns about the Novapipe entrance attracting prions to Chatham petrel burrows seem unjustified; the advantage of preventing tunnel collapse certainly outweighs any possible subtle attraction to the burrow entrance.

6. Effectiveness of burrow entrance flaps

6.1 INTRODUCTION

The impact of burrow competition between seabirds of different sizes has been reduced by artificially reducing the size of the burrow entrance, thus excluding the larger competitors (Wingate 1977; Ramos *et al*. 1997). Reducing the size of the entrance is not an option in this situation as prions and Chatham petrels are similar-sized, both weighing approximately 200 g (Marchant & Higgins 1990). However behavioural differences between the two species may be exploited, as competition occurs during different stages of their annual cycles.

Our research investigated the effectiveness of 'burrow entrance flaps' attached to the entrance of Chatham petrel burrows at deterring prions from entering. Such flaps would be attached after the chick hatches: adults have by then formed a bond with the burrow thus have a high incentive to push through the flap to reach the chick. Prions with no prior bond with that burrow have a much lesser incentive to push through a constricting barrier.

6.2 METHODS

Observations at Chatham petrel burrows took place in the Kokopu Creek catchment. The prion trials used the artificial prion burrows discussed in Part 1 of this report. The trials were kept separate so prions discouraged from entering their own burrows would not invade nearby Chatham petrel burrows.

Two burrow flap designs were used. One was made of 3 mm Neoprene stretched over the Novapipe tunnel entrance with an inverted T cut made in the Neoprene. The cross bar of the T was cut following the curve of the lower lip of the Novapipe and was about 8 cm in length. It was important that the lower cut followed the line of the Novalipe, if it was above the lip the birds were hindered when removing debris that accumulated in the tunnel. The vertical cut was in the centre of the Novapipe entrance and was about 7 cm long. The second burrow flap was made of 1 mm thick mountain bike tyre cut into four 25 mm strips that hung curtain-like from the top of the Novapipe entrance. Both flap designs were attached to the Novapipe using hose clamps (see figure in Sullivan 2000).

6.2.1 Chatham petrel burrow flap trials

To measure the response of Chatham petrels to the burrow entrance flaps, 21 burrows were selected from the total of 54 known breeding burrows with chicks.

Each observer watched one burrow each night, for 3 to 5 hours beginning at dusk. Behaviour was observed through a night-vision scope (Zenit NV100 and Apple Nightspy) while about 3 m from the burrow entrance.

A pre-treatment phase was completed on 10 Chatham petrels to determine the time elapsed, from when the bird was 1 m from the burrow, to when it entered its burrow and the number of attempts made to enter. Elapsed time was determined using a digital timer, The term 'attempt' was defined as when a petrel looked into the burrow entrance. These values provided a measure of how disturbed petrels were by the flaps.

During the treatment stage, burrows were observed for three visits by the same Chatham petrel, to determine the extent of habituation. Observations ceased after five nights if the bird did not visit the burrow during the observation period. If the petrel appeared to be distressed and refused to enter the burrow after approximately 7 min (twice the average time determined from the pre-treatment stage), the flap was gently pulled away using an attached string so the bird could enter unimpeded.

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 compared using analysis of variance and Fisher's least significant difference tests in SYSTAT.

6.2.2 Prion burrow flap trial

To measure the effectiveness of flaps in deterring prions from entering burrows, we used 47 of our artificial burrows.

In a pre-treatment phase of 20 days we determined the natural visitation rates at burrows. For the treatment phase, 20 burrows had a flap attached (10 of each design) with the remainder left as controls. To monitor movement into the burrow and therefore the effectiveness of the flap, a 'fence' made of sticks was placed inside the entrance; its displacement indicated that the burrow had been entered. The fences were checked and if necessary replaced between 0100 hours and 0200 hours, and again after dawn. Any unbanded prion found within a burrow was banded.

Birds found in the burrows were categorised as occupiers or prospectors. Occupiers were prions that had previously been found in that burrow two or more times. Our prion studies gave the occupancy history for each burrow for up to 4 years. The frequency at which prions entered burrows was compared between treatment and control burrows; data were compared using analysis of variance in SYSTAT.

6.3 RESULTS

6.3.1 Chatham petrel burrow flap trial

For both burrow entrance flap designs, the time it took for Chatham petrels to enter their burrow increased significantly (Fisher's LSD test: $P < 0.01$). Neither flap caused the number of attempts to significantly differ (One-way ANOVA: F_3

TABLE 5. RESPONSE OF CHATHAM PETRELS TO BURROW ENTRANCE FLAPS, SOUTH EAST ISLAND.

	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 from within 0.05 m
Significance: NS, $P > 0.05$; **, $P < 0.01$

= 1.69, $P = 0.18$), and 90% of Chatham petrels went through the flap compared to 100% in the control burrows (Table 5). 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: $P = 0.81$).

Natural behaviour of Chatham petrels around their burrow entrances was highly variable. Time to enter the control burrows ranged from 11 s to 5 min 12 s, and the number of attempts made before entering ranged from 1 to 12.

6.3.2 Prion burrow flap trial

There was a highly significant decrease in the frequency at which prions entered 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 6).

For the neoprene flap trial, the majority of prions found in the burrows were 'occupiers'. Within the control burrows and those with the tyre flap attached, few prions that entered were found in the burrows, thus the status of these birds is unknown.

TABLE 6. EFFECT OF BURROW ENTRANCE FLAPS ON THE FREQUENCY AT WHICH BURROWS WERE ENTERED BY PRIONS, SOUTH EAST ISLAND.

	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 or more known visits over 4 seasons in one burrow (data also from Was & Wilson 1998)
[2] Prion found in a burrow in which it has never previously been recorded
[3] Burrow had been entered but no prion captured

6.4 DISCUSSION

Behavioural differences between two species of seabird do not appear to have been used previously to reduce burrow competition. Our research showed that exploiting behavioural differences has the potential to be an effective management tool. The results of the burrow entrance flap trials indicate that the flaps do not prevent adult Chatham petrels from entering their own burrows. While they took longer to enter the burrow with a flap in place, the number of attempts to enter the burrow did not change, and the majority of Chatham petrels still entered. Only 3 of 19 Chatham petrels trialed did not enter: of these, one Chatham petrel pulled off the flap which was not firmly secured then entered, and one refused to enter after doing so the previous visit. We were 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. To minimise disturbance to the Chatham petrels during these trials, none of the birds were caught and identified. Thus it is possible that the birds that refused to enter were non-breeders and therefore did not have a high incentive to enter.

Attaching a burrow entrance flap to a burrow effectively deterred prospecting prions from entering. Of the two designs trialed, the 'neoprene' flap proved the most effective. This design requires the neoprene to be fitted taut over Novapipe, but Novapipe can not be installed at all burrows. The tyre design still reduced the frequency at which prions entered a burrow, and could be used for burrows under logs or tree roots.

7. Management options

Two management techniques are currently used by the Department of Conservation to minimise the impact broad-billed prions have on Chatham petrels at South East Island.

1. Blockading of Chatham petrel burrows once their chicks fledge until the petrels return for the next breeding season. The burrows are thus unavailable to prions at this time which includes the prions' own breeding season (Gardner & Wilson 1999). Our study indicates that blockading prion burrows in the same manner and for the same period discourages the return of prions to these burrows. However these results were not statistically significant, possibly due to the small sample size. Blockading all known Chatham petrel burrows takes little time (estimate 1 day by one or two people) and few resources and the success at discouraging prions is probably sufficient to justify continuing blockading all known Chatham petrel burrows (Gardner & Wilson 1999).
2. Culling of all broad-billed prions found in Chatham petrel burrows.

Two other options have been suggested. These are:

- Culling all prions within either 1 or 5 m of a Chatham petrel burrow.
- Culling all prions occupying the 20 burrows closest to each Chatham petrel burrow.

Current management of Chatham petrel chicks involves fieldworkers patrolling Chatham petrel burrows through much of the night and culling any prions present. It enhances chick survival but prions can enter Chatham petrel burrows between inspections and oust or kill the Chatham petrel chick. Killing prions found in Chatham petrel burrows is effective on a nightly basis, but is labour-intensive and is disruptive to the Chatham petrels.

Our study showed that more extensive culls, where prions within a predetermined distance of a Chatham petrel burrow were killed, would have virtually no effect in reducing prion interference and would have a negative impact on the habitat surrounding Chatham petrel burrows. Many prions visit burrows other than their own, mostly burrows within 5 m of a burrow previously occupied. However, a small number were recorded in burrows up to 100 m from the banding burrows. Many prions will be killed while harmlessly moving past Chatham petrel burrows to reach their take-off point or their own burrows. Our data shows that the vast majority of prions nesting or prospecting within 5 m of a known Chatham petrel burrow pose no threat to the petrels. Prions are a protected native species and, therefore, unnecessary or ineffective culling should be avoided.

More extensive culls would cause considerable damage to the already fragile nesting habitat on South East Island. Whichever culling method was employed, fieldworkers would need to move quickly over extremely friable substrate and many burrows would be destroyed in the process. This could result in increased competition for burrows and the destruction of previously unknown Chatham petrel burrows.

Understanding differences in habitat preferences could be useful in managing burrow competition. When trying to reduce competition between rare and abundant species, it is important that habitat requirements of both 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). Our study found that Chatham petrels selected old growth forest. Because of the generalist behaviour of prions and their high population numbers, we found no habitat factors that could be modified to disadvantage prions or discourage them from the vicinity of Chatham petrel burrows. In the past, Chatham petrels have nested along the Summit track and close to the coast in what was at that time open terrain, suggesting that they can utilise a wider range of habitats. The scrub in these areas has now grown up and most of these burrows have been abandoned.

Establishing a Chatham petrel population outside the species current range is one possible option (Conant 1988). Such translocations have been attempted with other seabirds, using techniques such as amplified vocalisations combined with artificial burrows to attract birds to alternative sites (e.g. Grubb 1973; Kress 1983; Dusi 1985; Kress & Nettleship 1988; Podolsky & Kress 1989).

If translocations are attempted for Chatham petrels, the following habitat features appear to be important:

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 .
5. Open forest, mixed age and size classes.
6. Take-off trees available, with leans >11°.

Broad-billed prions also selected some of these characteristics. However, by translocating Chatham petrels to an area with no or few prions, elimination or control of prions that colonise the area should be feasible. Areas that should be avoided are those with a dense understorey; 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 dominated by akeake are avoided on South East Island; however, akeake is now restricted to exposed coastal areas and the summits.

While translocation of Chatham petrel chicks to an island with similar habitat is possible, a suitable location free from introduced predators, stock or colonising prions is yet to be found. Burrow competition with prions is a threat to the Chatham petrel, but depredation by cats, rats, or weka (*Gallirallus australis*) would pose a much greater threat. Holdaway (1999) has shown that on the mainland of New Zealand the presence of Kiore alone caused a slow decline to extinction in petrels greater in body mass than Chatham petrels. *Pterodroma* petrels are especially vulnerable. With the larger European rats, cats and pigs (*Sus scrofa*) the decline to extinction would be very rapid.

A better understanding of habitat preferences can also guide searches for new Chatham petrel burrows on South East Island. Although Chatham petrel burrows have not been found along the lower portion of Kokopu Creek, this area contains many of the characteristics Chatham petrels prefer. However our results may show some bias as we used known burrows, searches for which have previously been concentrated in one area. Other habitat types need to be searched to confirm that the selection values in our study are representative of the whole population.

With the difficulties posed by prion culls and the issues involved with translocation, the exclusion of prions from known Chatham petrel burrows appears to be the most effective strategy for managing burrow competition. Burrow flaps that discourage prions from entering Chatham petrel burrows appear to be the best option. Currently we envisage attaching the burrow entrance flap after hatching and it being removed before the Chatham petrel chick first leaves the burrow. Chicks of many petrel species leave the burrow at night before fledging to exercise and orientate themselves (Harper 1976; Warham 1990). Incidental observations suggest Chatham petrel chicks start leaving the burrow up to 15 days prior to fledging (P. Gardner, pers. comm.).

8. Future research

Further information is needed on the following :

- Burrow use habits of prions.
- Nest site selection in *Pterodroma* petrels including the roles of aerial and ground displays and habitat features in nest site selection. This type of research would be more easily done on a less threatened analogue species.
- Vegetation change on South East Island to determine how changes in the past have influenced the current distribution of Chatham petrels and prions.
- Historic breeding range and habitats used by both Chatham petrels and prions.
- Best management options for Pohuehue (*Muehlenbeckia*) to facilitate forest regeneration to prevent smothering of forest fragments, and therefore improve existing Chatham petrel habitat.
- Investigate how do Chatham petrels locate their burrows. Before any changes are made to the microhabitat we recommend experimental trials, where logs within 3 m of a Chatham petrel burrow are removed. The effect of this change on prion and Chatham petrel behaviour should be determined.
- Correlations between microhabitat features and the number of prions entering Chatham petrel burrows is needed. Only one season's data were available and prion numbers on the island that year were relatively low compared to previous (Bancroft 1999) and subsequent years (Gummer 2000).
- More information is required on the effects the burrow entrance flap may have on Chatham petrel behaviour. This work is best done on an analogue species.

The stage in the breeding cycle during which the flap is attached may influence subsequent behaviour by Chatham petrels. The following questions need to be answered:

1. Does the flap disrupt the chick's exploratory behaviour, or prevent the chick returning to the chamber?
2. Would Chatham petrels' incentive to enter through the flap lessen if the flap was attached before the breeding season or left in place between breeding seasons?
3. If the flap had been in place during the previous breeding season, would the Chatham petrel recognise its own burrow if the flaps were not attached until after incubation?

Disturbance to burrows may cause breeding birds to shift to a new burrow. Such shifts could result in the break-up of pairs and consequently lower reproductive success (Morse & Kress 1984; Warham 1990). Monitoring is required to ensure that the flap does not disrupt mate and burrow fidelity more so than the current intensive management regime.

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10. References

Bancroft, F. 1999: End of breeding season report 1998-1999; Chatham Island petrel (*Pterodroma axillaris*). Department of Conservation, Chatham Islands Area Office (unpublished report). 28 p.

Brooke, M de L. 1978: A test for visual location of the burrow by manx shearwater *Puffinus puffinus. Ibis 120*: 347-349.

Burger, J.; Gochfield, M. 1991: Nest-site selection by the Herald petrel and white-tailed tropic bird on Round Island, Indian Ocean. *Wilson Bulletin 10(3)*: 130-132.

Conant, S. 1988: Saving endangered species by translocation. *Bioscience 38*: 254-257.

Dusi, J.L. 1985: Use of sounds and decoys to attract herons to a colony site. *Colonial Waterbirds 8*: 178-180.

Feare, C.J.; Gill E.L.; Carty, P.; Carty, H.; Ayrton, V.J. 1996: Habitat use by Seychelles sooty terns and implications for colony management. *Biological Conservation 81*: 69-76.

Gardner, P.; Wilson, K-J. 1999: Chatham petrel (*Pterodroma axillaris)* studies—breeding biology and burrow blockading. *Science for Conservation 131*. 37 p.

Grubb, T.C. 1973: Colony location by Leach's storm petrel. *Auk 90*: 78-82.

Grubb, T.C. 1974: Olfactory navigation to the nesting burrow in Leach's petrel. *Animal Behaviour 22*: 192-202.

Gummer, H. 2000: End of season report, Chatham petrel (*Pterodroma axillaris*), June. Department of Conservation, Chatham Islands Area Office (unpublished report). 43 p.

Harper, P.C. 1976: Breeding biology of the fairy prion (*Pachyptila turtur*) at the Poor Knights Islands, New Zealand. *New Zealand Journal of Zoology 3*: 351-371.

Holdaway, R.N. 1999: Introduced predators and avifaunal extinctions in New Zealand. Pp. 189-238 in R.D.E. MacPhee *Ed.* Extinctions in Near Time; causes, contexts and consequences. Kluwer Academic/Plenum, New York.

Imber, M.J. 1975: Petrels and predators. *XII Bulletin of the International Council for Bird Preservation 12*: 260-263.

James, P.C. 1986: How do manx shearwaters find their burrows? *Ethology 71*: 287-294.

Kennedy, E. 1994: Chatham Petrel Recovery Plan, 1994-1998. Unpublished report held by Canterbury Conservancy, Department of Conservation.

Kharitonov, S.I.; Siegel-Causey, D. 1990: Colony formation in seabirds. Chapter 5. *Current Ornithology 5*. [DETAILS?]

Kress, S.W. 1983: The use of decoys, sound recordings and gull control for re-establishing a tern colony in Maine. *Colonial Waterbirds 6*: 185–196.

Kress, S.W.; Nettleship, D.N. 1988: Re-establishment of Atlantic puffins (*Fratercula arctica*) at a former breeding site in the gulf of Maine. *Journal of Field Ornithology 59 (2)*: 161–170.

Manly, B.; McDonald, L.; Thomas, D. 1993: Resource selection by animals: statistical design and analysis for field studies. Chapman and Hall, London. 177 p.

Marchant, S.; Higgins, P.J. 1990: Handbook of Australian, New Zealand and Antarctic birds 1 (A). Oxford University Press. Australia.

Minguez, E. 1997: Evidence of occasional re-laying in the British storm petrel (*Hydrobates pelagicus*). *Colonial waterbirds 20 (1)*: 102–104.

Morse, D.H.; Kress, S.W. 1984: The effect of burrow loss on mate choice in Leach's storm petrel. *Auk 101*: 158–160.

Podolsky, R.H.; Kress S.W. 1989: Factors affecting colony formation in Leach's storm petrel. *Auk 106*: 332–336.

Priddle, D.; Carlisle, N. 1997: Conservation of the endangered Gould's petrel *Pterodroma leucoptera leucoptera. Pacific Conservation Biology 3*: 322–329.

Ramos, J.A.; Monteiro, L.R.; Sola, E.; Moniz, Z. 1997: Characteristics and competition for nest cavities in burrowing Procellariiformes. *Condor 99*: 634–641.

Richdale, L.E. 1965: Breeding of the narrow billed and broad billed prion. *Transactions of the Royal Society of London 31 (1)*: 140–155.

Segonzac, M. 1972: Donnees recentes sur la faune des Iles Saint-Paul et Nouvelle Amsterdam. *Oiseau Rev Fr Orn 42*: 1–68.

Sullivan, W. 2000: 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. Unpublished Master of Science thesis. Lincoln University.

Taylor, G. A. 1991: Report on the Chatham Island taiko and Chatham Island petrel recovery programmes (1990/91). *Threatened species occasional publication 2.*

Warham, J. 1990: *The Petrels, their Ecology and Breeding Systems*. London. Academic Press.

Warham, J. 1996: *The Behaviour, Population Biology and Physiology of the Petrels*. London. Academic Press.

Was, N.W. 1999. Burrow occupancy and related behaviour of broad-billed prions (*Pachyptila vittata*) on Rangatira (South East) Island, Chatham Islands, New Zealand. Unpublished Master of Science thesis. Lincoln University.

West, J.A. 1994. Chatham petrel (*Pterodroma axillaris*)—an overview. *Notornis (supplement) 41*: 19–26.

West, J.A.; Nilsson, R. 1994: Habitat use and burrow densities of burrow-nesting seabirds on South East Island, Chatham Islands, New Zealand. *Notornis (supplement) 41*: 27–37.

Wingate, D.B. 1977: Excluding competitors from Bermuda petrel nesting burrows. In: S. A. Temple, *Ed.: Proceedings of Symposium on Management Techniques for Preserving Endangered Birds*. pp 93–102. University of Wisconsin Press and Croom Helm, Madison.

Appendix 1

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 in which the category occurred / total number of quadrats.

VARIABLE	CATEGORY	WI	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
Understorey 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

VARIABLE	CATEGORY	WI	SE	LCL	UCL	SELECTION	AVAILABILITY
No. stems/m2							
	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 < 50 mm (%)							
	0-20	1.25	1.25	0.00	4.46		8
	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 51–100 mm (%)							
	0-10	0.56	0.11	0.29	0.83	-	48
	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 >100 mm (%)							
	0-10	0.61	0.14	0.24	0.98	-	38
	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 (tot)							
	None	1.15	0.78	0.00	3.26		13
	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

Appendix 2

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 inwhcih the category occurred / total number of quadrats.

VARIABLE	CATEGORY	WI	SE	LCL	UCL	SELECTION	AVAILABILITY
Dominant species							
	Olearia traversii	12.5	0.00	0.00	0.00	-	3
	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 compaction							
	Soft	8.46	1.75	4.10	12.82	+	7
	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 cover (%)							
	0-20	0.80	1.16	0.00	3.79		10
	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
Understorey cover (%)							
	0-20	1.22	0.89	0.00	3.50		60
	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 height (m)							
	0-5	0.98	0.15	0.60	1.36		40
	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

VARIABLE	CATEGORY	WI	SE	LCL	UCL	SELECTION	AVAILABILITY
No. logs (3 m radius quadrat)							
	0	1.27	0.18	0.81	1.73		44
	1	2.03	0.31	1.23	2.83	+	1
	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 <50 mm (%)							
	0-20	0.25	0.17	0.00	0.69	-	8
	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 51–100 mm (%)							
	0-10	1.06	0.03	0.98	1.14		48
	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 >100 mm (%)							
	0-10	1.00	0.15	0.62	1.38		38
	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 (tot)							
	None	0	0.00	0.00	0.00	-	13
	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