

# Birds of Enderby Island, Auckland Islands, New Zealand subantarctic

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**ABSTRACT:** Enderby Island is a much-visited small island in the New Zealand subantarctic, and is an important area for birdlife. However, despite this, the bird community of Enderby Island has never been systematically described. We summarise bird records on Enderby Island from 1840 to 2018. Using these data we describe the bird community with an emphasis on resident species, and compare the frequency of sightings before and after eradication of invasive mammals in 1993. We also investigate trends in bird sightings from 1992 to 2018. There was a significant increase in the sightings of some species, including tui (*Prothemadera novaeseelandiae*) and silvereye (*Zosterops lateralis*), and a significant decrease in others, including white-fronted tern (*Sterna striata*). Some species, such as New Zealand falcon (*Falco novaeseelandiae*) and Auckland Island snipe (*Coenocorypha aucklandica aucklandica*), have recovered successfully following dramatic historical declines. We hypothesise that these trends in sightings are driven by changes in human exploitation, the introduction and subsequent eradication of browsing mammals and mice, changes in the abundance and structure of the invertebrate community, and changes in vegetation cover. However, we believe that trends in sighting rates of southern royal albatross (*Diomedea epomophora*) may be an artefact of changes in visitor behaviour following the construction of a boardwalk, rather than changes in the species' abundance.

French, R.K.; Miskelly, C.M.; Muller, C.G.; Russ, R.B.; Taylor, G.A.; Tennyson, A.J.D. 2020. Birds of Enderby Island, Auckland Islands, New Zealand subantarctic. *Notornis* 67(1): 189–212.

**KEYWORDS:** Auckland Islands, Enderby Island, subantarctic, New Zealand, population ecology, biogeography

# Introduction

Enderby Island (50°30'S, 166°17'E) is part of the Auckland Island archipelago, and is situated to the north-east of the main Auckland Island, in the New Zealand subantarctic. The island is relatively small (695 ha), comprising approximately 1% of the total land area of the Auckland islands (R.H. Taylor 1971; Torr 2002). It has a fairly flat topography and low elevation, rising only 45 m above sea level. This is much lower than Auckland Island (with a maximum elevation of 659 m), and Adams Island (705 m). Due to its position and low elevation, the climate also differs from that of the other Auckland Islands, with less rainfall and higher average temperatures (de Lisle 1965; Higham 1991).

Southern rātā (*Metrosideros umbellata*) forest covers the southern and eastern sides of the island (Fig. 1). Closer to the interior are areas of

thick scrub. The centre of the island consists primarily of low herbs and cushion plants, interspersed with small gullies of scrub. The northern and western sides of the island are much more exposed to weather and ocean spray, and are primarily covered in tussock (*Poa litorosa*). Close to the northern cliffs, only salt- and wind-tolerant plants such as *Bulbinella rossii* and *Anisotome latifolia* appear to be able to grow. To the south there is a large bay with a sandy beach (Sandy Bay), and above the beach a sward area with short lawn-like vegetation. This is thought to be the result of human-induced fire and of browsing by introduced mammals (R.H. Taylor 1971; Torr 2002). Pigs were released in 1807 and 1867, rabbits in 1865, and cattle in 1894, and mice were accidentally introduced probably before 1840 (R.H. Taylor 1971; Russell *et al.* 2020 – Chapter 6 in this book). These species were all eradicated

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**FIGURE 1.** Map of Enderby Island showing sites mentioned in text in white. Vegetation types are in black. South-west Point is also known as Rapoka Point, North-east Cliffs as Fur Seal Cliffs, and South-east Point as Pebble Point. The Department of Conservation hut (near Sandy Bay) is marked with a hut symbol, and the boardwalk with a dotted line. Adapted from image provided by Dave Houston.

in 1993, with the exception of pigs, which had already died out (Torr 2002; Russell *et al.* 2020 – Chapter 6).

Enderby Island is considered an important breeding area for several species and subspecies endemic to the Auckland Islands, including the Auckland Island shag (*Leucocarbo colensoi*), Auckland Island snipe (*Coenocorypha aucklandica aucklandica*), Auckland Island teal (*Anas aucklandica*), Auckland Island banded dotterel (*Charadrius bicinctus exilis*), and Auckland Island tomtit (*Petroica macrocephala marrineri*) (BirdLife International 2019). It is also a key breeding site for the yellow-eyed penguin (*Megadyptes antipodes*) (Muller *et al.* 2020 – Chapter 9 in this book). The entire Auckland Islands archipelago is designated as an Endemic Bird Area (EBA) and world heritage site (BirdLife International 2019), and is managed as a nature reserve by the New Zealand Department of Conservation.

Enderby Island has a rich history of human visitation (Miskelly & Taylor 2020 – Chapter 1 in this book). Māori occupied the island before European discovery (Anderson 2005), but the island was uninhabited when it was first discovered by Europeans in 1806 (R.H. Taylor 1971; Miskelly & Taylor 2020 – Chapter 1). Scientific exploration of the Port Ross area began with visits of ships from the United States, France, and the United Kingdom in 1840, and a German expedition to observe the transit of Venus in 1874 (Fraser 1986; Jones 2009). Much new information was gathered almost 70 years later, when military personnel (equipped with small boats) were posted at nearby Ranui Cove during the Second World War 'Cape Expedition' (Miskelly & Taylor 2020 – Chapter 1). Personnel included experienced ornithologists, who produced for the first time a description of the bird community on Enderby Island (Turbott 2002).

Following the war, there were several scientific expeditions in the 1950s through to the 1980s, including Dominion Museum and Department of Scientific and Industrial Research (DSIR) expeditions in 1954, 1962–63, and 1966 led by Robert Falla, a 1972–73 expedition led by Brian Bell, and a broad ornithological survey in 1988 by Graeme Taylor (Wodzicki & Taylor 1955; Bell 1963; Falla 1975a; G.A. Taylor 1988; Miskelly & Taylor 2020 – Chapter 1). Since 1975, New Zealand sea lion

(*Phocarctos hookeri*) researchers have occupied the island almost annually over the summer months. During this period, the researchers monitored southern royal albatross (*Diomedea epomophora*) nest numbers (Childerhouse *et al.* 2003; Baker *et al.* 2020 – Chapter 10 in this book) and undertook yellow-eyed penguin beach counts (Chilvers 2014; Muller *et al.* 2020 – Chapter 9), as well as making other sporadic wildlife observations. Enderby Island has also been a key site for ecotourism in the New Zealand subantarctic. Heritage Expeditions (an ecotourism company that has visited the island every year since 1992) compiles a list of bird records from every trip, which we use in this article to assess recent trends in bird sightings.

The ecology of Enderby Island has been affected by human activities, including the burning of vegetation and the release of mammalian pests (R.H. Taylor 1971). By 1875 there were at least 100 pigs on Enderby Island (R.H. Taylor 1971). After 127 years on Enderby Island, rabbits had an estimated population size of 5,000–6,000 immediately prior to eradication (Torr 2002; Russell *et al.* 2020 – Chapter 6). These introduced mammals had a large effect on the ecology of the island, confining vulnerable plants such as *Stilbocarpa polaris* and *Anisotome latifolia* to cliff edges, and replacing tussock areas (which were almost eliminated) with cropped sward (Challies 1975; R.H. Taylor 1975; Torr 2002; Russell *et al.* 2020 – Chapter 6). The lack of vegetation cover is likely to have made species such as the Auckland Island snipe more vulnerable to avian predators, including subantarctic skua (*Catharacta antarctica lonnbergi*) and New Zealand falcon (*Falco novaeseelandiae*) (Torr 2002). Mice were thought to have a large impact on invertebrates, which are an important part of the diet of native birds such as the snipe and tomtit (Torr 2002).

Despite the island's ecological importance, long history of visitation, and invasive mammal eradication, the bird community of Enderby Island has never been described in detail. In this study, we describe the bird communities on Enderby Island using records from 1840 to 2018, with an emphasis on resident species. We compare the frequency of sightings before and after the invasive mammal eradications in 1993, and investigate trends in bird sightings from 1992 to 2018.

## Materials and methods

A database of bird sightings on Enderby Island was collated. A detailed description of the collation methods and sources of information (including abbreviations for observers) can be found in Miskelly *et al.* (2020 – Chapter 2 in this book, and see Supplementary materials <http://notornis.osnz.org.nz/node/4445> for the full dataset). We investigated trends in bird sightings in two ways:

1. We compared the frequency that New Zealand falcon, Auckland Island dotterel, Auckland Island teal, and Auckland Island snipe were reported on Enderby Island before and after cattle, mice, and rabbits were eradicated in 1993, using bird lists compiled by researchers and Heritage Expeditions. The number of bird lists that reported the species was divided by the total number of bird lists to produce a presence-only percentage of sightings for each time period. The number of expeditions (and therefore bird lists) to Enderby Island increases greatly over time, and so the years have been

grouped into time periods with a similar number of lists for comparison (Table 1).

2. We studied recent trends in bird sightings using the data collected by Heritage Expeditions from 1992 to 2018. For each year, the number of times a bird species was noted as present was divided by the total number of voyages conducted (Table 2), giving a presence-only proportion of sightings per trip/voyage for each species

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Year	Number of lists
1942–45	7
1946–61	0
1962–79	16
1980–92	9
1993–95	8
1996–98	10
1999–2000	10
2001–03	9
2004–06	8
2007–08	13
2009–10	13
2011–12	13
2013–14	17
2015–16	16
2017–18	19

**TABLE 1.** The number of bird lists in each time period, used to generate the frequency that species were reported on Enderby Island between 1942 and 2018. The number of expeditions to Enderby Island (and therefore bird lists) increases greatly over time, and so the years have been grouped into time periods with a similar number of lists for comparison. There were no lists during 1946–1961.

Year	Number of Heritage Expedition trips
1992	1
1993	5
1994	3
1995	4
1996	6
1997	2
1998	3
1999	6
2000	5
2001	3
2002	2
2003	4
2004	3
2005	2
2006	5
2007	6
2008	5
2009	6
2010	6
2011	7
2012	4
2013	6
2014	8
2015	7
2016	9
2017	8
2018	5

**TABLE 2.** The number of Heritage Expedition trips in each year, used to generate the proportion of bird sightings on Enderby Island (presence only) per voyage for each year between 1992 and 2018.

per year. The relationship between year and the proportion of sightings was analysed using linear regression models in R (Wickham 2009; R Core Team 2019). Graphs and statistics from this analysis are only presented for those species that had significant ( $P < 0.05$ ) trends in sightings.

We describe the bird communities in each of the vegetation types identified by Godley (1965): (i) coastal rātā forest; (ii) lowland scrub (consisting of *Veronica elliptica*, *Dracophyllum* spp., and *Myrsine divaricata*); (iii) low ground vegetation (open cushion plant areas, and *Bulbinella rossii* and *Anisotome latifolia* fields and the grassy sward area); (iv) tussock grassland; and (v) coastal areas (rocky areas devoid of tall vegetation). We describe Sandy Bay and the Derry Castle saltmarshes (Fig. 1) separately as their vegetation and bird communities are unique.

## Results

We collated a total of 5,735 bird records from 1840 to 2018, of 109 different species. The yellow-eyed penguin was the most frequently recorded species (398 records, 6.9%), followed by the southern royal albatross (336 records, 5.9%) and subantarctic skua (313 records 5.5%). The largest source of records was from Heritage Expeditions trip logs (2,468 records, 44.9%).

Species considered to currently breed on Enderby Island are discussed below. Species known or likely to have bred historically (before 1940) on Enderby Island, or that visit the island from breeding sites elsewhere in the Auckland Islands, are listed in Appendix 1. Prehistoric bird remains found in sand dunes at Sandy Bay are not summarised here, but are presented by Tennyson (2020 – Chapter 7 in this book).

### BREEDING SPECIES

#### Auckland Island teal

#### *Anas aucklandica*

The first probable recording of the Auckland Island teal on Enderby Island was in 1840 by the French expedition, when they captured 'a few ducks of a small species' (Dumont d'Urville 1846). They were also seen in the late-1800s and early-1900s

(Ogilvie-Grant 1905; Cass 2014; Bugayer accepted ms). The species was thought to be relatively numerous in the 1940s, when it was frequently sighted by Cape Expedition members (Falla 1975b). The first population estimate was not until 1966, when 30–40 pairs were estimated to be present (Falla 1975b). In 1982 and 1983, similar estimates of 60 and 76 birds were made (Williams 1986a, b). Since then, teal have been noted regularly in small numbers (usually fewer than five) around freshwater and in the littoral zone, and ducklings are also regularly seen in December and January (RKF, CGM). There was a large increase in the frequency of teal being reported from the 1980s to 1992, before cattle, mice, and rabbits were eradicated in 1993 (Fig. 2).

#### Grey duck *Anas superciliosa* and mallard *A. platyrhynchos*

Grey ducks were first reported in 1901, when a male was collected (Ogilvie-Grant 1905). The largest number seen was 17 in 1943 (Miskelly *et al.* 2020 – Chapter 2). Such numbers were not recorded again until 2011, when Heritage Expeditions reported a flock of 16. There are no records of the grey duck breeding on Enderby Island.

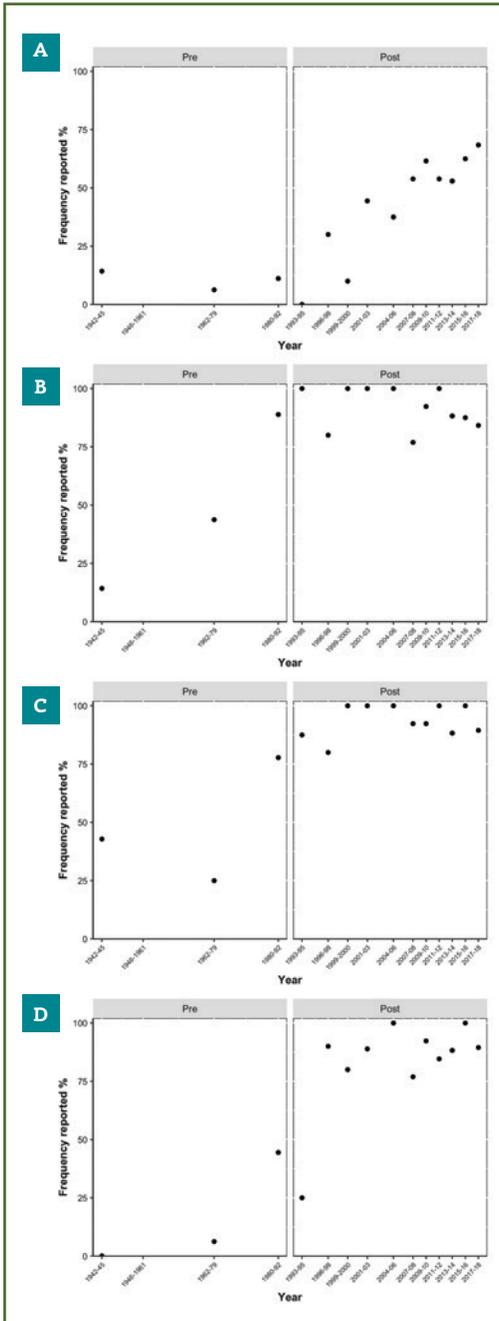
The introduced mallard was first sighted in 1962, and two adults with ten ducklings were observed on Teal Lake in 1985 (Miskelly *et al.* 2020 – Chapter 2). The species has been sighted frequently since, in groups of up to ten. Mallard and grey duck hybrids have also been sighted since 1991, with sightings of at least one hybrid most years between 2010 and 2018.

#### Yellow-eyed penguin

#### *Megadyptes antipodes*

Yellow-eyed penguin was first recorded on Enderby Island by the French expedition in 1840 (Dumont d'Urville 1846), when they were described as being present 'in great quantity' (Miskelly & Taylor 2020 – Chapter 1). Breeding was first noted in 1906, and eggs were collected (Miskelly *et al.* 2020 – Chapter 2).

In 1981, 120+ individuals were counted from a helicopter (Robertson & Jenkins 1986), and in 1986 the first population survey was conducted, estimating 96–150 pairs (Darby & Seddon 1986). Three years later in 1989, Moore (1992) estimated the population to be 260–360 pairs, demonstrating the



**FIGURE 2.** The frequency that (A) New Zealand falcon, (B) Auckland Island banded dotterel, (C) Auckland Island teal, and (D) Auckland Island snipe were reported on Enderby Island in all bird lists between 1942 and 2018. The left panel 'Pre' is before cattle, mice, and rabbits were eradicated in 1993, and the right panel 'Post' is after the eradications. The gap in 1946–61 shows the absence of bird lists, not species absence. Total number of bird lists = 168.

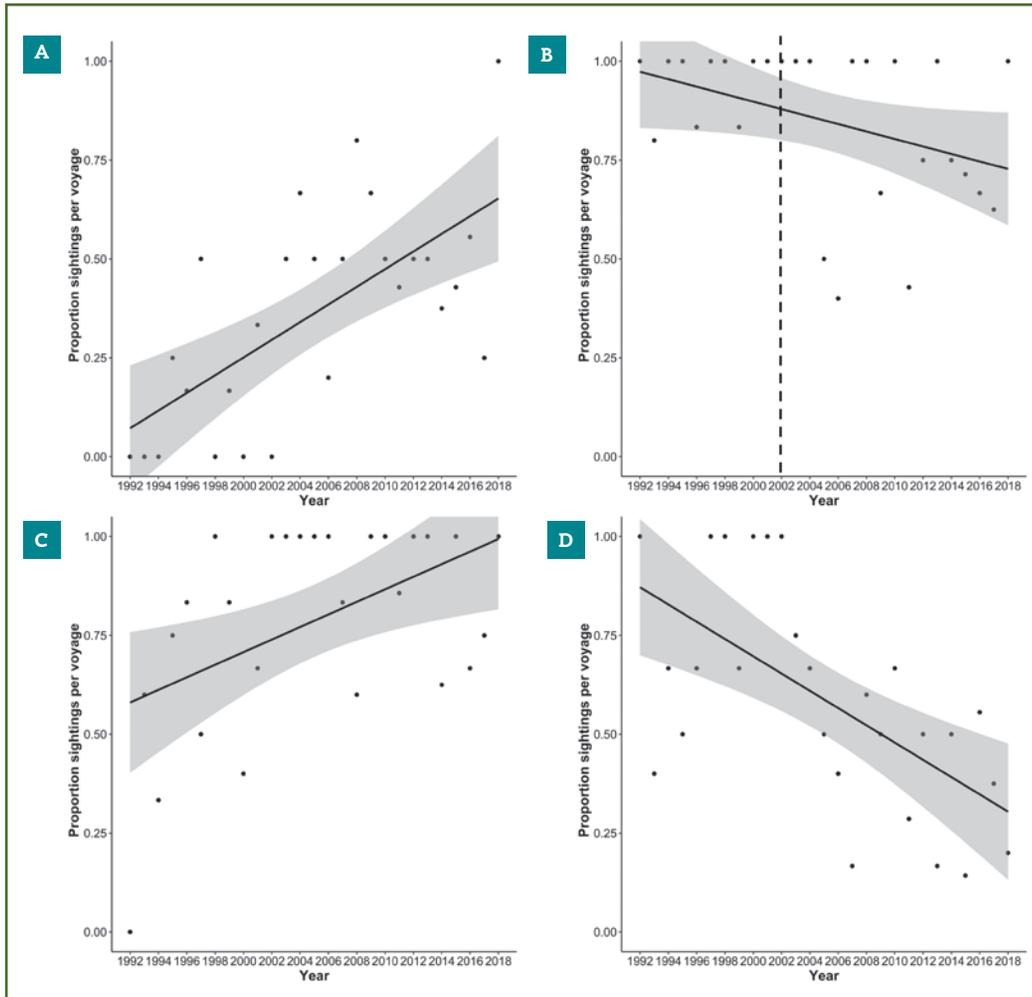
difficulties of generating a population estimate for these cryptic nesters. Probably due to these practical difficulties, there were no other population estimates until Muller *et al.* (2020 – Chapter 9), who generated population estimates for 2015–17 ranging from  $197 \pm 85$  to  $380 \pm 93$  breeding pairs, similar to those produced by Moore (1992).

Enderby Island is an important breeding site for the yellow-eyed penguin, with nests at high density compared to the rest of the Auckland Islands group (Moore 1990, 1992; Muller *et al.* 2020 – Chapter 9). Their breeding season differs in timing from mainland New Zealand, with the mean hatch date 2 weeks later on Enderby and Campbell Island than on mainland New Zealand (Richdale 1957; French 2018).

Leucistic yellow-eyed penguins were reported on Enderby Island as early as 1944 (Miskelly *et al.* 2020 – Chapter 2). At least one and occasionally two birds described as albino, leucistic, or isabelline have been sighted regularly, including a juvenile in 2011 (Louise Chilvers, Amélie Augé & CGM, *pers. obs.*). A partially leucistic bird with white patches on the back of the head below the yellow crest (but with normal dorsal colour) was seen successfully breeding in 2016 (RKF, CGM, *pers. obs.*).

### Southern royal albatross *Diomedea epomophora*

The southern royal albatross population has undergone extreme fluctuations on Enderby Island. In 1840 there were estimated to be more than 100 nests (Miskelly *et al.* 2020 – Chapter 2). However, less than 30 years later, in 1868, they were reportedly extinct on Enderby Island, eliminated due to hunting by humans (R.H. Taylor 1971). In 1901 they were still absent (Ogilvie-Grant 1905). The first report of albatrosses returning to Enderby Island was in 1941–45, when an average of 7–8 nests was recorded (Bell 1963). Nest numbers slowly increased in the 1950s–1970s, with 15 nests counted in 1966 and 22 nests in 1973 (Falla 1975a; Childerhouse *et al.* 2003). Nest numbers appeared to decrease in the 1980s, with 16 nests in 1980 and 1982 (Mitchell & Ensor 1986); however, by 1988 nest numbers had increased to 31 (G.A. Taylor 1988), and they continued to increase up to 69 nests in 2001 (Childerhouse *et al.* 2003). This increase has not continued since then, with nest



numbers varying from 23 to 66 nests, with the latest estimate being 43 nests in 2018 (Baker *et al.* 2020 – Chapter 10). Nests numbers are variable but do not appear to be declining. Heritage Expedition logs showed a significant decrease in the proportion of southern royal albatross sightings per visit between 1992 and 2018 (Fig. 3;  $t = -2.07$ ,  $P$ -value = 0.049); however, this is likely due to increasing constraints faced by tourists on access routes across the island as a result of the construction of the boardwalk in stages between 2002 and 2012 (Fig. 1). We thus suggest that nest counts are more useful in this case.

Most chicks fledge by November; however, a very late chick (still partly downy) was found alive on 19 Dec 2017 but died 6 days later (RKF, CGM, *pers. obs.*).

**FIGURE 3.** The proportion of bird sightings on Enderby Island (presence only) per Heritage Expeditions voyage for each year between 1992 and 2018, for (A) New Zealand falcon, (B) southern royal albatross, (C) Auckland Island snipe, and (D) white-fronted tern. Lines are linear regression models with grey shading representing 95% confidence intervals. The vertical dashed line in (B) represents the beginning of the construction of the boardwalk. Total number of voyages = 96.

### Light-mantled sooty albatross *Phoebastria palpebrata*

This species was first noted on Enderby Island in 1943, and the first nest was recorded in 1954 (Miskelly *et al.* 2020 – Chapter 2). The albatrosses breed on the northern and western cliffs (Fig. 1), and were regularly sighted around and over the island in 1988–2018 (Miskelly *et al.* 2020 – Chapter 2). The only population survey found 14 pairs nesting here in 2014 (Baker & Jensz 2014).

### Northern giant petrel *Macronectes halli*

Remains of the northern giant petrel were first found on Enderby Island in 1874, but the first live bird was not recorded until 30 years later in 1904 (Krone 1877; E. Wilson 1966). The species was apparently rare on Enderby in the early-1900s, with one bird only seen ashore during a landing in 1907 (Waite 1909). By the 1940s, giant petrels were described as ‘numerous’, and were observed scavenging in the New Zealand sea lion colony (R. Falla, *unpublished*). In 1954, one was observed carrying a small rabbit, showing that giant petrels were also feeding on the introduced mammals present on Enderby Island (Wodzicki & Taylor 1955).

The first recorded breeding was not until 1972, when a downy chick was seen (Miskelly *et al.* 2020 – Chapter 2). The first estimate of the breeding population size was in 1988, when a comprehensive survey found only two chicks (G.A. Taylor 1988). There has been a large increase in the breeding population since then, with 96 chicks counted in 2015, 126 in 2016, 104 in 2017, and 123 in 2018 (Parker *et al.* 2016, 2020 – Chapter 13 in this book). Giant petrels breed in highest density in the scrub on the eastern end of Sandy Bay and in the tussock grassland on the western half of the island (Fig. 1), although they nest at lower density in several other scrub and tussock areas of the island.

### White-headed petrel *Pterodroma lessonii*

Remains and possible burrows of white-headed petrels were recorded in 1942 (McEwen 2006). The first evidence of breeding (eggs) was recorded in 1976 (Bartle & Paulin 1986). The species is frequently preyed on by subantarctic skua, as their remains are regularly recorded in skua middens

(Miskelly *et al.* 2020 – Chapter 2). Graeme Taylor (1988) conducted the first population estimate, concluding that ‘perhaps less than 1,000 pairs nest on the island’. They nest behind Sandy Bay and above the cliffs in the south-west and north, as well as south-west of Derry Castle Reef (Fig. 1; G.A. Taylor 1988).

### Antarctic prion *Pachyptila desolata*

Antarctic prions were reported to breed on Enderby Island clifftops in the 1940s (Turbott 2002). They were recorded as present in the 1980s, 1990s, and in 2016–18, and probably breed in small numbers (Miskelly *et al.* 2020 – Chapter 2). They have been recorded in groups as large as 1,000 offshore, and are also sometimes seen in spotlights over land at night (Miskelly *et al.* 2020 – Chapter 2).

### White-chinned petrel *Procellaria aequinoctialis*

Remains of white-chinned petrels were found on Enderby Island in 1875 (Krone 1900). The species was present on the island in 1901, but was not recorded here again for 79 years, apart from bone remains found in the 1960s (Tennyson 1998, 2009). The species was seen in flight in 1980 (Pierce 1986), 1990, 1999, and 2017, and in 2010 remains were found in skua middens (Miskelly *et al.* 2020 – Chapter 2). Two or three isolated burrows were found in 2017 and 2018, as well as further remains in skua middens (Miskelly *et al.* 2020 – Chapter 2; RKF, CGM, CMM, AJDT, *pers. obs.*).

### Sooty shearwater *Ardenna grisea*

The sooty shearwater was described as the ‘commonest breeding petrel’ in 1944, based on skua midden remains and burrow inspections (Turbott 2002). Remains were recorded in the 1950s and 1960s (Tennyson 2009; R. Falla, *unpublished*), and in 1978 they were described as ‘plentiful’ from findings in skua kills (R. Falla, *unpublished*). In 1988 there were estimated to be ‘perhaps less than 1,000 pairs’ (G.A. Taylor 1988). No population estimate has been made since, but the species was occasionally sighted between 1988 and 2018, and often offshore (Miskelly *et al.* 2020 – Chapter 2). Burrows are concentrated along the southern cliff tops (G.A. Taylor 1988).

### Subantarctic diving petrel *Pelecanoides urinatrix exsul*

Large numbers of diving petrels were reported to be breeding on Enderby Island in 1944, and in 1988 there were estimated to be at least 1,000 pairs (G.A. Taylor 1988; Turbott 2002). They have been recorded as breeding at Sandy Bay in small numbers (ten active burrows found in 2016), in the shrubs above the western cliffs, and in the tussock and peaty soil of the southern cliff faces at either end of Sandy Bay (Fig. 1; Bartle & Paulin 1986; G.A. Taylor 1988; Fischer *et al.* 2017).

### Grey-backed storm petrel *Garrodia nereis*

Grey-backed storm petrels were thought to be absent from Enderby Island before 1950. Remains were found in 1962 and the first live sighting was in 1963. The species was not seen again until 1980, and has only occasionally been seen in small numbers (< 7) since. In 2016 a mean of one grey-backed storm petrel per hour was recorded during night spotlighting (Fischer *et al.* 2017). Although grey-backed storm petrels probably breed on Enderby Island, no eggs or chicks have been recorded. This is unsurprising as even on islands where nests do occur (such as Adams Island and the Antipodes Islands), finding a nest is a rare event (Miskelly *et al.* 2020 – Chapter 2).

### Black-bellied storm petrel *Fregatta tropica*

Black-bellied storm petrels were thought to be absent from Enderby Island before 1950. The species was first sighted in 1962 (Bell 1963) and was thought to be breeding at South-west Point (Fig. 1) in 1963, although nests were not found (R. Falla, *unpublished*). They were seen occasionally 1976–2018, often offshore or in skua middens (Miskelly *et al.* 2020 – Chapter 2). The only burrow recorded was in 2018, when a bird was found incubating an egg under *Bulbinella rossii* above the North-west Cliffs (Miskelly *et al.* 2020 – Chapter 2).

### Auckland Island shag *Leucocarbo colensoi*

The first record of the Auckland Island shag was in 1840 when an adult was collected; in 1875, 60 adults and one downy chick were recorded (Krone

1900). In 1891 a colony was recorded, with adults carrying nesting material (R.A. Wilson 1891). The species was described as 'common' in 1901, and 140 nests were counted at two colonies on the North-east Cliffs in 1942 (McEwen 2006). Through the 1960s and 1970s the species appeared to be breeding in higher numbers, with colonies on the North-east Cliffs, the eastern and southern coastline, at Butterfield Point, and the northern coastline west of Derry Castle Reef (R. Falla, *unpublished*; K.-J. Wilson, *unpublished*; Miskelly *et al.* 2020 – Chapter 2; Fig. 1). In 1988, the first comprehensive survey by Graeme Taylor (1988) found 11 colonies with 475 nests in these same areas. In 2012, a similar survey counted 1,388–1,899 nests, suggesting a substantial increase in numbers in the 24 years between surveys (Chilvers *et al.* 2015). An island-wide survey in 2018 counted 1,540 nests (CMM, AJDT, *pers. obs.*).

There appears to be little breeding synchrony; nests were observed with eggs and large downy chicks in the same colony at the same time in Jan 2018 (CMM, AJDT, *pers. obs.*), and this was also observed by Chilvers *et al.* (2015) in Dec 2011 to Jan 2012. The species has been observed with up to three young. It is not known whether they double-clutch (Chilvers *et al.* 2015).

### New Zealand falcon *Falco novaeseelandiae*

The New Zealand falcon was first recorded on Enderby Island in 1866, when the species was 'abundant', with at least one nestling present (Eunson 1974). There were a number of sightings between 1890 and the 1940s (R.A. Wilson 1891; E. Wilson 1966; Cass 2014), but by 1954 falcons appeared to be absent from the island (R.H. Taylor 1971). This absence continued until a sighting in 1977, and the first nest was found in 1989 (M. Cawthorn, *unpublished*). The sighting rates have increased steadily since 1995, following the mammal eradications in 1993 (Fig. 2). The Heritage Expeditions logs also showed a significant increase in New Zealand falcon sightings per visit between 1992 and 2018 (Fig. 3,  $t = 4.39$ ,  $P = 0.0002$ ). Breeding was recorded in 1998, 2006, 2007, 2015, and 2018, although it may also have occurred in other years. Falcons have been seen breeding at Sandy Bay and North East Cape (Fig. 1).

### Auckland Island snipe *Coenocorypha aucklandica aucklandica*

Auckland Island snipe were sighted on expeditions between 1840 and 1891 (Krone 1875; McCormick 1884; R.A. Wilson 1891; Cass 2014). This was followed by more than 80 years with no records (Shepherd *et al.* 2020 – Chapter 16 in this book). Since the 1980s they have been sighted most years, but a thorough survey in 1988 found no sign of snipe (G.A. Taylor 1988). This may suggest they were not established on Enderby Island during this time and were periodically flying from Rose Island (where birds are genetically indistinguishable from those on Enderby Island; Shepherd *et al.* 2020 – Chapter 16). The first chick was seen in 1998 (Miskelly *et al.* 2006).

In 2000 the species was abundant, with an encounter rate of around one snipe per 7.5 minutes of teal-trained dog searching (Miskelly *et al.* 2006). There have been no population estimates of Auckland Island snipe on Enderby Island, but the population appears to have increased considerably since the 1970s, particularly after the cattle, mouse, and rabbit eradications in 1993 (Fig. 2). The Heritage Expedition logs also showed a significant increase in the frequency of Auckland Island snipe sightings during 1992–2018 (Fig. 3,  $t = 2.79$ ,  $P = 0.001$ ). Adults with accompanying chicks were observed most years during 1999–2018.

### Auckland Island banded dotterel *Charadrius bicinctus exilis*

The Auckland Island banded dotterel was first recorded on Enderby Island in 1944, and was seen in small flocks (1–30 individuals) during 1944–72 (Bell 1963; Falla 1978; Miskelly *et al.* 2020 – Chapter 2). In 1973, 50–60 birds were present, and in 1976 the population was estimated at fewer than 50 individuals (Falla 1978). In 1982 the population was estimated at 150–200 birds (Thomson 1986). Five years later, Graeme Taylor (1988) estimated the population at 200–300. The following year an estimate of 440 was made, which may indicate a large population increase (Walker *et al.* 1991). Alternatively, it could be due to changes in dispersal rates from Adams Island and the number of resident breeders, juveniles, and non-breeders, as this species is thought to disperse after breeding in late-summer, when the surveys were undertaken. Nesting was also recorded

for the first time in 1989, with eight nests found (Walker *et al.* 1991). Since then breeding has been noted sporadically. There appears to have been a large increase in the frequency of reporting from the 1960s to 2000, including the period before cattle, mouse, and rabbit eradication in 1993 (Fig. 2). A survey in 2018 counted 308 individuals, a nest with two eggs, two broods of downy chicks, and some fledglings (CMM, AJDT, *pers. obs.*).

### Subantarctic skua *Catharactica antarctica lonnbergi*

Subantarctic skuas were first recorded on Enderby Island in 1840 and thereafter by most ornithologists who visited the island (Sanguilly 1869; McCormick 1884; Cass 2014). They were found to be common and breeding in the 1940s (R. Falla, *unpublished*). A survey in 1988 counted 47 adults and six chicks, and similar numbers were counted the following year (40+ adults and seven nests) (G.A. Taylor 1988; Moore & McClelland 1990). It was estimated that approximately two-thirds of the population was killed through secondary poisoning during the rabbit eradication in 1993 (Torr 2002).

Torr (2002) counted 52 individuals in 2000. Skuas have been seen frequently since, sometimes congregating in large flocks (30–50) when researchers were conducting sea lion dissections. They were observed breeding most years during 1993–2018. A survey in 2018 counted 81 individuals, including 14 chicks (one duo and the rest probably single chicks; CMM, AJDT, *pers. obs.*).

Enderby Island skuas take a wide range of prey species, particularly small seabirds but also teal, shags, snipe, dotterels, rabbits (a key prey prior to their eradication), and sea lion waste and carcasses (Miskelly *et al.* 2020 – Chapter 2). They have also been seen attempting to depredate shag nests, and possibly yellow-eyed penguin nests (RKF, CGM, *pers. obs.*). They commonly nest near Teal Lake, and occasionally on the sward at Sandy Bay and the west of the island (Fig. 1).

### Southern black-backed gull *Larus dominicanus*

The southern black-backed gull was first recorded on Enderby Island in 1904, and nesting was first noted in 1943 (R. Falla, *unpublished*). In 1955 there were thought to be at least 40 on

the island (Wodzicki & Taylor 1955). Similarly, a survey in 1988 found two colonies, totalling 31 adults and two juveniles (G.A. Taylor 1988). The species was noted as present every year during 1994–2018, but breeding was reported only sporadically. A survey in 2018 counted 34 adults and six fledglings – very similar numbers to the 1988 survey, suggesting a stable population (CMM, AJDT, *pers. obs.*). Nesting locations have varied, having been noted at Derry Castle Reef, South-east Point, Teal Lake, the southern coast, and the western corner of the island (Miskelly *et al.* 2020 – Chapter 2).

### Red-billed gull *Chroicocephalus novaehollandiae scopulinus*

The red-billed gull was first noted on Enderby Island in 1840 (McCormick 1884). It was not recorded again until more than 60 years later in 1904, when ‘many’ adults and juveniles were seen (E. Wilson 1966). The species was described as common in the 1940s (R. Falla, *unpublished*), but the first record of nesting was not until 1962 (Bell 1963, 2–3 nests). There was further evidence of breeding in 1972, and at least seven nests recorded in 1973 (Miskelly *et al.* 2020 – Chapter 2). Graeme Taylor (1988) counted at least 50 individuals in 1988, but was not able to count nests as they would have already fledged by the time of the survey. Red-billed gulls were observed breeding only in 2010 and 2018 during this period (Miskelly *et al.* 2020 – Chapter 2), despite being regularly sighted during 1994–2018. A survey in 2018 counted 44 individuals, with evidence of at least eight nests at Derry Castle Reef and the western side of the island (CMM, AJDT, *pers. obs.*).

### White-fronted tern *Sterna striata*

The white-fronted tern was first reported on Enderby Island in 1941, including evidence of nesting (one egg collected; McEwen 2006). In 1954 a small colony was recorded on the cliffs west of Sandy Bay (R. Falla, *unpublished*), and in 1993 they were observed nesting on the north-east coast, with one nest seen near Teal Lake (Miskelly *et al.* 2020 – Chapter 2). No nesting has been reported since 1993; in 2018 a survey counted 27 individuals (CMM, AJDT, *pers. obs.*) but no evidence of breeding was noted. Heritage Expedition logs showed a significant decrease in the proportion

of white-fronted tern sightings per visit during 1992–2018 (Fig. 3,  $t = -3.96$ ,  $P = 0.0006$ ).

### Antarctic tern *S. vittata*

The first record of Antarctic terns on Enderby Island was in 1943: an estimated 40–50 individuals, with at least three nests (R. Falla, *unpublished*; Miskelly *et al.* 2020 – Chapter 2). In 1954 a flock of around 100 was seen at Derry Castle Reef (Miskelly *et al.* 2020 – Chapter 2). They were observed breeding in small numbers in the 1960s (Bell 1963; R. Taylor, *unpublished*), and a survey in 1972 counted ten nests (K.-J. Wilson, *unpublished*). Graeme Taylor (1988) counted 121 individuals in 1988, including at least 54 breeding pairs in numerous locations around the island. The species was seen every year during 1990–2018, but breeding has been noted only occasionally. However, its cryptic nesting makes breeding difficult to observe. A survey in 2018 counted 62 individuals; no nests were seen but aggressive behaviour suggested that nests were present at Derry Castle Reef and the North-west Cliff tops (CMM, AJDT, *pers. obs.*).

### Red-crowned parakeet *Cyanoramphus novaeseelandiae* and yellow-crowned parakeet *C. auriceps*

Red-crowned parakeets were sighted on Enderby Island in 1840 (McCormick 1884). The species was noted as common in the 1940s and 1960s (Bell 1963; McEwen 2006). This trend continued; in 1976 they were described as the second most common bird of the forest and shrubland (Bartle & Paulin 1986). Although they were seen every year, only three breeding attempts have ever been observed – in 1991, 2011, and 2017 (Miskelly *et al.* 2020 – Chapter 2); however, this is unlikely to represent the true breeding effort as they are cryptic cavity-nesters, meaning that nesting is difficult to observe.

Red-crowned parakeets hybridise with yellow-crowned parakeets on Enderby Island, but the frequency of hybridisation appears to have varied over time. Thirty percent of red-crowned parakeets had yellow in their crown in 1973, but a similar survey in 1982 found this had dropped to 10% (Bartle & Paulin 1986; Penniket 1986). Hybrid birds continue to be seen periodically, but the frequency of observed hybridisation has not been reported since 1982.

### Bellbird *Anthornis melanura*

Bellbirds were collected on Enderby Island in 1840, and they were also noted in the 1870s and 1890s (Sherwill 1877; McCormick 1884; R.A. Wilson 1891; Krone 1900; Cass 2014). In 1954 bellbirds were described as the 'commonest landbird', and in the 1960s–1980s they were described similarly, with an estimated 400 immature birds present on the island in 1976 (Bartle & Paulin 1986; Thomson 1986; G.A. Taylor 1988). Evidence of breeding was noted most years during 2014–18 (Miskelly *et al.* 2020 – Chapter 2), and they likely breed in high numbers on Enderby Island.

### Tui *Prosthemadera novaeseelandiae*

Tui were present on Enderby Island in 1875 (Krone 1900) and were regularly noted in low numbers (1–4 individuals) between the 1940s and 2000. In 2001, 2014, and 2018 larger groups of 10–14 were seen, including flocks arriving on the island from across Port Ross (Miskelly *et al.* 2020 – Chapter 2). One nest was seen in 2004 (Miskelly *et al.* 2020 – Chapter 2). Heritage Expeditions logs showed a significant increase in tui sightings per visit 1992–2018 (Fig. 4,  $t = 3.98$ ,  $P = 0.0005$ ).

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### Auckland Island tomtit *Petroica macrocephala marrineri*

Tomtits were first recorded on Enderby Island in 1840 and were also seen in the late-1800s and early-1900s (R.A. Wilson 1891; Archey 1923; Fleming 1950). They were common in the 1940s (Fleming 1950; McEwen 2006) through to the present and were frequently observed nesting (Miskelly *et al.* 2020 – Chapter 2).

When researchers arrived in Nov 2017, a nest was discovered in the outdoor toilet shelter, which allowed close observation for the remainder of the nesting period (RKF, CGM, *pers. obs.*). The three eggs all hatched 9 days after the nest was discovered. Both adults were observed feeding invertebrates to the chicks, and all three fledged 19 days after hatching. Clutch sizes of 3–5 eggs were reported by Charles Fleming on Auckland Island in 1942 (Miskelly *et al.* 2020 – Chapter 2). This is a similar nestling period to other tomtit subspecies (17–22 days; Powlesland 2013).

### Silvereye *Zosterops lateralis*

Silvereyes were recorded on Enderby Island in

1901, and flocks were seen in 1904 (Ogilvie-Grant 1905; E. Wilson 1966). They were present in the 1940s (R. Falla, *unpublished*) and described as numerous in 1962 (Bell 1963) and 1966 (R. Taylor, *unpublished*), with many small flocks on the island. After the 1960s they may have decreased in number, with only incidental sightings (1–5 individuals) during 1972–2008 (Miskelly *et al.* 2020 – Chapter 2). They may have increased again after 2008; a flock was seen in 2009 and up to ten individuals were recorded per trip (Miskelly *et al.* 2020 – Chapter 2). This is also supported by the Heritage Expedition logs, which show a significant increase in silvereye sightings per visit during 1992–2018 (Fig. 4,  $t = 5.89$ ,  $P = 3.77 \times 10^{-6}$ ). Breeding has never been reported on Enderby Island.

### Eurasian blackbird *Turdus merula*

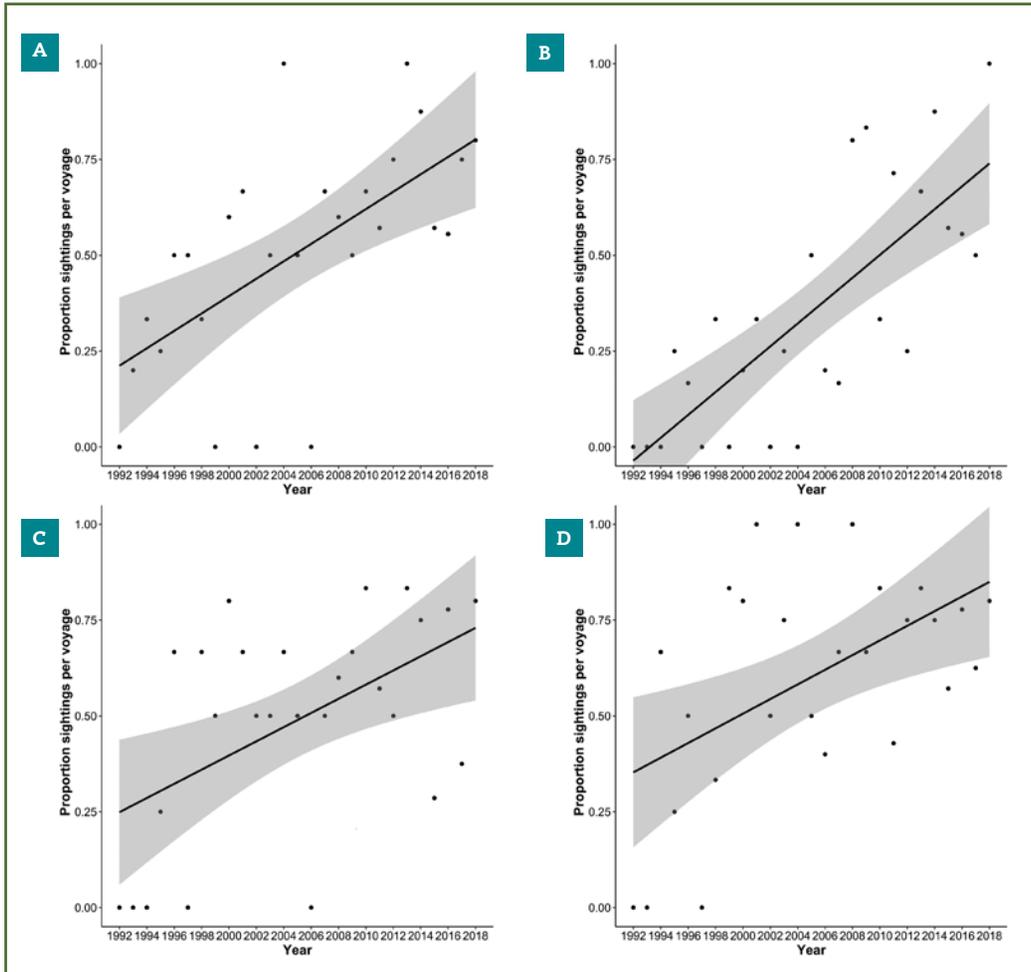
Blackbirds were present on Enderby Island in 1901 and 1904, and they were sighted regularly in the 1940s (E. Wilson 1966; McEwen 2006). In 1962 they were described as the most numerous introduced bird species (Bell 1963). However, the first record of breeding was not until 1980, when a dead fledgling was found (Mitchell & Ensor 1986). They were sighted almost every year during 1995–2018. In 2015, three nests were found in the rātā forest, including two close to the hut in Sandy Bay (CGM, *pers. obs.*). In one of these nests three small chicks were seen in November (CGM, *pers. obs.*). In Dec 2016 a nest was found with three empty eggs, thought to have been depredated (small holes in each shell, CGM, *pers. obs.*). The Heritage Expeditions logs show a significant increase in blackbird sightings per visit during 1992–2018 (Fig. 4,  $t = 3.04$ ,  $P = 0.005$ ).

### Song thrush *Turdus philomelos*

Song thrushes were first recorded on Enderby Island in Aug 1943, and were observed breeding 2 months later (Miskelly *et al.* 2020 – Chapter 2). They were sighted in small numbers (1–2) in the 1960s through to the 1980s (Miskelly *et al.* 2020 – Chapter 2), and were sighted almost every year during 1995–2018. A fledgling was observed in 2017 (RKF, *pers. obs.*), but no other breeding attempts have been recorded since 1943.

### Common starling *Sturnus vulgaris*

Starlings were present and breeding on Enderby



Island in the 1940s, and there were estimated to be 100 on Butterfield Point and 200 in the northeast corner in 1954 (R. Falla, *unpublished*) (Fig. 1). They appear to have remained at high numbers over the next 20 years, with 300–350 birds seen in 1973. However, from the 1980s until the present day they have been seen only in much smaller numbers (typically 1–40 individuals). A survey in 2018 counted 59 birds on and around Derry Castle Reef (CMM, AJDT, *pers. obs.*). No breeding has been recorded since 1944, although they may nest on the southern cliffs.

### Auckland Island pipit *Anthus novaeseelandiae aucklandicus*

Pipits were common in 1840 and were first recorded breeding in 1891 (McCormick 1884; R.A. Wilson 1891). In the 1940s they were very common

**FIGURE 4.** The proportion of bird sightings on Enderby Island (presence only) per Heritage Expeditions voyage for each year between 1992 and 2018, for (A) tui, (B) silvereye, (C) Eurasian blackbird, and (D) common redpoll. Lines are linear regression models with grey shading representing 95% confidence intervals. Total number of voyages = 96.

and frequently found breeding (R. Falla, *unpublished*), and this has continued through to 2019. A survey in 1988 counted 74 individuals and estimated there were 150 in total on the island: 60 pairs and 30 juveniles (G.A. Taylor 1988). They can be found across all the vegetation types on the island apart from forest, but are commonly seen around the coastline and in tussock. A survey in 2018 counted at least 84 pipits on the island (CMM, AJDT, *pers. obs.*), similar to numbers in 1988 (G.A. Taylor 1988). A nest with three chicks was observed in late-2018 (RKF, CGM, *pers. obs.*).

### Dunnock *Prunella modularis*

In 1962 the dunnock was described as 'nowhere common' and only two were seen (Bell 1963). However, by 1976 it was considered common and was described as more abundant than the tomtit (Bartle & Paulin 1986). Dunnocks were present in the early-1980s but were not seen at all in 1988 (Cawthorn 1986a, b; G.A. Taylor 1988). They have been recorded almost every year between 1999 and 2018. They are likely to breed on Enderby Island; while no nests or fledglings have been reported, introduced bird species are under-reported in bird lists from the Auckland Islands (Miskelly 2020 – Chapter 19 in this book).

### Common redpoll *Carduelis flammea*

Redpolls were present and considered numerous in the 1940s (McEwen 2006). They were sighted in the 1960s and 1970s, and in 1982 there were thought to be at least 50 on the island (Thomson 1986). They were seen almost every year during 1994–2018, sometimes in large numbers: 50 in 2003, 85 in 2014, and 50 in 2016. The Heritage Expeditions logs show a significant increase in common redpoll sightings during 1992–2018 (Fig. 4,  $t = 3.05$ ,  $P = 0.005$ ). Similarly to the dunnock, the under-reporting of introduced species (Miskelly 2020 – Chapter 19) means that redpoll are likely to breed on Enderby Island despite no nests or fledglings having been reported.

## MIGRANT AND VAGRANT BIRD SPECIES

Vagrant bird species are reported on Enderby Island far more frequently than elsewhere in the Auckland Islands (Miskelly *et al.* 2020 – Chapter 2). At least 44 migrant and vagrant bird species have

been reported from Enderby Island, 20 of which have not been reported elsewhere in the Auckland Islands (species listed in Appendix 2). Within Enderby Island, 17 species of vagrant waders and waterfowl have been reported, mainly or solely from the saltmarshes and intertidal zone at Derry Castle Reef on the north coast (Fig. 1). The large number of vagrant species reported from Enderby Island is due to a combination of the very high observer presence and the diversity of habitats (including the extensive intertidal zone and saltmarsh at Derry Castle Reef, unique in the Auckland Islands).

## Vegetation types and bird communities

### Sandy Bay

This long, open bay on the southern coast of Enderby Island has a different vegetation and avifauna than other coastal areas. Above the sand, the vegetation consists of short lawn-like plants, primarily grasses and bidi-bidi (*Acaena minor* var. *antarctica*) (Fig. 5A). Here, banded dotterels, pipits, and parakeets are sometimes seen foraging, and subantarctic skuas occasionally nest. During summer, the sea lion colony (which now exists only at Sandy Bay) provides key foraging opportunities for subantarctic skuas, northern giant petrels, southern black-backed gulls, and red-billed gulls, and so these birds are all seen in higher densities than elsewhere on the island. Pipits and teal are frequently seen along the shoreline, and teal and other ducks are also commonly seen in the streams that run through the grassy sward towards the beach.

### Coastal rātā forest

The forest on Enderby Island is dominated by southern rātā trees, which make up almost the entire canopy. The rātā are typically stunted and twisted due to the harsh growing conditions. Beneath the canopy some areas are quite open, with only *Stilbocarpa polaris*, ferns, mosses, and liverworts on the forest floor, interspersed with small *Dracophyllum longifolium* and *D. cockayneanum* (Fig. 6). However, in some areas there is a thick understorey of primarily *D.*

*longifolium*, *D. cockayneanum*, *Coprosma foetidissima*, and *Myrsine divaricata*. At the north-eastern end of Sandy Bay there is a large area of dead rātā trees, which have been there for at least 50 years (Fig 6; R.H. Taylor 1971).

The forest bird community is dominated by bellbirds and red-crowned parakeets, both of which occur in high density. Tomtits, Auckland Island snipe, and Auckland Island teal are also common. Tui are seen only occasionally and probably fly from neighbouring islands, as there

are few breeding records from Enderby Island (Miskelly *et al.* 2020 – Chapter 2). Silvereyes and the non-native blackbirds, starlings, and redpolls inhabit the forest. The forest is also habitat for seabirds, and there are burrows of sooty shearwaters, white-headed petrels, and Antarctic prions, and the area is also key habitat for nesting yellow-eyed penguins. Falcons nest in the forest, often near open areas, such as close to the sward area in Sandy Bay.



**FIGURE 5.** Some of the vegetation types of Enderby Island. **A.** Sandy Bay, showing the sward vegetation and one of the small streams. **B.** Lowland scrub, with Auckland Island in the background. Here the scrub is dominated by *Veronica odora*, *Dracophyllum longifolium*, *D. cockayneanum*, and juvenile rātā. Bands of *Myrsine divaricata* can also be seen in the centre of the photo. **C.** Tussock grassland. **D.** Coastal habitat, with Auckland Island shags. **E.** Derry Castle Reef saltmarshes. Images: Rebecca French (A, B, D), Chris Muller (C, E).



**FIGURE 6.** Coastal rātā forest. **A.** Dead rātā trees at the eastern end of Sandy Bay. **B.** Rātā forest and understorey. Photos: Rebecca French.

### Lowland scrub

The lowland scrub primarily consists of *Veronica elliptica*, *Dracophyllum longifolium*, and *Myrsine divaricata*, with different species dominating in different areas. In some areas *V. elliptica* dominates, often growing in bands along valleys. In the gaps between each band are smaller plants, including *Gentianella concinna* and *Anisotome latifolia*. In other areas *M. divaricata* forms thick, impenetrable thickets. Closer to the centre of the island *Veronica odora*, *D. longifolium*, *D. cockayneanum*, and juvenile rātā dominate the scrub (Fig. 5B).

The scrub supports most of the birds found in the forest community (bellbirds, red-crowned parakeets, tomtits, silvereyes, teal, snipe), but generally at a lower density. The self-introduced dunnock is also present, as are low densities of seabird burrows. New Zealand pipits are frequently seen in the scrub, and yellow-eyed penguins nest in the scrub more frequently than in the forest (French 2018). Northern giant petrels breed among open areas of scrub as well as the tussock grassland.

### Open areas (low ground vegetation)

The open areas consist primarily of low herbs and the cushion plant *Oreobolus pectinatus* (Fig. 7). The centre of the island is dominated by cushion plants, while further to the north are fields of *Bulbinella rossii* and *Anisotome latifolia*.

Open areas have a smaller bird community, probably due to decreased nesting opportunities and increased predation risk. Banded dotterels and snipe frequent the open cushion areas, and subantarctic skuas breed on the open areas near Teal Lake (Fig. 1). Southern royal albatrosses breed on the boundaries between lowland scrub and open areas. Mallards, grey ducks, and teal are often sighted in and around Teal Lake on the south-east coast.

### Tussock grassland

The tussock grassland consists almost entirely of fields of *Poa litorosa*, occasionally interspersed with stands of *Veronica elliptica*, *Carex appressa*, or *C. trifida* (Fig. 5C). The tussock grassland provides greater cover than the open areas and is a key habitat for snipe and pipits. Northern giant petrels also nest in these areas.

### Coastal

In coastal areas devoid of vegetation, the bird community is primarily made up of seabirds and shorebirds (Fig. 5D). Auckland Island shags, white-fronted terns, Antarctic terns, southern black-backed gulls, and red-billed gulls all breed around the island on rocky coastal habitat (Miskelly *et al.* 2020 – Chapter 2). Light-mantled sooty albatrosses breed on the steep cliffs on the northern and western sides of the island. Auckland Island teal are frequently sighted among the kelp along the water's edge.



**FIGURE 7.** Open areas (low ground vegetation).

**A.** *Bulbinella rossii* fields. **B.** *Anisotome latifolia* fields. **C.** Cushion plant spp. and other low vegetation. Images: Chris Muller (**A**), Rebecca French (**B, C**).

### Derry Castle Reef saltmarshes

The coastal areas at Derry Castle have distinctive vegetation and bird communities (Fig. 5E). The vegetation consists of salt-tolerant plants in the high inter-tidal zone, dominated by *Isolepis cernua*, *Colobanthus muscoides*, *Crassula moschata*, *Plantago triantha*, *Rumex neglectus*, and *Samolus repens*. A wide variety of shorebirds can be seen here, including terns, dotterels, gulls, skuas, and migrant waders, and red-crowned parakeets feed on the low turf (Miskelly *et al.* 2020 – Chapter 2).

## Discussion

There have been changes in sighting rates of forest birds on Enderby Island, including increases in snipe, falcon, tui, silvereyes, redpolls, and blackbirds between 1992 and 2018. Based on nest counts, there have also been changes in the abundance of nesting seabirds on Enderby Island. Numbers of northern giant petrel nests increased between 1988 and 2016 (Parker *et al.* 2020 – Chapter 13 in this book), and numbers of Auckland Island

shag nests appear to have increased between 1988 and 2012 (Chilvers *et al.* 2015; this study). This was not reflected in (presence/absence) sighting rates, which showed no significant trend, probably because these species are so commonly sighted even when at lower nesting numbers. In contrast, nest numbers and sighting rates both appear to indicate a decrease in white-fronted terns since 1992, perhaps due to changes in vegetation.

The number of southern royal albatross nests increased greatly following their local extinction in the late-nineteenth and early-twentieth century. However, while numbers clearly increased in the 1990s, this increase did not continue into the 2000s, and southern royal albatross currently nest at much lower numbers than in 1840, prior

to human exploitation (Childerhouse *et al.* 2003; Baker *et al.* 2020 – Chapter 10). This could be related to marine rather than terrestrial threats. Gibson's wandering albatross (*Diomedea antipodensis gibsoni*) and Antipodean wandering albatross (*D. a. antipodensis*) populations underwent a dramatic decline in the early-2000s, thought to be related to changes in oceanic conditions, and possibly to fishing pressure and by-catch (Francis *et al.* 2015; Walker *et al.* 2017; Elliott *et al.* 2018). Similar stressors could be suppressing the southern royal albatross population on Enderby Island. Although the population did not crash (as with other subantarctic albatrosses), marine threats could be preventing the population from increasing back to pre-exploitation numbers. Nest numbers do not indicate a decreasing trend during 1992–2018, although sighting rates declined significantly from 1992. However, this may be due to the construction of a boardwalk affecting visitor behaviour and lowering sighting rates (discussed in more detail below).

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Some species have recovered successfully following dramatic declines. The Auckland Island snipe sighting rates have increased considerably after the species became nearly or completely locally extinct in the first half of the twentieth century (Shepherd *et al.* 2020 – Chapter 16). The New Zealand falcon started nesting again in 1989 following a 20-year disappearance during the 1950s–1970s. Falcon sighting rates have increased significantly since 1995. Auckland Island banded dotterel and Auckland Island teal sighting rates increased considerably in the 1980s, following low numbers in the 1970s and earlier.

### The effects of mammal eradication

Many of the changes in the avifaunal community appear to have been driven first by human exploitation and mammal introductions in the nineteenth and early-twentieth centuries, and second by the cattle, mouse, and rabbit eradications in 1993.

Cattle and rabbits, along with deliberate burning, changed the habitat structures on Enderby Island by clearing much of the tussock grassland and other ground vegetation (R.H. Taylor 1971; Russell *et al.* 2020 – Chapter 6). By 1962, the tussock grassland that had been present on the western side of the island was almost completely replaced

by *Bulbinella rossii* stands (Godley 1965; R.H. Taylor 1971). This will have exposed many of the smaller bird species (particularly the Auckland Island snipe) to avian predators such as skuas and falcons (Torr 2002), and reduced available nesting habitat for the northern giant petrel. Since the removal of rabbits, cattle, and mice, the tussock grassland has returned to most of the western side of the island (R.H. Taylor 1971; Fig. 1). Sighting rates of snipe and falcon have increased significantly since 1992, and giant petrels now nest in high numbers in the recovered tussock grassland. However, Auckland Island snipe, teal, and dotterel all showed increased rates of reporting in the decades immediately before cattle and rabbits were eradicated in 1993. This was mentioned for the dotterel by Walker *et al.* (1991) but had not been previously noted for snipe and teal.

The reasons for this increase, despite the presence of rabbits and cattle, is unclear but may be associated with a delayed recovery of vegetation following the local extinction of pigs on the island c. 1887 (Russell *et al.* 2020 – Chapter 6). Pigs may also have been the main cause of local extinction of white-faced storm petrel (*Pelagodroma marina*) and South Georgian diving petrel (*Pelecanoides georgicus*) on Enderby Island, and the scarcity of the remaining 6–7 species of burrow-nesting petrels (Challies 1975; R.H. Taylor 1971; Miskelly *et al.* 2020 – Chapter 2; Russell *et al.* 2020 – Chapter 6), as the low reproductive output and high philopatry of petrels greatly limit their rate of natural recovery following disturbance (Miskelly *et al.* 2009). The absence of pigs on Enderby Island since c. 1887 is thought to be the reason for the high density of yellow-eyed penguin nests on Enderby Island compared with the main Auckland Island, where pigs are known to depredate yellow-eyed penguin nests (Muller *et al.* 2020 – Chapter 9; Russell *et al.* 2020 – Chapter 6). When pigs were at high densities in the 1800s on Enderby Island, they are likely to have severely affected the yellow-eyed penguin and burrowing seabird populations (R.H. Taylor 1971; Russell *et al.* 2020 – Chapter 6).

Mice also likely had an impact on the invertebrate community of Enderby Island, which would have reduced food availability for insectivorous birds such as the snipe, tomtit, pipit, and banded dotterel (St Clair 2011; Russell *et al.* 2020 –

Chapter 6). Differences in the invertebrate community between islands in the archipelago indicate that mice alter its composition. In addition, recent eradication of mice from Antipodes Island (in the New Zealand subantarctic) resulted in large increases in invertebrate abundance, indicating that mice also suppress invertebrate populations (Russell *et al.* 2018, 2020 – Chapter 6). No evidence of birds being depredated by mice was reported at Enderby Island before mouse eradication in 1993, in contrast to the heavy predation rates reported on seabirds at islands such as Gough Island and Marion Island (Cuthbert & Hilton 2004; Dilley *et al.* 2016, 2018; Caravaggi *et al.* 2019).

### Limitations

The nature of the data we have used to describe the avifaunal community – that is, presence/absence sighting rates – mean that we cannot draw definitive conclusions on the population trends over time. The population sizes of many of the species resident on the island have never been estimated or have been estimated only once, which makes it difficult or impossible to determine population changes over time. Even for species that have had multiple population estimates, the search effort and methods used to generate these estimates often differ.

Within our dataset, there have been large variations in sighting and recording effort, with very little before the 1940s, and increased effort after 1990, when researchers and tourists were present every year. The likelihood of sighting a species also depends on factors such as time spent in each vegetation type, and birdwatching experience. For example, sea lion researchers based on the island spend the majority of their time at Sandy Bay and South-east Point, and their birdwatching interest and experience vary hugely depending on the personnel. To standardise sighting effort and area covered, we investigated trends in bird sightings using data collected by Heritage Expeditions from 1992 to 2018 (sighting effort and the area covered were expected to be similar for each trip). This mitigates some of the limitations mentioned above; however, they are not entirely eliminated. For example, the construction of a boardwalk 2002–12 restricted the path tourists take across the middle of the island (Fig. 1). We believe this may have led to the decreased southern royal

albatross sightings rather than this being due to a decrease in the actual population, given evidence from island-wide nest counts that nest numbers ranges from 23 to 69 over this period but did not appear to decline (Childerhouse *et al.* 2003; Baker *et al.* 2020 – Chapter 10). As boardwalk construction did not affect the routes tourists take in other areas of the island (such as around the coast), we do not think the absence or presence of the boardwalk would have affected the sighting rate of other species.

## Conclusion

The bird community on Enderby Island has undergone many changes in the past 200 years. Many populations of native species declined or became locally extinct in the 1800s due to human exploitation and the introduction of mammals, and then increased after mammals were eradicated in 1993. This demonstrates the positive effect mammal eradications can have on subantarctic ecosystems.

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## Acknowledgements

Many people have generously contributed to this review through loaning their notebooks, diaries, or logbooks, or those of deceased family members. We particularly thank the late Hilary Haylock (Robert Wilson's daughter) and Elizabeth Bell (Brian Bell's daughter) for the loan of their fathers' diaries and notebooks, and Martin Cawthorn, Kerry-Jayne Wilson, and Murray Williams for providing copies or originals of their unpublished bird records. Thank you to Lynn Tough who helped facilitate access to 25 years of Heritage Expedition reports. Igor Debski and Joseph Roberts facilitated access to unpublished reports and diaries held by DOC in Wellington and Invercargill. Emma Burns (Otago Museum), Joanne Cooper (Natural History Museum, UK), Matt Rayner (Auckland Museum), Paul Scofield (Canterbury Museum), and Jens Jakobitz, Frederik Albrecht, and Martin Paeckert (Senckenberg Naturhistorische Sammlungen, Dresden) provided details of specimens in their care.

We gratefully acknowledge the scholarship of James Braund (University of Auckland)

and his generosity in providing translations of the writings of Hermann Krone, and Grant McAlpine for his assistance with translations of French texts. Te Papa librarians Victoria Boyack, Christine Kiddey, and Martin Lewis provided much assistance with our research, as did the staff of Archives New Zealand and the Alexander Turnbull Library, Wellington.

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## Appendices

### APPENDIX 1: Locally extinct species recorded as seen on or from Enderby Island, along with species that visit from breeding sites elsewhere in the Auckland Islands

The number of arrival events or records are given in parentheses, followed by the year or year range of sightings. South Georgian diving petrel and white-faced storm petrel both formerly bred on Enderby Island, but apparently no longer breed on the Auckland Islands. Further detail on each species is given by Miskelly *et al.* (2020 – Chapter 2).

Eastern rockhopper penguin *Eudyptes filholi* (19, 1943–2018); erect-crested penguin *E. sclateri* (16, 1944–2013); Gibson's wandering albatross *Diomedea antipodensis gibsoni* (4, 1983–2015); white-capped mollymawk *Thalassarche cauta steadi* (8, 1989–2017); Cape petrel *Daption capense* (22, 1901–2018); lesser fulmar prion *Pachyptila crasirostris flemingi* (15, 1962–2018); South Georgian diving petrel *Pelecanoides georgicus* (1, 1840); white-faced storm petrel *Pelagodroma marina* (1, 1840).

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### APPENDIX 2: Migrant and vagrant bird species reported on or from Enderby Island

The number of arrival events or records are given in parentheses, followed by the year or year range of sightings. \* = recorded only from Enderby Island within the Auckland Islands. Species recorded only as skeletal remains or isolated bones are not included. Further detail on each species is given by Miskelly *et al.* (2020 – Chapter 2).

Canada goose *Branta canadensis* (1, 1989–90); chestnut-breasted shelduck *Tadorna tadornoides* (9\*, 1983–2014); grey teal *Anas gracilis* (1\*, 2011–12); Australasian shoveler *A. rhynchotis* (2, 2003 & 2015); king penguin *Aptenodytes patagonicus* (4, 1972–2006); chinstrap penguin *Pygoscelis antarctica* (1\*, 1985); Fiordland crested penguin *Eudyptes*

*pachyrhynchus* (1, 1999); Snares crested penguin *E. robustus* (4, 2000–17); northern royal albatross *Diomedea sanfordi* (6, 1982–2010); southern giant petrel *Macronectes giganteus* (12, 1973–2017); mottled petrel *Pterodroma inexpectata* (2, 1990–2016; probably birds offshore); blue petrel *Halobaena caerulea* (5, 2018; in skua middens); broad-billed prion *Pachyptila vittata* (3, 1964–2018; in skua middens); subantarctic little shearwater *Puffinus elegans* (8, 1963–2018; includes birds in skua middens); Australasian gannet *Morus serrator* (2, 1999–2001); white heron *Ardea modesta* (1, 1980); cattle egret *A. ibis* (1\*, 1983); white-faced heron *Egretta novaehollandiae* (9, 1980–2016); swamp harrier *Circus approximans* (7, 1943–2013); spotless crane *Porzana tabuensis* (1\*, 2003); pukeko *Porphyrio melanotus* (1\*, 2011); Australian coot *Fulica atra* (1\*, 2012); lesser knot *Calidris canutus* (6, 1954–2015); sanderling *C. alba* (1\*, 2007–08); sharp-tailed sandpiper *C. acuminata* (3\*, 1973–2009); pectoral sandpiper *C. melanotus* (1\*, 2015); red-necked stint *C. ruficollis* (7\*, 1963–2008); whimbrel *Numenius phaeopus* (1\*, 1994); bar-tailed godwit *Limosa lapponica* (18, 1891–2016); black-tailed godwit *L. limosa* (3\*, 1963–2004); wandering tattler *Tringa incana* (1\*, 1988); grey-tailed tattler *T. brevipes* (4\*, 1980–84); ruddy turnstone *Arenaria interpres* (104, 1944–2018); South Island pied oystercatcher *Haematopus finschi* (2\*, 2012–14); Pacific golden plover *Pluvialis fulva* (4\*, 1944–82); [New Zealand] banded dotterel *Charadrius bicinctus bicinctus* (2\*, 1954 & 1980); spur-winged plover *Vanellus miles* (14, 1985–2018); white-throated needle-tail *Hirundapus caudacutus* (1, 2014); Eurasian skylark *Alauda arvensis* (9, 1942–2017); welcome swallow *Hirundo neoxena* (6, 1983–2018); house sparrow *Passer domesticus* (6, 1943–2016); chaffinch *Fringilla coelebs* (11, 1943–2014); European greenfinch *Carduelis chloris* (1\*, 2013); European goldfinch *C. carduelis* (11, 1943–2014); yellowhammer *Emberiza citrinella* (1\*, 2000).