

Breeding petrels of Chalky and Preservation Inlets, southern Fiordland – a test of the ‘refugia from resident stoats’ hypothesis

COLIN M. MISKELLY*

Museum of New Zealand Te Papa Tongarewa, PO Box 467, Wellington 6140, New Zealand

COLIN R. BISHOP

Department of Conservation, PO Box 29, Te Anau 9600, New Zealand

GRAEME A. TAYLOR

Department of Conservation, PO Box 10420, Wellington 6011, New Zealand

ALAN J.D. TENNYSON

Museum of New Zealand Te Papa Tongarewa, PO Box 467, Wellington 6140, New Zealand

Abstract: Forty breeding colonies of three petrel species were found on 35 of 71 islands surveyed in southern Fiordland, Fiordland National Park, New Zealand, in November and December 2017. Almost all islands in Chalky Inlet, Preservation Inlet, Cunaris Sound, Long Sound, and Isthmus Sound were surveyed. Sooty shearwater (*Ardenna grisea*) was the most widespread and abundant species, with an estimated 23,425 burrows on 25 islands. Broad-billed prions (*Pachyptila vittata*) were breeding on nine islands (9,940 burrows estimated), and mottled petrels (*Pterodroma inexpectata*) on five islands (1,240 burrows estimated). This is a 3-fold increase in the number of petrel colonies in Chalky and Preservation Inlets and associated waterways identified in published accounts, and the first estimate of the number of burrows on each island. Long-term survival of most of these colonies is dependent on ongoing control of stoats (*Mustela erminea*) on islands in these southern fjords. The persistence of remnant petrel colonies on small islands is probably due to stoats being infrequent invaders that are unable to persist when migratory petrels depart at the end of the breeding season.

Miskelly, C.M.; Bishop, C.R.; Taylor, G.A.; Tennyson, A.J.D. 2019. Breeding petrels of Chalky and Preservation Inlets, southern Fiordland – a test of the ‘refugia from resident stoats’ hypothesis. *Notornis* 66(2): 74–90.

Key words: breeding; Chalky Inlet; colony; Fiordland; Green Islets; petrel; Preservation Inlet; prion; seabird; shearwater; stoat predation

INTRODUCTION

The glaciated landscapes of Fiordland, in south-western New Zealand, contain many hundreds of islands that are within the broad breeding ranges of at least seven species of burrow-nesting petrels (Procellariiformes) – breeding ranges summarised in Marchant & Higgins (1990), and Taylor (2000a

& b). While a few Fiordland breeding sites of mottled petrel (*Pterodroma inexpectata*) have been known for several decades (Warham *et al.* 1977; Taylor 2000b), information on burrowing seabird diversity, distribution, and colony sizes in the region remain poorly known, and many authors have recommended the need for further surveys (e.g. Taylor 2000b; Waugh *et al.* 2013; Jamieson *et al.* 2016; Wildland Consultants & Department

Received 21 March 2019; accepted 8 May 2019

Correspondence: colin.miskelly@tepapa.govt.nz

of Conservation 2016). A first step to filling this information void occurred in November 2016, when a survey of 56 islands in Dusky Sound located 49 breeding colonies of three petrel species, with 27,640 burrows estimated (Miskelly, Tennyson *et al.* 2017). We here report the findings of a subsequent survey for petrels on islands in Chalky Inlet, Preservation Inlet and associated waterways in November and December 2017, and compare and contrast these results with those from the 2016 survey. Information on petrels breeding on the Green Islets, 16 km south-east of Preservation Inlet, is also presented based on surveys undertaken in December 2013 and 2018.

Chalky Inlet and Preservation Inlet and their connected inland waterways of Edwardson, Cunaris, Isthmus, and Long Sounds are the southernmost fjords in Fiordland. Each of the two major inlets is partially protected from the open sea by a single large island (Chalky Island and Coal Island respectively), and between them they contain more than 70 vegetated islands (Figs 1-3, and see Department of Conservation 2017). Conservation management on these islands has included some of the earliest stoat (*Mustela erminea*) eradications in New Zealand, on Chalky Island (514 ha) and the Passage Islands (177 ha) in 1999, followed by Coal Island (1,163 ha) in 2005 (Elliott *et al.* 2010; Department of Conservation 2017), and subsequent translocations of seven species of rare and threatened land birds to these islands (Miskelly & Powlesland 2013; Department of Conservation 2017; Miskelly *et al.* 2018).

Three species of petrels have been reported breeding in Chalky and Preservation Inlets. The earliest record was of mottled petrels breeding at an unspecified site on the South Island mainland in Preservation Inlet (Buller 1892), with more recent reports of this species from Single Tree Island in Preservation Inlet and on a nearby islet in Isthmus Sound (Morrison & Morrison 1982; McEwen 1987; McLean *et al.* 1993; Peat & Patrick 1996; Miskelly *et al.* 2019). Broad-billed prions (*Pachyptila vittata*) were found breeding on Zero Nugget and Finger Rock off the north coast of Chalky Island in 1986 (Kim Morrison in Cooper 1986; Miskelly, Tennyson *et al.* 2017), and sooty shearwaters (*Ardenna grisea*) were reported from Chalky Island, Great Island, Passage Islands, Garden Islands, and Small Craft Harbour Islands in Chalky Inlet (McLean *et al.* 1993; Miskelly, Tennyson *et al.* 2017) and Spit Island, Round Island, Single Tree Island, and outer Cording Island in Preservation Inlet (Miskelly, Tennyson *et al.* 2017 – based mainly on information provided by Pete Young).

Apart from the eradication of stoats on Chalky, Passage and Coal Islands, and the 2008 eradication of mice (*Mus musculus*) on Coal Island (Elliott

et al. 2010; Department of Conservation 2017), little information has been published on the presence of introduced predators on islands in Chalky and Preservation Inlets. Stoats are presumed to have reached the area *c.* 1900, based on the documented date of their arrival in nearby Dusky Sound (Hill & Hill 1987). All the islands in Chalky and Preservation Inlets are within the swimming range of stoats (Elliott *et al.* 2010; Veale *et al.* 2012). Until their eradication, stoats were resident on the two most seaward islands (Chalky Island and Coal Island; Department on Conservation 2017), and they have been detected on at least 11 islands that are further inland (King & Murphy 2005; Veale *et al.* 2012, and data presented herein). Apart from sites exposed to extreme wave action, it is likely that stoats have periodically reached all the islands in these waterways.

Chalky and Coal Islands, and both of the Passage Islands, plus Steep-to Island (58 ha) in Preservation Inlet are now considered to be free of all introduced mammals (Department of Conservation 2017). Self-resetting traps with lures designed to attract both stoats and rats *Rattus* sp. are maintained on many of the smaller islands in the two inlets (Colin Bishop and Lindsay Wilson, Department of Conservation *unpubl. data*).

We report on a survey to identify the petrel species breeding, and estimate the number of burrows, on 71 islands in Chalky Inlet, Cunaris Sound, Preservation Inlet, Long Sound, and Isthmus Sound. We attempt to explain the distribution of petrel colonies on these islands based on stoat and petrel behaviour and ecology, and specifically in the context of the ‘refugia from resident stoats’ hypothesis proposed by Miskelly, Tennyson *et al.* (2017) to explain the paradox of numerous petrel colonies persisting on islands that are accessible to stoats. This hypothesis predicts that populations of migratory petrels will persist for many decades on islands that are within swimming range of stoats, provided that the islands are too small to provide sufficient permanent food resources to sustain a resident stoat population year-round. It is assumed that stoats are unable to extirpate a petrel population during a single invasion due to a proportion of the petrel population being absent from the colony (particularly pre-breeders), and (at larger colonies) due to the sheer number of potential prey present, with the stoats having to vacate the island once the migratory petrels depart at the end of the breeding season.

The minimum island size that can support a resident stoat population is unclear. King & Murphy (2005: 266) named Chalky Island (514 ha) as the smallest island in New Zealand known to have supported a permanent population of stoats (before they were eradicated in 1999), while Veale

et al. (2012) suggested that stoats were resident on 57 ha Motuoruhi Island (near Coromandel) based on eight stoats being caught there during initial trapping, and considered islands under 50 ha to be too small for a resident stoat population to establish. On small islands it is assumed that stoat invasion events have been too brief and infrequent to kill all individuals of all age classes of the breeding petrels during the *c.* 120 years since stoats reached southern Fiordland. In contrast, petrels will be rapidly extirpated from islands that are large enough to sustain resident stoats.

METHODS

A boat-based survey of islands in Chalky Inlet, Cunaris Sound, Preservation Inlet, Long Sound, and Isthmus Sound, Fiordland National Park, south-west New Zealand, was undertaken 20–25 November 2017, with a primary focus of locating petrel breeding colonies. Outer headlands of Great Island, Chalky Inlet, were surveyed by Colin Bishop on 19 December 2017. Information on breeding petrels on the Green Islets (46.228°S, 166.800°E) is included following surveys undertaken there on 13 December 2013 and 15 December 2018 (Colin Bishop *unpubl. data*; Rebecca Jackson & Ben Barr *pers. comm.* to CMM Jan 2019; James Reardon *pers. comm.* to CMM 19 Feb 2019).

The November timing of the main survey was chosen to maximise the chance of simultaneously locating the three petrel species known to breed in Fiordland (broad-billed prion, mottled petrel and sooty shearwater), and in the knowledge that other possible breeding petrel species would also be present at colonies at this time of year. Landings were made from a small inflatable dinghy, with 1–7 team members landing on each island for between 5 min and 3 h 45 min (mean = 46 min, median = 30 min; Appendix 1). Most landings were during daylight, with two islands landed on at night. Spot-lighting was undertaken from the deck of the main vessel (the 22 m M.V. *Southern Winds*) while anchored or moored at night at five locations. Great Island was surveyed during a 9 h visit a month later.

Seventy-one islands were surveyed for the presence of burrow-nesting petrels by 1 or more team members. Few of the islands had individual names on available maps and charts (where most are named as clusters of islands), and so we created tag names mainly based on island size and location within each cluster. A central latitude and longitude reference point for each island is provided in Appendix 1.

Petrel burrow entrances were searched for and counted on each island during walk-through surveys. The proportion of each island surveyed was estimated, with the estimated number of

burrows on each island based on the actual count extrapolated to allow for areas not surveyed. On large islands where burrows were apparently confined to a portion of the island, we estimated the proportion of the colony (rather than the entire island) that we surveyed. Landings were too brief to allow repeat surveys and estimation of error intervals. The accuracy of each estimate will vary in direct proportion to the proportion of each island surveyed (i.e. the ratio between counted and estimated burrows on each island, which varied between 0.4% and 100%).

The petrel species present were identified by any of: adults or chicks extracted from burrows or seen on the colony surface or in collapsed burrows; vocalisations from birds inside burrows; corpses, plucked feathers (by New Zealand falcons *Falco novaeseelandiae*) or failed eggs on the colony surface; burrow location and burrow entrance size. Any intact eggs were measured (length x maximum width) as a guide to species identification.

Basal areas of islands were obtained from ArcGIS. Distance from the sea for each island was estimated from Google Earth, as a straight-line distance from the midpoint of the nearest fjord entrance (north-west or south-east of Chalky or Coal Islands), based on straight lines between outer headlands of these two large islands and adjacent South Island headlands.

Distances from resident (or historically present) stoat populations are the shorter of the minimum straight line distance between the island and the nearest part of the South Island mainland (or other site with resident stoats), or the cumulative water gaps between 'stepping stone' islands (*sensu* Elliott *et al.* 2010) where present.

RESULTS

Evidence of breeding petrels was found on 35 islands in Chalky Inlet, Preservation Inlet, Cunaris Sound, Long Sound, and Isthmus Sound in November and December 2017, and on five of the Green Islets in December 2013 and 2018. Petrel breeding islands ranged in size from 0.02 to 727 ha, and were up to 29 km from the open sea (Tables 1–3). We found mottled petrel burrows, sometimes within a couple of metres of the shore, mainly on small low-lying islands, and usually among dense ground cover of moss and ferns. In contrast, sooty shearwater burrows (which had larger entrances) were mainly found in areas with less ground cover on the upper slopes and island summits of larger islands. Broad-billed prion burrows were smaller than for the two other species, and were mainly found on the tops of steep-sided stacks on exposed outer coasts.

Table 1. Evidence for mottled petrel presence on islands in southern Fiordland in November 2017, with the estimated number of burrows on each island (based on the proportion of each island surveyed). Islands are presented in a loop from Cunaris Sound to Chalky Inlet, then Preservation Inlet, and Isthmus Sound, finishing in Long Sound. See Appendix 1 for island locations and search effort.

Island name	Area (ha)	Distance from sea (km)	Evidence	Burrows counted	Estimated burrows on island
Small Craft Harbour Is 'north-east island'	2.2	14.9	small burrow	1	0
Small Craft Harbour Is 'small middle islet'	0.1	13.8	burrows, corpses, bird landed at night	28	35
South of Stripe head – north-east islet	0.1	7.9	small burrow	1	0
North Passage Island	8.7	4.7	small burrow	4	0
Passage I. south coast stack 6	0.1	3.5	empty burrows, feather	2	0
Passage I. south coast stack 5	0.02	3.6	burrows, adult	25	100
Chalky Island	453.0	0	burrows	55	155
Cording Island (main)	24.5	7.4	old inactive burrows	27	0
Cording Is, '35 spot height'	3.6	8.5	old inactive burrows	5	0
Single Tree Island	0.3	6.9	burrows, corpses,	326	450
Isthmus Sound Islet	1.8	9.8	burrows, skull, eggs, feathers	258	500
'Only islet'	0.2	29.0	old burrows, egg - not active	25	50
Total (5 active sites)	455.2	-		692	1,240

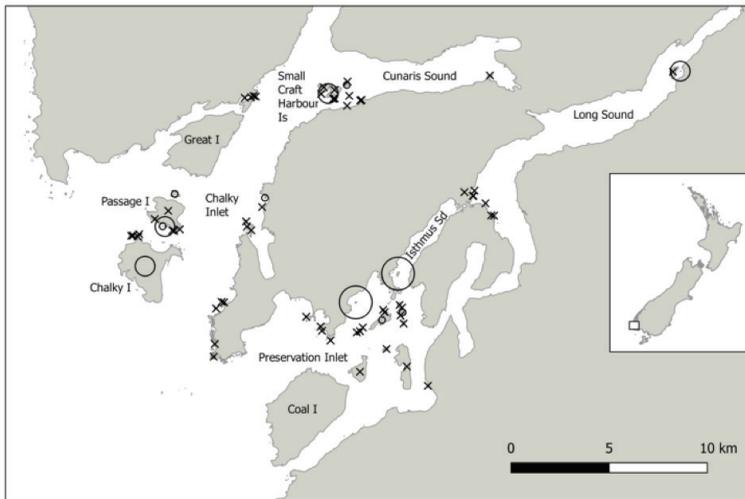


Figure 1. Distribution of mottled petrel colonies surveyed in Chalky Inlet, Preservation Inlet, Cunaris Sound, Long Sound, and Isthmus Sound in 2017. Circle sizes denote colony size, with large circles showing colonies with 400–500 burrows estimated, medium circles 30–160 burrows estimated, and small circles sites with fewer than 30 old or inactive burrows estimated. Crosses show islands visited without mottled petrels being recorded.

Mottled petrel (*Pterodroma inexpectata*)

Mottled petrels, or their burrows, were found on up to 12 islands, although on seven islands only old, inactive burrows were found, or evidence was based solely on burrow size (Table 1, Fig. 1). The five sites with substantial active colonies were Single Tree Island, the islet in Isthmus Sound, Chalky Island, a stack off the south coast of Passage Island, and a small islet within the harbour of Small Craft Harbour Islands.

Apart from Chalky Island (which is on the outer coast), these sites were 3.6–14 km from the open sea. An apparently vacated mottled petrel colony was found on the islet alongside Only Island in Long Sound, 29 km from the sea. With the exception of 453 ha Chalky Island, the four other active mottled petrel breeding sites were on very small low-lying forested islands of 0.08–1.8 ha.

The only live mottled petrel handled was on a stack off the south coast of Passage Island, but

corpses or skulls were found on three islands, and failed eggs on two islands (Table 1). An intact egg from 'Only islet' measured 56.6 x 42.2 mm.

Single Tree Island and the islet in Isthmus Sound were the two largest colonies (450–500 burrows estimated on each), and were the only mottled petrel breeding sites previously known from the area (Miskelly *et al.* 2019). The highest actual burrow count was 326 burrows on Single Tree Island, and the total burrow estimate for the

five islands with active burrows was 1,240 (Table 1).

The only mottled petrel island that we landed on at night was the small islet within the harbour of Small Craft Harbour Islands on the night of 24 November 2017. Many birds were calling in flight and one was heard to land among the vegetation, but no birds were seen on the ground. Mottled petrels were heard and seen in flight at three of the five spot-lighting locations (Table 2), all of which were alongside breeding islands.

Table 2. Petrels observed during spot-lighting sessions at five sites in southern Fiordland in November 2017. Minimum number of individuals (MNI) is the maximum number of birds seen at any one time; in most cases the actual number of individuals will have been higher than this, with an upper limit indicated by the number of sightings. Scientific names for all six species are given in the text.

Date	Location	Timed search	Petrels observed (MNI)
20 Nov	Off Only Island, Long Sound	2238 – 2338 h	Grey-backed storm petrel 1 (7 sightings)
21 Nov	Near Single Tree Island, Preservation Inlet	2300 – 2340 h	Mottled petrel 8 (continuously present) Sooty shearwater heard
22 Nov	Sealers Bay, Chalky Island	2255 – 0040 h	Mottled petrel 5 (continuously present) Broad-billed prion 1 caught Antarctic prion 1 caught Sooty shearwater 3 (continuously present; 1 caught) Common diving petrel 2 caught Grey-backed storm petrel 2 (4 sightings; 1 caught)
23 Nov	West of Little Island, Chalky Inlet	2255 – 2330 h	Nil
24 Nov	Small Craft Harbour, Chalky Inlet	2345 – 0015 h	Mottled petrel 2 (7 sightings) Sooty shearwater 1 (3 sightings; 1 caught) Grey-backed storm petrel 1

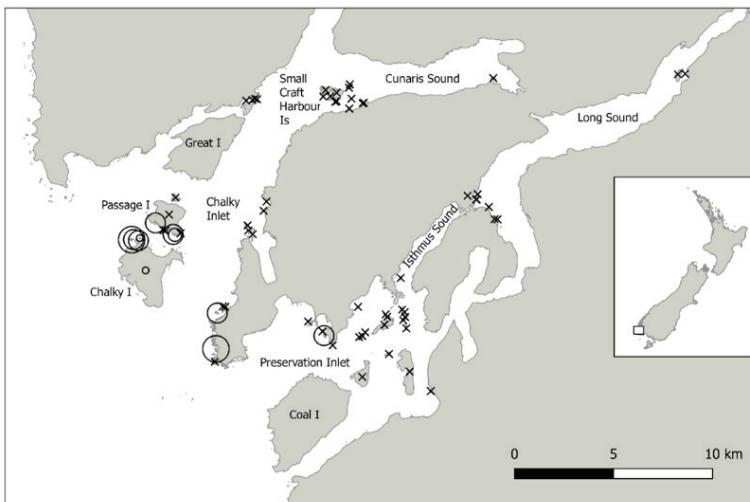


Figure 2. Distribution of broad-billed prion colonies surveyed in Chalky Inlet, Preservation Inlet, Cunaris Sound, Long Sound, and Isthmus Sound in 2017. Circle sizes denote colony size, with very large circles showing colonies with 1,000–7,500 burrows, large circles 100–900 burrows, and medium circles 10–25 burrows estimated. Small circles denote sites with fewer than 30 old or inactive burrows estimated. Crosses show islands visited without broad-billed prions being recorded.

Broad-billed prion (*Pachyptila vittata*)

Broad-billed prions were found breeding on nine small islets or stacks up to 0.2 ha, mainly in outer Chalky Inlet within 4 km of the open sea (Table 3, Fig. 2). All sites were close to adjacent shores (the South Island mainland, Chalky Island or south Passage Island), but were in high energy environments exposed to strong wave action.

The largest colony was of an estimated 7,500 burrows on an unnamed stack ('Riki Rock') west of Gulches Head (the headland separating Chalky and

Preservation Inlets), with 1,000 burrows estimated on the main Zero Nugget (off the north-west coast of Chalky Island). The total population estimate on the nine sites was 9,940 burrows.

Prions were nesting under kokomuka (*Veronica elliptica*) and shore spleenwort (*Asplenium obtusatum*) at densities up to 3 burrows/m². Large downy chicks were found on one stack, eggs on three additional sites, and corpses or feathers on six further sites, although two prion kill sites (by New Zealand falcons) on Chalky Island may have

Table 3. Evidence for broad-billed prion presence on islands in southern Fiordland in November 2017, with the estimated number of burrows on each island (based on the proportion of each island surveyed). All sites are in Chalky Inlet apart from the last, which is in Preservation Inlet. See Appendix 1 for island locations and search effort.

Island name	Area (ha)	Distance from sea (km)	Evidence	Burrows counted	Estimated burrows on island
Passage I. south coast stack 7	0.2	3.4	burrows, 5 falcon kills	80	500
Passage I. south coast stack 4	0.1	3.7	burrows, feathers	50	100
Passage I. south coast stack 3	0.1	4.0	burrows, down	10	10
Zero Nugget (main)	0.1	1.9	burrows, 12 corpses, 3 eggs	367	1,000
Zero Nugget (eastern)	0.03	1.9	burrows, 2 corpses, old egg	20	100
Finger Rock (inner)	0.1	2.1	burrows	12	250
Finger Rock (tall stack)	0.04	2.2	old burrows, old egg	16	0
Chalky Island	453.0	0	possible burrow, 2 falcon kills	0?	0
'Hebe pyramid'	0.1	1.0	burrows, 5 chicks	58	240
'Riki Rock'	0.2	0	burrows, corpse	30	7,500
Southern stack west of Cavern	0.1	4.9	burrows, feathers	58	240
Total (9 active sites)	0.9	-		685	9,940

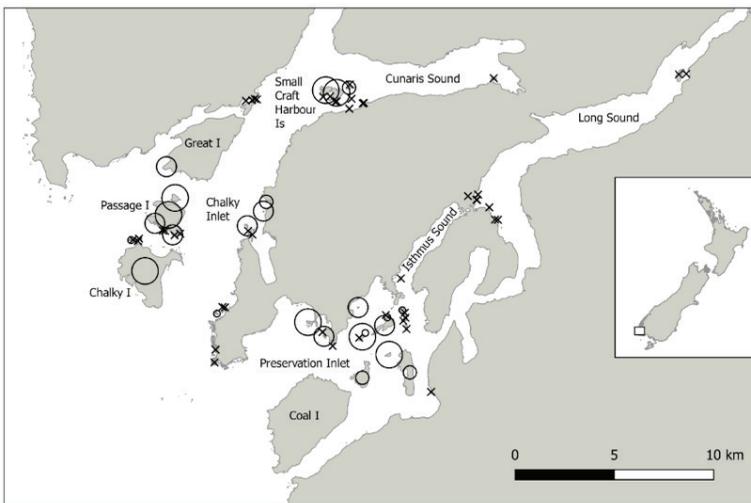


Figure 3. Distribution of sooty shearwater colonies surveyed in Chalky Inlet, Preservation Inlet, Cunaris Sound, Long Sound, and Isthmus Sound in 2017. Circle sizes denote colony size, with very large circles showing colonies with 1,400–5,000 burrows, large circles 100–780 burrows, and medium circles 20–75 burrows estimated. Small circles denote sites with fewer than 4 burrows found. Crosses show islands visited without sooty shearwaters being recorded.

been of birds captured on adjacent islets (Table 3). Three failed eggs measured 51.7 × 35.0 mm (eastern Zero Nugget), and 47.5 × 34.4 mm and 48.9 × 36.0 mm (main Zero Nugget).

An adult broad-billed prion landed on the deck of M.V *Southern Winds* during a spot-lighting session off Sealers Bay, Chalky Island, on 22 November 2017 (Table 2). No prions were seen at the four other more inland spot-lighting sites.

Sooty shearwater (*Ardenna grisea*)

The sooty shearwater was the most widespread and abundant petrel species found during the survey, with an estimated 23,425 burrows on 25

islands (Table 4, Fig. 3). Excluding islands where fewer than 5 burrows were seen or estimated, sooty shearwaters bred on 20 islands that were 0.05–727 ha in size (mean 80 ha), and 0–15 km (mean 6.8 km) from the open sea.

Our survey was about a week before peak egg-laying (Warham *et al.* 1982), and no fresh eggs were found. Old eggs were found on five islands in Chalky Inlet (Table 4), with two eggs sufficiently intact for full measurement: 75.5 × 46.1 mm (Chalky Island), and 79.0 × 48.4 mm (Small Craft Harbour Islands, western main island).

The largest colony was on north Passage Island (5,000 burrows estimated), with colonies of 1,400 to 3,500 burrows estimated on 7 other islands (Table

Table 4. Evidence for sooty shearwater presence on islands in southern Fiordland in November and December 2017, with the estimated number of burrows on each island (based on the proportion of each island surveyed). Islands are presented in a loop from Cunaris Sound to Chalky Inlet, then Preservation Inlet. See Appendix 1 for island locations and search effort.

Island name	Area (ha)	Distance from sea (km)	Evidence	Burrows counted	Estimated burrows on island
Small Craft Harbour Is 'north-east island'	2.2	14.9	burrows	16	20
Small Craft Harbour Is 'main east island'	24.2	14.1	burrows	141	1,400
Small Craft Harbour Is 'main west island'	18.2	13.8	burrows, 5 corpses, 2 eggs, bird calling	507	2,150
South of Stripe Head – north-east islet	0.1	7.9	burrows	59	75
South of Stripe Head – south-west islet	0.1	7.5	burrows, 2 corpses	196	250
Garden Island (outer)	1.0	5.9	burrows, 5 corpses	564	780
Great Island ¹	726.9	5.2	burrows	50	200
North Passage Island	8.7	4.7	burrows	492	5,000
South Passage Island	167.9	4.0	burrows, egg	265	1,400
Passage I. south coast stack 7	0.2	3.4	burrows, corpse	92	200
Passage I. south coast stack 4	0.1	3.7	burrows, skull, egg	50	100
Zero Nugget (main)	0.1	1.9	burrows, old egg	2	2
Chalky Island	453.0	0	burrows, egg	918	3400
'Hebe pyramid'	0.1	1.0	burrows	2	2
Spit Island	2.0	4.7	burrows	60	2,500
Stack west of Cavern Head	0.1	4.9	burrows	156	450
Steep-to Island	57.6	5.2	burrows	11	20
Weka or Long Island	109.7	8.6	burrows	28	40
Round Island	2.6	7.1	burrows	141	1,400
Cording Islands (outer)	3.7	6.1	burrows, 3	669	3,500
Cording Is, outer (NW islet)	0.4	6.4	burrow	1	1
Cording Islands (main)	24.5	7.4	burrows	47	200
Cording Is, NW islet (inner)	1.6	7.7	burrows	2	2
Cording Is, '28 spot height'	4.3	8.5	burrows	3	3
Single Tree Island	0.3	6.9	burrows, feathers	230	330
Total	1,609.5	-		4,700	23,425

4, Fig. 3). Most burrows were under tall forest on island summits and spurs.

No live sooty shearwaters were seen in burrows or on the ground, but one was heard calling from a burrow at night on western main island of the Small Craft Harbour Islands on 24 November 2017, and several were calling from Single Tree Island on the night of 21 November (heard from offshore). Sooty shearwaters were common north-west of Chalky Inlet as we travelled from and to Dusky Sound on 20 & 25 November, but were not seen within the fjords during the daytime. At night while spotlighting, many sooty shearwaters were seen in flight off Chalky Island on 22 November and at least one bird in Small Craft Harbour on 24 November (Table 2).

Other petrel species

Three further petrel species were observed and captured during the spot-lighting session off Chalky Island on 22 November 2017 (Table 2). Two of these species, common diving petrel (*Pelecanoides urinatrix*) and grey-backed storm petrel (*Garrodia nereis*) are known or likely to breed nearby (Appendix 2; Miskelly, Stahl & Tennyson 2017). The nearest known breeding site for common diving petrel is on the Green Islets, 27 km south-east of Chalky Island (Appendix 2). The storm petrel and one of the two diving petrels had bare brood patches indicative of birds incubating or brooding. The Antarctic prion (*Pachyptila desolata*) and the second diving petrel had downy brood patches. Additional sightings of grey-backed storm petrels were made during spot-lighting sessions off Only Island in Long Sound and the Small Craft Harbour Islands at the entrance to Cunaris Sound (Table 2).

Two diving petrels were seen off the entrance to Preservation Inlet during the day on 20 November 2017. Subantarctic skua (*Catharacta antarctica*) prey remains on the Green Islets on 15 December 2018 included a broad-billed prion (on the largest islet south of the headland to the west), a Cook's petrel (*Pterodroma cookii*), and three common diving petrels, but it is likely that some of these birds were caught at sea.

Spatial segregation of petrel breeding colonies in southern Fiordland

The 2016 and 2017 surveys between them located 95 breeding colonies of three petrel species on 83 islands in southern Fiordland (data herein and in Miskelly, Tennyson *et al.* 2017, plus unpublished data for four additional sites between Dusky Sound and Breaksea Sound surveyed in November 2017 held by the authors). Apart from two petrel species found breeding on each of 12 islands, the three species for the most part were found as single-species colonies on separate islands that can be categorised for each species based on island size and distance from the open sea (Fig. 4).

Sooty shearwaters bred mainly on medium to large islands (1–1,000 ha) within 15 km of the open sea. Mottled petrels were found mainly on very small islands (less than a hectare) up to 27 km from the sea, with nine colonies more than 20 km from the sea. Broad-billed prions were mainly found on very small steep-sided stacks (less than 0.3 ha) within 5 km of the open sea, with most sites on the exposed outer coast or receiving no shelter from other islands. Low numbers of sooty shearwaters were often found among larger colonies of the two other species, but mottled petrels and broad-billed prions were not found breeding on the same island.

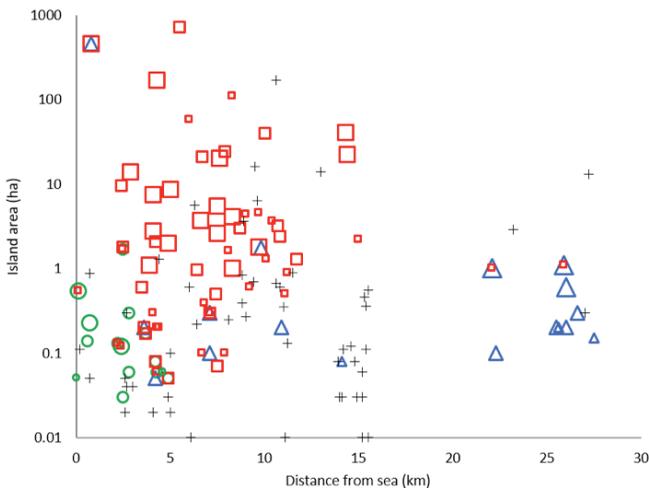


Figure 4. Segregation of breeding colonies of three species of petrels on 133 islands in southern Fiordland (from Breaksea Sound south to Preservation Inlet) based on island size (log scale ha) and distance from the open sea. Red squares = sooty shearwater; green circles = broad-billed prion; blue triangles = mottled petrel; black crosses = islands surveyed without breeding petrels being found. Symbol sizes are proportional to colony size: small symbols = 1 to 90 burrows; medium symbols = 100 to 900 burrows; large symbols = 1,000 to 9,000 burrows.

Testing the 'refugia from resident stoats' hypothesis

The 2016 Dusky Sound survey revealed that breeding populations of migratory petrels (mottled petrel and sooty shearwater) had persisted on more than 40 islands that were less than 100 ha in size despite all but one island ('Centre Island') considered likely to have been invaded by stoats on one or more occasion (Fig. 5A). No evidence was found of petrels persisting on larger islands in Dusky Sound that have (or had) resident stoat populations (Miskelly, Tennyson *et al.* 2017). A similar pattern was found in the 2017 survey of islands in Chalky and Preservation Inlets, with colonies of migratory petrels found on about 34 islands <170 ha and within swimming range of stoats (Fig. 5B). Stoats have been observed or trapped, or their scats and prey remains found, on at least 11 of these small to medium-sized petrel breeding islands, including Zero Nugget and

Finger Rock off Chalky Island (Kim Morrison *pers. comm.* to CMM 15 November 2018), three of the Small Craft Harbour Islands, south Passage Island, three of the Cording Islands, Steep-to Island and Weka or Long Island (King & Murphy 2005; Veale *et al.* 2012; Lindsay Wilson *pers. comm.* to CMM 19 Mar 2019; authors *pers. obs.*). However, in contrast to Dusky Sound, migratory petrels were found breeding on two large islands (>400 ha) in Chalky Inlet that have (or had) resident stoats: Great Island and Chalky Island, with sooty shearwaters also breeding on 2 ha Spit Island, which is attached to the South Island mainland. These three islands lie along the Y-axis in Fig. 5B (and see Table 4 for island areas). We do not consider south Passage Island (168 ha) to have had a resident stoat population, as only a single animal was caught there during trapping concurrent with the 1999 Chalky Island eradication programme (Murray Willans *pers. comm.* to CMM, 4 February 2019).

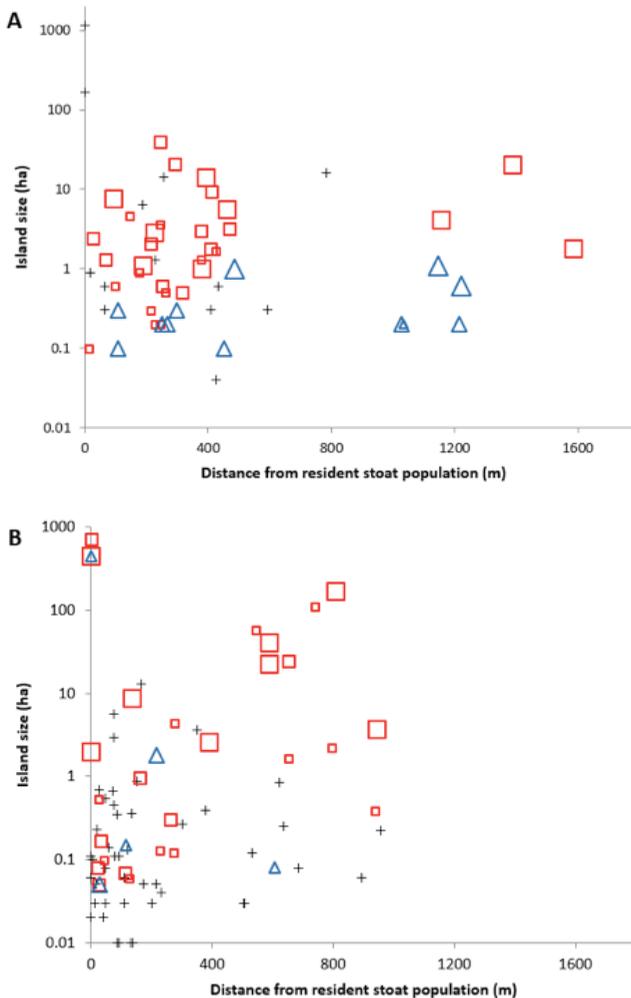


Figure 5. A. Sizes of sooty shearwater and mottled petrel colonies in Dusky Sound in relation to island size (log scale ha) and the minimum distance that stoats would have to swim from the nearest resident stoat population (including sites from which stoats have been eradicated). B. Comparative data for the same two species from islands in Chalky and Preservation Inlets. Red squares = sooty shearwater; blue triangles = mottled petrel; black crosses = islands surveyed without breeding petrels being found. Symbol sizes are proportional to colony size: small symbols = 1 to 90 burrows; medium symbols = 100 to 900 burrows; large symbols = 1,000 to 5,000 burrows.

DISCUSSION

Regional and national significance of Chalky and Preservation Inlet petrel colonies

The main finding of the 2017 survey was that Chalky and Preservation Inlets had many more, and far larger, petrel colonies than is evident in published accounts. Sooty shearwaters and broad-billed prions, in particular, are far more abundant there than indicated by recent reviews. Waugh *et al.* (2013) reported two known sooty shearwater colonies in Chalky Inlet, based on an old egg reported by McLean *et al.* (1993), and 500 burrows reported on Chalky Island (D. Scott in Newman *et al.* 2009). Jamieson *et al.* (2016) reported a single record of broad-billed prions breeding at an unspecified site in Chalky Inlet based on a 1986 report that this species was found “breeding in Breaksea Sd, Dusky Sd, and Chalky Inlet” (K. Morrison in Gaze 1988). Miskelly, Tennyson *et al.* (2017) reported 14 petrel colonies from Chalky and Preservation Inlets (10 sooty shearwater, 2 mottled petrel, 2 broad-billed prion), but did not provide colony sizes for any of them. The 40 breeding colonies found in 2017 therefore represent an almost threefold increase in the number of reported colonies, and a first estimate of colony size (based on burrow counts and estimates) for all but one of these sites.

The 23,425 sooty shearwater burrows estimated on 26 islands in Chalky and Preservation Inlets is similar in magnitude to the 21,400 burrows estimated on islands in Dusky Sound (Miskelly, Tennyson *et al.* 2017). When combined with the additional 16 breeding sites reported between Milford and Breaksea Sounds (Waugh *et al.* 2013; Miskelly, Tennyson *et al.* 2017), it is likely that up to 50,000 pairs of sooty shearwaters breed in Fiordland. Although much larger than other known populations north of Foveaux Strait, the combined Fiordland sooty shearwater population is far smaller than individual colonies on Whenua Hou/Codfish Island, Taukihepa/Big South Cape Island, Putauhinu Island, Poutama Island, and Snares Islands/Tini Heke to the south, all of which exceed 170,000 pairs or burrows (Lyver 2000; Newman *et al.* 2009; Waugh *et al.* 2013).

The 1,240 mottled petrel burrows estimated on five islands in Chalky and Preservation Inlets is considerably fewer than the 5,500 burrows estimated on 12 islands in Dusky Sound (Miskelly, Tennyson *et al.* 2017). Larger colonies of this New Zealand endemic species (of 10,000–160,000 pairs) have been reported from Whenua Hou/Codfish Island, Taukihepa/Big South Cape Island, and Snares Islands/Tini Heke (Warham *et al.* 1977; Scott *et al.* 2009; Miskelly *et al.* 2019).

In contrast to the two larger petrel species, the broad-billed prion colonies in Chalky Inlet are far larger than those reported elsewhere in

Fiordland. We estimated 9,700 burrows at 8 sites in Chalky Inlet, compared to 240 burrows (1 site) in Preservation Inlet and 560 burrows (2 sites) in Dusky Sound (data presented herein and in Miskelly, Tennyson *et al.* 2017). Several broad-billed prion colonies have been reported from islets in Breaksea Sound and off the west coast of Resolution Island, but little information is available on the size of these colonies (Taylor 2000b; Jamieson *et al.* 2016; Miskelly, Tennyson *et al.* 2017). Sizes of New Zealand prion colonies are poorly known, however, Chalky Inlet holds the second largest reported broad-billed prion population, after the 340,000+ pairs reported from the Chatham Islands (West & Nilsson 1994; Jamieson *et al.* 2016).

Grey-backed storm petrels in Fiordland

The capture of a grey-backed storm petrel with a bare brood patch offshore from Chalky Island on 22 November, along with sightings of birds at two other widely-spread spotlighting locations, adds to the body of evidence that this species breeds in Fiordland (Miskelly, Stahl & Tennyson 2017). Although no breeding grounds have yet been found, records of grey-backed storm petrels continue to accumulate throughout Fiordland. In addition to the minimum of 16 records summarised by Miskelly, Stahl & Tennyson (2017) and the three records reported here, there were at least two further reports during 2017–18. A grey-backed storm petrel flew on to a vessel at the head of Broughton Arm, Breaksea Sound, on the night of 17–18 August 2017 (Fraser Goldsmith record and image on eBird <https://ebird.org/newzealand/view/checklist/S38900677>; viewed 24 January 2019), and one was found dead (stoat-killed) above Routeburn Falls hut, Routeburn Track on 22 December 2018 (CMM *pers obs.*).

Fiordland is more than 480 km from the nearest known breeding site for grey-backed storm petrel (Auckland Islands). When combined with the complete absence of records of any other storm petrel species from Fiordland, these numerous records indicate that grey-backed storm petrels are predictably present in the region, rather than being vagrants from a distant population.

The impact of stoats on Chalky and Preservation Inlet petrel colonies

Interpreting the current distribution and sizes of petrel colonies in southern Fiordland is challenging in the absence of historical data on their distribution, and the timing of predator colonisation events. In addition to stoats, other introduced predators are likely to have had a role in petrel colony declines and extinctions. Within Dusky Sound, extinction of the enormous broad-billed prion colony

reported by Captain Cook on Anchor Island has been attributed to predation by Norway rats (*Rattus norvegicus*), as the prions disappeared before stoats reached western Fiordland (Medway 2011; Miskelly, Tennyson *et al.* 2017). However, stoats are far more capable swimmers than other predatory mammals present in Fiordland (Russell *et al.* 2008; Veale *et al.* 2012), and it is the only species present that is able to colonise the majority of islands without human assistance.

Several features of petrel behaviour and breeding ecology render them highly vulnerable to stoat predation, including burrow-nesting, low-breeding output (a maximum of one chick per pair per annum) and colonial nesting (Moors & Atkinson 1984; Warham 1996). The persistence of petrel colonies on islands that have been accessible to stoats for more than a century is counter-intuitive, unless stoats have been present too briefly and infrequently to kill all birds associated with a colony, or the petrel colonies are large enough for predation to have an insignificant impact on colony viability (Cuthbert 2002; Peck *et al.* 2008; Miskelly, Tennyson *et al.* 2017).

The 'refugia from resident stoats' hypothesis was proposed to explain the persistence of petrel colonies on islands in Dusky Sound that were within swimming range of stoats but which were too small to sustain resident stoat populations (Miskelly, Tennyson *et al.* 2017). A crucial parameter in the hypothesis is the minimum island size that can support a resident stoat population through provision of a year-round food supply. This island size remains unclear, and may require several years of monitoring or detailed genetic analysis of stoats to determine. Female stoats are pregnant almost continuously throughout their lives (including from the time juveniles leave the den), and produce an average of 8–10 kits (King & Murphy 2005). A single female stoat that reaches an island can therefore result in the impression that a substantial stoat population is present, if a survey or eradication attempt is undertaken soon after she has reached the island and given birth.

Six stoats were caught on 40 ha Parrot Island between 2001 and 2005 (Elliott *et al.* 2010), and Veale *et al.* (2012) reported eight stoats caught on 57 ha Motuoruhi Island in a short space of time, but were these animals resident? The near absence of stoats on 168 ha south Passage Island during the 1999 'eradication' (with only a single animal caught) points to stoats requiring the resources of islands in excess of 170 ha in order to persist in southern Fiordland. The Passage Islands are presumed to have been 'stepping stone' islands used by stoats to colonise Chalky Island, and a second stoat was trapped on south Passage Island in 2017 (C. Bishop *unpubl. data*).

The 'refugia from resident stoats' hypothesis is

based on the assumption that petrels are unable to persist on (large) islands or South Island mainland sites with resident stoats, as the petrels will be exposed to stoat predation every breeding season until the colony is extirpated. This was suggested as the reason why petrels were apparently absent from the larger islands in Dusky Sound while persisting on nearby small islands (Miskelly, Tennyson *et al.* 2017). However, within Chalky and Preservation Inlets, petrel colonies were detected on at least three islands that have (or had) resident stoats: Great Island, Chalky Island, and Spit Island (this last 'island' is attached to the South Island mainland) – indicating that the hypothesis is invalid or requires further refinement based on the carrying capacity of each site for stoats when the seabirds are absent (Peck *et al.* 2008). The presence or absence of rat populations as an alternative prey will likely affect stoat persistence. However, apart from the presence of Norway rats on six of the Cording Islands (Lindsay Wilson *pers. comm.* to CMM 19 Mar 2019), we have found little information on rodent distribution on islands in Chalky and Preservation Inlets.

There are a few sites on the South Island mainland where petrel colonies have persisted in the presence of stoats, including sooty shearwaters in Otago and Hutton's shearwaters (*Puffinus huttoni*) in the Seaward Kaikoura mountains. Stoats were the main predators present at both sites. However, at the largest Hutton's shearwater colony, the more than 100,000 pairs present were able to produce sufficient young each year to more than offset losses due to predation by the small number of resident stoats, despite stoats killing *c.* 12% of chicks per annum plus 0.25% of adults (Cuthbert & Davis 2002). In contrast, small mainland colonies of both shearwater species suffered higher predation rates and lower breeding success than this one large colony, and were declining in the absence of effective stoat control (Lyver *et al.* 2000; Cuthbert 2002). The few sooty shearwater colonies that survived on the Otago coast are the dwindling remnants of formerly much larger colonies exposed to multiple threats, and protection of adults, eggs and young chicks from predators is crucial if these small mainland colonies are to persist (Hamilton 1998; Lyver *et al.* 2000; Cuthbert 2002).

Cuthbert (2002) reported inverse density-dependent stoat predation at South Island mainland shearwater colonies, meaning that large colonies suffered relatively less predation (in terms of the proportion of adults and chicks killed) than small colonies. He suggested a threshold of 600 pairs, above which colonies should not decline in the face of stoat predation alone. However, if other factors (e.g. habitat disturbance or predation by other species) impact on colony viability, stoat predation may contribute to and accelerate colony decline. We did not estimate burrow occupancy during our

rapid survey, but it is likely that the eight largest sooty shearwater colonies found each held more than 600 pairs. These included Chalky Island and Spit Island where the birds were or are exposed to predation by resident stoats. The persistence of the small sooty shearwater colony on Great Island colony (estimated at 200 burrows only) in the presence of resident stoats is difficult to explain unless it is the remnant of a much larger colony, or the colony is sustained by immigration from nearby colonies, as proposed for Yelkouan shearwaters (*Puffinus yelkouan*) (see Bonnaud *et al.* 2009). This colony will have received some protection from stoat predation for the last 20 years or so as trap lines are maintained on Great Island to reduce the risk of stoats reaching the Passage Islands and Chalky Island.

Prions are more vulnerable to stoats than the two migratory petrel species, as they are not only smaller, but they visit colonies throughout the year and so transient stoats that reach prion breeding sites may persist longer than at sites where migratory petrels (e.g. sooty shearwater and mottled petrel) are absent for 3–4 months in winter (Miskelly, Tennyson *et al.* 2017). Broad-billed prion colonies in Fiordland have become confined to tiny stacks on the exposed outer coast, where extreme wave action is presumed to provide protection from stoat invasion. While the number of colonies and the number of birds surviving in Fiordland is substantially higher than reported by Jamieson *et al.* (2016), the colonies so far located in Fiordland are still far too small to have been the main source of the estimated 200,000 broad-billed prions killed in a storm in July 2011 (Tennyson & Miskelly 2011; Jamieson *et al.* 2016). The largest known broad-billed prion colony on Rangatira Island in the Chatham Islands was not impacted by this mortality event (authors *unpubl. data*), and the origin of these birds remains a mystery.

ACKNOWLEDGEMENTS

The November 2017 survey was organised and funded by the Department of Conservation, with Te Papa contributing staff time and air travel costs. The team was based on the DOC vessel M.V. *Southern Winds*; we thank crew members Chris Pascoe and Pete Kirkman for their expert seamanship getting us safely on and off so many islands, and Terry Green, Lawrie Mead and Riki Parata for assisting with the island surveys. Susan Waugh and Dafna Gilad (Te Papa) assisted with figure preparation. Thanks also to Kim Morrison for providing information about his 1986 survey of islets off Chalky Island, to Rebecca Jackson, Ben Barr, James Reardon, and Dylan van Winkel for information from the 2018 survey of the Green Islets, and to Murray Willans and Lindsay Wilson

for information on stoats on islands in Chalky and Preservation Inlets. This manuscript was greatly improved following comments received from James Russell and an anonymous referee.

LITERATURE CITED

- Bonnaud, E.; Bourgeois, K.; Vidal, E.; Legrand, J.; Le Corre, M. 2009. How can the Yelkouan shearwater survive feral cat predation? A meta-population structure as a solution? *Population Ecology* 51: 261–270.
- Buller, W.L. 1892. Further notes and observations on certain species of New Zealand birds (with exhibits). *Transactions of the New Zealand Institute* 24: 75–91.
- Cooper, W. 1986. Southland [Regional Roundup]. *OSNZ News* 41: 6.
- Cuthbert, R.J. 2002. The role of introduced mammals and inverse density dependent predation in the conservation of Hutton's shearwater. *Biological Conservation* 108: 67–78.
- Cuthbert, R.J.; Davis, L.S. 2002. The impact of predation by introduced stoats on Hutton's shearwaters. *Biological Conservation* 108: 79–92.
- Department of Conservation 2017. *Conserving Fiordland's biodiversity 1987–2015; the challenges, the achievements, the knowledge*. Ti Tiaki i te Taiao ki Tu Rua o te moko; ng wero, ng haum uiui, ng m tauranga. Te Anau, Department of Conservation. 128 pp.
- Elliott, G.; Willans, M.; Edmonds, H.; Crouchley, D. 2010. Stoat invasion, eradication and reinvasion of islands in Fiordland. *New Zealand Journal of Zoology* 37: 1–12.
- Gaze, P.D. (compiler) 1988. Classified summarised notes, South Island 1 July 1986 to 30 June 1987. *Notornis* 35: 311–323.
- Hamilton, S. 1998. Determining burrow occupancy, fledgling success and land-based threats to mainland and near-shore sooty shearwater (*Puffinus griseus*) colonies. *New Zealand Journal of Zoology* 25: 443–453.
- Hill, S.; Hill, J. 1987. *Richard Henry of Resolution Island*. Dunedin: John McIndoe in association with the New Zealand Wildlife Service.
- Jamieson, S.E.; Tennyson, A.J.D.; Wilson, K.-J.; Crotty, E.; Miskelly, C.M.; Taylor, G.A.; Waugh, S.M. 2016. A review of the distribution and size of prion (*Pachyptila* spp.) colonies throughout New Zealand. *Tuhinga* 27: 56–80.
- King, C.M.; Murphy, E.C. 2005. Stoat *Mustela erminea* Linnaeus, 1758. Pp. 261–287 in: King, C.M. (ed.) *The handbook of New Zealand mammals*. 2nd edn. Melbourne, Oxford University Press.
- Lyver, P.O'B. 2000. Sooty shearwater (*Puffinus griseus*) harvest intensity and selectivity on Poutama Island, New Zealand. *New Zealand Journal of Ecology* 24: 169–180.

- Lyver, P.O.B.; Moller, H.; Robertson, C.J.R. 2000. Predation at sooty shearwater *Puffinus griseus* colonies on the New Zealand mainland: is there safety in numbers? *Pacific Conservation Biology* 5: 347–357.
- Marchant, S.; Higgins, P.J. (eds) 1990. *Handbook of Australian, New Zealand and Antarctic birds*. Vol. 1, part A (Ratites to petrels). Melbourne, Oxford University Press.
- McEwen, M.W. (ed.) 1987. *Ecological Regions and Districts of New Zealand*. 3rd revised edition in four 1:500,000 maps. Booklet to accompany sheet 4. New Zealand Biological Resources Centre Publ. No. 5, part 4. Wellington, Department of Conservation.
- McLean, I.G.; Studholme, B.J.S.; Russ, R.B. 1993. The Fiordland crested penguin survey, stage III: Breaksea Island, Chalky and Preservation Inlets. *Notornis* 40: 85–94.
- Medway, D.G. 2011. The broad-billed prion (*Pachyptila vittata*) nesting colonies recorded during Cook's visit to Dusky Sound in 1773. *Notornis* 58: 165–168.
- Miskelly, C.M.; Bishop, C.R.; Greene, T.C.; Tennyson, A.J.D. 2018. Dispersal of translocated endemic passerines to nearby islands in Chalky and Preservation Inlets, southern Fiordland, New Zealand. *Notornis* 65: 239–241.
- Miskelly, C.M.; Gilad, D.; Taylor, G.A.; Tennyson, A.J.D.; Waugh, S.M. 2019. A review of the distribution and size of gadfly petrel (*Pterodroma spp.*) colonies throughout New Zealand. *Tuhinga* 30: 93–171.
- Miskelly, C.M.; Powlesland, R.G. 2013. Conservation translocations of New Zealand birds, 1863–2012. *Notornis* 60: 3–28.
- Miskelly, C.M.; Stahl, J.-C.; Tennyson, A.J.D. 2017. Do grey-backed storm petrels (*Garrodia nereis*) breed in Fiordland, New Zealand? *Notornis* 64: 109–114.
- Miskelly, C.M.; Tennyson, A.J.D.; Stahl, J.-C.; Smart, A.F.; Edmonds, H.K.; McMurtrie, P.G. 2017. Breeding petrels of Dusky Sound, Fiordland – survivors of a century of stoat invasions. *Notornis* 64: 136–153.
- Moors, P.J.; Atkinson, A.E. 1984. Predation on seabirds by animals, and factors affecting its severity. Pp 667–690 in Croxall, J.P.; Evans, P.G.H.; Schreiber, R.W. (eds) *Status and conservation of the world's seabirds*. International Council for Bird Preservation (ICBP) Technical publication No. 2. Cambridge, UK, ICBP.
- Morrison, K.; Morrison, J. 1982. Fiordland bird notes. *OSNZ News* 22: 1.
- Newman, J.; Scott, D.; Bragg, C.; McKechnie, S.; Moller, H.; Fletcher, D. 2009. Estimating regional population size and annual harvest intensity of the sooty shearwater in New Zealand. *New Zealand Journal of Zoology* 36: 307–323.
- Peat, N.; Patrick, B. 1996. *Wild Fiordland; discovering the natural history of a world heritage area*. Dunedin, University of Otago Press.
- Peck, D.R.; Faulquier, L.; Pinet, P.; Jaquemet, S.; Le Corre, M. 2008. Feral cat diet and impact on sooty terns at Juan de Nova Island, Mozambique Channel. *Animal Conservation* 11: 65–74.
- Russell, J.C.; Towns, D.R.; Clout, M.N. 2008. *Review of rat invasion biology; implications for island biosecurity*. Science for conservation 286. Wellington, Department of Conservation. 54 pp.
- Scott, D.; Moller, H.; Fletcher, D.; Newman, J.; Aryal, J.; Bragg, C.; Charleton, K. 2009. Predictive habitat modelling to estimate petrel breeding colony sizes: sooty shearwaters (*Puffinus griseus*) and mottled petrels (*Pterodroma inexpectata*) on Whenua Hou Island. *New Zealand Journal of Zoology* 36: 291–306.
- Taylor, G.A. 2000a. Action plan for seabird conservation in New Zealand. Part A: threatened seabirds. *Threatened Species occasional publication* 16. Wellington, Department of Conservation.
- Taylor, G.A. 2000b. Action plan for seabird conservation in New Zealand. Part B: non-threatened seabirds. *Threatened Species occasional publication* 17. Wellington, Department of Conservation.
- Tennyson, A.J.D.; Miskelly, C.M. 2011. An unprecedented prion wreck. *Southern Bird* 47: 11.
- Veale, A.J.; Hannaford, O.D.; Russell, J.C.; Clout, M.N. 2012. Modelling the distribution of stoats on New Zealand offshore islands. *New Zealand Journal of Ecology* 36: 38–47.
- Warham, J. 1996. *The behaviour, population biology and physiology of the petrels*. London, Academic Press.
- Warham, J.; Keeley, B.R.; Wilson, G.J. 1977. Breeding of the mottled petrel. *Auk* 94: 1–17.
- Warham, J.; Wilson, G.J.; Keeley, B.R. 1982. The annual cycle of the sooty shearwater *Puffinus griseus* at the Snares Islands, New Zealand. *Notornis* 29: 269–292.
- Waugh, S.M.; Tennyson, A.J.D.; Taylor, G.A.; Wilson, K.-J. 2013. Population sizes of shearwaters (*Puffinus spp.*) breeding in New Zealand, with recommendations for monitoring. *Tuhinga* 24: 159–204.
- West, J.A.; Nilsson, R.J. 1994. Habitat use and burrow densities of burrow-nesting seabirds on South East Island, Chatham Islands, New Zealand. *Notornis (supplement)* 41: 27–37.
- Wildland Consultants; Department of Conservation 2016. *Tamatea/Dusky Sound conservation and restoration plan*. Department of Conservation. 155 pp. <http://www.doc.govt.nz/Documents/our-work/dusky-sound-restoration-plan.pdf>

Appendix 1. Island locations and search effort. Full names of water bodies = Cunaris Sound, Chalky Inlet, Preservation Inlet, Isthmus Sound, and Long Sound. 'Petrels' refers to whether evidence of petrels breeding was recorded in November or December 2017 (see Tables 1, 3 & 4). 'Trap' refers to whether at least one stoat trap was maintained on the island at the time of our visit. Note that many islands receive protection by being adjacent to islands that are trapped. 'Time' is the approximate length of time (in minutes or hours:minutes) that observers were ashore.

Island name	Water body	Latitude S	Longitude E	Petrels	Trap	Date	Observers	Day/Night	Time
Cliff Cove islet	Cunaris Sd	45.9620°	166.7508°	No	No	25-Nov	AT, CB, CM, GT, LM, RP & TG	Day	30
Cunaris sw islet (inner)	Cunaris Sd	45.9732°	166.6661°	No	No	25-Nov	CB	Day	15
Cunaris sw islet (middle)	Cunaris Sd	45.9734°	166.6653°	No	No	25-Nov	TG	Day	15
Cunaris sw islet (outer)	Cunaris Sd	45.9758°	166.6566°	No	No	25-Nov	CB & TG	Day	15
Small Craft Harbour Is main west	Chalky Inlet	45.9674°	166.6412°	Yes	Yes	24-Nov	AT, CM, GT, LM & RP	Day + night	3:15
Small Craft Harbour Is main east	Chalky Inlet	45.9686°	166.6483°	Yes	Yes	24-Nov	CB, LM, RP & TG	Day	1:15
Small Craft Hbr Is NE island	Chalky Inlet	45.9663°	166.6564°	Yes	Yes	24-Nov	GT, LM & RP	Day	55
Small Craft Hbr Is NE islet	Chalky Inlet	45.9648°	166.6569°	No	No	24-Nov	AT & CM	Day	20
Small Craft Hbr Is SW islet	Chalky Inlet	45.9704°	166.6395°	No	Yes	24-Nov	CB & LM	Day	25
Small Craft Hbr Is middle islet	Chalky Inlet	45.9702°	166.6441°	Yes	No	24-Nov	AT, CB, CM, GT & TG	Day + night	2:20
Small Craft Hbr Is SE islet 1	Chalky Inlet	45.9727°	166.6474°	No	No	25-Nov	AT	Day	15
Small Craft Hbr Is SE islet 2	Chalky Inlet	45.9725°	166.6484°	No	Yes	25-Nov	CM	Day	15
Small Craft Hbr Is east islet	Chalky Inlet	45.9713°	166.6580°	No	Yes	25-Nov	AT & CM	Day	15
Little Island (east islet)	Chalky Inlet	45.9716°	166.5963°	No	No	25-Nov	AT & GT	Day	30
Little Island (middle tiny islet)	Chalky Inlet	45.9714°	166.5949°	No	No	25-Nov	CM	Day	5
Little Island – northern peninsula	Chalky Inlet	45.9719°	166.5932°	No	No	25-Nov	CB & LM	Day	30
Little Island (west islet)	Chalky Inlet	45.9722°	166.5891°	No	No	25-Nov	CM, RP & TG	Day	25
Great Island	Chalky Inlet	45.9935°	166.5609°	Yes	Yes	19-Dec	CB	Day	9:00
Stripe Head – north-east islet	Chalky Inlet	46.0179°	166.6024°	Yes	No	24-Nov	CB, LM & TG	Day	10
Stripe Head – south-west islet	Chalky Inlet	46.0221°	166.6005°	Yes	No	24-Nov	AT, GT & RP	Day	30
Garden Island (outer or little)	Chalky Inlet	46.0287°	166.5900°	Yes	No	24-Nov	AT, CB, CM, GT, LM, RP & TG	Day	50
Garden Island (main)	Chalky Inlet	46.0327°	166.5934°	No	No	24-Nov	AT, CB, CM, GT, LM, RP & TG	Day	1:05
Garden Island (islet NW of main)	Chalky Inlet	46.0310°	166.5905°	No	No	24-Nov	CM & TG	Day	5
Passage Island (north)	Chalky Inlet	46.0161°	166.5429°	Yes	Yes	23-Nov	AT, CB, CM, GT, LM, RP & TG	Day	1:35
Passage Island (south or main)	Chalky Inlet	46.0238°	166.5386°	Yes	Yes	24-Nov	AT, CB, CM, GT, LM, RP & TG	Day	2:00

Appendix 1. cont.

Island name	Water body	Latitude S	Longitude E	Petrels	Trap	Date	Observers	Day/Night	Time
Passage Island sth coast stack 7	Chalky Inlet	46.0276°	166.5297°	Yes	No	23-Nov	AT, CM & LM	Day	1:05
Passage Island sth coast stack 6	Chalky Inlet	46.0309°	166.5349°	No	No	23-Nov	AT & LM	Day	15
Passage Island sth coast stack 5	Chalky Inlet	46.0310°	166.5364°	Yes	No	23-Nov	CM	Day	40
Passage Island sth coast stack 4	Chalky Inlet	46.0328°	166.5413°	Yes	No	23-Nov	AT & LM	Day	50
Passage Island sth coast stack 3	Chalky Inlet	46.0330°	166.5425°	Yes	No	23-Nov	CM	Day	15
Passage Island sth coast stack 1	Chalky Inlet	46.0323°	166.5462°	Yes	No	23-Nov	AT & LM	Day	10
Chalky Island	Chalky Inlet	46.0491°	166.5233°	Yes	Yes	23-Nov	AT, CB, CM, GT, LM, RP & TG	Day	3:45
Zero Nugget (main)	Chalky Inlet	46.0345°	166.5194°	Yes	No	23-Nov	AT, RP & TG	Day	1:25
Zero Nugget (eastern)	Chalky Inlet	46.0345°	166.5194°	Yes	No	23-Nov	CB & LM	Day	20
Finger Rock (inner)	Chalky Inlet	46.0345°	166.5194°	Yes	No	23-Nov	CB & LM	Day	10
Finger Rock (tall stack)	Chalky Inlet	46.0345°	166.5194°	Yes	No	23-Nov	CM	Day	45
'Outer anisotome islet'	Chalky Inlet	46.0345°	166.5194°	No	No	22-Nov	RP & TG	Day	20
'Inner anisotome islet'	Chalky Inlet	46.0345°	166.5194°	No	No	22-Nov	CB & LM	Day	15
'Hebe pyramid'	Chalky Inlet	46.0345°	166.5194°	Yes	No	22-Nov	AT & CM	Day	1:10
'Riki Rock'	Chalky Inlet	46.0345°	166.5194°	Yes	No	22-Nov	CB, LM & RP	Day	55
Gulches Head stack	Preservation	46.0904°	166.5686°	No	No	22-Nov	AT & CM	Day	30
Spit Islands	Preservation	46.0722°	166.6296°	Yes	No	22-Nov	CB, GT, LM, RP & TG	Day	1:05
Nthn stack west of Cavern Head	Preservation	46.0767°	166.6391°	No	No	22-Nov	AT	Day	55
Sthn stack west of Cavern Head	Preservation	46.0786°	166.6400°	Yes	No	22-Nov	CM	Day	55
Cavern Head headland	Preservation	46.0830°	166.6457°	No	No	22-Nov	AT & CM	Day	40
Steepest to Island	Preservation	46.0973°	166.6651°	Yes	Yes	22-Nov	AT, CB, CM, GT, LM, RP & TG	Day	2:00
Weka or Long Island	Preservation	46.0949°	166.6961°	Yes	Yes	22-Nov	AT, CB, CM, GT, LM, RP & TG	Day	2:05
Cemetery Island	Preservation	46.1037°	166.7099°	No	No	20-Nov	AT, CB, CM, GT, LM, RP & TG	Day	35
Round Island	Preservation	46.0869°	166.6826°	Yes	Yes	22-Nov	AT, CB, CM, CP, GT, LM, PK, RP & TG	Day	1:30
Cording Islands, main	Preservation	46.0737°	166.6796°	Yes	Yes	21-Nov	CB, GT, LM & RP	Day	2:05
Cording Is, outer	Preservation	46.0788°	166.6651°	Yes	Yes	21-Nov	AT, CM & TG	Day	1:15
Cording Is, outer (SW islet)	Preservation	46.0793°	166.6630°	No	No	21-Nov	AT, CM & TG	Day	20

Appendix 1. cont.

Island name	Water body	Latitude S	Longitude E	Petrels	Trap	Date	Observers	Day/Night	Time
Cording Is, outer (NW islet)	Preservation	46.0771°	166.6670°	Yes	No	21-Nov	AT, CM & TG	Day	30
Cording Is, NW islet (inner)	Preservation	46.0701°	166.6814°	Yes	No	21-Nov	CM & TG	Day	20
Cording Is, NW islet (outer)	Preservation	46.0690°	166.6804°	No	Yes	21-Nov	AT	Day	20
Cording Is, eastern islet	Preservation	46.0753°	166.6939°	No	No	21-Nov	AT, CB, CM, GT, LM, RP & TG	Day	30
Cording Is, '35 spot height'	Preservation	46.0702°	166.6932°	Yes	Yes	21-Nov	AT, GT, LM & RP	Day	55
Cording Is, islet SW of '35'	Preservation	46.0716°	166.6918°	No	No	21-Nov	CM & TG	Day	10
Cording Is, '28 spot height'	Preservation	46.0668°	166.6912°	Yes	No	21-Nov	CB, CM & TG	Day	40
Cording Is, islet SE of '28'	Preservation	46.0680°	166.6928°	No	No	21-Nov	CB, CM & TG	Day	15
Single Tree Island	Preservation	46.0656°	166.6623°	Yes	Yes	21-Nov	AT, CB, CM, GT, LM, RP & TG	Day	20
Isthmus Sound Islet	Isthmus Sd	46.0525°	166.6902°	Yes	No	21-Nov	AT, CB, CM, GT, LM, RP & TG	Day	1:10
Jane Coves – southern islet	Long Sound	46.0260°	166.7535°	No	No	20-Nov	CB, LM & TG	Day	20
Jane Coves – middle tiny islet	Long Sound	46.0259°	166.7517°	No	No	20-Nov	CB, LM & TG	Day	10
Jane Coves – main islet	Long Sound	46.0204°	166.7479°	No	No	20-Nov	AT, CM, GT & RP	Day	30
Lady Bay main islet	Long Sound	46.0153°	166.7340°	No	No	20-Nov	AT, GT, LM & RP	Day	30
Lady Bay SE inner tiny islet	Long Sound	46.0170°	166.7395°	No	No	20-Nov	CB, CM & TG	Day	10
Lady Bay SE outer tiny islet	Long Sound	46.0170°	166.7400°	No	No	20-Nov	CB, CM & TG	Day	10
Lady Bay northeast islet	Long Sound	46.0146°	166.7406°	No	No	20-Nov	CB, CM & TG	Day	15
Only Island	Long Sound	45.9603°	166.8716°	No	No	21-Nov	AT, CM, LM, RP & TG	Day	1:35
'Only islet'	Long Sound	45.9600°	166.8764°	Yes	No	21-Nov	CB & GT	Day	50

Appendix 2. Seabird survey data from five vegetated islets within the Green Islets, off the southern Fiordland coast west of Big River. Surveys were undertaken by Colin Bishop, Lindsay Wilson, Brian Rance, and Rose Collen on 13 December 2013, and by Rebecca Jackson, Lynn Adams, Ben Barr, Andrew Legault, Jo Monks, James Reardon, and Dylan van Winkel on 15 December 2018.

Islet	Latitude S	Longitude E	Date	Seabird evidence	Burrow count or density
Attached to mainland	46.2275°	166.7879°	13 Dec 2013	Sooty shearwater burrows, fresh broken egg, corpse	c. 40 burrows, 3 in 9m ²
Inner islet	46.2262°	166.7915°	13 Dec 2013	Common diving petrel burrows, adults and downy chicks Sooty shearwater burrows, adults on eggs	11 burrows in 9m ² Sparse on main ridge
Outer – north	46.2260°	166.7985°	13 Dec 2013	Common diving petrel burrows, adults and downy chicks Sooty shearwater burrows with adults Southern skua – 3 adults	28 burrows in 9m ² Higher density than on the inner islet
Outer – central	46.2270°	166.7984°	15 Dec 2018	Common diving petrel burrows, skeletal remains Southern skua fledgling	
Outer – south-east	46.2292°	166.8035°	15 Dec 2018	Common diving petrel burrows, chick	