

Introduced land mammals and their impacts on the birds of the subantarctic Auckland Islands

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ABSTRACT: Since the European discovery of the Auckland Islands, at least ten species of land mammals have been introduced there. Most arrived in the first half of the nineteenth century during periods of exploitation by sealers and whalers, followed by short-lived Māori and European settlements at Port Ross. Several species required multiple introductions before becoming established. For those populations that naturalised, cattle (*Bos taurus*) occupied Enderby Island and were eradicated by 1993, goats (*Capra aegagrus hircus*) remained restricted to the northern end of Auckland Island and were eradicated by 1991, while pigs (*Sus scrofa*) spread across the entire Auckland Island and remain there today. Rabbits (*Oryctolagus cuniculus*) established on Rose and Enderby Islands, and were eradicated in 1993. Cats (*Felis catus*) and mice (*Mus musculus domesticus*) were both first recorded in 1840 on Auckland Island and remain there today. Rats (*Rattus* spp.) have never established on the Auckland Islands. Collectively, cattle, goats, sheep (*Ovis aries*), pigs, and rabbits transformed habitats and altered ecosystem processes, and suppressed tussock, megaherbs, and woody vegetation on Auckland, Enderby, Rose, Ewing, and Ocean Islands. Cats and pigs are together responsible for the extirpation or major reduction of surface-nesting and burrowing seabird colonies, and ground-nesting land birds from Auckland Island. Before dying out on Enderby Island, pigs had similar impacts there. Mice have altered invertebrate community composition and are likely responsible for lower abundances of wētā (*Dendroplectron aucklandense*) and large weevils (Curculionidae) on Auckland Island. Disappointment Island remained free of introduced mammals, while on Adams Island they had only fleeting and minimal impact. Humans also had direct impacts on birds through hunting for consumption, with large surface-nesting seabirds severely affected around Port Ross. The Auckland Island merganser (*Mergus australis*) was driven to extinction by presumed mammal predation and well-documented museum collecting. Eradication of pigs, cats, and mice from Auckland Island and Masked Island (Carnley Harbour) would remove the last introduced mammals from the New Zealand subantarctic region.

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Introduction

On remote islands, introduced mammals, particularly predatory mammals, have been the primary cause of decline and extinction in bird populations (Steadman 2006). Since AD 1500, 90% of bird extinctions have been on islands (Butchart *et al.* 2018). New Zealand has been no exception to this, having lost nearly half its original avifauna since human discovery (Murphy *et al.* 2019). Thirty species of introduced mammals are currently extant in New Zealand (Russell 2014), and the predators among them are the primary cause of endangerment in native birds (Murphy *et al.* 2019). In response to the threat of invasive predatory mammals to avifauna, New Zealand has pioneered their eradication from islands, having cleared invasive mammals from one-third of offshore islands over the past 50 years (Townes *et al.* 2013; Russell & Broome 2016).

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Ten species of land mammals are known to have been introduced to the Auckland Islands since the discovery of the archipelago. The introductions of these species corresponded with the early periods of Auckland Islands exploration (and concomitant exploitation), short-lived settlement, and shipwrecks (Dingwall *et al.* 2009). Subsequently, with farming abandoned and leaseholds returned to the Crown at the start of the twentieth century, the spread and impact of these introduced mammals were documented by scientific and wildlife expeditions, prior to conservation management (Table 1; Miskelly & Taylor 2020 – Chapter 1 in this book). In this paper we review historical observations of the presence and impacts of introduced mammals in the Auckland Islands, extending previous summaries by Taylor (1968, 1971) and Russell *et al.* (2018). Comparative differences in bird communities among islands, which in part are due to mammals, are discussed elsewhere (Miskelly *et al.* 2020 – Chapter 2 in this book), as are changes in bird communities following mammal eradications on Enderby Island (French *et al.* 2020 – Chapter 4 in this book).

Methods

We compiled and reviewed existing peer-reviewed scientific publications and reports predominantly

focusing on one or more introduced mammal species of the Auckland Islands. We also used a database of bird and mammal observations from original records compiled by one of us (see Miskelly *et al.* 2020 – Chapter 2 – for a full description). We then summarised key dates and observations from these sources to provide a narrative summary of the history of introduced mammals on the Auckland Islands, noting in particular the dates and locations of introductions, and any records of impacts. Where dates are unclear, or in conflict, we refer to the decade of the record only. A copy of all records referring to land mammals and their impacts on the birds of the Auckland Islands is provided as Supplementary material online (<http://notornis.osnz.org.nz/node/4445>).

Results

Island sizes and the presence of mammals on each island over time are summarised in Table 2.

Horses *Equus ferus caballus*

During the settlement era, three horses were introduced to and moved between Auckland and Enderby Islands in 1849, and were removed in 1852 when the Hardwicke settlement was abandoned (Taylor 1968).

Cattle *Bos taurus*

During the settlement era, 45 cattle were introduced to Auckland and Enderby Islands in 1849 (Taylor 1971). They were removed from Auckland Island in 1852, when the Hardwicke settlement was abandoned. Cattle remained on Enderby Island but had died out by the time Māori left in 1856 (Taylor 1968, 1971). In 1894, new stock were introduced to Enderby Island as part of W.J. Moffett's pastoral lease of northern Auckland Island (Taylor 1971; Dingwall 2009). They never reached large numbers, and were reported as being in poor condition, but nonetheless, tussock was virtually eliminated from Enderby Island by the start of the twentieth century (Taylor 1971). During the scientific expedition era, cattle impacts on the ecosystem through browsing forest, grazing grasslands, and causing

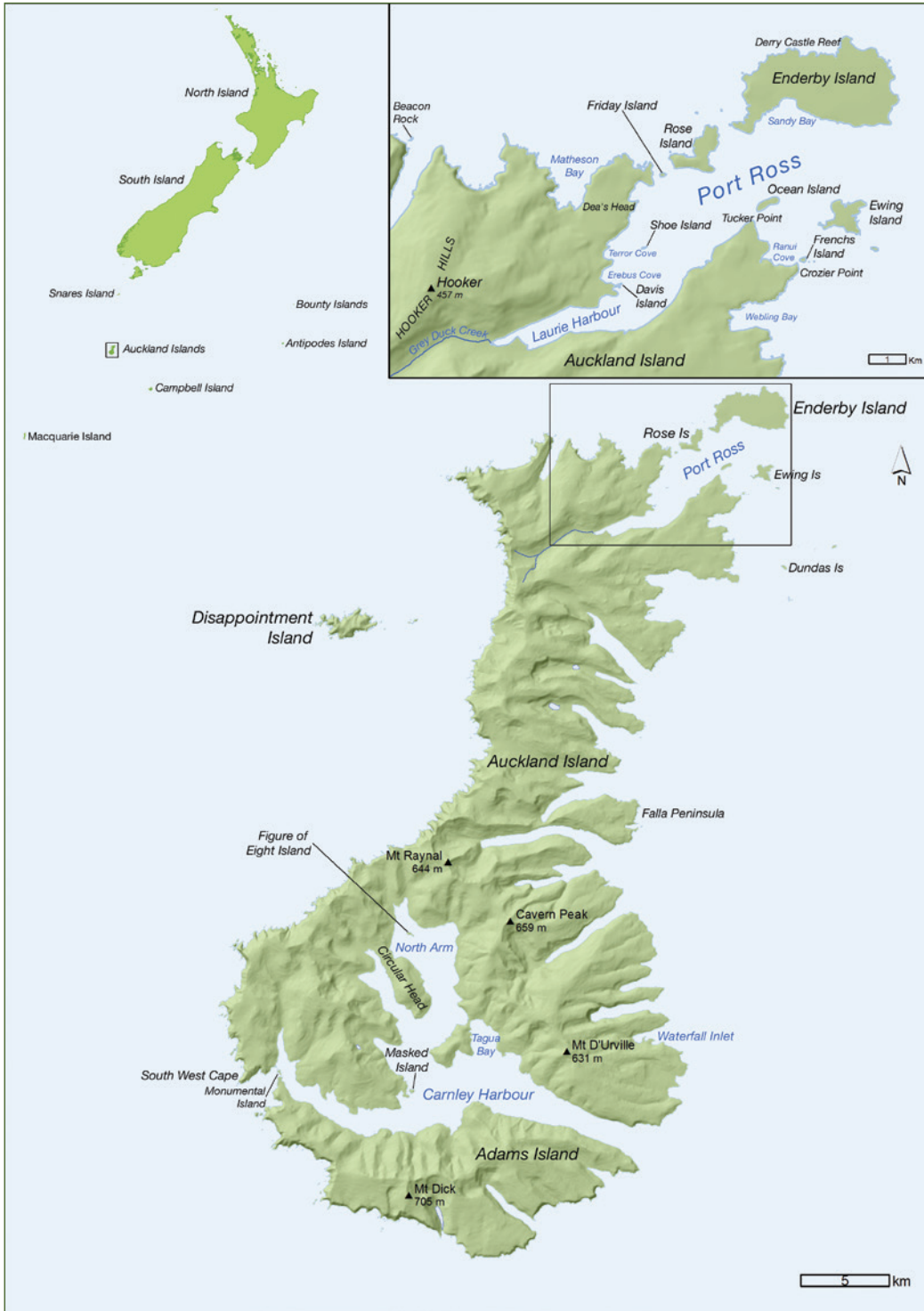


FIGURE 1. Auckland Island group showing island and location names referred to in the text.

erosion were noted during the Second World War (Sorensen archive in Alexander Turnbull Library [ATL]), and by the 1960s the population had reached around 50 (Fig. 2). Cattle were also introduced by Moffett to Rose Island in 1894 but had died out by the 1920s (Taylor 1971).

The cattle on Enderby Island were described in 1990 as hardy, small, and stocky. In Apr 1991 the Department of Conservation (DOC) shot 47 animals (25 of them females), but attempts to collect reproductive material (eggs and sperm) from shot cattle failed (P. McClelland, *pers. comm.* to authors, Jul 2019). In Feb 1993 only one cow and her heifer calf remained, and they were transported alive to the Dairy Unit at Massey University to establish a mainland breeding programme for the breed (www.rarebreeds.co.nz/enderby.html; viewed 4 Aug 2019).

Sheep *Ovis aries*

During the exploration era, sheep were first introduced to Auckland Island by James Clark Ross in 1840, and thereafter died out. They were reintroduced periodically during the Hardwicke settlement, and as food for castaways over the following six decades. Leaseholder Frederick Monckton ran

sheep briefly from 1874 to 1877 at Port Ross and on nearby Davis Island, and George Fleming ran sheep on Circular Head, Carnley Harbour, from 1900 (Dingwall 2009). However, by about 1910 sheep had died out completely on Auckland Island.

Three hundred sheep were introduced to Enderby Island with the founding of Hardwicke in 1849, but had been killed by the time Māori departed the Auckland Islands in 1856 (Taylor 1971). More sheep were landed on Enderby and Rose Islands in the 1890s, but had died out by the end of the decade. At least 20 sheep from Campbell Island were landed on Ocean Island in 1942 to provide meat for the coastwatchers, and in the following year they were recorded altering habitat, thereby exposing Auckland Island pipits (*Anthus novaeseelandiae aucklandicus*) to southern skua (*Stercorarius antarcticus*) predation. In 1944, 12 of the Ocean Island sheep were transferred to Rose Island, but all sheep on both islands were killed by the end of 1944. Sheep were also introduced to Adams Island during 1888–91, but died out by the mid-1890s. During this time a pair were landed on Figure of Eight Island in 1888, but died out the following year. Sheep were also observed on Monumental Island in 1890.

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FIGURE 2. A bull and heifer on Enderby Island, 1966. Image: Rowley Taylor.

TABLE 1. Key events in the ecological history of the Auckland Islands. Shipwrecks indicated where survivors landed.

Era	Date	Event
	13th century	Polynesian presence
Exploration	1806 1807–29 1840	European discovery Sealing and whaling expeditions Scientific expeditions
Settlement	1842–56 1849–52	Māori and Moriori from Chatham Islands (Maungahuka settlement) Europeans from Britain (Hardwicke settlement)
Shipwreck and farming	1864 1866 1874–75 1874–79 1880 1887 1891 1894–96 1900–10 1905 1907	<i>Grafton</i> and <i>Invercauld</i> shipwrecks <i>General Grant</i> shipwreck German Transit of Venus Expedition Monckton farm, Erebus Cove Castaway depots established; regular government inspections commenced <i>Derry Castle</i> shipwreck <i>Compadre</i> shipwreck Moffett farm, Enderby and Rose Islands Fleming farm, Carnley Harbour <i>Anjou</i> shipwreck <i>Dundonald</i> shipwreck
Scientific	1907 1910 1929 1934 1939 1941–45 1954 1954 1962–63 1966 1972–73 1978 1985	Philosophical Institute of Canterbury scientific expedition Adams Island Nature Reserve established Cessation of regular government inspections Auckland Islands Nature Reserve established <i>Erlangen</i> incident Cape Expedition/Second World War coastwatchers Dominion Museum/DSIR scientific expedition DSIR scientific expedition Dominion Museum scientific expedition Dominion Museum/DSIR scientific expedition Lands and Survey scientific expedition Alex Black sponsored expedition Lands and Survey/National Film Unit expedition
Conservation	1987 1989 1989–91 1993 1993 1998 2003 2003	Lands and Survey management plan published Department of Conservation scientific expedition Auckland Island goat eradication Enderby and Rose Islands mammal eradications Marine mammal sanctuary established UNESCO World Heritage status awarded Marine reserve established Auckland Islands archaeological and historical expedition

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TABLE 2. Status of introduced mammals on the Auckland Islands. Note that many of the short-lived introductions (sheep and goats particularly) were of 2–3 animals only. ‘Killed’ refers to animals killed for human consumption, where eradication was not an explicit objective. Scientific names are given in the main text.

Island & area	Species	Years	Status	References
Auckland I. (45,889 ha)	Pig	1807–present	Extant	Falla 1965; Challies 1975a
	Cat	<1840–present	Extant	McCormick 1884; Taylor 1968
	Mouse	<1840–present	Extant	Wilkes 1852; Taylor 1968
	Sheep	1840–43	Died out	Ross 1847; Taylor 1968
		1849–56	Died out	Taylor 1968
		1874–77	Died out	Krone 1900; Eunson 1974
		1888–93	Died out	Reischek 1889; Taylor 1968
		1900–07	Died out	Aston 1909; Taylor 1968
		Goat	1840–44	Died out
	1865–69		Died out	Norman & Musgrave 1866; Taylor 1968
	1888–1991		Eradicated	Taylor 1968; Chimera <i>et al.</i> 1995
	Dog	1842–87	Died out	McGhie 1888; Taylor 1968
		1900–06	Removed	Taylor 1968; Dingwall 2009
	Horse	1849–52	Removed	Taylor 1968
	Cattle	1849–52	Removed	Taylor 1968
	Possum	1890–?	Died out	Pracy 1962
Adams I. (9,693 ha)	Sheep	1888–?	Died out	Dougall 1888
		1891–96	Died out	Cockayne 1904
	Goat	1885	Died out	Taylor 1968
Enderby I. (695 ha)	Cat	?–1963	Died out	Tennyson 2020*
	Mouse	<1840–1993	Eradicated	Dumont d’Urville 1846; Torr 2002
	Rabbit	1840–c. 1846	Died out	Ross 1847; Taylor 1968
		1865–1993	Eradicated	Norman & Musgrave 1866; Torr 2002
	Goat	1850–?	Died out	G.M. Thomson 1922
		1865–89	Died out	Norman & Musgrave 1866; Taylor 1968
		1890–?	Died out	Cass 2014
	Dog	1842–56	Removed	Taylor 1968, 1971
		1887–95	Died out	Reischek 1889; Taylor 1968
	Pig	1807–56	Died out	Bristow 1810; Taylor 1968, 2006
		1867–87	Died out	Grey 1886; Eunson 1974
	Horse	1849–52	Removed	Taylor 1971
	Sheep	1849–56	Died out	Taylor 1968, 1971
		1890–1901	Died out	Taylor 1968; Cass 2014
	Cattle	1849–56	Killed	Taylor 1968, 1971
		1894–1993	Eradicated	Cockayne 1904; Turbott 2002

Island & area	Species	Years	Status	References
Rose I. (78 ha)	Rabbit	1850–1993	Eradicated	Taylor 1971; Torr 2002
	Sheep	1887–94	Died out	Joyce 1894; Taylor 1968, 1971
		1944	Killed	Turbott 2002
	Cattle	1894–<1920	Died out	Cockayne 1904; Taylor 1971
Ewing I. (58 ha)	Goat	1850–?	Died out	Waite 1909
		1895–1907	Died out	Cockayne 1904; Taylor 1968
	Pig	c.1851–?	Died out	Martin [1852]
	Rabbit	<1875–?	Died out	Krone 1900
Ocean I. (12 ha)	Goat	1865–1944	Eradicated	Bollons 1929; Turbott 1944
	Sheep	1942–44	Killed	Eden 1955; McEwen 2006
Masked I. (6 ha)	Cat	<1973	Extant	Rowley Taylor <i>pers. obs.</i>
	Mouse	<1907–present	Extant	Waite 1909; Taylor 1975
Figure of Eight I. (5 ha)	Sheep	1888–<1890	Died out	Dougall 1888; Chapman 1891
	Goat	1890–?	Died out	Chapman 1891
Monumental I. (4 ha)	Sheep	1890–?	Died out	Falla archive (Alexander Turnbull Library)
	Goat	1891–?	Died out	Rudge & Campbell 1975
Friday I. (1.6 ha)	Rabbit	1850–?	Removed/died out	Enderby 1875
Shoe I. (0.4 ha)	Pig	1840–?	Died out	McCormick 1884
Davis I. (0.2 ha)	Pig	1840–?	Dispersed	McCormick 1884
	Sheep	1874–75	Killed	Krone 1900

* Chapter 7 in this book.

Goats *Capra aegagrus hircus*

Goats were first introduced to Auckland Island c. 1840, but did not survive long (Taylor 1968). During the settlement era, goats were introduced to Enderby and Ewing Islands in 1850, but did not survive. During the shipwreck era, they were introduced again in 1865 to Auckland, Enderby, and Ocean Islands as a hunting resource for castaways. On Auckland Island they died out in the late 1860s, while on Enderby Island they persisted until dying out in the 1880s, with two further animals landed there in 1890 (Cass 2014). In about 1885, goats were again introduced for castaways on Adams Island, but died out the same year. In the late 1880s further goats were introduced to the Port Ross area of Auckland Island, and subsequently to Figure of Eight Island (1890) and

Monumental Island (1891). Two or three goats were released on Ewing Island in 1895, and they persisted there until at least 1904, when ‘a good many’ were seen (Cockayne 1904; Wilson 1966).

During the scientific expedition era, goats were eradicated from Ocean Island, starting in 1941, to make way for the introduction of sheep from Campbell Island (McEwen 2006). The last goats there were shot in 1944 (Graham Turbott archive in Auckland Museum).

Eradication of goats from Auckland Island was first proposed in 1968 (Rudge & Campbell 1977). By the 1970s about 100 goats persisted across about 4,000 ha of the Hooker Hills at the northern end of Auckland Island (Fig. 3). They spent their days feeding in small groups, and no reproductive behaviour, play or inactive rest was observed

(Rudge & Campbell 1977). From 1986–1987, 67 goats were transported alive to Landcorp properties on the South Island (Sherley 1988), but these captive animals had died out by the end of the 1990s (Brown 2002; Headland 2012). After more than a decade of debate (Rudge & Campbell 1977; Wardle *et al.* 1978; Campbell & Rudge 1984), eradication of goats from Auckland Island commenced in Nov 1989, when 105 goats were shot by two hunters (Brown 2002). The diet of goats on Auckland Island was studied through stomach contents of 49 of the shot animals, and consisted of 50 species of plant, of which three (southern rātā *Metrosideros umbellata*, snow tussock *Chionochloa antarctica*, and bull kelp *Durvillea antarctica*) made up over half of stomach contents by dried weight (Chimera *et al.* 1995). Goats were gradually transforming the vegetation, from tussock grassland to woody vegetation (Campbell & Rudge 1984). The few remaining goats on Auckland Island were shot in 1991 (Brown 2002).

Pigs *Sus scrofa*

Following its European discovery, pigs were rapidly introduced to Auckland Island, with Captain Abraham Bristow landing them on Enderby Island and at the northern end of Auckland Island in 1807 (Taylor 2006), presumably as a food source for visiting ships and castaways. The Auckland Island population was supplemented by an additional liberation on nearby Davis Island at Port Ross in 1840, with animals also landed on Shoe Island at the same time (McCormick 1884). Although pigs had not reached the southern end of Auckland Island by 1865 (Musgrave 1865; Norman & Musgrave 1866), they had reached 'large numbers' at the northern end of the island and were distributed across all habitats and altitudes. Within five years the population had crashed (Challies 1975a); however, today they remain widespread across the island (Figs 4, 5).

At the same time as their liberation on Auckland Island in 1807, pigs were also released on Enderby Island, and a different breed was liberated there again in 1842 with Māori settlement (Taylor 1971). They soon reached large numbers, with over 100 being seen at one time below the northern cliffs c. 1850 (Enderby 1875), but had died out or been killed by the time Māori left in 1856 (Taylor 1971). In 1867, additional pigs from Auckland Island were released on Enderby Island, but these too had died out by c. 1887, after being reported to be in poor condition the previous year (Grey 1886). The only record of pigs on Ewing Island was 'several droves' reported at the time of the Hardwicke settlement (Martin [1852]).

Pig impacts were already being noted on Auckland Island by the end of the exploration era, with extensive rooting (McCormick 1884), and consumption of the megaherbs *Stilbocarpa polaris*, *Anisotome latifolia*, and *Pleurophyllum criniferum* (Ross 1847). Depredation of birds (burrowing petrels) was first observed in 1874–75 (Krone 1900).

Direct predation impacts by pigs on Auckland Island have been recorded on white-capped mollymawk (*Thalassarche cauta steeadi*), northern giant petrel (*Macronectes halli*), Antarctic prion (*Pachyptila desolata*), yellow-eyed penguin (*Megadyptes antipodes*), Auckland Island shag (*Leucocarbo colensoi*), and southern black-backed gull (*Larus dominicanus*). The coastwatchers based at Ranui Cove observed the impacts of

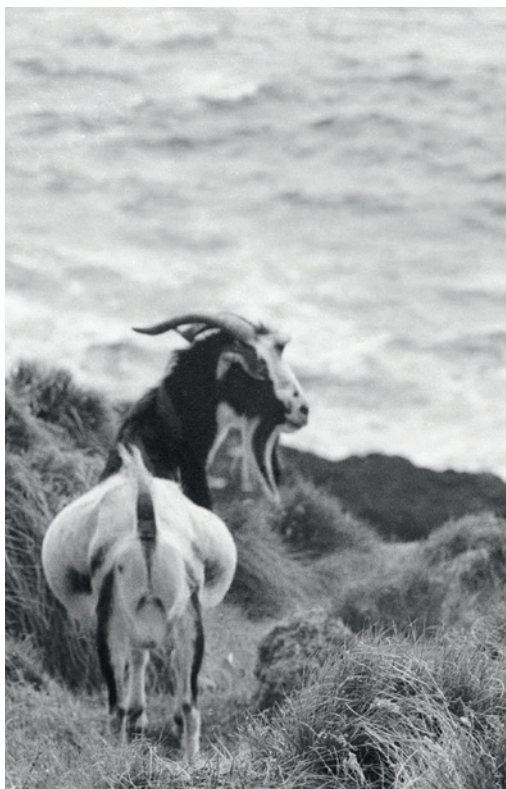


FIGURE 3. Feral goat east of Matheson Bay, Auckland Island, January 1973. Image: Mike Rudge, courtesy of John Campbell.



FIGURE 4. A feral pig on the shoreline at Musgrave Inlet, Auckland Island, January 2003.
Image: Tui De Roy/Roving Tortoise Photos.

pigs on Auckland Island shags nesting at Crozier Point, with accessible parts of the colony rooted up overnight and many eggs eaten (Turbott 2002). Several other colonies were similarly destroyed, as coastwatchers 'looked at a few such devastated areas' (Sorensen 1944–47, ATL MSX-7739, Book 3).

During the 'Cape Expedition', prion colonies on the mainland at Port Ross were mainly found along cliff edges. Members of the 1962–63 scientific expedition described pigs at Ranui Cove, Tucker Point, and Webling Bay 'driving wide trenches from inland towards the cliffs and thus coming in on [Antarctic prion] burrows from the rear' (Falla MS-Papers-2366-304, Auckland Islands Expedition 1962–63, bird notes and species list), and a boar shot at Webling Bay in Jan 1966 had prion remains in its stomach (R. Taylor, *pers. obs.*). Challies (1975a) described pigs excavating holes of up to 1.5 m³ and breaking roots up to 4 cm in diameter to access prion burrows during the 1972–73 expedition. Two of the eight pigs he sampled on the coast had remains of Antarctic prions in their stomachs. The few remaining petrel burrows were protected by large tree roots and rocks (Challies 1975b).

With the accessible shag and prion colonies destroyed, most of the recent reports of pig impacts on birds on Auckland Island have been at the accessible fringes of the white-capped mollymawk colony at South West Cape. Flux (2002) observed a sow with the head of a freshly killed mollymawk chick in her mouth, and a piglet chewing on a mollymawk foot. Another sow snuffled around freshly destroyed nest mounds, and a large boar was seen in another part of the colony where there were destroyed nests, and where feet and other remains of several chicks were seen. The pigs also had indirect impacts, as a mollymawk chick displaced from a destroyed nest was observed to be killed by a skua (Flux 2002). Thompson & Sagar (2008) reported that every white-capped mollymawk nest accessible to pigs was either empty or partly or wholly destroyed, and De Roy *et al.* (2008) observed a pig eating a mollymawk chick (Fig. 5).

Other large surface-nesting seabirds have also been eaten by pigs. The remains of a yellow-eyed penguin were found inside a pig stomach (Challies 1975a), pig faeces full of penguin feathers have

been found (Beer 2010), and the remains of a yellow-eyed penguin chick consumed by pigs was found south of Dea's Head in Jan 2018 (C. Miskelly, pers. obs.). Parker *et al.* (2016) reported on the remains of a northern giant petrel chick at Crozier Point in Dec 2015, with pig faeces, hoof-prints, and rooting throughout the area, and commented that due to the presence of pigs, 'the main Auckland Island is not viable habitat for northern giant petrels, nor for many native seabird species'.

Pigs likely had similar impacts on seabirds on Enderby Island, particularly when they were at high densities or near-starving before dying out in the mid-1850s and again in the mid-1880s (Grey 1886). The low density of burrow-nesting seabirds on Enderby Island compared with other islands in Port Ross is likely due to the former presence of pigs on Enderby Island combined with the slow population growth rate of petrels (Taylor 1971; Miskelly *et al.* 2020 – Chapter 2; French *et al.* 2020 – Chapter 4), possibly further exacerbated by the former presence of rabbits and cattle.

Range reductions in other seabirds on Auckland Island that are possibly attributable to pigs but

without observations of direct predation have been recorded for southern royal albatross (*Diomedea epomophora*), light-mantled sooty albatross (*Phoebastria palpebrata*), sooty shearwater (*Ardenna grisea*), subantarctic diving petrel (*Pelecanoides urinatrix exsul*), grey-backed storm petrel (*Garrodia nereis*), and eastern rockhopper penguin (*Eudyptes filholi*). Comparison of bird species with neighbouring pig-free islands reveals that, in conjunction with cats, pigs have also affected other vulnerable ground-nesting bird species, including New Zealand falcon (*Falco novaeseelandiae*), Auckland Island teal (*Anas aucklandica*), Auckland Island rail (*Lewinia muelleri*), Auckland Island snipe (*Coenocorypha aucklandica aucklandica*), Auckland Island banded dotterel (*Charadrius bicinctus exilis*), and Auckland Island pipit.

The diet of pigs on Auckland Island was studied through stomach contents of 16 pigs shot in summer 1972-73 (Challies 1975a), and 33 shot in Nov 1989 (Chimera *et al.* 1995). Their diet consisted of diverse mixed plant and animal species dominated by the megaherb *Anisotome antipoda* and

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FIGURE 5. A feral pig beside a white-capped mollymawk nest, from which it had just consumed a previously healthy chick, South West Cape, Auckland Island, Mar 2003. Image: Tui De Roy/Roving Tortoise Photos.

earthworms. On average, around 5–15% of the diet across all pigs consisted of bird remains, although in each sample the diet of just a few pigs contained a substantial proportion of birds. The movement of pigs on Auckland Island was studied Jun–Dec 2007; home ranges varied considerably in size, but were larger in the tussock highlands (D.P. Anderson *et al.* 2010). Pigs also forage in the intertidal zone, on kelp fly maggots, and kelp and other algae (R. Sagar *pers. obs.*; P. McClelland, *pers. comm.* to authors, Jul 2019).

Eradication of pigs from Auckland Island was first considered in 1968, but shortly thereafter deemed impractical and unnecessary (Challies 1975a). Eradication has been periodically actively pursued since that time (Russell *et al.* 2018). Seventeen live pigs were transported to quarantine in Invercargill in Jan 1999 in order to protect the genetic stock (Robins *et al.* 2003), as eradication was being actively promoted at that time (P. McClelland, *pers. comm.* to authors, Jul 2019). Because of their long isolation from humans and their disease-free state, the pigs of Auckland Island origin were considered to have importance for diverse medical research and development applications (Fan *et al.* 2005). However, the mainland breeding facility at Awarua was closed in 2016 (www.nzavs.org.nz/articles/auckland-island-pigs-where-are-they-now/; viewed 4 Aug 2019). Mitochondrial and nuclear DNA genetic studies of the Auckland Island pigs revealed them to be of European origin (Robins *et al.* 2003; Fan *et al.* 2005).

Dogs *Canis familiaris*

Dogs were first present in the Auckland Islands with Polynesian voyagers in the thirteenth century. Kuri (Polynesian dog) gnaw marks on New Zealand fur seal (*Arctocephalus forsteri*) and New Zealand sea lion (*Phocarctos hookeri*) bones from that era have been recorded on Enderby Island (A. Anderson 2005). During the settlement era, Māori introduced dogs to Auckland Island, which escaped and ran wild across the entire island but had died out by the time Māori left in 1856 (Taylor 1968). Dogs of European origin, likely to have been lost or abandoned by sealers, were also sporadically reported across Auckland Island from 1864 to 1887. Dogs were similarly reported on Enderby Island throughout the shipwreck

era in the second half of the nineteenth century, but had disappeared by the mid-1890s. Dogs were associated with George Fleming's farm on the western shore of Carnley Harbour from 1900 to 1906 (Dingwall 2009), and have been used in the conservation era for management of other pest mammals (e.g. rabbits and pigs), as well as searching for birds (teal and snipe).

Cats *Felis catus*

Cats were first recorded on Auckland Island in 1840 at Terror Cove, Port Ross (McCormick 1884), presumably having been introduced earlier by sealers, probably in response to nuisance from mice. Thereafter they were regularly observed throughout the nineteenth and twentieth centuries. However, it was not until the Cape Expedition during the Second World War that cat impacts began to be recorded. Tamed feral cats adopted as companion animals by the coastwatchers at the two stations at Ranui Cove (Port Ross) and Tagua Bay (Carnley Harbour) probably killed more than 100 birds during 1942–45 (Fig. 8). Surviving records reveal that the cats at Ranui Cove killed at least 60 Antarctic prions (many carrying eggs), with several observers reporting the station cats killing 1–3 prions per night during Oct–Dec in 1942 and 1943 (see Supplementary material). Other species killed by the station cats at Ranui Cove included four white-faced storm petrels (*Pelagodroma marina*), two silvereyes (*Zosterops lateralis*), and one each of black-bellied storm petrel (*Fregetta tropica*), yellow-crowned parakeet (*Cyanoramphus auriceps*), and song thrush (*Turdus philomelos*). There were fewer seabirds around Tagua Bay, but the station cats there were recorded killing several sooty shearwaters and prions, a fledgling yellow-crowned parakeet, and a bellbird (*Anthornis melanura*).

Away from the coastwatcher buildings, cat impacts were most apparent at colonies of two small seabird species. Robert Falla reported 40–50 cat-killed white-faced storm petrels at Crozier Point in Jan 1943, eight cat-killed Antarctic prions at Ranui Cove, and numerous remains of prions at Erebus Cove in Sep–Oct 1943. Brian Bell found many remains of cat-killed Antarctic prions along the track to Crozier Point in Dec 1962, and commented that nesting by these birds was confined to cliff faces and inaccessible ledges as



258 **FIGURE 6.** A feral cat pauses while eating a nearly fledged white-capped mollymawk chick at South West Cape, Auckland Island, in late August 2019. *Image: Stephen Bradley.*



FIGURE 7. A feral cat feeding on a yellow-crowned parakeet, Smith Harbour, Auckland Island, September 2019. *Image: Finlay Cox.*

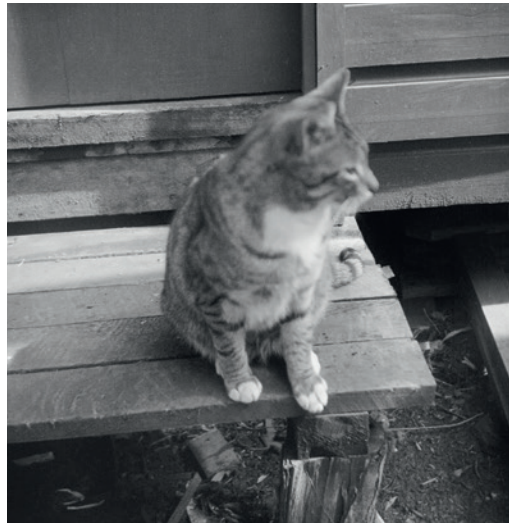


FIGURE 8. 'Toodles' at Ranui Cove station, 1944 or 1945. The Second World War coastwatchers tamed several feral cats as companion animals at both Ranui Cove and Tagua Bay. *Image: Allan Eden; courtesy of Richard Nester, Department of Conservation.*

'any bird landing above appears to fall an immediate prey to the feral cats' (details in Supplementary material). John Gardiner reported dozens of prions killed by cats at Dea's Head in Jan 1976, and Phil Thomson found over 100 cat-killed prions between Erebus Cove and Grey Duck Creek in early 1983 (Gardiner 1986; P. Thomson 1986). Three years later, John Campbell estimated c. 100 freshly killed prions along 2.5 km on the south side of Laurie Harbour (Campbell 1986). Few prions now remain on Auckland Island (Miskelly *et al.* 2020 – Chapter 2).

Direct predation impacts by cats away from the coastwatcher stations have also been observed on white-capped mollymawks, Auckland Island shags, red-billed gulls (*Chroicocephalus novaehollandiae scopulinus*), sooty shearwaters, subantarctic diving petrels, black-bellied storm petrels, and yellow-crowned parakeets (Figs 6, 7). Land birds still extant on Auckland Island are wrier than those on neighbouring cat-free islands, and are less inclined to forage on the ground (Turbott 2002). Comparison of bird species with those on neighbouring cat-free islands reveals that in conjunction with pigs, cats have also affected other vulnerable ground-nesting bird species, including New Zealand falcon, Auckland Island teal, Auckland Island rail, Auckland Island snipe, Auckland Island banded dotterel, and Auckland Island pipit, and also red-crowned parakeet (*Cyanoramphus novaeseelandiae*) (Miskelly *et al.* 2020 – Chapter 2).

An old cat dropping containing bird remains was found on Masked Island (100 m from the main island) in Feb 1973 (R. Taylor *pers. obs.*), and cat-killed prions, sooty shearwaters, white-headed petrels (*Pterodroma lessonii*), and a blackbird (*Turdus merula*) were found there in Feb 1993 (Graeme Elliott, *pers. comm.* to CMM, Oct 2018). However, this 6 ha island is unlikely to have a resident cat population. A cat mandible was found in the Sandy Bay dunes on Enderby Island on 18 Jan 1964, which suggests that cats may have once been present there also but died out (Tennyson 2020 – Chapter 7 in this book).

The diet of cats on Auckland Island was studied through analysis of one cat stomach and 11 scats in summer 1972–73 (Taylor 2002), and 11 cat stomachs and 40 scats in winter 2007 (Harper 2010a). They had consumed land birds (bellbirds, a parakeet,

and a blackbird) and mice, supplemented by seabirds (a subantarctic diving petrel and an Auckland Island shag) and insects. Cats are also known to consume crustaceans and shellfish in the intertidal zone (R. Sagar, *pers. obs.*). Eradication of cats from Auckland Island was first considered in 1987 (Department of Lands and Survey 1987).

Brushtail possums *Trichosurus vulpecula*

Nine possums were introduced to Auckland Island in 1890 (Anonymous 1891; Pracy 1962) probably by the crew of the *Hinemoa* at Erebus Cove on 25 Oct 1890 (based on information in Cass 2014). Having not established, they must have died out.

Rabbits *Oryctolagus cuniculus*

Captain Cole of the whaling vessel *Huntress* of New Bedford released four rabbits at the Auckland Islands in Mar 1837 (journal of John S. Abbott, New Bedford Whaling Museum PMB microfilm O285; Rhys Richards, *pers. comm.* to CMM, 27 Jul 2019). However, this record is not included in Table 2, as it is not known which island within the group the animals were released on. During the settlement era, rabbits were introduced to Enderby Island in 1840 but died out not long after. Rabbits were then introduced to Friday Island in 1850, but not long after this most (perhaps all) were relocated to Rose Island by Charles Enderby, and they became numerous there (Fig. 9A). Twelve rabbits of the English silver-grey breed from Australia (not Argente de Champagne as frequently reported), different to those of New Zealand origin on Rose Island, were then introduced to Enderby Island in 1865 as food for castaways (Norman & Musgrave 1866; Taylor 1971; Fig. 9B). They became abundant by the end of that decade, eventually numbering 5,000–6,000 in 1991 (Torr 2002), although numerous only on certain parts of the island (Taylor 1971). There was a single report of rabbits on Ewing Island (or possibly Ocean Island) in Feb 1875 (Krone 1900).

It was not until the Cape Expedition during the Second World War that rabbit impacts began to be recorded, predominantly through habitat transformation, and as a food resource for southern skua, thereby increasing their population and encouraging elevated 'hyperpredation' of native birds (Bell 1963). On Enderby Island the



FIGURE 9. A. A rabbit on Rose Island, January 1973. B. A rabbit on Enderby Island, 1973. Rabbits were eradicated from both islands in 1993. Images: Rowley Taylor.

megaherbs *Stilbocarpa polaris* and *Anisotome latifolia* were restricted to cliffs (Fig. 10), and *Pleurophyllum criniferum* had been eliminated from the island by 1993 (Torr 2002). The diet of rabbits on Enderby and Rose Islands was studied through the stomach contents of six rabbits in Nov 1954 (Taylor 1971), and comprised mainly annual poa (*Poa annua*) and a *Scirpus* sp. (Taylor 1971). Compared with those in mainland New Zealand, Enderby Island and Rose Island rabbits had a shorter breeding season and their litters were smaller. Skeletal analysis also revealed that on average they lived much longer, almost certainly due to lack of human control (Taylor 2018). In Sep 1992, 50 rabbits (15 does and 35 bucks) from Enderby Island were captured, of which 49 were transported live to quarantine on Matiu/Somes Island, Wellington, to start a breeding programme. In Feb 1993 DOC eradicated rabbits from Enderby and Rose Islands using aerially distributed 0.002% brodifacoum cereal pellets dyed green, followed by hunting with a dog, shooting, spotlighting, and trapping (Torr 2002).

Rats *Rattus* spp.

Rats have never become established on the Auckland Islands. A record of abundant rats present in a whalers' hut on Enderby Island in Mar 1840 likely confuses mice with rats, when Dumont d'Urville (1846) reported that some of his officers had a disturbed night: 'pendant la nuit leur demeure était envahie par des bandes de rats qui dévoraient tout, jusqu'aux hamacs dans lesquels ils couchaient' [during the night their home was invaded by bands of rats that devoured everything, even to the hammocks in which they slept]. Headland (2012) stated that 'the colonial settlement at Port Ross was also troubled by rats and there are reports of the vessels being fumigated to remedy them', but at the time such observations were refuted by Enderby (1850), who commented that 'the English mouse appears to thrive about the houses, and I hear that there are rats, but they have not yet crossed my path'. Further (apparently erroneous) reports of rats were made by Colonel Colquhoun (in Murchison 1847), Raynal (1880: 94), Greig (1886), and Ritchie (1971, quoted in Taylor 1975). The rat-free status of all of the Auckland Islands was confirmed during the 1972-73 expedition (Taylor 1975).

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FIGURE 10. The megaherb *Anisotome latifolia* growing (and flowering) beyond the reach of cattle and rabbits, Enderby Island northern cliffs, January 1966. Image: Rowley Taylor.

Mice *Mus musculus domesticus*

At the end of the exploration era, mice were first recorded on Auckland Island in 1840 at Port Ross (Wilkes 1852), presumably having been accidentally introduced by sealers. Thereafter they were a persistent human nuisance. They are distributed across all habitats and altitudes, preferring tussock, where their population fluctuates with mast-seeding (Harper 2010b; Russell *et al.* 2018; Fig. 11). They are also on Masked Island, having first been reported there in 1907 (Waite 1909). There are no records of direct impacts of mice on birds on Auckland Island, but comparison of invertebrate species with those on neighbouring mouse-free islands reveals lower abundances of Auckland Island wētā (*Dendroplectron aucklandense*) and large weevils (particularly *Oclandius laeviusculus*), indicating that mice may have reduced some food sources that may be used by birds. Further to such gross changes, mice may have altered invertebrate community composition in more subtle ways, although seabird absence and the impacts of pigs also play a role (Russell *et al.* 2018).

Mitochondrial DNA genetic studies of mice from Auckland Island reveal that they are of the subspecies *M. musculus domesticus*, similar to those introduced to mainland New Zealand (Searle *et al.* 2008; King *et al.* 2016), but nuclear DNA

genetic studies reveal that they have an independent origin with North American linkages (Veale *et al.* 2018). When mice arrived on Enderby Island is unknown, but Dumont d'Urville (1846) noted rodents being present there in Mar 1840, suggesting a contemporaneous invasion with Auckland Island. The Department of Conservation eradicated mice from Enderby Island in Feb 1993, at the same time as rabbit eradication (Torr 2002).

Humans *Homo sapiens*

Besides their role in the introduction of other mammals, humans also had other direct and indirect impacts on birds on the Auckland Islands. During Polynesian presence in the thirteenth century, seabirds (Auckland Island shag, yellow-eyed penguin, sooty shearwater, white-chinned petrel *Procellaria aequinoctialis*, white-headed petrel, southern royal albatross), and Auckland Island teal, as well as New Zealand sea lions and New Zealand fur seals, were all consumed (A. Anderson 2005).

During the exploitation era, New Zealand fur seals were rapidly exterminated, within 20 years, and New Zealand sea lions were greatly reduced in number (Taylor 1971). This is likely to have had multiple effects on bird populations through habitat changes, and through virtual elimination of seal predation and competition.

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FIGURE 11. A mouse at Smith Harbour, Auckland Island, Sep 2019. Image: Finlay Cox.



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FIGURE 12. Impacts of browsing mammals on ground-cover vegetation under forest on islands in Port Ross. **A.** Enderby Island while cattle and rabbits were present, Feb 1985. **B.** A dense stand of the megaherb *Stilbocarpa polaris* on Ocean Island in January 1973, 28 years after sheep were eradicated. *Images: Rowley Taylor.*

Sealers are likely to have inadvertently introduced seeds of the tree daisy *Olearia lyallii* to Ewing Island (Wilmshurst *et al.* 2015), and, potentially accelerated by the habitat changes caused by goats and pigs, this has greatly altered the forest structure there. Other species such as harakeke (*Phormium tenax*), koromiko (*Veronica salicifolia*), and kōtukutuku (*Fuchsia excorticata*) are known plant introductions that were probably intentional (Walls 2009). During the exploitation and settlement eras, forest clearance and intentional fires occurred, mainly around Port Ross and on Enderby Island (Taylor 1971), along with habitat transformation through the

introduction of non-native plant species such as annual poa, chickweed (*Stellaria media*), sow thistle (*Sonchus asper* and *S. oleraceus*), common daisy (*Bellis perennis*), sheep's sorrel (*Rumex acetosella*), white clover (*Trifolium repens*), browntop (*Agrostis capillaris*), and jointed rush (*Juncus articulatus*) (Johnson & Campbell 1975; Walls 2009). Some invertebrates were probably also introduced (Gressitt & Wise 1971).

Māori settled in two parties, on Enderby Island and at Tucker Point, Port Ross, from 1842 to 1856, while Europeans settled in Port Ross and farmed on Enderby Island from 1849 to 1852 (Fraser 2014). Through the exploitation to shipwreck eras, southern royal albatross and other seabirds were eaten by humans, the albatross to such an extent that they were exterminated from Enderby Island by the 1870s but began recovering there from the 1940s (French *et al.* 2020 – Chapter 4). Yellow-eyed penguins and northern giant petrels also became scarce or were absent in Port Ross over the settlement period (Miskelly & Taylor 2020 – Chapter 1; Miskelly *et al.* 2020 – Chapter 2).

Shipwreck survivors had localised, short-term impacts on birdlife, with both the *Grafton* and *Invercauld* survivors consuming hundreds of Auckland Island shags (from Carnley Harbour and Rose Island, respectively) in 1864–65, and an estimated 12,000 white-capped mollymawk chicks being consumed by the survivors of the *Dundonald* wreck on Disappointment Island in 1907 (Miskelly & Taylor 2020 – Chapter 1).

The Auckland Island merganser (*Mergus australis*) was last seen in 1902, the final individuals all being collected for museums, alongside many other bird species also killed for museum collections or simply for sport (Taylor 1971; Miskelly & Taylor 2020 – Chapter 1).

Discussion

The history of mammal introductions to the Auckland Islands mirrors that of other subantarctic islands (Headland 2012), with introductions rapidly following discovery and occurring during periods of exploitation and settlement, and supplementary introductions during the shipwreck era. Introductions were generally motivated by acclimatisation or shipwreck provisioning.

As well as mammal introductions, attempts were made to introduce chickens (*Gallus gallus*), Muscovy ducks (*Cairina moschata*), geese (*Anser anser*), and weka (*Gallirallus australis*), but without success (Miskelly *et al.* 2020 – Chapter 2). Intentional establishment of most introduced mammal species took multiple attempts, and other work has shown that a population was generally guaranteed to persist on a New Zealand island only once established for over 25 years (Duncan & Forsyth 2006). Mice were undoubtedly an inadvertent introduction, but despite the broad range of pathways by which rodents might have arrived at the Auckland Islands, rats have apparently never established.

No introduced mammals have ever been reported on Disappointment Island, likely reflecting its low utility value to humans, particularly given the difficulty of accessing this small island on the exposed western side of the group. Farm stock were the only mammals ever reported being introduced to the larger Adams Island, but they died out rapidly, probably due to the harsh environment at the more exposed southern end of the group, and the small number of animals introduced at each release. Both Disappointment and Adams Islands thus serve as benchmarks for comparative analysis of the impacts of introduced mammals on the other islands of the group (Miskelly *et al.* 2020 – Chapter 2; Elliott *et al.* 2020 – Chapter 3 in this book; Walker *et al.* 2020 – Chapter 5 in this book), and indeed Adams Island is the largest island in New Zealand on which introduced mammalian predators have never become established (Townes *et al.* 2013).

The introduced mammals that naturalised on the Auckland Islands (cattle, goats, pigs, cats, rabbits, and mice) together had a broad suite of impacts on the biodiversity of the islands. Given the different associations of introduced herbivorous mammals on different islands, it is generally possible to ascribe certain impacts to particular species. However, in their totality as a group, the herbivorous mammals altered plant species composition, leading to habitat transformation such as tussock to forest (goats) or tussock to short sward (rabbits), and alteration of ecosystem processes such as soil turnover and erosion rates (Fig. 12). The native megaherbs were particularly strongly affected, being suppressed to

zero density except on inaccessible cliff ledges (Fig. 10). However, there were differing responses to browser presence and subsequent eradication even on superficially similar adjacent islands. Red-crowned parakeets persisted in the presence of cattle on Enderby Island, but did not return to Rose Island until the 1950s, after sheep and cattle died out (Miskelly *et al.* 2020 – Chapter 2). Tomtits died out on Rose Island soon after rabbits were eradicated in 1993, but are still present on Enderby Island following the eradication of rabbits, mice, and cattle in the same year (Miskelly *et al.* 2020 – Chapter 2). These differences among islands are likely due to the extent of different plant communities, and to interactions between land-bird species as they respond differentially to browser presence or absence (discussed further by Taylor 1971, and Miskelly *et al.* 2020 – Chapter 2).

The predatory impacts of cats and pigs are harder to disentangle, as both species are present and widespread on the same island, but they can be separated using direct observations of predation. Both had strong impacts on seabirds and ground-nesting land birds, but cats had the strongest impact on the small- to medium-sized burrowing seabirds, efficiently hunting out colonies and entirely and rapidly extirpating them. Such impacts continued for well over a century following introduction of cats, suggesting that seabird populations were originally very large, with densities likely comparable with those still found on adjacent Adams Island in the absence of cats and pigs (Elliott *et al.* 2020 – Chapter 3). The absence of ground-nesting birds from Auckland Island is also almost certainly attributable to predation by pigs and cats. The only native bird species regularly reported by observers on Auckland Island since 1998 have been bellbird, tui, tomtit, and silvereye, with all other native species encountered more frequently on adjacent islands lacking cats and pigs (Miskelly *et al.* 2020 – Chapter 2). Beyond lethal impacts, the presence of cats has also apparently increased wariness in arboreal land birds on Auckland Island, reflected in a reluctance towards ground foraging (Turbott 2002).

Auckland Island is among the earliest sites in New Zealand to be colonised by mice, but historically these have been considered only a human nuisance, and no direct observations of impact

on the biodiversity of Auckland Island have been recorded. However, the rarity of species such as Auckland Island wētā and large weevils (known to be preferred prey of mice) from Auckland Island suggests that mice have played a role, although the weevils are also strongly associated with megaherbs, which pigs have suppressed. The entomology of the Auckland Islands is not well known beyond species descriptions (Gressitt & Wise 1971), but differences in invertebrate community composition among islands also imply a role of mice (Russell *et al.* 2018). On nearby Antipodes Island, the eradication of mice led to immediate and strong recoveries in invertebrates and land-bird species (Russell *et al.* in press). Mice are also an important component of cat diet, potentially to the extent that they may even maintain cat populations on Auckland Island over winter when seabirds are absent (Russell & Kaiser-Bunbury 2019). As occurred with rabbits on Macquarie Island (Taylor 1979), this creates a hyperpredation scenario (Ringler *et al.* 2015), facilitating the persistence of cats and their ongoing impact on native birds. A similar hyperpredation scenario potentially also took place with rabbits on Enderby Island, where they probably supported the southern skua population. This impact was further exacerbated by browsing mammals removing much of the ground cover on Enderby Island, exposing species like snipe, teal, dotterel, and pipit to aerial predators (French *et al.* 2020 – Chapter 4). All these species are now far more abundant on Enderby Island (after removal of browsing mammals) than they were in the 1940s to 1970s, when cattle and rabbits were present and pigs had died out only 60–90 years previously. While some ‘post-pig’ vegetation recovery and re-establishment of a breeding population of Auckland Island banded dotterels occurred in the presence of cattle and rabbits (Taylor 1971; Walker *et al.* 1991), the snipe population on Enderby Island has exploded since eradication of cattle, rabbits, and mice, and New Zealand falcon has re-established as a breeding species (French *et al.* 2020 – Chapter 4; Shepherd *et al.* 2020 – Chapter 16 in this book). Such indirect impacts mediated by introduced mammals play an important role when considering the total consequences of introduced species on islands (Russell & Kaiser-Bunbury 2019).

Eradications of introduced mammals have been successful in the Auckland Islands; indeed, the eradication of mice from Enderby Island remained a record for the largest island from which mice had been removed well into the twenty-first century (Elliott *et al.* 2015). Given their early introduction dates, and prolonged persistence in isolation from the mainland, many of the mammals introduced to the Auckland Islands had retained unique breed traits, while also adapting to the subantarctic environment. This made them of interest to the Rare Breeds Society of New Zealand, which was involved in repatriation of live cattle, goats, pigs, and rabbits back to quarantine on the mainland prior to their eradications from the Auckland Islands. The pigs of Auckland Island are also considered to have various medical applications due to their disease-free state from prolonged isolation. Nonetheless, eradication of the pigs, cats, and mice from Auckland Island would complete the removal of introduced land mammals from the New Zealand subantarctic World Heritage Site region (Roberts 2007). The eradication of any of these species would enable recoveries of components of the biodiversity of Auckland Island, but the simultaneous eradication of all three species is recommended as the appropriate management action to minimise operational costs while maximising restoration opportunities (Dowding *et al.* 2009). Such an eradication programme may have some non-target impacts on birds, potentially including New Zealand falcons, parakeets, tomtits, and Auckland Island pipits, but these are considered manageable and negligible relative to the benefits that would be accrued to these and other species following mammal eradication.

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