

# Breeding petrels of Breaksea and Dusky Sounds, Fiordland; responses to three decades of predator control

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**Abstract:** Twenty-four breeding colonies of three petrel species were found on 18 of 26 islands surveyed in Breaksea Sound/Te Puaitaha, Fiordland National Park, New Zealand, in November 2017 and December 2019. All vegetated islands within Breaksea Sound were surveyed, along with 20 islands in Dusky Sound/Tamatea that were not included in an initial survey in November 2016 (eight of these additional Dusky Sound islands had breeding petrels, including three with broad-billed prions *Pachyptila vittata*). Sooty shearwater (*Ardenna grisea*) was the most widespread and abundant species in Breaksea Sound, with an estimated 6,950 burrows on 14 islands, while broad-billed prions were breeding on seven islands (2,100 burrows estimated). We record the first evidence of mottled petrels (*Pterodroma inexpectata*) breeding in Breaksea Sound, which is now their northernmost breeding location. Burrow occupancy rates were not assessed for any of the species. Most of the islands in Breaksea Sound had previously been surveyed during 1974 to 1986, before Norway rats (*Rattus norvegicus*) were eradicated from Hāwea and Breaksea Islands, and stoats (*Mustela erminea*) controlled to near zero density on Resolution Island and adjacent islands (including the inner Gilbert Islands and Entry Island). Following pest mammal control or eradication, broad-billed prions have colonised at least four additional sites. Sooty shearwaters were found at five sites in Breaksea Sound where they had not been recorded in 1980–83, and at one site they had increased by more than 50-fold since rat eradication. When combined with data from the 2016 and 2017 surveys, more than 75,700 petrel burrows are estimated to be present in southern Fiordland.

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**Key words:** Breaksea Island; breeding; colony; Fiordland; petrel; predation; prion; rat; seabird; shearwater; stoat

## INTRODUCTION

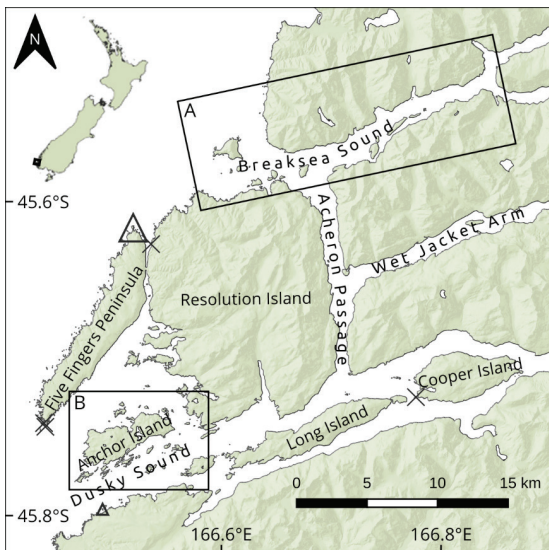
Breaksea Island/Te Au Moana (170 ha) and nearby Hāwea Island (9 ha) in outer Breaksea Sound/

Te Puaitaha, Fiordland, were among the first sites in New Zealand where rats were successfully eradicated, in 1988 and 1986 respectively (Taylor & Thomas 1989, 1993). The presence of Norway rats (*Rattus norvegicus*) on these two islands up until their eradication indicates that Breaksea and

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Hāwea Islands were among the few islands in Fiordland that were not reached by stoats (*Mustela erminea*) (Taylor & Tilley 1984). Stoats apparently extirpated Norway rats on 20,887 ha Resolution Island/Tau Moana and the numerous islands off its north coast (Fig. 1; and see Taylor 1978 and Miskelly *et al.* 2017a). Following control of stoats to almost zero density on Resolution Island since 2008 (Edge *et al.* 2011), all the islands in Breaksea Sound west of (and including) Entry Island are now effectively free of predatory mammals. Stoats were eradicated from Anchor Island in Dusky Sound in 2001 (Elliott *et al.* 2010; Edge *et al.* 2011), resulting in all the smaller islands surrounding Anchor Island being free of all introduced mammal species since then (Wildland Consultants & DOC 2016; Department of Conservation 2017).



**Figure 1.** Breaksea and Dusky Sounds, Fiordland, showing the locations of the more detailed maps that follow (A = Breaksea Sound, B = Anchor Island and surrounding islands), and petrel colony data for six islands lying outside these two core study areas. Symbol sizes denote colony size, with the large triangle showing a site with an estimated 3,000 broad-billed prion burrows and 60 sooty shearwater burrows, and the small triangle a site with an estimated 600 broad-billed prion burrows and at least one sooty shearwater burrow. Crosses show four islands visited with no evidence of breeding petrels being found.

Before these pioneering rat and stoat eradication efforts were initiated, ecological surveys were undertaken on most islands in Breaksea Sound, to determine the distribution of pest mammals and their impacts on native fauna. The surveys were undertaken between 1974 and 1986 by Fiordland National Park staff and scientists from Ecology

Division, Department of Scientific and Industrial Research (DSIR), and were summarised in a series of unpublished reports (Morrison 1975, 1982, 1983, 1984; Thomas 1975; Taylor *et al.* 1986) and island survey forms held by the Te Anau Department of Conservation (DOC) office. Information on burrow-nesting petrels contained in the reports was summarised in Appendix 2 of Miskelly *et al.* (2017b). These reports provide an invaluable benchmark for assessing changes in the distribution and abundance of burrow-nesting petrels (and other fauna) since predatory mammals were eradicated.

Two species of burrow-nesting petrels were known to breed on islands in Breaksea Sound, with sooty shearwaters (*Ardenna grisea*) on at least seven islands, and broad-billed prions (*Pachyptila vittata*) on two islands and attempting to colonise a third (Taylor 2000; Jamieson *et al.* 2016; Miskelly *et al.* 2017b). In March 1986, Norway rats caused complete failure of sooty shearwater breeding attempts assessed on Breaksea and Hāwea Islands, and they preyed on broad-billed prions attempting to colonise Hāwea Island (Taylor & Thomas 1989; Taylor 2000). Stoats killed large numbers of adult prions at colonies they could reach (Bruce Thomas quoted in Taylor 2000). Our 2019 survey provided the first opportunity to assess how these seabird populations had responded to rat eradication, and to search for evidence of them expanding onto nearby islands where they have been protected from rat predation since 1986 or 1988, and stoat predation since 2008.

## METHODS

A boat-based survey of islands in Breaksea Sound/Te Puaitaha (45.59°S, 166.67°E), Fiordland National Park, south-west New Zealand, was undertaken between 9 and 12 December 2019, with a primary focus of locating petrel breeding colonies and estimating their size. The team then shifted to nearby Dusky Sound/Tamatea (45.77°S, 166.55°E) 12–14 December and surveyed islands that had not been included in a previous survey of 59 islands there in November 2016 (Miskelly *et al.* 2017b). Information from three additional islands in Dusky Sound, an islet off the outer coast of Resolution Island, and an islet just north of Breaksea Sound was collected on 25 and 26 November 2017, on the way back from a similar survey in Chalky Inlet/Taiari and Preservation Inlet/Rakituma to the south (Miskelly *et al.* 2019a).

The timing of the three surveys was chosen to maximise the chance of locating the three petrel species known to breed in Fiordland (sooty shearwater, broad-billed prion, and mottled petrel *Pterodroma inexpectata*). Other petrel species that could potentially breed in Fiordland (including

fairy prion *Pachyptila turtur*, common diving petrel *Pelecanoides urinatrix*, and grey-backed storm petrel *Garrodia nereis*) would also be attending breeding colonies at this time of year if present (Marchant & Higgins 1990; Miskelly *et al.* 2019a). For the 2019 survey, priority was given to islands where rats had been eradicated or stoats controlled, and sites where breeding petrels had been reported previously.

Landings were made from a small inflatable dinghy, with 2–8 team members landing on each island for between 5 min and 5 h 10 min (mean = 60 min; Appendix 1). Forty-nine islands (additional to the 2016 survey) were landed on and surveyed for the presence of burrow-nesting petrels. Few of the islands had individual names on available maps and charts (where most are named as clusters of islands), and so we created names/numbers for them, usually numbering islands in each cluster from west to east. A central latitude and longitude reference point for each island is provided in Appendix 1, along with the reference number for each island used by DOC, from a GIS database of 713 islands in Dusky and Breaksea Sounds created by Wildlands Consultants (see Wildland Consultants & DOC 2016).

Island areas were obtained from the DOC GIS database. Distance from the sea for each seabird breeding colony was estimated from Google Earth, as a straight-line distance from the nearest portion of a line between outer headlands at the fiord entrance. Where multiple colonies occurred on large islands, this measurement was estimated for the most seaward colony detected.

Information on predator control history, effort, and trapping results on islands in Dusky Sound was provided by Pete McMurtrie (DOC, Te Anau). There are currently 4,971 'DOC 150' stoat traps set in Breaksea and Dusky Sounds (3,571 on Resolution Island), which are checked 3 times per annum.

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. Where we found burrows to be confined to a portion of the island, we estimated the proportion of the colony (rather than the entire island) that we surveyed. Only burrows that appeared to be in use were included in counts, and the limited time spent on each island meant that we were unable to obtain estimates of burrow occupancy (e.g. through use of a burrowscope; Parker & Rexer-Huber 2020). The exclusion of 'disused' burrows that were filled with leaf litter or covered with cobwebs may have meant that some active burrows were overlooked; however, none of the three petrel species recorded breeding on Fiordland islands are known to

deliberately conceal or block burrow entrances.

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, feathers, or failed eggs on the colony surface; burrow location, and burrow entrance size. Any intact eggs were measured (length x maximum width; to the nearest 0.1 mm, using Vernier callipers) as a guide to species identification (cf. measurements in Marchant & Higgins 1990). The few mottled petrel burrows found were identified by their 'medium' size (about 10–12 cm wide), and white droppings at two of the three sites (prion droppings are typically stained pink by carotenoids and undigested carapaces from their crustacean diet).

Data on petrel breeding sites from 1974–1986 island survey reports held by the DOC Te Anau office are summarised where relevant in the tables and text.

Taxonomy and nomenclature follow Gill *et al.* (2010), apart from where we follow Heidrech *et al.* (1998) in referring sooty shearwater to the genus *Ardenna*.

## RESULTS

Evidence of breeding petrels was found on 18 islands in or near Breaksea Sound, on one islet off the outer coast of Resolution Island, and on eight additional islands in Dusky Sound that were not included in the 2016 survey. These 27 breeding islands ranged in size from 0.1 to 153 ha, and were up to 16 km from the open sea (Tables 1–3, Figs 1–5).

### Sooty shearwater (*Ardenna grisea*)

The sooty shearwater was the most widespread and abundant breeding petrel in both Breaksea Sound and Dusky Sound, with an estimated 6,950 burrows on 14 islands in Breaksea Sound and an additional 790 burrows at eight previously unsurveyed sites in Dusky Sound (Table 1). Burrows were found mainly under forest on ridges and spurs facing the sea, or close to sea level (but still under forest).

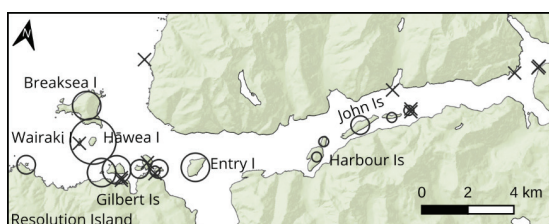
The largest colonies in Breaksea Sound were on Hāwea and Breaksea Islands (5,400 and 800 burrows estimated respectively), with more than 100 burrows estimated to be present on each of Entry Island and two of the inner Gilbert Islands. Sooty shearwaters had been recorded at all five of these sites between 1974 and 1986 (Table 1), but at that time their breeding success was close to zero in the presence of Norway rats on Hāwea and Breaksea Islands (G. Taylor, *pers. obs.*, Apr 1986).

The largest sooty shearwater colonies were within 5 km of the entrance to Breaksea Sound, with a few isolated burrows up to 15 km from the open

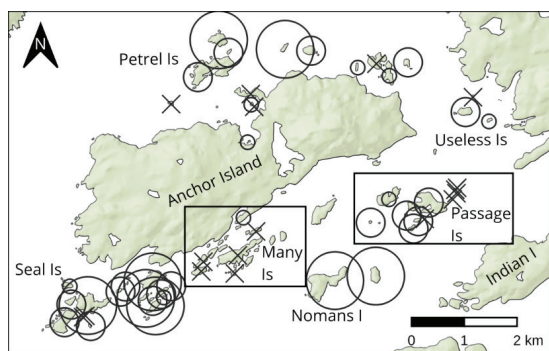


sea (Table 1, Fig. 2). The five easternmost sites were new breeding locations, but only 1–4 burrows were found at each of these sites. ‘North-west Resolution islet’ was also a new breeding location, with 40 burrows estimated to be present (Table 1).

Within Dusky Sound, we did not find petrel burrows on any of the inner Many Islands (close to Luncheon Cove on the south coast of Anchor Island), but there were 200 and 500 sooty shearwater burrows estimated on two islets south of Passage Island (Table 1, Fig. 3). We did not find sooty shearwater burrows on three islets north-east of Passage Island [islets 6 to 8], where a few active burrows were found on each islet on 8 Nov 1986 (Kim Morrison, *pers. comm.* to CMM, 21 Jan 2020).



**Figure 2.** Distribution of known sooty shearwater colonies within Breaksea Sound (see Fig. 1 for broader location). Circle sizes denote colony size, with the very large circle showing the estimated 5,400 burrows on Hāwea Island, large circles 130–800 burrows, and medium circles 20–75 burrows estimated. Small circles denote sites with fewer than four burrows found. Crosses show islands visited with no evidence of sooty shearwaters being found.



**Figure 3.** Distribution of known sooty shearwater colonies on and around Anchor Island, Dusky Sound (see Fig. 1 for broader location). The two rectangles enclose sites surveyed in 2019, with the remaining sites surveyed in 2016 (see Fig. 4 in Miskelly *et al.* 2017b). Circle sizes denote colony size, with large circles showing colonies with 1,000–2,500 burrows, medium circles 10–400 burrows, and small circles 1–5 burrows estimated. Crosses show islands visited with no evidence of sooty shearwaters being found.

### Broad-billed prion (*Pachyptila vittata*)

Broad-billed prions, or evidence of their presence, were found at seven sites in or near Breaksea Sound, on one islet off the outer coast of Resolution Island, and on three additional islets in Dusky Sound (Table 2, and Figs 1, 4 & 5). All 11 sites occupied by broad-billed prions in 2017 and 2019 had been surveyed during 1981–86, with prions recorded at seven of the sites (Table 2). The four new sites were all within 4.5 km of known breeding locations on Wairaki Island and ‘Inner Gilbert 1’, with the new colonies on the south-eastern point of Breaksea Island and the western end of ‘Inner Gilbert 2’ being only 200–600 m from known colonies. All the Breaksea Sound colonies were within 3.5 km of the open sea (Table 2, Fig. 4). Colonies were under shrubs (*Veronica elliptica*, *Dracophyllum longifolium*, or *Olearia oporina*), often under a dense ground cover of *Asplenium obtusatum* fern.

Broad-billed prions were listed as a breeding species on Hāwea Island (in the presence of Norway rats) by Taylor & Thomas (1989), but the evidence for their presence was a few pairs attempting to colonise ‘The Hump’ (an islet just off the south-west coast). We estimated 1,200 burrows to be present on Hāwea Island in December 2019, 33 years after rats were eradicated.

Broad-billed prion chicks were found on two small islets south-west of Passage Island, Dusky Sound, in December 1986 (Kim Morrison, *pers. comm.* to CMM, 15 Nov 2018). We confirmed their ongoing presence at both sites in December 2019, with corpses of fledglings found on both islets (Table 2, Fig. 5).

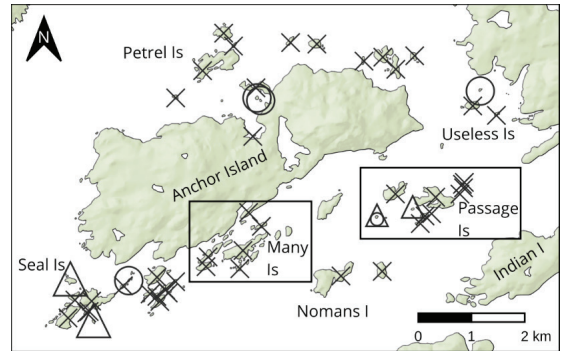
### Mottled petrel (*Pterodroma inexpectata*)

We found active burrows believed to be of mottled petrels on three islands in Breaksea Sound, 4–16 km from the open sea (Table 3, Fig. 4). Burrows were under podocarp/southern rātā (*Metrosideros umbellata*) forest, close to the shore. We did not observe live birds, corpses, feathers or eggs at any of the sites, and so were unable to confirm the presence of mottled petrels.

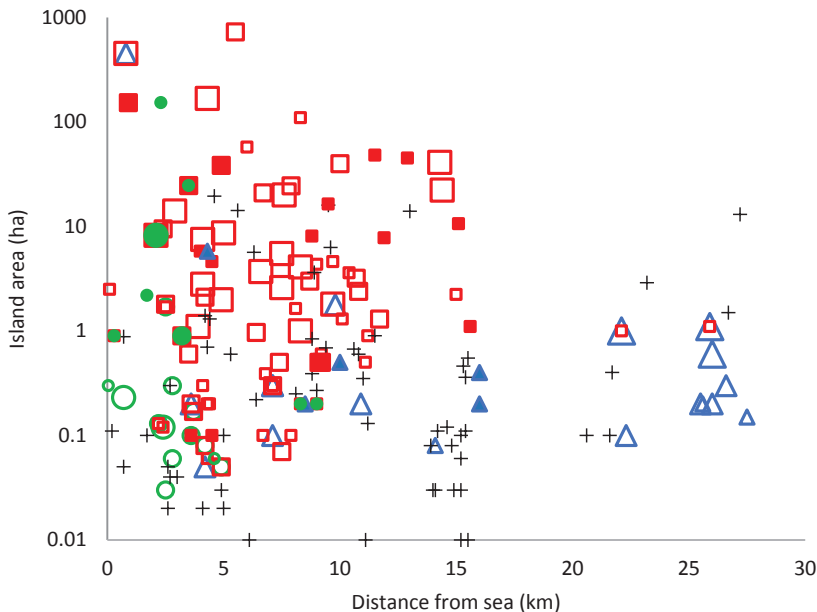
At least four medium-sized burrows and the distinctive vermiculated ventral feathers of mottled petrels were found on ‘Passage Islet 1’ in Dusky Sound (Table 3, Fig. 5). This is the only site in Fiordland where three species of petrels have been found breeding sympatrically (and the first site in Fiordland where mottled petrels and broad-billed prions have been found together).



**Figure 4.** Distribution of broad-billed prion colonies (triangles) and mottled petrel colonies (circles) surveyed in Breaksea Sound in 2019 (see Fig. 1 for broader location). For broad-billed prion, triangle sizes denote colony size, with the large triangle showing the estimated 1,200 burrows on Hāwea Island, medium triangles showing colonies with 90–700 burrows, and small triangles 10–50 burrows estimated. The three mottled petrel sites each had 5–25 burrows estimated. Crosses show islands visited with no evidence of either species being found.



**Figure 5.** Distribution of broad-billed prion colonies (triangles) and mottled petrel colonies (circles) on and around Anchor Island, Dusky Sound (see Fig. 1 for broader location). The two rectangles enclose sites surveyed in 2019, with the remaining sites surveyed in 2016 (see Fig. 1 in Miskelly *et al.* 2017b). Symbol sizes denote estimated colony sizes. For broad-billed prions, large triangles show colonies with 160–400 burrows, and small triangles show two colonies both with 35 burrows estimated. For mottled petrels, large circles show colonies with 100–700 burrows, and the small circle a site with 10 burrows estimated. Crosses show islands visited with no evidence of either species being found.



**Figure 6.** Segregation of breeding colonies of three species of petrels on 176 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: large symbols = 1,000 to 9,000 burrows; medium symbols = 100 to 900 burrows; small symbols = 1 to 90 burrows. Solid symbols show petrel colonies surveyed in 2019 (these are superimposed on 2016 & 2017 data, as presented in Fig. 4 in Miskelly *et al.* 2019a).

**Table 1.** Evidence for sooty shearwater presence on islands in Breaksea Sound in December 2019 and Dusky Sound in November 2017 and December 2019, with the estimated number of burrows on each island. ID ISLAND is the Department of Conservation Dusky + Breaksea Sound island database reference no. for each island. See Appendix 1 for island locations and search effort.

Island name	Water body	ID ISLAND	Area (ha)	Distance from sea (km)	Evidence	Count	Estimate	1974–1986
Roof-top stack	Breaksea	699	0.3	0	not found	0	0	active burrows, Oct 1981
Breaksea I	Breaksea	5	152.9	0.9	burrows, adult on egg	199	800	many burrows, Feb 1984
Hāwea I	Breaksea	13	8.2	2.1	burrows, adults on eggs	270	5,400	40–100 burrows, Apr 1986
NW Resolution islet	Breaksea	661	0.9	0.3	burrows, adult on egg	18	40	not recorded, Oct 1981
Inner Gilbert 1	Breaksea	666	0.6	3.2	burrows, 4 eggs, adult	0.5/m <sup>2</sup>	200	6 chicks banded, Apr 1986
Inner Gilbert 2	Breaksea	110	24.7	3.5	burrows, adult & eggs	129	250	burrows present, Dec 1974
Inner Gilbert 5	Breaksea	111	5.8	4.0	burrows, adult confirmed	6	25	a few burrows, Dec 1974
Inner Gilbert 7	Breaksea	112	4.6	4.5	burrows, fresh egg, adult calling	18	75	burrows present, Dec 1974
Inner Gilbert 7 SW islet	Breaksea	part112	0.1	4.5	burrow	1	1	no data
Entry Island	Breaksea	27	38.5	4.9	burrows, droppings	43	130	a few burrows, Mar 1979
Harbour Is (large)	Breaksea	102	48.2	11.5	burrows	3	3+	not recorded, Feb 1983
Harbour Is (small)	Breaksea	103	7.8	11.9	burrow	1	1+	not recorded, Sep 1985
John Islands (large)	Breaksea	100	45.1	12.9	burrows	4	20	not recorded, Feb 1983
John Islands (small)	Breaksea	101	10.6	15.1	burrows at east end	3	3	not recorded, Oct 1981
John Islet (west)	Breaksea	701	1.1	15.6	burrow	1	1+	not recorded, Oct 1981
Five Finger Pen. stack	Outer coast	619	2.5	0	burrows, adult on egg	3	60	not recorded, Dec 1986
Luncheon Cove pen., Anchor I	Dusky	21	1136.6	6.1	burrow, calls from 2 sites at night	1	1+	not recorded
Prove Island	Dusky	11	8.1	8.8	burrow	1	1+	not recorded, Dec 1986
Passage Island	Dusky	71	16.4	9.5	burrows	10	20	not recorded, Sep 1985
Passage Islet 1	Dusky	323	0.2	8.3	burrows, dead fledgling, droppings	17	35	1 chick, 100+ burrows, Dec 1986
Passage Islet 2	Dusky	70	0.2	9.0	burrows; 2 corpses, feathers	35	35	1 chick, burrows, Dec 1986
Passage Islet 3	Dusky	69	0.7	9.2	burrows, egg, droppings, feathers	143	200	no data
Passage Islet 4	Dusky	68	0.8	9.1	burrows, warm egg, adult in burrow	248	500	no data
Passage Islet 6	Dusky	no no.	0.2	10.0	2 inactive burrows	0	0	a few burrows, Nov 1986
South Dusky stack	Dusky	253	0.6	3.6	burrow and skull	1	1+	not recorded, Dec 1986

**Table 2.** Evidence for broad-billed prion presence on islands in Breaksea Sound in December 2019 and Dusky Sound in November 2017 and December 2019, with the estimated number of burrows on each island. ID ISLAND is the Department of Conservation Dusky + Breaksea Sound island database reference no. for each island. See Appendix 1 for island locations and search effort.

Island name	Water body	ID ISLAND	Area (ha)	Distance from sea (km)	Evidence	Count	Estimate	1974–1986
Roof-top stack	Breaksea	699	0.3	0	burrows, 2 chicks, falcon kill	16	25	not recorded Oct 1981
Breaksea Island	Breaksea	5	152.9	2.3	burrows, 5 with white feathers	50	50+	not recorded 1974–1986
Wairaki Island	Breaksea	12	2.2	1.7	burrows, 1 chick	4	20	c.50 burrows, Apr 1986
Hāwea Island	Breaksea	13	8.2	2.1	burrows, feathers, down, feather scale	60	1,200	4 adults banded, Apr 1986; 19 burrows in use, Dec 1986
NW Resolution islet	Breaksea	661	0.9	0.3	burrows, chick, falcon kill	45	90	not recorded Oct 1981
Inner Gilbert 1	Breaksea	666	0.9	3.2	burrows, 2 chicks	0.5/m <sup>2</sup>	700	abundant, Apr 1986
Inner Gilbert 2	Breaksea	110	24.7	3.5	white feathers and down	10	10+	not recorded 1974–1983
Five Finger Pen. stack	Outer coast	619	2.5	0	burrows, 4 chicks, falcon kill	151	3,000	1 chick, burrows common, Dec 1986
Passage Islet 1	Dusky	323	0.2	8.3	burrows, dead fledgling, droppings	17	35	1 chick, 100+ burrows, Dec 1986
Passage Islet 2	Dusky	70	0.2	9.0	burrows; 2 corpses, feathers	35	35	1 chick, burrows, Dec 1986
South Dusky stack	Dusky	253	0.6	3.6	burrows, chicks, skull	177	600	1 chick & 3 eggs, Dec 1986

**Table 3.** Evidence for mottled petrel presence on islands in Breaksea Sound and Dusky Sound in December 2019, with the estimated number of burrows on each island. ID ISLAND is the Department of Conservation Dusky + Breaksea Sound island database reference no. for each island. See Appendix 1 for island locations and search effort.

Island name	Water body	ID ISLAND	Area (ha)	Distance from sea (km)	Evidence	Count	Estimate	1974–1986
Inner Gilbert 5	Breaksea	111	5.8	4.3	burrows, dropping	6	25	not recorded, Dec 1974
John Islet (north)	Breaksea	702	0.4	16.0	burrow, dropping	1	<5	not recorded, Oct 1981
John Islet (south)	Breaksea	700	0.2	16.0	burrows	2	8	not recorded, Oct 1981
Passage Islet 1	Dusky	323	0.2	8.5	burrows, feathers	4	10	not recorded, Dec 1986
Passage Islet 6	Dusky	no no.	0.2	10.0	old burrows	3	0	not recorded, Dec 1986
Paget Passage islet	Dusky	420	1.5	0.2	not found	0	0	heard in burrows, May 1980

**Table 4.** Summary of known petrel colonies in coastal Fiordland. A = number of colonies by species and location; B = estimated number of burrows.

A. Islands/colonies	Sooty shearwater	Mottled petrel	Broad-billed prion	Total
Milford to Doubtful	9	0	1	10
Breaksea Sound	14	3	7	24
Outer Resolution	1	0	1	2
Dusky Sound	44	13	5	62
Chalky Inlet	14	3	8	25
Preservation Inlet	11	2	1	14
Total	84	21	22	127

B. Burrows				
Milford to Doubtful	unknown	0	unknown	unknown
Breaksea Sound	6,950	38	2,125	9,113
Outer Resolution	60	0	3,000	3,060
Dusky Sound	22,189	5,510	1,230	28,929
Chalky Inlet	14,979	290	9,700	24,969
Preservation Inlet	8,446	950	240	9,636
Total	52,624	6,788	16,295	75,707

### Status and spatial segregation of petrel breeding colonies in southern Fiordland

The three surveys undertaken between 2016 and 2019 located 127 breeding colonies of three petrel species on 107 islands in southern Fiordland (data herein and in Miskelly *et al.* 2017b & 2019a). The most abundant and widespread species was sooty shearwater, with more than 52,000 burrows estimated, on 84 islands (Table 4). There were an estimated 16,300 broad-billed prion burrows on 22 islands, and *c.* 6,800 mottled petrel burrows on 21 islands (Table 4).

The sooty shearwater colonies surveyed in 2019 had similar physical characteristics to those found in 2016 and 2017, with the larger colonies found on medium to large islands (0.5 to 150 ha) and within 9 km of the open sea (Fig. 6). The mottled petrel colonies found in 2019 were all small in size (<30 burrows), and mainly fitted the pattern found previously, occurring on islands less than a hectare in size and more than 9 km from the open sea (Fig. 6).

Broad-billed prion colonies found in 2016 and 2017 were almost all on tiny islands (less than a hectare) and within 5 km of the open sea. Those found in 2019 included colonies on much larger islands (up to 150 ha) and on two islets that were more than 9 km from the open sea (Table 2, Fig. 6).

### DISCUSSION

#### Regional significance of Breaksea Sound and Dusky Sound petrel colonies

Breaksea Sound holds about 19% of the known petrel colonies in Fiordland and about 12% of the known burrows (Table 4). Dusky Sound has far more islands than the other sounds; partly as a consequence, it holds about 49% of known Fiordland petrel colonies, and about 38% of the known burrows. When combined with islets off the outer coast of Resolution Island, the islands in the interlinked Breaksea and Dusky Sounds hold about 69% of the known petrel colonies in Fiordland, and about 54% of the known burrows (Table 4).

Dusky Sound is the stronghold for mottled petrels within Fiordland, with more than 80% of the known burrows. In contrast, Chalky Inlet is currently the Fiordland stronghold for broad-billed prions (60% of known burrows), while sooty shearwaters are more evenly distributed throughout (Table 4).

#### National significance of Fiordland petrel colonies

As recently as 2016, Fiordland was considered a region where almost nothing was known about breeding petrel numbers and distribution (Taylor 2000; Waugh *et al.* 2013; Jamieson *et al.* 2016; Wildland Consultants & Department of Conservation



2016). While estimates of burrow numbers are not yet available for at least ten Fiordland petrel colonies north of Breaksea Sound (Table 4), it is now apparent that Fiordland holds substantial populations of three petrel species (Miskelly *et al.* 2017b, 2019a, Table 4 herein). All three species have wider breeding distributions, including on islands around Stewart Island and at the Snares Islands/Tini Heke (Waugh *et al.* 2013; Jamieson *et al.* 2016; Miskelly *et al.* 2019b).

It is not possible to convert our burrow counts and estimates into breeding population estimates as we did not attempt to estimate rates of burrow occupancy. However, the burrow estimates reported here provide an 'order of magnitude' guide to the importance of Fiordland for breeding petrels. Both sooty shearwater and mottled petrel have much larger populations south of Foveaux Strait. Several of the larger sooty shearwater colonies exceed the entire known Fiordland population: colonies on Whenua Hou/Codfish Island, Taukihepa/Big South Cape Island, Putauhinu Island, Poutama Island, and the Snares Islands all exceed 170,000 pairs or burrows (Lyver 2000; Newman *et al.* 2009; Waugh *et al.* 2013). Similarly, at least three more southern mottled petrel colonies (of 10,000–160,000 pairs each, on Whenua Hou/Codfish Island, Taukihepa/Big South Cape Island, and Snares Islands) all exceed the entire known Fiordland population (Warham *et al.* 1977; Scott *et al.* 2009; Miskelly *et al.* 2019b).

Broad-billed prion colony sizes on islands around Stewart Island/Rakiura remain poorly known (Taylor 2000; Jamieson *et al.* 2016), with the largest known New Zealand colony (340,000+ pairs) reported from Rangatira Island in the Chatham Islands (West & Nilsson 1994). Fiordland holds the next-largest reported colony (7,500 burrows estimated on an islet in Chalky Inlet; Miskelly *et al.* 2019a), but it is likely that other larger colonies are as yet unreported or under-estimated, either in Fiordland or around Stewart Island. An estimated 200,000 broad-billed prions were killed during a storm in July 2011, which apparently did not impact the Rangatira Island colony (Tennyson & Miskelly 2011; Jamieson *et al.* 2016). This implies that the birds that died were from colonies in Fiordland, around Stewart Island, and/or at the Snares Islands, and yet none of these colonies individually or collectively are known to be large enough to contribute more than a tiny proportion to mortality of this magnitude.

Although relatively small compared to the vast colonies found elsewhere, Fiordland petrel colonies have considerable historical, ecological, and conservation significance. Anchor Island in Dusky Sound is considered the type locality for the broad-billed prion, which was the first New Zealand bird

to be given a binomial name (as *Procellaria vittata* by Forster 1777; see Mathews & Hallstrom 1943 for restriction of the type locality). The four small broad-billed prion colonies surviving on islets around Anchor Island are remnants of the 'innumerable... blue Petrels' (i.e. broad-billed prions) that Captain Cook and his naturalists encountered on Anchor Island and the adjacent Seal Islands in 1773 (Hoare 1982; Medway 2011). Prions and other petrels clearly bred in vast colonies in coastal Fiordland before the introduction of predatory mammals, and would have influenced the structure of vegetation communities through input of marine-sourced nutrients, burrowing activity, trampling, and the transportation of leaf litter and ground vegetation underground as nest lining (Warham 1990; Smith *et al.* 2011). The surviving colonies on small islands throughout Fiordland are therefore microcosms of this pre-human environment, where seabirds play an important role as ecosystem engineers (Smith *et al.* 2011; Ellis *et al.* 2011; Kolb *et al.* 2011), as well as being rare examples of sites where petrels continue to nest under tall podocarp forest. The remaining colonies should also provide source populations for the recolonisation of adjacent larger islands and the mainland if these sites can be cleared of predatory mammals (Wildland Consultants & DOC 2016; Department of Conservation 2017). An additional conservation and potential research benefit of sooty shearwater colonies on islands within Fiordland National Park is that, along with the Snares Islands and Whenua Hou/Codfish Island, they provide sanctuaries where the shearwaters are protected from the annual harvest of their young (as titi/muttonbirds) that occurs at most of their colonies around Stewart Island and in Foveaux Strait (Newman *et al.* 2009).

### Response of petrels to rat and stoat eradications

The most notable finding of the 2019 survey was the discovery of broad-billed prions breeding at sites previously occupied by rats (Breaksea and Hāwea Islands), and at two sites formerly accessible to stoats, where prions had not been found in earlier surveys (Inner Gilbert 2, and islet 661). Prions were attempting to colonise Hāwea Island in the presence of rats before 1986 (Taylor & Thomas 1989; G. Taylor, *pers. obs.*), and a substantial colony estimated at 1,200 burrows had established there 33 years after rat eradication. Hāwea Island is (since 1986) the most likely source for a broad-billed prion colony estimated at 50 pairs on the south-eastern headland of Breaksea Island, about 580 m away. This small colony was discovered 31 years after Norway rats were eradicated from Breaksea Island (Taylor & Thomas 1993). In contrast, the small colony on Wairaki Island (where rats and stoats

were never recorded) had declined from *c.* 50 to *c.* 20 burrows, probably due to crushing of burrows, and vegetation changes caused by a large increase in the local New Zealand fur seal (*Arctocephalus forsteri*) population.

Although more than 100 New Zealand islands have been cleared of rats (Towns *et al.* 2013; Russell & Broome 2016), there are relatively few documented examples of petrels naturally recolonising sites after rat eradication. Examples include: common diving petrels (*Pelecanoides urinatrix*) that recolonised Cuvier Island after Pacific rats/kiore (*Rattus exulans*) were eradicated in 1993 (Jones *et al.* 2011); white-chinned petrels (*Procellaria aequinoctialis*) and grey-backed storm petrels (*Garrodia nereis*) that recolonised Campbell Island within eight years of Norway rats being eradicated (Jones *et al.* 2011); black-winged petrels (*Pterodroma nigripennis*), Kermadec petrels (*Pt. neglecta*), and wedge-tailed shearwaters (*Ardenna pacifica*) that recolonised Raoul Island (Kermadec Islands) within six years of eradication of Norway and Pacific rats (Gaskin 2011; Jones *et al.* 2011), and sooty shearwaters, fluttering shearwaters (*Puffinus gavia*), little shearwaters (*Puffinus assimilis*), common diving petrels, and white-faced storm petrels (*Pelagodroma marina*) that recolonised Burgess Island, Mokohinau Islands within two decades of Pacific rats being eradicated (Ismar *et al.* 2014). Natural recolonisation by petrels is largely dependent on the proximity of the nearest potential source population (Jones *et al.* 2011; Buxton *et al.* 2014). In all these cases (including within Breaksea Sound) source populations existed on rat-free islets within 2 km of sites colonised by petrels after rat eradication.

We are unaware of previous examples of petrels recolonising islands cleared of stoats.

Rat eradication is also expected to lead to increased colony size (and reduced clustering) of remnant petrel colonies that survived the presence of rats (Jones 2010; Buxton *et al.* 2016). This was most apparent on Hāwea Island, where the 40–100 sooty shearwater burrows estimated in April 1986 (G. Taylor *pers. obs.*) had increased more than 50-fold to an estimated 5,400 burrows in 2019. Population modelling indicates that this large increase over the 33 years since rat eradication could potentially have occurred with minimal immigration, provided productivity and survival rates were close to the maximum recorded for petrel populations in the absence of predation (*c.* 50% of eggs producing breeding adults recruiting to their natal population, with 90% of pairs persisting between years; *authors' unpubl. data*). However, we suggest that immigration from other sites in Fiordland or nearby (Newman *et al.* 2009; Miskelly *et al.* 2017b, 2019a) is likely to have contributed to this rapid population increase.

### Habitat use by broad-billed prions in Fiordland

The 2019 survey found broad-billed prions to be breeding on larger islands (Breaksea, Hāwea, and Inner Gilbert 2) and islands further from the sea (Passage islets 1 & 2) than where they were found on during the 2016 and 2017 surveys (Fig. 6). These findings are consistent with previous suggestions that the use of small stacks on the exposed outer coasts of Fiordland as breeding sites by broad-billed prions is an artefact caused by predation by introduced mammals (Norway rats and stoats) at more accessible sites (Miskelly *et al.* 2017b, 2019a). Once this predation pressure is removed, the prions are able to reclaim larger and more inland islands.

At all these sites, broad-billed prions were found breeding under low shrubby coastal vegetation (*Veronica*, *Dracophyllum*, *Olearia*), and have yet to spread into taller podocarp or broadleaved forest (including southern rātā, kāmahī *Weinmannia racemosa*, silver beech *Lophozonia menziesii*, pigeonwood *Hedycarya arborea*, patē *Schefflera digitata*, and kōtukutuku *Fuchsia excorticata*) away from coastal headlands and slopes. Broad-billed prions breed under forest elsewhere in New Zealand, including on Rangitira Island, Chatham Islands (West & Nilsson 1994), and on at least three islands west of Stewart Island (Kundy Island, Rerewhakaupoko/Solomon Island, Whenua Hou/Codfish Island; C. Miskelly & G. Taylor, *pers. obs.*). James Cook (*in* Beaglehole 1961) and Reinhold Forster (*in* Hoare 1982) did not describe the vegetation where prion burrows were found on Anchor Island in 1773, but this is likely to have been under tall forest: 'When we came to the Creek which was on the NW side of Anchor Isle we found their an immense number of Blue Peterls [sic], some on the Wing, others in the Woods, in holes in the ground, under the roots of trees and in the crevices of rocks where they had desposited their young' (Cook *in* Beaglehole 1961: 120). Use of the term 'woods' implies that the prions were nesting under forest, and we expect that broad-billed prions will expand back into forest habitat in Breaksea and Dusky Sounds as the population continues to grow in response to ongoing pest mammal control.

### CONCLUSIONS

There are numerous breeding colonies of three petrel species (sooty shearwater, broad-billed prion, and mottled petrel) on islands in Breaksea Sound and Dusky Sound, Fiordland. Broad-billed prions have recolonised two islands following eradication of Norway rats, and a further two islands following control of stoats to zero density. Sooty shearwaters have similarly colonised or recolonised five islands where stoats are no longer present or are unlikely to visit. The most dramatic response to predator eradication was on 9 ha Hāwea Island, where sooty shearwaters had increased more than 50-fold within

33 years of Norway rats being eradicated.

Broad-billed prions have started to recolonise larger islands, and islands further from exposed outer coasts following eradications of rats and stoats. However, the prions have yet to re-occupy the tall forest habitats where they were apparently breeding when Captain Cook visited Dusky Sound in 1773.

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**APPENDIX 1.** Island locations and search effort. ID ISLAND is the Department of Conservation (DOC) Dusky + Breaksea Sound island database reference no. for each island. ‘Petrels’ refers to whether evidence of petrels breeding was found (see Tables 1–3). ‘Trap’ refers to whether at least 1 stoat trap was maintained on the island by DOC at the time of our visit. Note that many islands receive protection by being adjacent to islands that are trapped. ‘Duration’ is the approximate length of time (hours:minutes) that observers were ashore.

Island name	Water body	ID ISLAND	Lat (S)	Long (E)	Petrel	Trap	Date	Observers	Duration
Roof-top stack	Breaksea Sound	699	45.5567°	166.6666°	Yes	No	26 Nov 17	AT & CM	0:25
Breaksea Island	Breaksea Sound	5	45.5775°	166.6380°	Yes	Yes	11 Dec 19	AT, CB, CM, GT, JR, PC, PL & TG	5:10
Wairaki Island	Breaksea Sound	12	45.5925°	166.6367°	Yes	No	10 Dec 19	AT, CB, CM, PC, PL & TG	1:15
Hawea Island	Breaksea Sound	13	45.5910°	166.6441°	Yes	Yes	10 Dec 19	AT, CB, CM, GT, JR, PC, PL & TG	2:55
North-west Resolution islet	Breaksea Sound	661	45.6035°	166.6089°	Yes	No	25 Nov 17	AT & CM	0:15
North-west Resolution islet	Breaksea Sound	661	45.6035°	166.6089°	Yes	No	12 Dec 19	AT, CB, CM, GT, PC, PL & TG	0:55
Inner Gilbert 1	Breaksea Sound	666	45.6027°	166.6511°	Yes	No	11 Dec 19	CM, GT & PC	2:00
Inner Gilbert 2	Breaksea Sound	110	45.6009°	166.6592°	Yes	Yes	11 Dec 19	AT, CB, JR, PL & TG	2:30
Inner Gilbert 3	Breaksea Sound	665	45.6037°	166.6624°	No	No	11 Dec 19	CB, JR & TG	0:40
Inner Gilbert 4	Breaksea Sound	663	45.6047°	166.6626°	No	No	11 Dec 19	CB, JR & TG	0:35
Inner Gilbert 5	Breaksea Sound	111	45.5994°	166.6718°	Yes	Yes	12 Dec 19	CB, GT & TG	1:48
Inner Gilbert 6	Breaksea Sound	113	45.5965°	166.6757°	No	Yes	12 Dec 19	AT, CB, CM, GT, JR, PL & TG	2:35
Inner Gilbert 7	Breaksea Sound	112	45.5984°	166.6824°	Yes	No	12 Dec 19	AT, CM, JR & PL	1:05
Inner Gilbert 7 (SW islet)	Breaksea Sound	part 112	45.5994°	166.6805°	Yes	Yes	12 Dec 19	CM & PL	0:15
Inner Gilbert 8	Breaksea Sound	668	45.6004°	166.6807°	No	No	12 Dec 19	AT & JR	0:20
Entry Island	Breaksea Sound	27	45.5959°	166.7025°	Yes	Yes	9 Dec 19	AT, CB, CM, GT, JR, PC, PL & TG	2:40
Harbour Islands (large)	Breaksea Sound	102	45.5857°	166.7687°	Yes	No	9 Dec 19	AT, CB, CM, GT, JR, PC, PL & TG	1:20
Harbour Islands (small)	Breaksea Sound	103	45.5794°	166.7715°	Yes	No	9 Dec 19	AT & PL	0:19
John Islands (large)	Breaksea Sound	100	45.5711°	166.7904°	Yes	No	10 Dec 19	AT, CB, CM, GT, JR, PC, PL & TG	1:10
John Islands (small)	Breaksea Sound	101	45.5665°	166.8073°	Yes	No	10 Dec 19	AT, CB, CM, PC, PL & TG	1:42
John Islet (west)	Breaksea Sound	701	45.5629°	166.8162°	Yes	No	10 Dec 19	CM & JR	0:50
John Islet (north)	Breaksea Sound	702	45.5622°	166.8172°	Yes	No	10 Dec 19	GT & PC	0:44
John Islet (south)	Breaksea Sound	700	45.5633°	166.8174°	Yes	No	10 Dec 19	AT & PL	0:40
islet in Second Cove	Breaksea Sound	704	45.5558°	166.8057°	No	No	10 Dec 19	CB & TG	0:07
islet west of Third Cove	Breaksea Sound	710	45.5429°	166.8718°	No	No	10 Dec 19	GT, JR & PC	0:15
large islet opposite Third Cove	Breaksea Sound	709	45.5390°	166.8848°	No	No	10 Dec 19	AT & CM	0:45

Appendix 1. continued

Island name	Water body	ID	ISLAND	Lat (S)	Long (E)	Petrel	Trap	Date	Observers	Duration
small islet opposite Third Cove	Breaksea Sound	708		45.5397°	166.8843°	No	No	10 Dec 19	CB & TG	0:10
Woodhen Cove islet	Outer coast	594		45.6346°	166.5588°	No	No	12 Dec 19	AT, CB & CM	0:10
Five Finger Peninsula stack	Outer coast	619		45.6233°	166.5438°	Yes	No	25 Nov 17	AT, CB, CM, LR & RP	0:50
Inner Finger (Five Fingers)	Dusky Sound	361		45.7435°	166.4481°	No	No	25 Nov 17	CB & LM	0:25
Outer Finger (Five Fingers)	Dusky Sound	353		45.7447°	166.4991°	No	No	25 Nov 17	AT & CM	0:35
South Dusky stack	Dusky Sound	253		45.8011°	166.4952°	Yes	No	25 Nov 17	AT, CB & CM	0:35
Luncheon Cove pen., Anchor I	Dusky Sound	21		45.7657°	166.5231°	Yes	Yes	14 Dec 19	AT, CB, CM, GT, PL & TG	0:35
Many Islands (largest)	Dusky Sound	93		45.7720°	166.5210°	No	No	14 Dec 19	CB, CM, PC & TG	1:10
Many Islands (north-east)	Dusky Sound	98		45.7682°	166.5259°	No	No	14 Dec 19	CB, JR & TG	0:07
Many Islands (west)	Dusky Sound	85		45.7726°	166.5125°	No	No	14 Dec 19	AT & PL	0:30
Many Islands (south-west)	Dusky Sound	78		45.7742°	166.5118°	No	No	14 Dec 19	GT & JR	0:42
Many Islands (south)	Dusky Sound	77		45.7750°	166.5199°	No	No	14 Dec 19	AT & PL	0:45
Prove Island	Dusky Sound	11		45.7646°	166.5588°	Yes	Yes	13 Dec 19	GT, PC & PL	1:10
Passage Island	Dusky Sound	71		45.7657°	166.5684°	Yes	Yes	13 Dec 19	AT, CB, CM, JR & TG	2:37
Passage Islet 1	Dusky Sound	323		45.7683°	166.5539°	Yes	No	13 Dec 19	CM, GT, PC & PL	0:50
Passage Islet 2	Dusky Sound	70		45.7676°	166.5628°	Yes	No	13 Dec 19	AT, CB, JR & TG	0:35
Passage Islet 3	Dusky Sound	69		45.7687°	166.5655°	Yes	No	13 Dec 19	AT, CB, JR & TG	0:45
Passage Islet 4	Dusky Sound	68		45.7699°	166.5642°	Yes	No	13 Dec 19	CM, GT, PC & PL	0:27
Passage Islet 5	Dusky Sound	no no.		45.7684°	166.5671°	No	No	13 Dec 19	AT, CB, JR & TG	0:07
Passage Islet 6	Dusky Sound	no no.		45.7655°	166.5743°	No	No	13 Dec 19	GT, PC & PL	0:40
Passage Islet 7	Dusky Sound	72		45.7639°	166.5751°	No	No	13 Dec 19	AT & CM	0:25
Passage Islet 7a	Dusky Sound	no no.		45.7645°	166.5753°	No	No	13 Dec 19	AT & CM	0:05
Passage Islet 8	Dusky Sound	no no.		45.7636°	166.5756°	No	No	13 Dec 19	AT & CM	0:20
Paget Passage islet	Dusky Sound	420		45.7455°	166.7882°	No	Yes	12 Dec 19	AT, CB, CM & TG	0:50