

Breeding petrels of northern and central Fiordland, with a summary of petrel populations for the Fiordland region

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Abstract: Thirty breeding colonies of three petrel species were found on 23 of 41 islands and one of three headlands surveyed between Milford Sound/Piopiotahi and Dagg Sound/Te Rā in Fiordland National Park, New Zealand, in November 2020. Sooty shearwater (*Ardenna grisea*) was the most widespread and abundant species, with an estimated 7,300 burrows on 20 islands and one mainland site. Broad-billed prions (*Pachyptila vittata*) were found breeding on five islands (600 burrows estimated), including an islet in Poison Bay, 70 km north-east of their previous northernmost Fiordland breeding location. We record the first evidence of mottled petrels (*Pterodroma inexpectata*) breeding in Doubtful Sound/Patea (on Seymour Island), which is now their northernmost breeding location. When combined with data from surveys in southern Fiordland between 2016 and 2021, more than 66,000 pairs of petrels are estimated to be present in 168 colonies in Fiordland. This total comprises 42,100–52,400 sooty shearwater pairs, 11,700–14,500 broad-billed prion pairs, 5,090–6,300 mottled petrel pairs, and at least 1,000 common diving petrel (*Pelecanoides urinatrix*) burrows. This is the first near-complete estimate of petrel population sizes for the Fiordland region.

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INTRODUCTION

Until 2017, there was almost no published information on the identity, distribution, and status of petrels (Procellariidae) breeding in Fiordland, south-western New Zealand (Taylor 2000; Waugh *et al.* 2013; Jamieson *et al.* 2016). This absence of information was the impetus for an initial survey

of petrels on islands in Dusky Sound/Tamatea undertaken by staff from the Museum of New Zealand Te Papa Tongarewa (Te Papa) and the Department of Conservation (DOC) in November 2016 (Miskelly *et al.* 2017a). With support from both institutions, we undertook further surveys of islands in Chalky Inlet/Taiari and Preservation Inlet/Rakituma in November 2017, and Breaksea Sound/Te Puaitaha and Dusky Sound in December 2019 (Miskelly *et al.* 2019a, 2020). We report the

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findings of the fourth and final survey in the series, from Milford Sound/Piopiotaahi south to Dagg Sound/Te Rā, along with a summary of petrel breeding distribution and status in the entire Fiordland region.

Although few Fiordland petrel colony sites were identified in publications before 2017, many others were known by DOC staff and others who had worked in the region. During the 2016 Dusky Sound survey, Pete Young (then skipper of the DOC vessel *Southern Winds*), suggested which islands in the fiord had petrel burrows and could be landed on. He also informed Colin Miskelly and Alan Tennyson of 17 additional Fiordland petrel breeding sites north or south of Dusky Sound, all of which we have managed to confirm in subsequent surveys. The second, and more extensive, source of unpublished information was from surveys undertaken on at least 182 Fiordland islands between 1974 and 1986 by former Fiordland National Park ranger Kim Morrison and his colleagues. While much of this information was summarised in at least 14 internal reports authored by Morrison, few of these reports can be found in archives accessible to the public. Following the formation of DOC in 1987, a trailer-load of Department of Lands & Survey Fiordland National Park files was taken to the Dunedin Archives New Zealand office (Ken Bradley via Jeanette Charteris *pers. comm.* to CMM, 14 March 2017). However, Te Anau DOC biodiversity staff considered the Morrison reports too valuable to send to archives. The reports were removed from the trailer and retained as a working file – unfortunately not registered within DOC's internal filing system. Over the ensuing 30 years, institutional memory of the existence of this file was lost, and the box of precious reports was not relocated until retired DOC staff member Murray Willans returned to the Te Anau DOC office and pointed out where it was sitting on a shelf (Jeanette Charteris *pers. comm.*, 2 May 2017). However, the file was incomplete, with several reports apparently misplaced over the years.

Kim Morrison retired from DOC soon after it was formed, and now lives (without internet connection) in northern Scotland. Fortunately he kept copies of most or all of his reports, along with his personal notebooks. As our surveys progressed through Fiordland, Kim and the British postal service provided us with six substantial bundles of Fiordland island survey information (received between July 2017 and November 2020), comprising 198 hand-written pages, and 162 typed pages and maps from his unpublished reports. Most significant among these was information from the 'Operation Raleigh' survey of 137 islands in Doubtful, Dagg, Breaksea, and Dusky Sounds, undertaken in November and December 1986. This survey was

never written up, due to the turmoil created by DOC's formation (Kim Morrison *pers. comm.* to CMM, 15 November 2018). The data contained in these pages have guided our subsequent surveys, as well as providing historical comparisons with our own data (e.g. Miskelly *et al.* 2020, 2021). As described below, there are only two (small) petrel colonies found in Fiordland during 1974–86 that we were unable to include in the 2016–20 surveys.

METHODS

A boat-based survey of islands and headlands in northern and central Fiordland, Fiordland National Park, south-west New Zealand (Fig. 1), was undertaken 11–17 November 2020, with a primary focus of locating petrel breeding colonies and estimating their size. The northernmost sites surveyed were at the entrance to Milford Sound/Piopiotaahi, and the southernmost were at the entrance to Dagg Sound/Te Rā. Most survey effort was focused on the numerous islands near the entrance to Doubtful Sound/Patea.

The timing of the survey was chosen to maximise the chance of locating the four petrel species known to breed in Fiordland (sooty shearwater *Ardenna grisea*, broad-billed prion *Pachyptila vittata*, mottled petrel *Pterodroma inexpectata*, and common diving petrel *Pelecanoides urinatrix*). Other species that could breed in the region (including fairy prion *Pachyptila turtur* and grey-backed storm petrel *Garrodia nereis*) should also be caring for eggs or chicks in November (Marchant & Higgins 1990; Miskelly *et al.* 2017b).

Landings were made from a small inflatable dinghy, with 1–5 team members landing at each site for between 4 min and 9 h (mean = 50 min, ignoring the single '9 h' outlier; Appendix 1). Forty-one islands and three headlands were surveyed. A central latitude and longitude reference point for each site is provided in Appendix 1.

Petrel burrow entrances were searched for and counted on each island or headland during walk-through surveys. The proportion of each site surveyed was estimated, with the estimated number of burrows based on the actual count extrapolated to allow for areas not surveyed. Where burrows were confined to a portion of an island or headland, we estimated the proportion of the colony that we surveyed (rather than the proportion of the entire island or headland).

The petrel species present were identified by any of: adults or chicks extracted from burrows; vocalisations from birds inside burrows; corpses, feathers, or failed eggs on the colony surface; faecal deposit (dropping) size and colouration; burrow location and burrow entrance size (Miskelly *et al.* 2020).

Island areas were estimated from 'LINZ Island Polygons' (layer ID 50288, updated August 2020), using the GRS80 ellipsoid. Distance from the open sea for each island was estimated from Google Earth, as a straight-line distance from the island or headland surveyed to the nearest portion of a line between outer headlands at the fiord entrance.

Stoats (*Mustela erminea*) and rats (*Rattus* sp.) are known predators of petrels, and are present throughout Fiordland (Department of Conservation 2017). However, predator trapping within the survey region was only being undertaken on islands in Doubtful Sound. There are currently 67 stoat traps set on five islands south and south-east of Secretary Island, which are checked four times per annum (Pete McMurtrie *pers. comm.* to CMM). Note that additional islands in the Shelter Islands in Doubtful Sound receive some protection by being adjacent to islands that are trapped.

Information on petrel breeding sites from the 1974–1986 island survey reports and data provided by Kim Morrison and Pete Young are summarised where relevant in the tables and text. Additional data on petrel presence or absence (and burrow estimates) were gathered by the authors and colleagues (see Acknowledgements) on the Green Islets (east of Preservation Inlet, between Puysegur Point and Big River) on 13 December 2013 (C. Bishop), on 'Motukorure Island' south of Mary Island, Lake Hauroko on 16 December 2019 (A. Tennyson & C. Miskelly), on Secretary Island 18–22 February 2020 (C. Miskelly), on Coal Island, Preservation Inlet on 23–25 February 2020 (C. Miskelly), and on Anchor Island, Dusky Sound, 26 February – 15 March 2021 (C. Miskelly, Appendix 2).

RESULTS

Breeding petrels of northern and central Fiordland

Evidence of breeding petrels was found on 23 islands and one headland between Milford Sound and Dagg Sound. The islands ranged in size from 0.02 to 459 ha, and were from 0 to 13 km from the open sea (Tables 1–3, Figs 1–3).

Sooty shearwater (*Ardenna grisea*)

Sooty shearwater was the most widespread and abundant breeding petrel in northern and central Fiordland, with an estimated 7,209 burrows on 20 islands, and an additional 100 burrows on Saint Anne Point at the southern entrance to Milford Sound (Table 1). Twelve of these colonies were previously unreported (Table 1).

The largest colonies were on an unnamed islet at the southern entrance to Dagg Sound (2,800 burrows estimated) and on Styles Island, Caswell Sound (1,400 burrows estimated). There were an estimated 500 burrows on both Anxiety Island,

Nancy Sound, and western Shelter Island, Doubtful Sound (Table 1).

The largest sooty shearwater colonies were within 3 km of the open sea; however, Seymour Island (with an estimated 80 burrows) is more than 13 km from the entrance to Doubtful Sound (Table 1, Figs 1 & 2).

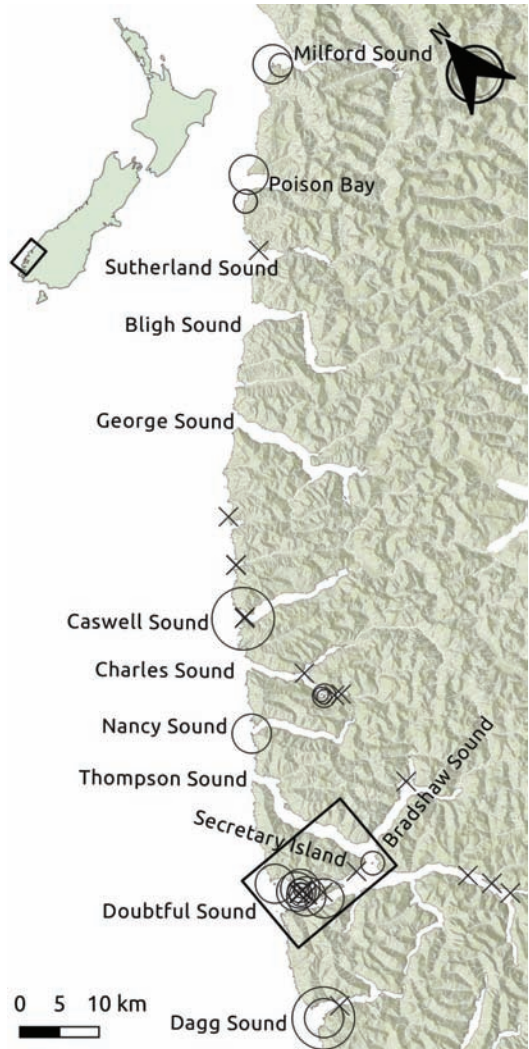


Figure 1. Distribution of sooty shearwater colonies in northern and central Fiordland. Circle sizes denote colony size, with very large circles showing 1,400–2,800 burrows, large circles 100–500 burrows, and medium circles 10–80 burrows estimated. Small circles denote sites with fewer than 6 burrows found. Crosses show islands and headlands visited without evidence of sooty shearwaters being found. The area enclosed in the rectangle is enlarged in Fig. 2.

Table 1. Evidence for sooty shearwater presence on one peninsula and 20 islands between Milford Sound and Dagg Sound in November 2020, with the estimated number of burrows at each site. See Appendix 1 for site locations and search effort. Data for 1975 to 1986 provided by Kim Morrison (*pers. comm.* to CMM).

Site name	Water body	Area (ha)	Distance from sea (km)	Evidence	Count	Estimate	Previous information
St Anne Point	Milford Sound	9.2	0.1	burrows, droppings, corpse	53	100	Reported by Pete Young
Post Office Rock	Milford Sound	0.02	1.2	burrows, droppings, feathers	73	75	Reported by Pete Young
Poison Bay islet	Poison Bay	2.4	0.1	burrows, droppings, feathers	170	200	burrows, Jun 1978
Outer nugget	South of Poison Bay	0.1	0.1	burrows	5	15	no data
Inner nugget	South of Poison Bay	0.2	0.1	burrows, feather	23	50	no data
Styles I	Caswell Sound	12.0	0.4	burrows, droppings, feathers, eggshell	357	1400	Reported by Pete Young
Fanny I	Charles Sound	1.8	10.2	burrow	1	1	no data
Catherine I (main)	Charles Sound	3.0	10.6	burrows	5	10	no data
Catherine I (SW)	Charles Sound	0.5	10.7	burrows	3	3	no data
Anxiety I	Nancy Sound	2.1	0	burrows, 2 adults, 2 eggs	379	500	no data
Nee I	Doubtful Sound	4.9	0.7	burrows, droppings	123	400	burrows numerous, Oct 1975
Western Shelter I	Doubtful Sound	7.1	2.8	burrows, droppings, feathers	272	500	burrows common, Apr 1984
Western Shelter islet 4	Doubtful Sound	1.2	3.4	burrows, droppings	34	50	no data
Eastern Shelter I	Doubtful Sound	11.6	3.1	burrows, droppings	130	260	no data
Eastern Shelter islet 1	Doubtful Sound	1.0	3.2	burrows, droppings	35	50	no data
Eastern Shelter islet 2	Doubtful Sound	0.5	3.5	burrows, droppings	5	5	no data
Bauza I (NW headland)	Doubtful Sound	16.7	3.9	burrows, droppings, feathers	27	150	no data
Utah I	Doubtful Sound	5.0	6.3	burrows, droppings, skeleton	152	300	Reported by Pete Young
Seymour I	Doubtful Sound	3.1	13.3	burrows, droppings	65	80	few burrows, 1 egg, Jan 1975
Outer island	Dagg Sound	1.3	1.5	burrows, droppings, feathers	706	2800	burrows common, Dec 1986
Inner island	Dagg Sound	0.2	1.6	burrows, droppings	121	360	no data

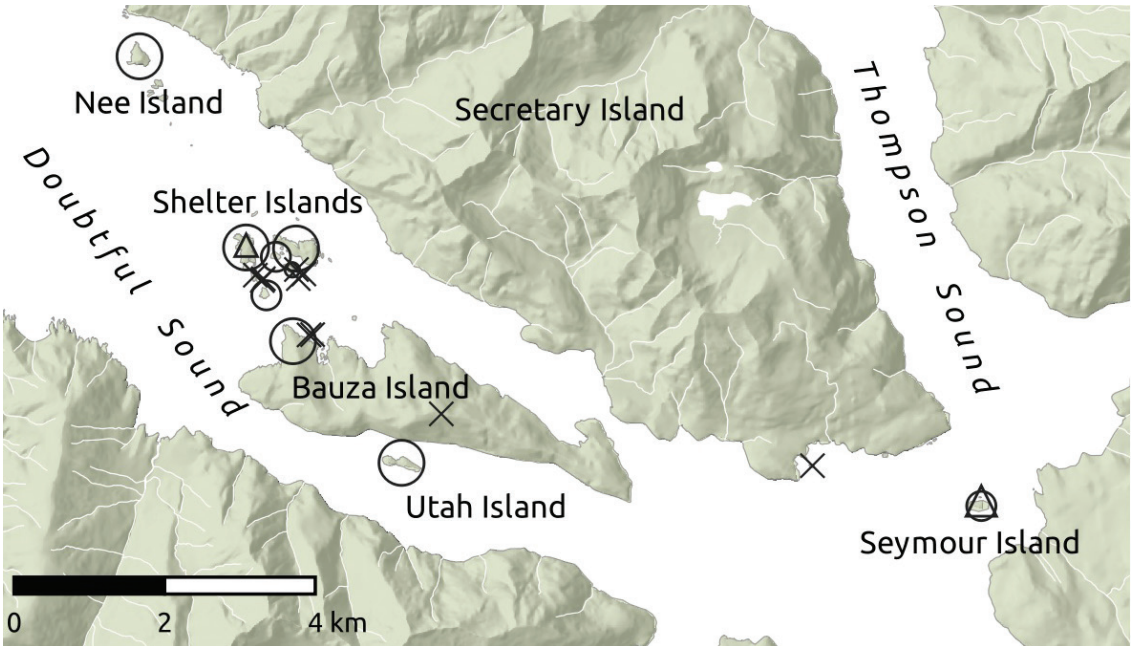


Figure 2. Distribution of sooty shearwater and mottled petrel colonies near the entrance to Doubtful Sound, Fiordland. Symbol size and shape denote colony size and species, with large circles showing 150–500 sooty shearwater burrows estimated, medium circles 50–80 sooty shearwater burrows estimated, and the small circle showing 5 sooty shearwater burrows counted. For mottled petrel, the larger triangle shows the 50 burrows estimated on Seymour Island, and the small triangle shows a single burrow found on western Shelter Island. Crosses show islands visited without evidence of petrels being found.

Broad-billed prion (*Pachyptila vittata*)
 Broad-billed prions, or evidence of their presence, were found at six sites between Poison Bay and Dagg Sound, with an estimated 600 burrows in total (Table 2, Fig. 3). Only one of these sites had apparently been reported previously, as “a headland near Nancy Sound” (Peat & Patrick 1996, p.82). The new sites found were up to 70 km north-east of Nancy Sound (Fig. 3).

All the broad-billed prion sites were islands 0.1–2.4 ha in size and within 1.5 km of the open sea (Table 2, Fig. 3). All the burrows found were under *Veronica elliptica* shrub cover.

Mottled petrel (*Pterodroma inexpectata*)
 An estimated 50 mottled petrel burrows (and two corpses) were found on Seymour Island, Doubtful

Table 2. Evidence for broad-billed prion presence on islands between Milford Sound and Dagg Sound in November 2020, with the estimated number of burrows on each island. See Appendix 1 for island locations and search effort. Data for 1978 and 1986 provided by Kim Morrison (*pers. comm.* to CMM).

Island name	Water body	Area (ha)	Distance from sea (km)	Evidence	Count	Estimate	Previous information
Poison Bay islet	Poison Bay	2.4	0.1	burrows, chick, feathers	20	200	not recorded Jun 1978
Outer nugget	South of Poison Bay	0.1	0.1	burrows, 2 corpses	32	70	no data
Outer stack	Sutherland Sound	0.2	0.2	burrows, feathers, down	10	30	no data
Inner islet	Two Thumb Bay	0.1	0.3	burrows, feathers, down	28	100	no data
Anxiety I	Nancy Sound	2.1	0	burrows, 2 corpses, 2 eggs	72	200	breeding (Peat & Patrick 1996)
Outer island	Dagg Sound	1.3	1.5	corpse	0	?	not recorded Dec 1986

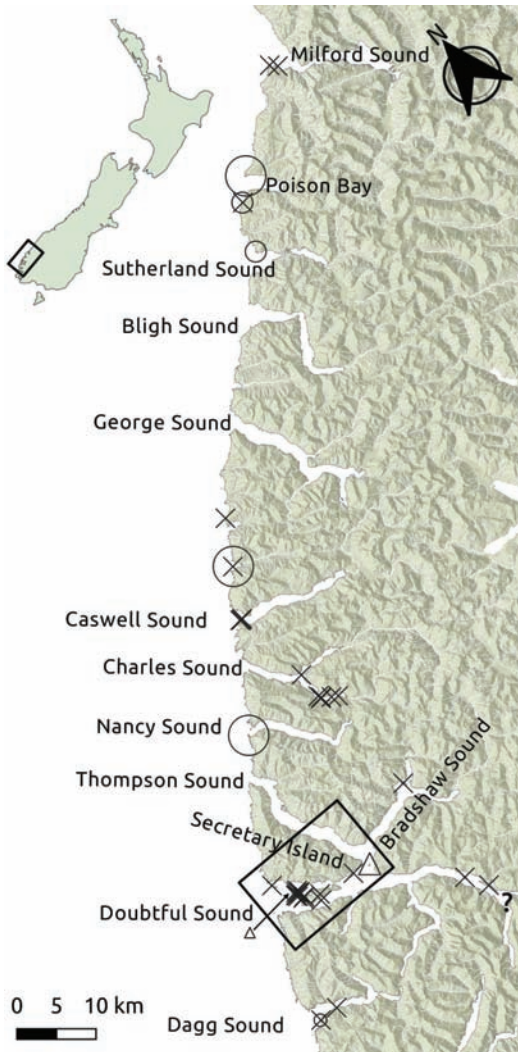


Figure 3. Distribution of broad-billed prion colonies (circles) and mottled petrel colonies (triangles) in northern and central Fiordland. Symbol sizes denote colony size. For broad-billed prion, large circles show 100–200 burrows estimated, medium circles 30–70 burrows estimated, and the small circle shows where a corpse (but no recognised burrows) was found on an islet at the southern entrance to Dagg Sound. For mottled petrel, the larger triangle shows the 50 burrows estimated on Seymour Island, the small triangle shows where a single burrow was found on western Shelter Island, and the question mark shows the site of a possible burrow found on Rolla Island (all three sites in Doubtful Sound). Crosses show islands and headlands visited without evidence of either species being found. The area enclosed in the rectangle is enlarged in Fig. 2.

Sound (Table 3, Figs 2 & 3). Seymour Island (3.1 ha) is a low-lying island covered with tall southern rata (*Metrosideros umbellata*) and podocarp forest, situated 13.3 km from the open sea. We also found a single burrow attributed to mottled petrel on western Shelter Island and a possible burrow on Rolla Island (both in Doubtful Sound; Table 3, Figs 2 & 3). Mottled petrels had not been reported previously at any of these sites.

Petrel breeding island sizes and distance from the sea

The petrel colonies located in northern and central Fiordland broadly matched the patterns previously found in southern Fiordland. Broad-billed prions were breeding on small, steep-sided islands in high-energy environments close to the open coast (Fig. 4). Mottled petrels were found on small low-lying islands well inland, and sooty shearwaters were mainly found breeding on medium or large islands within 10 km of the sea (Fig. 4). The small sooty shearwater colony on Saint Anne Point is the only mainland petrel colony known in Fiordland.

Breeding petrels of the Fiordland region

The November 2020 survey from Milford Sound south to Dagg Sound completed the initial survey of petrel breeding sites in Fiordland. The only known colony that we were unable to survey was a stack on the outer coast of Resolution Island just south of the northern tip of Five Fingers Peninsula, (centred on 45.6309°S, 166.5329°E), where sea conditions were unsuitable for landing on 12 Dec 2019. This stack had broad-billed prion burrows and feathers on 7 December 1986 (Kim Morrison *pers. comm.*), with no estimate of the number of burrows present. Another broad-billed prion breeding site, recorded off Oliver Point, at the northern entrance to Breaksea Sound, on 8 December 1986 could not be relocated, and is presumed to have lost its soil and vegetation cap since 1986.

Four species of petrel were found breeding in Fiordland (Table 4, Fig. 5). Sooty shearwaters and broad-billed prions were found throughout the length of Fiordland. In contrast, mottled petrels occurred only as far north as Doubtful Sound, while common diving petrels were confined to the Green Islets, south-east of the fiords. Mottled petrels also breed on a small island in Lake Hauroko (centred on 45.9978°S, 167.3239°E), where we counted 499 burrows and estimated 530 burrows on 16 December 2019.

The number of colonies in each fiord was roughly proportional to the number of islands present, with 76% of the colonies and 74% of the burrows in the four large southern fiords of Dusky and Breaksea Sounds and Chalky and Preservation Inlets (Table 4).

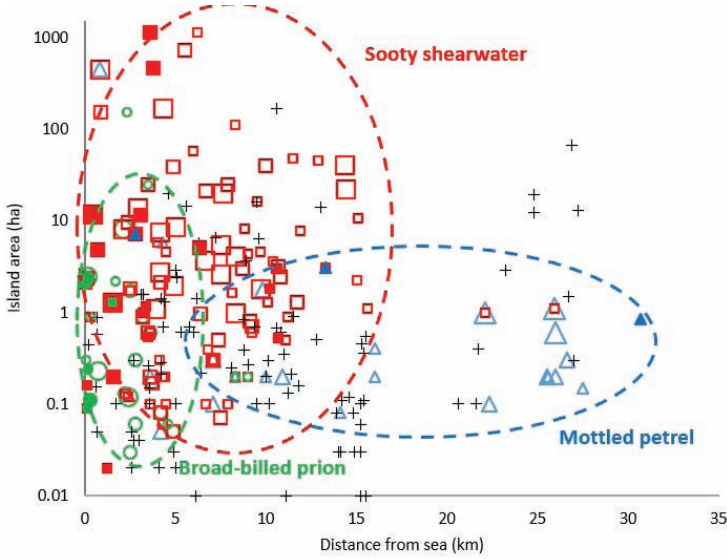


Figure 4. Segregation of breeding colonies of three species of petrels on 214 islands in coastal Fiordland, based on island size (log scale ha) and distance from the open sea. Red squares = sooty shearwater; green circles = broad-billed prion; blue triangles = mottled petrel; black crosses = islands 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 2020 & 2021 (these are superimposed on 2016–19 data, as presented in Fig. 6 in Miskelly *et al.* 2020).

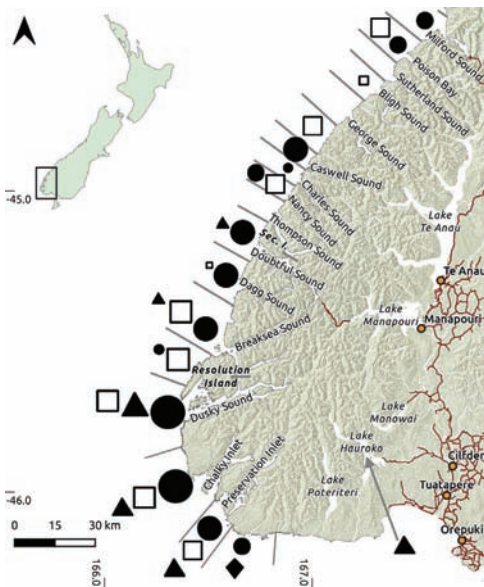


Figure 5. Distribution of breeding petrels throughout Fiordland. Grey lines are used to separate each of the 15 main fiords, plus three sections of outer coast. Solid circles = sooty shearwater; open squares = broad-billed prion; solid triangles = mottled petrel; solid diamond = common diving petrel. Symbol sizes are proportional to local population sizes (based on a logarithmic scale, to emphasise small populations). Estimated burrow counts for each section are provided in Table 4B.

Sooty shearwater was by far the most numerous petrel species breeding in Fiordland, with 66% of the colonies and 71% of the burrows (Table 4). Broad-billed prion was the next most numerous species, with 17% of the colonies and 20% of the burrows.

Although comprehensive, the 2016–21 surveys were not a complete survey of potential petrel breeding sites in Fiordland. There are many islands in Dusky Sound that we were unable to survey in the time available, including about 15 islands close to the south coast of Anchor Island (see Figs 3 & 5 in Miskelly *et al.* 2020). A corpse of sooty shearwater was found in a stoat trap on one of these islands (Stop Island, 45.7660° S 166.5419° E) on 18 Feb 2021 (Brody Philp *pers. comm.* to CMM, 8 March 2021), indicating that at least one colony was missed.

DISCUSSION

Regional and national significance of petrel colonies in northern and central Fiordland

Apart from Doubtful Sound, the fiords north of Breaksea Sound hold few islands, and this was reflected in the numbers of petrel colonies found in November 2020. Although the survey covered more than 50% of the outer coast of Fiordland National Park, this 124 km-long section produced only 18% of the known petrel colonies in Fiordland, and 9% of the burrows.

The most significant discoveries of the 2020 survey were substantial extensions of the northern breeding limits for broad-billed prion and mottled

Table 3. Evidence for mottled petrel presence on islands in Doubtful Sound in November 2020, with the estimated number of burrows on each island. See Appendix 1 for island locations and search effort. Data for 1975 and 1984 provided by Kim Morrison (*pers. comm.* to CMM).

Island name	Area (ha)	Distance from sea (km)	Evidence	Count	Estimate	Previous information
Seymour I	3.1	13.3	burrows, droppings, 2 corpses	43	50	not recorded, Jan 1975
Western Shelter I	7.1	2.8	burrow	1	1	not recorded, Apr 1984
Rolla I	0.8	30.7	possible burrow	1?	-	not recorded, Nov 1975

Table 4. Summary of known petrel colonies in Fiordland. A = number of colonies by species and location; B = estimated number of burrows. No petrel colonies are known in or near Bligh Sound, Catseye Bay, George Sound, Looking Glass Bay, Thompson Sound, or Bradshaw Sound.

A. Colonies	Sooty shearwater	Mottled petrel	Broad-billed prion	Common diving petrel	Total
Milford Sound	2	0	0	0	2
Poison Bay	3	0	2	0	5
Sutherland Sound	0	0	1	0	1
Two Thumb Bay	0	0	1	0	1
Caswell Sound	1	0	0	0	1
Charles Sound	3	0	0	0	3
Nancy Sound	1	0	1	0	2
Doubtful Sound	9	3	0	0	12
Dagg Sound	2	0	1	0	3
Breaksea Sound	14	3	7	0	24
Outer Resolution	1	0	1	0	2
Dusky Sound	47	13	5	0	65
Chalky Inlet	14	3	8	0	25
Preservation Inlet	11	2	1	0	14
Green Islets	3	0	0	4	7
Lake Hauroko	0	1	0	0	1
Total	111	25	28	4	168
B. Burrows					
Milford Sound	175	0	0	0	175
Poison Bay	265	0	270	0	535
Sutherland Sound	0	0	30	0	30
Two Thumb Bay	0	0	100	0	100
Caswell Sound	1,400	0	0	0	1,400
Charles Sound	14	0	0	0	14
Nancy Sound	500	0	200	0	700
Doubtful Sound	1,795	52	0	0	1,847
Dagg Sound	3,160	0	?	0	3,160
Breaksea Sound	6,950	38	2,125	0	9,113
Outer Resolution	60	0	3,000	0	3,060
Dusky Sound	22,739	5,510	1,230	0	29,479
Chalky Inlet	14,979	290	9,700	0	24,969
Preservation Inlet	8,446	950	240	0	9,636
Green Islets	500	0	0	1,000	1,500
Lake Hauroko	0	530	0	0	530
Total	60,983	7,370	16,895	1,000	86,248

petrel within Fiordland. The mottled petrel colony found on Seymour Island, Doubtful Sound is a 28 km northern extension from the John Islets in Breaksea Sound (Miskelly *et al.* 2020), and is the northernmost known extant colony anywhere. The broad-billed prion colony on the island in Poison Bay (51 km north of Nancy Sound; Peat & Patrick 1996) is the northernmost known colony near the New Zealand mainland. However, broad-billed prions breed about 120 km further north on the Chatham Islands (Aikman & Miskelly 2004).

Significance of Fiordland petrels – population sizes

The 2016 to 2021 surveys revealed petrels to breed in much larger numbers in Fiordland than previously understood (Taylor 2000; Waugh *et al.* 2013; Jamieson *et al.* 2016; Wildland Consultants & Department of Conservation 2016). While we were unable to determine burrow occupancy rates during our brief surveys (which would allow burrow counts to be converted into breeding pair estimates; Parker & Rexer-Huber 2020; Wolfaardt & Phillips 2020), estimates of overall population size can be derived from burrow occupancy rates at other sites. Estimates for sooty shearwater and mottled petrel burrow occupancy on Whenua Hou / Codfish Island and on the Snares Islands / Tini Heke were in the range 0.69–0.86% (Warham *et al.* 1977; Newman *et al.* 2009a & b; Scott *et al.* 2010). There are no estimates available for broad-billed prion burrow occupancy rates (West & Nilsson 1994; Jamieson *et al.* 2016). If these estimates are applied to all three species, Fiordland populations are likely to be in the ranges of 42,100–52,400 pairs for sooty shearwaters, 5,090–6,300 pairs for mottled petrels, and 11,700–14,500 pairs for broad-billed prions. We acknowledge that using burrow occupancy rates from elsewhere (and other species) introduces a potential source of error. These population estimates could be improved if occupancy data are collected at Fiordland colonies.

Although these populations are substantial, all three species have much larger populations elsewhere in New Zealand. The five largest known sooty shearwater colonies south of Foveaux Strait each far exceed the entire Fiordland population. Colonies on Whenua Hou, 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.* 2009b; Waugh *et al.* 2013).

The mottled petrel is endemic to southern New Zealand (from Fiordland south to the Snares Islands, although it bred previously as far north as the central North Island; Miskelly *et al.* 2019b). The three largest mottled petrel colonies known, on Whenua Hou / Codfish Island, Taukihepa / Big South Cape Island, and Snares Islands each hold

10,000–160,000 pairs, and similarly all exceed the entire Fiordland population (Warham *et al.* 1977; Scott *et al.* 2009; Miskelly *et al.* 2019b).

The Fiordland petrel surveys failed to answer the conundrum of the source of the estimated 200,000 broad-billed prions that washed ashore on North Island west coast beaches during a winter storm in 2011 (Tennyson & Miskelly 2011; Jamieson *et al.* 2016). At least 340,000 pairs of broad-billed prions bred at their largest known colony, on Rangatira Island in the Chatham Islands, in 1989 (West & Nilsson 1994; Jamieson *et al.* 2016). The mass mortality event did not impact the Rangatira Island colony (Miskelly *et al.* 2019a), and our surveys did not reveal sufficiently large (populated or unpopulated) colonies within Fiordland for this region to have been the primary source of the wreck. However, they did reveal the second largest known New Zealand colony (7,500 burrows estimated on an unnamed islet in Chalky Inlet; Miskelly *et al.* 2019a). The Snares Islands hold fewer than 5,000 pairs of broad-billed prions (Miskelly *et al.* 2001). This process of elimination suggests that the birds that died in 2011 were predominantly from the only remaining population known in the New Zealand region – i.e. from colonies on islands around Stewart Island / Rakiura. None of the known colonies there is large enough to contribute more than a tiny proportion to mortality of this magnitude (Jamieson *et al.* 2016); however, little is known about population sizes of petrels other than sooty shearwater on islands around Stewart Island (Taylor 2000; Jamieson *et al.* 2016; Miskelly *et al.* 2019b).

Significance of petrels in Fiordland – history, ecology, and conservation

Petrel colonies in Fiordland have historical, ecological, and conservation significance beyond their modest sizes. They are the remnants of formerly much larger populations, although their original size and extent are poorly understood (Waugh *et al.* 2013; Jamieson *et al.* 2016; Miskelly *et al.* 2019b).

Before and after European contact, Māori lived in or visited coastal Fiordland, and harvested and consumed the seabirds breeding there (Carey 2020). Captain Cook and the naturalists in his entourage described “innumerable... blue Petrels” (i.e. broad-billed prions) breeding in “immense” numbers on Anchor Island and the adjacent Seal Islands in Dusky Sound in 1773 (Beaglehole 1961: 120; Hoare 1982; Medway 2011). Fewer than 630 pairs of broad-billed prions breed on islands around Anchor Island now (Miskelly *et al.* 2017a, 2020). Following Cook’s visit, the broad-billed prion was the first New Zealand bird to receive a binomial name (as *Procellaria vittata* Forster, 1777), with Anchor Island

as the type locality (Mathews & Hallstrom 1943).

The first mottled petrel breeding site found by European naturalists in Fiordland was of birds breeding in deep burrows under “bog-pine” (probably *Halocarpus bidwillii*) on a hill in or near Preservation Inlet (Buller 1892). No mainland breeding sites have been reported since (Miskelly *et al.* 2019b).

The decline and loss of petrel colonies in Fiordland since 1773 is attributed to the impacts of Norway rats (*Rattus norvegicus*) initially, followed by stoats since 1900 (Medway 2011; Department of Conservation 2017; Miskelly *et al.* 2017a, 2020). The impacts of these two predators on Fiordland petrels is evident in the rapid recovery of sooty shearwaters and broad-billed prions on Fiordland islands that have been cleared of rats and stoats (Miskelly *et al.* 2020). Fiordland has been at the forefront of developments in eradication of both these introduced predators (Townes & Broome 2003; Edge *et al.* 2011; Carey 2020). These included pioneering projects that eradicated Norway rats from Hāwea and Breaksea Islands in Breaksea Sound (Taylor & Thomas 1989, 1993), and eradication of stoats from Chalky Island in Chalky Inlet, and Anchor Island in Dusky Sound (Elliott *et al.* 2010; Edge *et al.* 2011; Carey 2020). Broad-billed prions have recolonised both Hāwea and Breaksea Islands since 1990, along with two sites formerly accessible to stoats (Miskelly *et al.* 2020). The colony on Hāwea Island was estimated at 1,200 burrows a mere 33 years after rat eradication (Taylor & Thomas 1989; Miskelly *et al.* 2020). Rat eradication on Hāwea Island also resulted in a more than 50-fold increase in the sooty shearwater population over the same time period, to an estimated 5,400 burrows in 2019 (Miskelly *et al.* 2020).

The Fiordland mottled petrel colonies are the last remnant of colonies formerly spread over 1,100 km from southern Fiordland through the foothills of the Southern Alps and into the mountain ranges of the southern North Island and the Volcanic Plateau (Stead 1932; Oliver 1955; Miskelly *et al.* 2019b). The few surviving colonies are exemplars of this pre-human environment, where seabirds still transport marine nutrients into tall mainland forests (Smith *et al.* 2011; Ellis *et al.* 2011; Kolb *et al.* 2011). The colony on ‘Motukorure Island’ in Lake Hauroko is particularly significant as the only known site in New Zealand where petrels breed on an island in a freshwater ecosystem (and requiring a minimum 12 km flight over land).

The petrel colonies that have survived in Fiordland will become even more important as further progress is made with clearing rats and stoats from the largest Fiordland islands and the adjacent mainland (Russell *et al.* 2015; Department of Conservation 2017; Anonymous 2017). These colonies should act as source populations for the

recolonisation of nearby sites, as proximity is the single best predictor of successful recolonisation by petrels of sites cleared of predators (Jones *et al.* 2011; Buxton *et al.* 2014). Maintaining colonies of all three of the widespread petrel species throughout their Fiordland range would ensure that this ecological restoration potential remains undiminished.

CONCLUSIONS

At least 168 colonies and an estimated 59,500–74,200 pairs of four petrel species have persisted in Fiordland, despite all Fiordland islands being within 1.6 km of the nearest land mass, which is within the swimming range of stoats (Veale *et al.* 2012; Miskelly *et al.* 2017a). Many colonies have benefitted from several decades of predator control and eradications in the southern fiords (Breaksea Sound to Preservation Inlet), which has allowed remnant populations to recover numerically on some islands, and for birds to recolonise other sites where they were formerly excluded by the presence of rats or stoats (Miskelly *et al.* 2020). Further advances in pest control should allow petrels to recolonise larger islands and the Fiordland mainland, and for petrels to resume their primeval role as ecosystem engineers in mainland forests (Hawke *et al.* 1999; Holdaway *et al.* 2001; Worthy & Holdaway 2002; Hawke 2004). This summary of the extent, diversity, and size of petrel colonies throughout Fiordland should allow predator control effort to be prioritised to protect the largest colonies, and also those sites with the greatest restoration potential due to their geographical location and proximity to current and potential restoration sites.

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APPENDIX 1. Island and peninsula locations and search effort in northern and central Fiordland, November 2020. '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 at the time of our visit. Note that islands in the Shelter Islands in Doubtful Sound receive protection by being adjacent to islands that are trapped. 'Duration' is the approximate length of time (hours:minutes) that observers were ashore.

Site name	Water body	Lat S	Long E	Petrel	Trap	Date	Observers	Duration
Saint Anne Point	Milford Sound	44.5731°	167.7812°	Yes	No	11 Nov 20	AT, CB, CM, HB & PM	0:45
Post Office Rock	Milford Sound	44.5803°	167.7897°	Yes	No	11 Nov 20	AT, CB, CM & PM	0:30
Poison Bay islet	Poison Bay	44.6454°	167.6319°	Yes	No	12 Nov 20	AT, CB, CM & PM	1:45
Outer nugget	South of Poison Bay	44.6646°	167.5985°	Yes	No	12 Nov 20	CB & CM	0:15
Inner nugget	South of Poison Bay	44.6649°	167.5990°	Yes	No	12 Nov 20	AT & PM	0:45
Outer stack, northern entrance	Sutherland Sound	44.7154°	167.597°	Yes	No	12 Nov 20	CB	0:20
North peninsula, Round Head	Looking Glass Bay	44.9100°	167.2289°	No	No	12 Nov 20	AT, CB, CM & PM	0:15
Outer islet	Two Thumb Bay	44.9554°	167.1836°	No	No	12 Nov 20	CM & PM	0:35
Inner islet	Two Thumb Bay	44.9556°	167.1842°	Yes	No	12 Nov 20	AT & CB	0:35
Styles I	Caswell Sound	45.0050°	167.1319°	Yes	No	12 Nov 20	AT, CB, CM & PM	2:35
Styles islet 1 (northern)	Caswell Sound	45.0052°	167.1361°	No	No	12 Nov 20	AT, CB, CM & PM	0:10
Styles islet 2 (southern)	Caswell Sound	45.0058°	167.1340°	No	No	12 Nov 20	AT & CM	0:15
Eleanor I	Charles Sound	45.0981°	167.1414°	No	No	13 Nov 20	AT, CM, J-CS & PM	2:15
Fanny I	Charles Sound	45.1289°	167.1371°	Yes	No	13 Nov 20	AT, CM & PM	1:05
Catherine I (main)	Charles Sound	45.1322°	167.1391°	Yes	No	13 Nov 20	AT, CB, CM & PM	1:00
Catherine I (south-west)	Charles Sound	45.1329°	167.1376°	Yes	No	13 Nov 20	AT, CB, CM & PM	0:30
Lloyd I	Charles Sound	45.1400°	167.1514°	No	No	13 Nov 20	CB & CM	0:15
Islet 800 m SE of Lloyd I	Charles Sound	45.1444°	167.1605°	No	No	13 Nov 20	CB & CM	0:15
Anxiety I	Nancy Sound	45.1056°	167.0130°	Yes	No	11 Nov 20	AT, CB, CM & PM	1:40
Macdonell I	Bradshaw Sound	45.2673°	167.1375°	No	No	15 Nov 20	AT, CB, CM & PM	1:20
Nee I	Doubtful Sound	45.2464°	166.8710°	Yes	No	13 Nov 20	AT, CB, CM & PM	1:15
Western Shelter Island	Doubtful Sound	45.2698°	166.8865°	Yes	No	14 Nov 20	AT, CB, CM & PM	1:55
Western Shelter islet 1	Doubtful Sound	45.2734°	166.8873°	No	No	13 Nov 20	AT & PM	0:27
Western Shelter islet 2	Doubtful Sound	45.2741°	166.8884°	No	No	13 Nov 20	AT & PM	0:10
Western Shelter islet 3	Doubtful Sound	45.2739°	166.8886°	No	No	13 Nov 20	AT & PM	0:04
Western Shelter islet 4	Doubtful Sound	45.2759°	166.8889°	Yes	No	13 Nov 20	CB & CM	0:30
Eastern Shelter Island	Doubtful Sound	45.2706°	166.8945°	Yes	Yes	14 Nov 20	AT, CB, CM & PM	1:40
Eastern Shelter islet 1	Doubtful Sound	45.2714°	166.8910°	Yes	No	14 Nov 20	AT, CB, CM & PM	0:30
Eastern Shelter islet 2	Doubtful Sound	45.2731°	166.8936°	Yes	No	13 Nov 20	AT & PM	0:52

APPENDIX 1. *continued*

Site name	Water body	Lat S	Long E	Petrel	Trap	Date	Observers	Duration
Eastern Shelter islet 3	Doubtful Sound	45.2731°	166.8943°	No	No	13 Nov 20	CM	0:30
Eastern Shelter islet 4 (SE)	Doubtful Sound	45.2737°	166.8955°	No	No	13 Nov 20	CB & CM	0:10
Eastern Shelter islet 5 (tiny, SW)	Doubtful Sound	45.2742°	166.8945°	No	No	13 Nov 20	CM	0:05
Bauza I (whole island)	Doubtful Sound	45.2916°	166.9169°	No	Yes	14 Nov 20	DA, J-CS & LP	9:00
Bauza I (NW headland)	Doubtful Sound	45.2816°	166.8928°	Yes	Yes	16 Nov 20	AT, CB, CM & PM	1:05
West Bauza islet (NW of Bauza)	Doubtful Sound	45.2810°	166.8956°	No	No	16 Nov 20	AT & PM	0:20
East Bauza islet (NW of Bauza)	Doubtful Sound	45.2810°	166.8962°	No	No	16 Nov 20	CB & CM	0:20
Utah I	Doubtful Sound	45.2976°	166.9113°	Yes	Yes	14 Nov 20	AT, CB, CM & PM	2:25
Blanket Bay islet	Doubtful Sound	45.3011°	166.9789°	No	Yes	14 Nov 20	AT, CB, CM & PM	0:25
Seymour I	Doubtful Sound	45.3074°	167.0069°	Yes	Yes	15 Nov 20	AT, CB, CM & PM	1:10
Ferguson I	Doubtful Sound	45.3929°	167.1031°	No	No	16 Nov 20	AT, CB, CM & PM	1:10
Elizabeth I	Doubtful Sound	45.4184°	167.1220°	No	No	16 Nov 20	AT, CB, CM & PM	1:20
Rolla I	Doubtful Sound	45.4409°	167.1325°	Yes	Yes	17 Nov 20	AT, CB, CM & PM	0:40
Outer island	Dagg Sound	45.3944°	166.7750°	Yes	No	16 Nov 20	AT, CB, CM & PM	1:05
Inner island	Dagg Sound	45.3949°	166.7758°	Yes	No	16 Nov 20	CM & PM	0:35
Peninsula opposite Adieu Point	Dagg Sound	45.3972°	166.8078°	No	No	16 Nov 20	AT, CB, CM & PM	0:35

APPENDIX 2. Locations and estimated sizes (number of burrows) of three sooty shearwater colonies found on the north-western peninsula of 1137 ha Anchor Island, Dusky Sound, in Feb–Mar 2021. The outermost colony is about 3.6 km from the open sea

Lat S	Long E	Date	Evidence	Count	Estimate
45.7532°	166.4880°	26 Feb 21	burrows, 7 adults	40	50
45.7529°	166.4935°	26 Feb 21	burrows, 2 adults	17	20
45.7522°	166.4933°	1 Mar 21	burrows, 2 eggs, 8 adults	119	480