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Distribution, population status and trends of grey-faced petrel (*Pterodroma macroptera gouldi*) in the northern North Island, New Zealand

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Abstract The distribution, status and trends of grey-faced petrel (*Pterodroma macroptera gouldi*) populations are summarised from historical records from as early as the 1800's, but predominantly over a 40 year period from the 1970's and 1980's to the present day. We tallied the most recent of 104 island population estimates to give a total range of 72,398-286,268 burrows over a minimum area of 37,967 ha. On predator-free islands (n = 9) during winter, the mean burrow occupancy rate was 60% (± 18 % SD). Fewer than 1000 burrows were detected from 20 mainland sites over an unspecified area. Implications for the conservation of this species are discussed.

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INTRODUCTION

Grey-faced petrel or oi (*Pterodroma macroptera gouldi*) is a gadfly petrel endemic to New Zealand. Grey-faced petrels are predominantly an oceanic species, foraging across the Pacific Ocean and the Tasman Sea on sparsely distributed squid, small fish, and krill (Imber 1973; MacLeod *et al.* 2008). They are typically encountered on land only when they start breeding (Imber 1976; Miskelly *et al.* 2009).

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Grey-faced petrels typically nest in burrows in the northern half of the North Island/Te Ika a Maui. They occur from near New Plymouth in the west, north to the Three Kings/Manawatawhi Islands, and south to Portland Island in the east (Taylor 2000). Burrows are usually found in deep soil, and tend to be larger than those of most other seabirds in this region (Buxton *et al.* 2015).

Grey-faced petrel adults can live up to 41 years or more (New Zealand National Bird Banding Scheme 2014). Fledged chicks spend the first few years entirely at sea, returning to breeding colonies at 3-5 years old (Jones *et al.* 2011) and first breeding

typically at 8-10 years old (G. Taylor, *pers. obs*.). One white egg (68 mm x 48 mm, 86 g) is laid during winter (mid-June to late July), and incubated by both sexes for ~54 days, during which time the egg may be left unattended for 1-5 days (Heather & Robertson 2015; Imber 1976). Hatching occurs from mid-August to mid-September and the chick is guarded for 1-3 days, and then fed on average every 4 days. Most chicks fledge during December (Imber 1976).

Traditionally, grey-faced petrel chicks or northern muttonbird were harvested by northern iwi, and are still legally harvested on some offshore islands in the Bay of Plenty and Hauraki Gulf. Harvesting mostly occurs on gazetted islands within public conservation land that give effect to Maori manuwhenua or hereditary harvesting. Harvesting was largely discontinued during the 1960's onwards due to Maori concern over declines in the population (Lyver *et al.* 2008). Rahui or traditional temporary bans on harvest were put in place in 1984 on Fanal/Motukino Island off Great Barrier Island. Muttonbirding on Motukokako/Piercy Island or Hole in the Rock in the Bay of Islands continued until about 1970 (Cameron & Taylor 1991). Hauraki Maori iwi have established Mauiora ki nga oi using traditional and scientific knowledge to sustainably manage harvesting (Lyver *et al.* 2008).

On the mainland, loss of nesting habitat, human disturbance, and predation by introduced mammals, particularly feral cats (*Felis catus*), dogs (*Canis lupis*), feral pigs (*Sus scrofa*), Norway rats (*Rattus norvegicus*), ship rats (*R. rattus*) and stoats (*Mustela erminea*) are the greatest threats to grey-faced petrel populations (Taylor 2000). While a few birds are caught on fishing long-lines, commercial fishing is not a major source of grey-faced petrel mortality in the New Zealand EEZ (Bell *et al.* 2003) but birds may be at more risk from fisheries in the high seas, where this species predominately feeds (Taylor 2000; MacLeod *et al.* 2008).

Dense colonies of seabirds act as ecosystem drivers, aerating the soil and supporting larger populations of plants, birds, insects and lizards, as well as adjacent coastal ecosystems, which in turn improve the rate of ecosystem functioning. Insect and lizard populations, as well as plants benefit from the high nutrient content of guano that is dug into the ground (Mulder *et al.* 2009). The recovery of some coastal plants is linked to the recovery of seabird populations (Norton *et al.* 1997). The decline of seabirds on the mainland to scattered colonies of typically fewer than 50 pairs has resulted in the loss of nutrient transfer, particularly of nitrogen, from the sea to the land, resulting in declines in terrestrial productivity and biodiversity (Mulder *et al.* 2009).

The total population of grey-faced petrel has been previously estimated at 100,000 - 1,000,000 pairs (Robertson & Bell 1984), 200,000-300,000 breeding pairs (Taylor 2000), and 250,000 pairs (Heather & Robertson 2015). In this paper, we summarise available published and unpublished information to determine the current population distribution, status and trends of grey-faced petrel in northern New Zealand.

METHODS

The published literature was summarised and the most up-to-date unpublished data was sought from the Ornithological Society of New Zealand, Department of Conservation (DOC), Regional Councils, other government agencies and local community groups.

The majority of estimates of grey-faced petrel populations were based on opportunistic observations rather than systematic surveys. Most of these island surveys were undertaken by the Auckland University Field Club and Offshore Islands Research Group (OIRG), and published in the journal *Tane*. Islands were usually visited during the University holidays (May, August and January). The Field Club and OIRG were very active during the 1970's, but this activity decreased during the 1980's then ceased in 1999. Since then, the majority of counts were undertaken by individuals, Regional Councils and DOC.

The distribution of grey-faced petrel on islands was plotted in ArcGIS (ESRI 2011) and summarised in Microsoft Excel 2007 and tabular form. Data recorded included region, island group, island or site name, location (easting and northing), size (ha; based on Taylor 1989), and estimates of the number of burrows and/or number of pairs and/or total number of individuals.

Difficulties in compiling this data base mainly related to inconsistencies in the naming of islands and locating mainland colonies. Many islands had the same and/or multiple names, and location was often not recorded using standard map references.

Grey-faced petrel distribution

The location and area over which grey-faced petrel nested on the mainland was mapped based on descriptions of vegetation and landform, and therefore is an approximate location. As there was insufficient information to determine which islands had potential burrow habitat, we identified 200 islands > 1 ha within the known range of grey-faced petrel with trees visible via GOOGLE Earth satellite images. Deep soil that supports large trees will be deep enough for burrows, as tree roots reduce the risk of burrow collapse (Buxton *et al.* 2015). Although there were numerous islands and rock stacks < 1 ha that may support petrel burrows, the probability of detecting burrows on these sites was

low, and as a consequence, these sites are under-represented. Grey-faced petrel population data was collated mainly from the 1970's onwards from 105 islands, comprising 37,967 ha, predominantly on the east coast of the northern North Island.

Mainland population estimates based on observations

The number of burrows on the mainland was mainly based on observational estimates and qualitative descriptions (*e.g.*, few, frequent, common). The time of year counts were estimated was seldom recalled or recorded.

Island population estimates based on observations

The number of burrows, pairs, or individuals (breeding and non-breeding birds) in the air, on land and on water was based on observations at unrecorded or various times of the year. The area surveyed and search effort was not recorded. Repeated observations were undertaken for 35 islands, the majority of which (n = 16) were in the Auckland region. Between the 1940's and 2015, grey-faced petrel populations were estimated on an average of 19 islands (range 3-43) per decade.

Population estimates were sometimes descriptive (*e.g.*, "few"), or a range (*e.g.*, < 20), recorded as an order of magnitude (*e.g.*, 10-100), or were based on extrapolated counts in proportion to island area. To allow estimates to be tallied, we assigned a range (*e.g.*, the range for <20 was 1-20, and the range for "a few" was 1-10).

Island population estimates based on systematic sampling

Systematic sampling is a rigorous, repeatable method over a defined area that records search effort and time taken. Sampling methods included complete counts, banding studies (mark recapture), transects and plots. Monitoring through time (repeated sampling) occurred on some islands, typically during the winter breeding period and again during the spring.

Complete counts are time intensive and tended to be undertaken on small islands. Banding studies are similarly time intensive, as hundreds of birds must be banded and recaptured before accurate population estimates can be made. The most common monitoring method was counts of burrows in plots or on transects. Transects and plots were often placed in areas that were convenient to sample (existing track systems on islands) and contained known colonies. Plot locations were therefore not necessarily representative of the island as a whole.

Population estimates were given as a mean and a range. Results were often extrapolated to the island as a whole, potentially over-estimating the population if there were large areas of unsuitable breeding habitat (*e.g.*, rocky ground, low dense shrubs). A few studies established a sampling design that was representative of island habitat, and recorded mean and credibility intervals (CI) or standard error (SE) or standard deviation (SD).

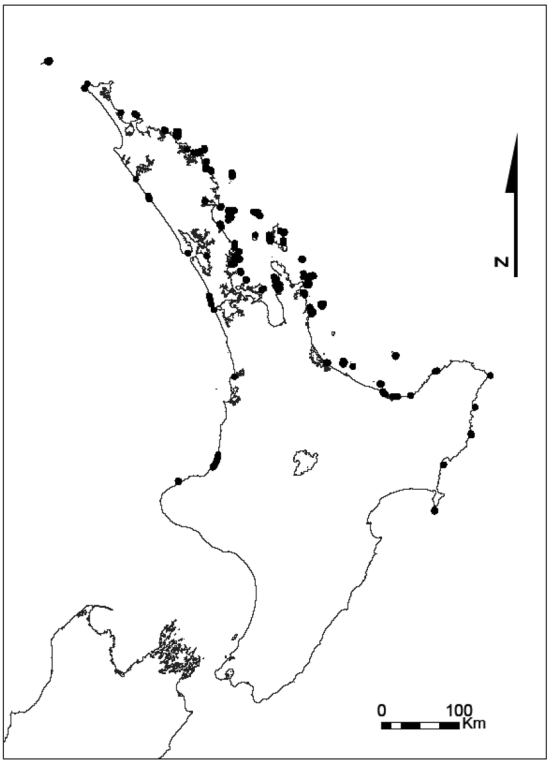

Fig. 1. Distribution of grey-faced petrel. Dark circles represent breeding sites on the mainland and islands.

Burrow occupancy

Burrow occupancy by an adult, egg or chick varies over the course of a breeding season, peaking about mid- to lateJuly (soon after most laying is completed). Estimates of burrow occupancy were commonly determined by counting all burrows within an area, and assessing whether or not a burrow was occupied. Some calculations recorded the number of occupied burrows, and others the number of occupied and active burrows. The difference between occupied and active burrows was not defined. Some recorded occupancy based on burrowscope observation, whereas others relied on indirect methods. The majority of studies did not record burrow occupancy.

Predator status

The past and current status of introduced mammals on islands where grey-faced petrel were known to occur was recorded using Clout & Russell (2006)

Table 1. Estimated number of grey-faced petrel burrows on the mainland of the northern North Island of New Zealand.

Site	Estimated burrows	Region
CapeReinga	5	Northland
Cape Maria van Diemen	5	Northland
Bream Head	5	Northland
Bream Tail	5	Northland
Kaipara Head	5	Northland
Home Point	10	Northland
Cornwallis, WaitakereRange	40	Auckland
Karekare, WaitakereRange	5	Auckland
Erangi Point, Bethell's Beach, Waitakere Range	12	Auckland
Piha, WaitakereRange	10	Auckland
TakatuPeninsula	5	Auckland
Ti Point	10	Auckland
Bryant Memorial Scenic Reserve	10	Waikato
Whitecliffs to MokauTaranakiCoast	50-	Taranaki
New Plymouth region	20	Taranaki
Mt Maunganui	200	Bay of Plenty
OhopeBeach	250	Bay of Plenty
Ohiwa	20	Bay of Plenty
Tokatea (local name)	1	Bay of Plenty
WhanaruaBay	1	Bay of Plenty
Total	657	20 sites

and from DOC unpublished databases. Since the 1940's, DOC and its former agencies have eradicated introduced mammals from 40 islands on which grey-faced petrel breed, 29 of which became predator-free from the 1990's onwards. The mammalian species and date of eradication was recorded for each island on which grey-faced petrel was known to occur. Predators present on (and often subsequently eradicated from) islands with grey-faced petrel were: cat, dog, stoat, ship rat, Pacific rat/kiore (*R. exulans*), and Norway rat. Other introduced mammals were pig, European rabbit (*Oryctolagus cuniculus*), goat (*Capra hircus*), mouse (*Mus musculus*), sheep (*Ovis aries*), cattle *(Bos taurus*), and possum (*Trichosurus vulpecula*). Predator status was determined as present, absent or unknown. We compared the estimated median number of burrows to predator status and time since predator eradication (the estimated time between the survey date and eradication date). If predators had never been present, we assigned a nominal minimum period of 30 years. If predator status was unknown, we assumed that predators were present.

Population status

Seabird burrow density tends to remain stable over decades, but its long term change can indicate changes in recruitment which in turn influences the size of a colony (Moller *et al*. 2009). As the majority of studies counted burrows, we converted the number of pairs into the equivalent number of burrows. A few studies gave estimates of the total number of grey-faced petrels, which included breeding and non-breeding birds. We converted total counts into the number of pair by halving the estimates, and then converted the number of pairs into the equivalent number of burrows. Converting total counts into burrow counts overestimates the population. We then tallied the most recent burrow estimates for each island and the mainland, and allocated a range based on the range provided in the literature. If no range was provided, we assigned a range based on order of magnitude or as described above. An estimate of 10 pairs, for example, was given an order of magnitude range of 1-100. Although we did not convert many counts of pairs or total counts into burrow counts, we are more likely to have

over-estimated than under-estimated the effective breeding population. Overall, we are confident that we have provided the best available estimate.

RESULTS

Grey-faced petrel distribution

On the North Island west coast, mainland colonies occurred at 8 sites, and on the North Island east coast, mainland colonies occurred at 12 sites (Table 1, Fig. 1). The largest number of islands and therefore the majority of the grey-faced petrel population were on the east coast, particularly in the Bay of Plenty, Hauraki Gulf Maritime Park in Auckland, and the Far North (Appendix 1).

Mainland population estimates based on observations

There were 657 grey-faced petrel burrows recorded at 20 sites on the mainland (Table 1). Sites are summarised below from north to south.

There was a small grey-faced petrel colony on Cape Reinga. (J. Maxwell, *pers. comm.* 2011). In 2004, following the construction of a predator-proof fence at Tawharanui Regional Park, the Auckland Council eradicated possum, cat, ferret (*M. fero*), stoat, weasel (*M. nivalis*), ship rat and Norway rat (Maitland 2011). Hedgehog (*Erinaceus europaeus*), house mouse and rabbit remained, but are not known to impact on grey-faced petrel populations. A re-invasion of ship rat in 2008 was subsequently eradicated. During 2009 one grey-faced petrel burrow with a chick was located at Ngaio Bay. By 2013, up to 10 active burrows were located (C. Gaskin, *pers. comm.*).

Grey-faced petrels have been observed nesting and rearing chicks in a number of headland sites on the Waitakere Ranges coastline west of Auckland. Small colonies of tens of pairs are known from Erangi Point (Bethells Beach), North Piha, Karekare Beach and Cornwallis Peninsula in the Manukau Harbour (G. Taylor, *pers. obs.*, J. Russell and K. Bourgeois, *pers. comm.*).

The Ornithological Society of New Zealand has been actively involved in monitoring and protecting about 200 breeding pairs at Mauao (Mount Maunganui) for about 20 years (Jones *et al.* 2011).

Since 2009, Te Whakaoranga o Karioi Incorporated Society and A Rocha Aotearoa NZ together with Whaingaroa hapu, DOC and other community groups and individuals have undertaken pest control to protect < 10 grey-faced petrel burrows on the coastal cliffs of the Bryant Memorial Scenic Reserve below Mount Karioi, near Raglan. About 50-100 birds are sometimes seen coming ashore, and at least one chick has been successfully reared at this site.

Ohope Beach in the Eastern Bay of Plenty has the largest mainland colony of grey-faced petrel with 200-300 burrows but has a low chick survival rate. Some protection is provided by a coincident kiwi pest control programme coordinated by the Whakatane Kiwi Trust.

During April 1987, a very small mainland colony (<10 burrows) was found at Whanarua Bay, eastern Bay of Plenty (G. Taylor, *pers. obs.*).

Small scattered colonies of grey-faced petrels were located in a petrel survey along the Taranaki coastline in May 1989 (G. Taylor, *pers. obs.).* Adults were heard calling at night in response to war-whoops (Tennyson & Taylor 1990). Between 1-20 burrows were found by day at each of the following sites: Rapanui, Whitecliffs, Wai-iti Beach, Urenui, beach at Centennial Drive (New Plymouth) and west of Omata.

Grey-faced petrel chicks have been translocated to Cape Kidnappers in Hawkes Bay (Ward-Smith *et al.* 2010) and adults attracted by acoustic playback of grey-faced petrel calls to Young Nicks's Head in Poverty Bay (Sawyer & Fogel 2010). The current status of these new populations is unknown, but likely to be < 20 burrows, as this is typical for mainland populations.

Island population estimates based on repeated observations

Estimates and trends based on opportunistic island observations of grey-faced petrel are summarised below from north to south.

Difficulties in accessing and searching the Ngamotukaraka/Three Kings Island Group combined with limited search times have prevented accurate burrow estimates. The majority of counts have been undertaken during summer when the majority of adult grey-faced petrels would have departed. "Many" burrows were observed during the 1940's (Turbott & Buddle 1948), and "a few" burrows were observed during the late summer of the 1970's (Ramsay & Watt 1971). Thirty active burrows were recorded during an hour search at night near the campsite in Castaway Valley on Great Island, on 13 December 1982 (McCallum 1985). More burrows were seen but not counted on the saddle between the north-west and south-east bays of Great Island, under the forest and on the upper cliff tops of this large island. No grey-faced petrels were found on the North-east, South-west or West Islands.

Although no total burrow estimate was provided, the description of grey-faced petrel in at least 3 separate areas of Great Island (Castaway Valley, under forest and on cliffs on the saddle), implies that the population was much larger than the 30 recorded burrows. Given the limited area sampled by McCallum (1985), the large size of Great Island (408 ha), and the absence of predators, we consider it likely that Great Island has a significant breeding

population. Currently the status and trends of the grey-faced petrel population at this site is unknown. A more definitive survey is required.

There were more than 35 grey-faced petrel burrows on the Simmonds/Motukiore Island during the 1960's (Wagener 1966), and an estimated 30 burrows seen during 2012 (K. Matthews, *pers. comm.*).

There were small numbers of grey-faced petrel on the Poor Knights/Tawhiti Rahi Islands during the 1940's (Buddle 1941, 1948) and the 1950's (Kinsky & Sibson 1959). No evidence of grey-faced petrels (*e.g.,* adults, eggs or chicks) was seen on Aorangi Island during December 2012. If birds are still present, the population is likely to be very small, perhaps less than 50 breeding pairs (G. Taylor, *pers. obs.* 2013).

Four burrow sites have been monitored annually on Moturoa Island in the Bay of Islands during summer 2004-2014, and 3-15 burrows recorded (P. Asquith, *pers. comm.*).

A total of 174 Grey-faced petrel chicks from Hen/Taranga Island were translocated to Limestone/Matakohe Island during 2004–2008 (Miskelly *et al.* 2009). Of these, 165 fledged, and by 2012, up to 5 adults had returned. Pairs have yet to successfully nest although 1 fertile egg was laid but not hatched (L. Davison, *pers. comm.*). Norway rats and stoats periodically re-invade the island and are eradicated (L. Davison, *pers. comm.*). Bland Rocks was visited during September 2003 and April 2012, and 15 and 40 burrows were counted, respectively (E. Cameron, *pers. comm).*

Motukawanui Island, in the Cavalli Islands Group off Matauri Bay, north of Kerikeri had few grey-faced petrel burrows (G. Taylor, *pers. obs.* 1988). Motutara/Henry Island has few or no grey-faced petrel burrows (E. Cameron, *pers. comm.).*

In the Mokohinau Island Group during May 1979, grey-faced petrels were rare on Burgess Island, abundant on Maori Bay Island, which had been burned in 1932 to enable harvesting access to burrows, frequent on Trig Island, which had also been burned, rare on Motupapa Island, and not seen on Lizard Island or on Stack H. All islands in the group except Stack H and Groper Rock had kiore present at some stage prior to 1990 (McCallum 1980). A 'significant number' of birds were noted over the whole island group (McCallum 1980). During 2012- 2014, there was a total of 10,000-12,000 burrows on all of the breeding islands identified by McCallum (1980), and 500-1,000 burrows on Flax Island (C. Gaskin, *pers. comm.*).

On Fanal/Motukino Island in the Mokohinau Island Group during September 1995, numerous grey-faced petrel burrows were noted along the cliff tops and down the steeper seaward faces (de Lange *et al.* 1995). Declines in the numbers of birds harvested by Aotea Ngati Wai resulted in the placement of a rahui or local ban on harvesting from 1985 onwards, although illegal harvesting may still occur. During September 1995, each burrow within a 60 m x 10 m plot located in one of the traditional harvesting sites was inspected by hand, and occupancy determined by the presence of down or chick vocalisation. Of 45 burrows, 6 contained chicks (de Lange *et al.* 1995). In 2012, approximately 1000 grey-faced petrel burrows were estimated on this island (C. Gaskin, *pers. comm.).*

Grey-faced petrels were observed from or on Great Barrier Island during the 1860's (Hutton 1868 in Bell, 1976). Remnant populations occur on nearby small islands, although those in proximity to the main island are particularly at risk from ship rat invasions.

Rakitu/Arid Island, off Great Barrier Island had numerous grey-faced petrel colonies, which declined due to the presence of rats (Hutton & Kirk 1868). By June 1957, ship rat, kiore, pig, goat and mice were present on the island, and grey-faced petrel burrows were in use, but numbers not estimated (Bell & Braithwaite 1964). A number of recently vacated burrows were recorded during the 1980's (Bellingham *et al.* 1982). During 2008, a ship rat eradication attempt was made on the Broken/Pig Islands and Grey Group Islands on the west coast of Great Barrier Island (Cameron *et al.* 2009).

Grey-faced petrels were recorded as present on Saddle Island off Great Barrier Island during the 1930's (Falla 1934) and on Saddle and Sugarloaf Island 1960's (Bell & Braithwaite 1964) when introduced mammals were absent. By the 1980's, ship rat had invaded Saddle Island (McCallum1985) but there were still 60-100 burrows present during 1990 (Cameron *et al.* 2009). During 1990, a ship rat eradication attempt was made on Saddle Island, but ship rats were detected again in 2000 (Cameron *et al.* 2009). During 2008, another ship rat eradication attempt was made (Cameron *et al.* 2009).

During the 1960's, Anvil/Mahuki Island had grey-faced petrels in unknown numbers (Bell & Braithwaite 1964), and 10 individual birds were recorded during the 1980's (McCallum 1985).

During the 1960's on Hauturu/Little Barrier Island, grey-faced petrels bred above the sea cliffs and inland cliffs and it is likely that the population was in decline, as by 1977, "this species was close to extinction" (Giardet *et al.* 2001). Cat eradication was completed by the New Zealand Wildlife Service by 1980. During the 1990's, 20-30 birds routinely prospected in burrows at the mouth of the Haowhenua Stream. One of these birds had been banded on Te Haupa/Saddle Island, near Mahurangi (inner Hauraki Gulf) (Tennyson & Taylor 1999). Small colonies were likely to have persisted in inaccessible areas elsewhere on Hauturu/Little Barrier Island (T. Greene, *pers. comm.*). Following

kiore eradication by DOC during 2004, 5 grey-faced petrels were found in burrows (Rayner *et al.* 2009).

The Auckland University Field Club made 4 day-trips to the Noises Island Group during 1933–1938, and landed on Otata Island (Cunningham & Moors 1985). Stoats were recorded as temporarily present on Otata Island during the 1950's and Norway rats are thought to have colonised the islands in 1956/57 (*op. cit.*). In 1963, 200 grey-faced petrel pairs were estimated on Otata Island, compared to observations during 1977-1983 which estimated 75 burrows with less than 50% occupancy (Cunningham & Moors 1985). In 1985, about 75 grey-faced petrel burrows were located on Motuhoropapa Island in the Noises Island Group. There were also 75 burrows found during 2007 when Norway rats were again eradicated (MacKay *et al.* 2007).

Cuvier/Repanga Island is located about 23 km south east of Great Barrier Island. Feral cats were eradicated during 1964 (Clout & Russell 2006). During the 1980's there were an estimated 3,000 grey-faced petrel pairs (Bellingham *et al.* 1981), which has increased to an estimated >5000 pairs (G. Taylor, *pers. obs.* 2005).

During June to August 2005, 406 active burrows containing 260-280 incubating pairs were located on the periphery of Motuora Island in the Hauraki Gulf (Gardner-Gee *et al.* 2008). Nine permanent plots of various sizes (72-174 m^2) were established within different colonies during 2005, and re-visited during 2006 and 2007. There was no change in the number of burrows.

During October 1988 at least 20 grey faced petrel burrows were found on Ruthe Island, located off Ponui Island in the Hauraki Gulf, and rodent sign was evident (Cameron & Taylor 1992). By October 1994 there was no evidence of successful breeding (de Lange & McFadden 1995). Norway rats were eradicated in 1992, but re-invaded (Cameron *et al.* 2007).

Moturekareka, Motutara and Kohatutara or the Rocky Islets are a group of connected islands located amongst a scattering of small islands in the lee of Kawau Island. During 1988 several burrows were found at the western end of Moturekareka Island. During 2013, there were fewer than 50 burrows (T. Lovegrove, *pers. comm.).* On Motutara Island during June 1988, just over 100 burrows were counted at the south-eastern end, extending up to, but not onto, the top of the eastern hill. Another 10 or more burrows were found on a knoll at the western end. No burrows were found on Kohatutura Island, as the soil depth was too shallow (Tennyson *et al.* 1997).

On Needle Rock, off eastern Coromandel there were several large burrows attributed to grey-faced petrels (Taylor 1995).

No grey-faced petrels were detected on Great Mercury/Ahuahu Island during early May 1975 when birds are active and conspicuous (Grace 1976). There were an estimated 50 grey-faced petrel pairs found on Great Mercury/Ahuahu Island during 2012 (J. Russell, *pers. comm.* 2012).

White/Whakaari Island is unusual amongst seabird islands in that it is New Zealand's most active volcano, located 48 km offshore in the eastern Bay of Plenty. Mutton-birding occurred on the island when the birds were common (Gillham 1966). Grey-faced petrel burrows were still common on the island 3 decades later (Clarkson & Clarkson 1994). Since then ash and mud from eruptions have smothered burrows on the southern side, and there are likely to be no more than 75 active burrows on the northern side, in moderate densities associated with the pohutukawa (*Metrosideros robusta*) forest (P. Lyver, *pers. comm.* 2013).

Island population estimates based on systematic sampling

Estimates and trends based on systematic sampling are summarised below from north to south.

On Mauitaha/West Chicken Island nearly every seabird burrow was inspected during December 1994, and a total of 16 live grey-faced petrel chicks recorded (Tennyson & Pierce 1995). On Mauitaha/West Chicken Island (December 2011 and October 2012) and Taranga/Hen Island (November 2011 and October 2012) in the Hen and Chickens Island Group, burrow densities were estimated using 3 m radius plots randomly located along transects laid evenly spaced and perpendicular to the long axis of the island. Mean burrow density was 0.03 m^{-2} (± 0.01 C.I.; n = 68) and 0.05 m^{-2} (± 0.01 C.I.; n = 120), respectively (Buxton *et al.* 2014).

On Goat Island near Leigh in Auckland, a complete count of 100 burrows was undertaken in 2012 (Dunn 2012). In 2013, 120 burrows were found on the same island (K. Bourgeois, *pers. comm.*). Rats were successfully eradicated from Goat Island in 1994, but subsequently reinvaded (Clout & Russell 2006). Rats were again eradicated in 2005, but subsequently reinvaded (Russell *et al.* 2009). Rats are now controlled during the grey-faced petrel breeding season (J. Russell, *pers. comm.* 2013).

Complete counts of all grey-faced petrel burrows on Saddle/Te Haupa Island were made repeatedly during a 10 year period from 1987-1997 (Tennyson & Taylor 1999). There were no differences in the number of nesting pairs found (5-15) during 1987-1990 compared to a repeat survey during 1997. By 2012, the population was estimated at 50 pairs, indicating a substantial population increase following the eradication of Norway rats during 1994-1999 (J. MacKay, *pers. comm.*).

A complete count of 120 grey-faced petrel burrows was undertaken on Otata Island in 2014 (J. Thoresen, *unpubl. data*). Initially, the perimeter of the island was walked, and the first burrow seen marked on GPS. A

Table 2. Estimated island winter burrow occupancy rates (%).

Island	%	Reference
Ihumoana	72	G. Taylor, *unpubl.data*
Goat	61	K. Bourgeois, *pers. comm.* (2013)
Tiritiri Matangi	37	Dunn (2012)
Otata 1963	< 50	Cunningham & Moors (1985)
Motuora periphery	83	Gardner-Gee *et al.* (2008)
Motuora central	55	Gardner-Gee *et al.* (2008)
Moutohora/Whale Island	87	Imber *et al.* (2000)
Moutohora/Whale Island	52	Whitehead *et al.* (2014)
Alderman's group	40	Whitehead *et al.* (2014)

5 m radius plot was established with the first burrow at the centre. All other burrows were counted within the plot. A 10 m line was then systematically walked N, S, W, and E from the central burrow. The first burrow encountered was then marked on a GPS, a new 5 m plot established, and the process repeated. When no more burrows were found, then the walk around the perimeter continued. Once the perimeter had been searched, the inner island was searched using the same method.

Ihumoana Island and Kauwahaia Island have been monitored for 25 years (G. Taylor, *pers. obs.* 2014). Preliminary population estimates published in 1990 indicated there were less than 200 pairs on each island (Tennyson & Taylor 1990; Taylor & Cameron 1990). Complete counts of all breeding burrows at these sites has shown that the population on Ihumoana Island has increased from 40 pairs in 1989 to 120 pairs in 2012 and that on Kauwahaia Island from *c.* 200 pairs in 1990 to 320 pairs in 2012 (G. Taylor, *pers. obs.* 2013).

Kawhitu/Stanley Island, in the Mercury Group, was estimated at >5000 pairs (Tennyson & Taylor, 1990). During November 2012, mean burrow density was calculated as 0.08 m^{-2} (± 0.01 C.I.; n = 132)(Buxton *et al.* 2014). On Korapuki Island in the Mercury Group, there were an estimated 7,500 burrows on the island based on a sample of 21 random transects of 40 m^{-2} each (G. Taylor, *unpubl. data* 2003). Mean burrow density during December 2012 was 0.09 m^{-2} (± 0.01 C.I.; n = 101)(Buxton *et al.* 2014). On Ohinau Island, south of the Mercury Group, during 2012, mean burrow density was 0.05 m^{-2} (± 0.01 C.I.; n = 100)(Buxton *et al.* 2014).

Hongiora/Flat, Middle Chain, Ruamahuanui and Ruamahuaiti Islands make up the Alderman/Ruamaahua Islands Group. Burrow density estimates on Hongiora Island were 0.042 m^{-2} and burrow densities on other islands in the group ranged from 0.02-0.45 m^{-2} (Fogarty & Douglas 1973). Permanent burrow density plots (10 x 10 m) were established during 2006, 2007, 2008 and 2010 on Hongiora/Flat (n = 10), Middle Chain (n = 30), Ruamahuanui (n = 21) and Ruamahuaiti (54) Islands (Whitehead *et al.* 2014). Burrow counts were undertaken and occupancy rates determined using a burrow scope during July and November. Mean burrow density estimates were Hongiora/Flat 0.76 m^{-2} (± 0.07 C.I.) and Middle Chain 0.04 m^{-2} (± 0.01 C.I.). On Ruamahuanui and Ruamahuaiti Islands, mean burrow density during 2010-2012 was 0.23 m^{-2} (± 0.03 C.I.; n = 76) and 0.21 m^{-2} (± 0.04 C.I.), respectively (Whitehead *et al.* 2014).

Burrow occupancy rates were estimated in 3 m radius circular plots on Ruamahuanui Island (n = 62), and Ruamahuaiti Island (n = 54), and these were combined with density estimates to give a total number of breeding pairs (mean ±95% C.I.) during 2006-2010 on Hongiora 13,800 (2,829-28,070), Middle Chain 20,730 (4,230-43,240), Ruamahuanui 19,640 (3,577-37,150) and Ruamaahuaiti 18,240 (3,517-35,580) (Whitehead *et al.* 2014). Burrow density varied between islands in the Alderman/Ruamaahua Island Group, increasing with increasing altitude, increasing soil depth, and in forests dominated by pohutukawa (Whitehead *et al.* 2014).

Based on extensive banding studies during the late 1960's through to the early 1970's, 30,000-40,000 grey-faced petrel pairs were estimated on Moutohora/Whale Island (Imber 1976). In 1986 on Moutohora/Whale Island, 820 burrows were estimated within a 1.4 ha area prior to the eradication of Norway rats and rabbits (1987), and 1,036 in 1991, following the eradication (Harrison 1992; Imber *et al.* 2003). Assuming similar densities over the entire island these estimates extrapolate to 100,341 and 126,773 burrows, respectively. Random plot sampling during 1998-2000 estimated 99,000-119,000 burrows on this island (Imber *et al.* 2003). An egg was assumed to have been laid in 87% of the burrows, and extrapolated to the entire island (Imber *et al.* 2003). As the occupancy rate was higher than the winter average (Table 2) it is likely that this is an over-estimate (Fig. 2).

On Moutohora/Whale Island during winter and spring 2007, 2008 & 2010, burrow counts were undertaken and occupancy rates determined using a burrow scope to coincide with peak egg laying and chick rearing (Whitehead *et al.* 2014). A total of 100 randomly located permanent plots (10 x 10m) were established, to give a mean burrow density of 0.07 m^{-2} (± 0.1 C.I.), and a mean number of breeding pairs (± 95% CI) of 69,330 (range: 10,590-128,300; Whitehead *et al.* 2014). Comparisons between Imber *et al.* (2000, 2003) and Whitehead *et al.*(2014) show that the former estimates are within the range of the

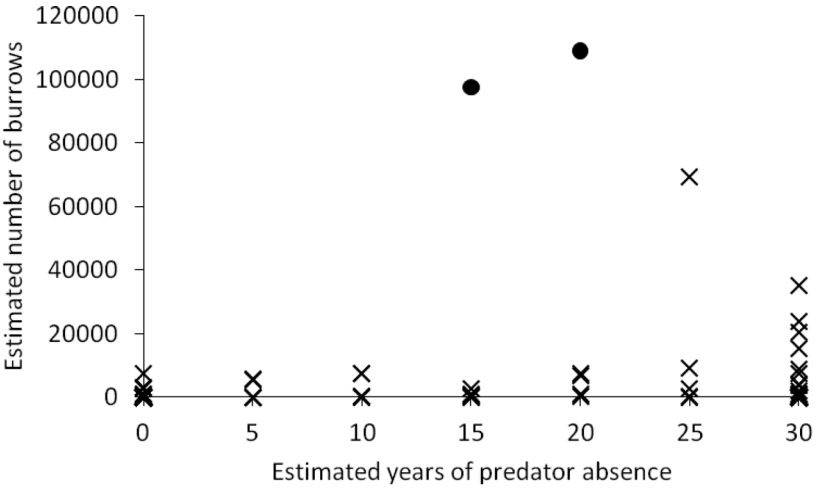

Fig. 2. Estimated median grey-faced petrel burrows on islands and years since predator absence (30 years is a nominal minimum). •Imber *et al.* (2000, 2003).

latter (Fig. 3). The patchiness of grey-faced petrel burrows, however, combined with the variability of occupancy makes accurate population estimates difficult.

Burrow occupancy rates

Burrow occupancy rates change throughout the breeding season when breeding attempts fail, and between seasons in response to marine conditions (Buxton *et al*. 2015; Sutherland & Dann 2012). In addition, there is no standardised method for determining occupancy, meaning that occupancy rate comparisons between islands must be undertaken with caution. To reduce to these errors, we only report occupancy rates gathered during the incubation period (July and August). Burrow occupancy estimates are summarised from north to south (Table 2). Overall, mean burrow occupancy rates on nine islands with no predators was 60% (±18% SD).

Population status

We tallied the most recent of 104 island population estimates over an approximate 40 year period from the 1970's onwards to give a range from 72,398-286,268 burrows, over a minimum area of 37,967 ha. Fewer than 1000 burrows were recorded from 20 mainland sites over an unspecified area.

Predator status

Of 31 grey-faced petrel islands (excluding Great Barrier Island) with predators still present, 14 had ship rat, 11 kiore, 9 Norway rat, 2 stoat, 1 pig and 1 cat. Five islands had mice, but these were not considered a major predator of grey-faced petrel chicks or eggs. Rabbits and goats occurred on a few islands. There was a general positive relationship between the estimated years since island predator eradication and the number of burrows (Fig. 2).

DISCUSSION

A description of the distribution and population status (increasing, stable, and declining) of seabird populations is important due to their critical role in the functioning in marine and terrestrial coastal ecosystems. Productivity, juvenile recruitment and survival of seabirds is closely linked to marine food availability, and, in the absence of predators, changes in breeding seabird populations act as sensitive indicators of changes in the marine environment (Piatt *et al.* 2007).

Major changes in the marine environment are driven by global warming and associated increases of carbon dioxide which alter the strength and location of ocean currents and fronts, increase storm frequency and intensity, and shift prevailing wind directions, all of which impact on marine prey distribution and abundance (Grémillet & Boulinier 2009). Although these factors likely drive population change in grey-faced petrel, they are difficult to measure. Based on observational studies, for example, gannet sightings per unit effort were weakly correlated to regional sea surface temperature (SST). SST, however, was predicted to have a limited impact prey abundance, particularly as a major prey item, pilchards (*Sardinops* spp.), were tolerant to a wide range of temperatures (Srinivasan *et al.* 2015). The timing and productivity of penguins is correlated with SST (Cullen *et al.* 2009). Detecting changes in seabird population in relation to environmental drivers, therefore, will be long term and large scale.

Grey-faced petrel distribution

The majority of the grey-faced petrel populations occur on islands > 2 km from the mainland, near the continental shelf. About 75% of the total breeding population occurred on about 20 islands: Marotere/Hen and Chicken Islands, Mercury Islands, Cuvier

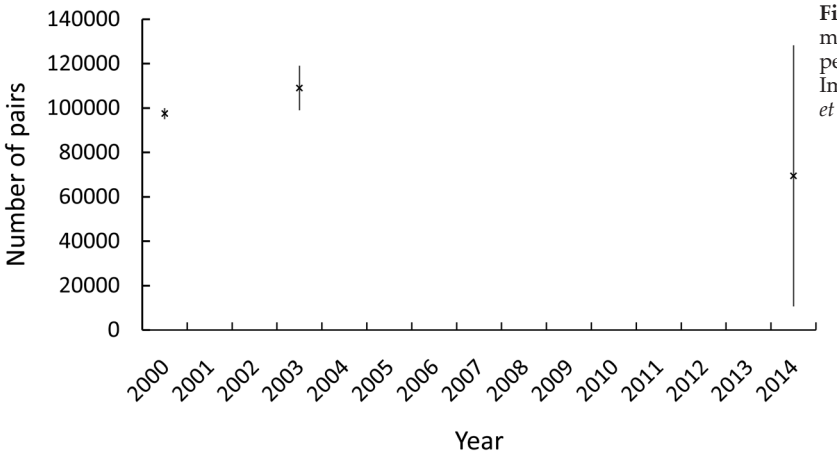

Fig. 3. Moutohora/Whale Island, median number of grey-faced petrel pairs (± 95% CI; data from Imber *et al.* 2000, 2003; Whitehead *et al.* 2014).

Island, Alderman Islands and Moutohora/Whale Island. Large populations are also likely to occur on Ngamotukaraka/Three Kings Islands Group.

Half of the 200 islands that had potential grey-faced petrel burrow habitat were < 10 ha and had no records of burrows. Islands < 10 ha may not have been surveyed, the survey results not yet published, suitable burrow habitat may not be present, or there may have been competition with other more aggressive seabirds.

Altitude, soil depth, slope and vegetation are important predictors of seabird burrow distribution and density (Rayner *et al*. 2007; Scott *et al.* 2009). Soil depth was the positively correlated with seabird (and grey-faced petrel) burrow presence, abundance and occupancy, but this relationship was less important for larger populations, and is more likely a feature of small or moderate populations (Buxton *et al.* 2014).

On East/Whangaokeno Island, the smaller fluttering shearwaters (*Puffinus gavia*), which can burrow in shallow soil, were the dominant species (49%), then grey-faced petrel (46%), sooty shearwaters (3%; *Puffinus griseus*), and black-winged petrels (2%; *Pterodroma nigrpennis*; A. Kirk, *pers. comm.* 2012). The rocky soils of the Poor Knights/Tawhiti Rahi Islands support Buller's shearwater (*Puffinus bulleri*) and Pycroft's petrel (*Pterodroma pycrofti*), but grey-faced petrel burrows are uncommon (McCallum1981). Soil depth is shallow on the West Chickens/Mauitaha Islands and smaller rock stacks (Keyhole, Gunsight, Starfish and Middle Rock) of the Hen and Chickens Islands, and these islands were dominated by the smaller diving petrels (*Pelecanoides urinatrix*) and fluttering shearwaters (McCallum *et al.* 1984).

As the breeding seasons overlap, there is competition for burrows between grey-faced petrel and flesh-footed shearwaters; the latter are known to occasionally kill grey-faced petrel adults and chicks (G. Taylor, *pers. obs*.). On the Mercury Group, Middle and Green Islands have deep soils, but these are dominated by flesh-footed shearwaters and common diving petrels, and few grey-faced petrels are present (Lovegrove *et al.* 1990).

Observations of small grey-faced petrel populations appear to be under-represented in our survey. In the initial stages of a large scale population decline, smaller populations (< 100 burrows) are socially attracted to larger populations (Buxton 2014). Consequently, larger populations increase in size, while smaller populations disappear. Changes in small grey-faced petrel populations may therefore provide an early warning of potential larger changes in the total population. Confirmed absences of grey-faced petrels (and other seabirds) on small islands with suitable burrow habitat, therefore, could indicate a large scale, long term population decline.

Mainland population estimates

Fewer than 1000 grey-faced petrel burrows were recorded at 20 sites on the mainland. The majority of burrows were located in the eastern Bay of Plenty, presumably colonised by prospecting grey-faced petrel from nearby Moutohora Island. Priority for mainland surveys, therefore, should focus on vegetated coastal areas (>10 ha) in proximity to large grey-faced petrel island populations (>1000 burrows).

Island population estimates based on observations

The majority of grey-faced population estimates is based on non-systematic observations, and is best interpreted as order of magnitude estimates. Trends must therefore be interpreted with caution, unless the population is confirmed to be absent.

Island population estimates based on systematic sampling

Systematic sampling has occurred within some large grey-faced petrel populations (Taranga/Hen

and Chickens Group, Mercury Group Islands, Alderman Islands, Moutohora/Whale Island). Complete island counts have been undertaken on some small islands (Te Haupa/Saddle, Goat, Otata, Ihumoana and Kauwahaia Islands), particularly in the Hauraki Gulf. Islands close to the mainland are most at risk from predator re-invasion and require more frequent monitoring.

Islands from which predators have been recently (< 20 years) eradicated have been subject to more regular systematic monitoring or complete counts. From north to south, these islands are: Lady Alice, Moturoa (Bay of Islands), Hauturu/Little Barrier, Otata, Te Haupa, Goat, Takangaroa, Sunday, Maria, Scott, Atiu/Middle, Whangaokeno/East, Kawhitu/Stanley and Fanal/Motukino Islands.

Burrow occupancy

Burrow occupancy rates were highly spatially variable within islands, within islands between months and years, and between islands over time. On predator-free islands ($n = 9$) during winter, mean occupancy rates were 60%. Population estimates based solely on burrow counts therefore probably overestimate the effective breeding population and should be scaled down by 40%.

Predator status

Burrow density is positively correlated with the length of time since kiore eradication (Buxton *et al.* 2015), however, the relationship between predator status and burrow density is complex, confounded by soil type, habitat modification, as well as factors relating to breeding biology (Sutherland & Dann 2012). Although cause and effect is difficult to prove, we also found a positive relationship between the number of burrows on islands and time since predator eradication. In the 1980's, kiore were observed preying on newly hatched grey-faced petrel chicks on Stanley Island (G. Taylor *pers. obs.*), so some level of response to pest eradications was expected.

Responses of long-lived species to large scale environmental change such as predator eradication will be delayed by the average age of first breeding and generation time, which for grey-faced petrel is estimated to be 4 years and 17.6 years, respectively (Buxton 2014). Population change will therefore only be detected over decadal periods. Both Buxton *et al.* (2014) and this study suggest that an increase in grey-faced petrel populations occurred about 20 years following predator eradication, which is consistent with the breeding biology of the species.

Population status

We tallied the most recent of 104 island estimates to give a best available estimate range of 72,398-286,268 burrows, with the majority of these estimates collated over a 40 year period from the 1970's onwards. This estimate covered a minimum area of 37,967 ha on offshore islands, and fewer than 1000 burrows on the mainland over an unspecified area.

Our collation of published and unpublished estimates supports previous order of magnitude population estimates of *c.* 250,000 pairs. All estimates, even those calculated from systematic sampling within islands, have very large ranges, demonstrating the difficulty in accurately estimating population size in patchily distributed and variable density colonies and accurately determining long term trends.

At a minimum, observers undertaking grey-faced petrel and other seabird surveys must record the following information: site name (accurately named and identified from a published recent map), area surveyed (accurately quantified by GPS map, ha, or m^2), the observers' names, dates and time spent searching (accurately quantified by hours, start and stop times e.g. 08:00-14:00). Ideally observations should occur of grey-faced petrel burrows during winter (July and August).

We recommend that surveys of grey-faced petrel and other seabirds adopt a 3 tiered approach. The objective of the first tier survey is to determine the population distribution. The objective in tier one is to survey for presence/absence of colonies at new sites using methods such as acoustic recording devices or by simply searching for the presence of active burrows on islands. Surveys of small inshore islands that confirm that grey-faced petrels and other seabirds are absent would also be useful as a record of future changes in distribution. If grey-faced petrel calls are heard or large burrows found, then second tier surveys should be undertaken.

The objective of the second tier survey is to estimate the population size based on observations. If time and/or resources are limited, we recommend that estimates are based on a numeric logarithmic scale of 1-10 burrows, 10-100 burrows, 100-1000 burrows, etc., rather than descriptions (rare, few, common). This provides a more practical, cost effective, standardised way of estimating seabird populations when time or resources for a systematic survey are not available. If there is sufficient time and resources, then third tier surveys should be undertaken.

The objective of the third tier survey is estimate the population size based on a quantitative study using repeatable techniques such as complete counts (census) random plots and transects. Complete counts may be possible on small islands (< 5 ha) with small seabird populations (< 500 burrows). For larger populations, all plots should be located using a GPS, and each burrow accurately counted. It

should be noted whether the burrows are occupied and/or appear active (assumed occupied, but an egg, chick or adult is not observed). Ideally the nest chamber of each burrow should be examined using a burrow scope (Buxton 2014).

This study is a testament to the efforts of past observers, and highlights the value of collating a large number of population estimates over a long period of time complemented by a smaller number of repeated systematic counts over shorter periods of time. Of 200 islands with potentially suitable grey-faced petrel burrow habitat, 104 have been recently surveyed (1964 - 2015). Of these, 40 have not been re-surveyed since the 1960's or 1970's and the majority of the 35 surveys undertaken from 2000 onwards were sourced from unpublished data. We therefore encourage observers to undertake repeat counts of grey-faced petrel burrows on a regular basis (*e.g.*, once every 5 years) during July/August, and publish their results.

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Appendix 1. Island estimates of burrows and status of introduced mammal species (year eradicated, ? = date unknown). Map references for each site are available in the DOC database.

Island name	Estimated burrows	Lower-upper estimate	Mammal status (species & year eradicated)	References
Great/King/ Manawa-tawhi	30	30	Absent (goat 1946)	McCallum *et al.* (1985)
Great/King/ Manawa-tawhi	Few	1-10	Absent (goat 1946)	Ramsay & Watt (1971)
North East	Many	50-100	Absent	Turbott & Buddle (1948)
Motuopao	100 pairs in 1990	100	Absent (kiore 1991)	Pierce & Parrish (1993)
Simmonds/Motukiore	<30	20-30	Absent (kiore?)	K. Matthews, *pers. comm.* (2012)
Simmonds/Motukiore	>35	35-50	Absent (kiore?)	Wagener (1966)
Aorangi	<50	1-10	Absent (pig 1936)	G. Taylor, *pers. obs.* (2013)
Aorangi	A few adults	1-10	Absent (pig 1936)	C. Miskelly, *pers. comm.* (1983)
Aorangi	Small numbers in 1938	10	Absent (pig 1936)	Buddle (1941)
TawhitiRahi	Several adults	1-10	Absent (pig 1936)	McCallum (1981)
TawhitiRahi	None December 1958	0	Absent	Kinsky & Sibson (1959)
TawhitiRahi	A number but only one seen November 1940	1-100	Absent	Buddle (1941)
Moturoa	15	3-15	Ship rat? (ship rat, Norway rat, stoat, mouse 2009)	P. Asquith, *pers. comm.* (2014)
Motukokako/Piercy/ Hole in the Rock	< 500 & 200-300 pairs	200-500	Absent	Cameron & Taylor (1991)
Motuoi	Rare	10	Unknown	Hitchmough & McCallum (1980)
Paeroa	Few	1-10	Unknown	Hitchmough & McCallum (1980)
Rangiatea	Rare	1-10	Unknown	Hitchmough & McCallum (1980)
Whakairipiha	Few	1-10	Unknown	Hitchmough & McCallum (1980)
Whangaapau	Rare	1-10	Unknown	Hitchmough & McCallum (1980)
Motuwheteke	Present	1-10	Unknown	Booth (2005)
Rimariki	Present	1-10	Unknown	Booth (2005)
Matakohe/Limstone	1 translocated	1	Mouse, Norway rat (Norway rat 1991, cat 1991, stoat 1996)	L. Davison, *pers. comm.* (2013)
Bland Rocks	40	40-50	Unknown	E. Cameron, *pers. comm.* 2012
Bland Rocks	15	15	Unknown	E. Cameron *pers. comm.*2003
Pupuha	< 10	0-10	Absent	G. Taylor *pers. obs.* 2013
Hen/Taranga	1000	1000	Absent	Taylor (2000)
Lady Alice	> 5000	5000-6000	Absent (kiore 1994)	Taylor (2000)
Mauitaha	16	15-20	Absent	Tennyson & Pierce (1995)
Sail Rock	Few	1-10	Absent	Atkinson (1972b)
Unnamed	1	1	Absent	Skegg (1964)
Whatupuke	>5000	5000-10000	Absent	Taylor (2000)
Motukawanui	Few	1-10	Kiore, stoat	G. Taylor, *pers. obs.* (1988)

Appendix 1. Continued.

Motukawanui	Few	1-10	Kiore, stoat	Adams (1969) in Millener (1980)
Moturahurahu	1	1-10	Unknown	E. Cameron, *pers. comm.* (2003)
Moturahurahu	Hundreds	200-300	Absent	Sibson (1953)
Sentinel Rock	>50, most occupied July 1992	50-100	Unknown	Cameron & Taylor (1997)
Green	>20	20-50	Absent	Farley (1977)
Moturoa	>20	20-50	Absent	Farley (1977)
Sugarloaf	>20	20-50	Absent	Farley (1977)
Whale/ Tuputupungahau	20	3-20	Absent (pig 1966)	Farley (1977)
Motuterakihi	Breeding	10-100	Absent	G. Taylor, *pers. obs.* (1990)
Motukehua/Nops	2	1-10	Unknown	E. Cameron, *pers. comm.* (2003)
Motutara/Henry	0	0	Unknown	E. Cameron, *pers. comm.* (2001, 2007)
Motutara/Henry	1?	1	Unknown	Parrish (1994)
Burgess/Pokohinu	800	800-1000	Absent (goat 1973, kiore 1990)	C. Gaskin, *pers. comm.* (2013)
Burgess/Pokohinu	0	0	Absent (goat 1973, kiore 1990)	McFadden & Greene (1994)
Burgess/Pokohinu	Rare	1-10	Kiore	McCallum (1980)
Fanal/Motukino	1000	1000	Absent (kiore 1997)	C. Gaskin, *pers. comm.* 2012
Fanal/Motukino	600	600	Absent (kiore 1997)	de Lange *et al.* (1995)
Flax	500	500-1000	Absent	C. Gaskin, *pers. comm.* (2013)
Hokoromea/Maori	2500	2500	Absent (kiore 1990)	C. Gaskin, *pers. comm.* (2013)
Motuharakeke	150	150-200	Absent	C. Gaskin, *pers. comm.* (2013)
Motupapa/Stack H	100	100	Absent (kiore unknown)	C. Gaskin, *pers. comm.* (2013)
Motupapa/Stack H	Absent	0	Absent	McCallum (1980)
Lizard	Absent	0	Kiore	McCallum (1980)
Maori Bay	Abundant	100	Kiore	McCallum (1980)
Motupapa	Rare	1-10	Kiore	McCallum (1980)
Stack D	Frequent	10-50	Kiore	McCallum (1980)
Trig	Frequent	10-50	Kiore	McCallum (1980)
Great Barrier	None	0	Ship rat, mouse, rabbit, pig, goat, cattle, dog, cat	Bell (1976)
"SouthWestern" Junction	75	75	Ship rat	McCallum (1985)
Cliff/Whangara	5	1-10	Ship rat	McCallum (1985)
Islet 'E'	Present	1-10	Ship rat	McCallum (1985)
Islet 'F'	50	50	Ship rat	McCallum (1985)
Motuhaku	Present	1-10	Ship rat	Bell & Braithwaite (1964)
Papakuri	9	9-10	Ship rat	McCallum (1985)
Pitokuku	Present	1-10	Unknown	Bell & Braithwaite (1964)
Anvil/Mahuki	10	10	Ship rat	McCallum (1985)
Anvil/Mahuki	Present	1-10	Absent	Bell &Braithwaite (1964)
Rakitu/Arid	A number of recently vacated burrows	10-50	Ship rat, kiore (pig 1960s, goat 2002, mouse?)	Bellingham *et al.* (1982)

Appendix 1. Continued.

Rakitu/Arid	Present	1-10	Ship rat, kiore (pig 1960s, goat 2002, mouse?)	Bell & Braithwaite (1964)
Rakitu/Arid	Very numerous	100-300	Ship rat, kiore (pig 1960s, goat 2002, mouse?)	Hutton & Kirk (1868)
Saddle	60-100	60-100	Ship rat	Cameron *et al.* (2009)
Saddle	Present	1-10	Absent	Bell & Braithwaite (1964)
Saddle	Present	1-10	Absent	Falla (1934)
Hauturu/Little Barrier	5	5	Absent (kiore 2004, cat 1980)	Rayner *et al.* (2009)
Hauturu/Little Barrier	Close to extinction	5	Absent (kiore 2004, cat 1980)	Girardet *et al.* (2001)
Cuvier/Repanga	>5000	5000-10000	Absent (kiore 1993, cat 1964, goat 1961)	G. Taylor, *pers. obs.* (2000)
Cuvier/Repanga	Several thousand	3000	Absent (goat 1961, cattle 1964, sheep 1964, cat 1964, kiore 1993)	Bellingham *et al.* (1981)
Goat/TeHawere a Maki	75	75	Ship rat (ship rat 1994)	K. Bourgeois, *pers. comm.* (2013)
Goat/TeHawere a Maki	100	100	Ship rat (ship rat 1994)	Dunn (2012)
Unnamed rock stack	>30	30-50	Unknown	Cameron (2012)
Challenger	100	100	Absent	G. Taylor, *pers. obs.* (2013)
Motuhoropapa	75	75	Absent (stoat 1955, rabbit 1945, Norway rat 2002)	MacKay *et al.* (2007)
Motuora	406	260-406	Absent	Gardner-Gee *et al.* (2008)
Moturekareka	<50	20-50	Mouse	T. Lovegrove, *pers. comm.* (2013)
Motutara	>110 in 1988	110-150	Mouse	Tennyson *et al.* (1997)
Rotoroa	<20	10-20	Norway rat (Norway rat 1992 unsuccessful)	T. Lovegrove, *pers. comm.* (2013)
Sunday	Present	1-10	Absent (stoat 1955, rabbit 1945, Norway rat 2002)	Cunningham & Moors (1985)
Tarakihi/Shag	100	100	Absent	T. Lovegrove, *pers. comm.* (2013)
TeHaupa/Saddle	50	50	Absent (Norway rat 1989, 1994-1999, mouse 1993, 2008)	B. Green, *pers. comm.* (2013)
TeHaupa/Saddle	24	24	Absent (Norway rat 1989, 1994-1999, mouse 1993, 2008)	Tennyson & Taylor (1999)
Tiritiri Matangi	150	150	Absent (rabbit <1920, cat 1970s, kiore 1993)	Dunn (2012)
Takangaroa/Pembles	50	50	Absent (Norway rat 1998, rabbit unknown)	T. Lovegrove, *pers. comm.* (2013)
Maria	Present	1-10	Absent (stoat 1955, rabbit 1945, Norway rat 2002)	Cunningham & Moors (1985)
Scott	Present	1-10	Absent (stoat 1955, rabbit 1945, Norway rat 2002)	Cunningham & Moors (1985)
Motuhoropapa	75	75	Absent (stoat 1955, rabbit 1945, Norway rat 2002)	Cunningham & Moors (1985)
Moturekareka	Several	3	Mouse	Tennyson *et al.* (1997)
Motutara	< 200	100-200	Mouse	Tennyson & Taylor (1990)
Otata	Census	120	Absent (stoat 1955, rabbit 1945, Norway rat 2002)	J. Thoresen *unpubl. data* (2014)

Appendix 1. Continued.

Otata	75 (<50% occupancy)	30-40	Absent (stoat 1955, rabbit 1945)	MacKay *et. al*. (2007)
Otata	150	150	Absent (stoat 1955, rabbit 1945)	Cunningham & Moors (1985)
Otata	200 in 1963	200	Absent (stoat 1955, rabbit 1945)	Cunningham & Moors (1985)
Ruthe	0	0	Norway rat	Cameron *et al.* (2007)
Ruthe	0	0	Norway rat? (Norway rat 1992, re-invaded)	de Lange & McFadden (1995b)
Ruthe	small colony	10-20	Norway rat	Cameron & Taylor (1992)
Moturemu	> 50	50-100	Norway rat (mouse, Norway rat 1992)	J. Russell, *pers. comm.*
Ihumoana	120	120	Absent (occasional Norway rat, ship rat, mouse)	G. Taylor, *pers. obs.* (2012)
Ihumoana	<200	100-200	Occasional Norway rat, ship rat, mouse	Tennyson & Taylor (1990)
Kauwahaia	320	320	Occasional stoat. Norway rat, ship rat, mouse	G. Taylor, *pers.obs.* (2013)
Kauwahaia	<200	100-200	Occasional stoat, Norway rat, ship rat, mouse	Tennyson & Taylor (1990); Taylor & Cameron (1990)
Karewa	1000	1000	Absent	McClellan (1996); A.Tennyson, *pers. comm.* (2013)
Penguin	Breeding 1973	10-50	Kiore, rabbit	Douglas & Gubb (1974)
Rabbit	Breeding 1974	10-50	Kiore, rabbit	Douglas & Gubb (1974)
Shoe/Motuhoa	Locally abundant under pohutukawa	50-100	Norway rat, rabbit, probably pig	Douglas & Gubb (1974)
Slipper/Whakahau	Breeding 1973	50-100	Norway rat	Douglas & Gubb (1974)
Mahurangi	Present	1-10	Norway rat (goat 1915)	Moore (1976); Atkinson (1972a)
Poikeke	Present	1-10	Unknown	Moore (1976)
Te Karaka	Present	1-10	Unknown	Moore (1976)
TePupuka	Considerable numbers	100	Unknown	Moore (1976)
Atiu/Middle	Among seabird colonies	1-10	Absent (kiore unknown)	Southey (1985)
Double/Moturehu	>5000	5000-10000	Absent (kiore 1989, ship rat 1983)	Taylor (2000)
Great Mercury/Ahuahu	50	50	Cat, ship rat, kiore	J. Russell, *pers. comm.* (2012)
Great Mercury/Ahuahu	0	0	Cat, ship rat, kiore	Grace (1976)
Kawhitu/Stanley	>5000	5000-10000	Absent (kiore 1991, rabbit 1991)	Tennyson & Taylor (1990)
Korapuki	7500	500-1000	Absent (kiore 1987, rabbit 1988 unsuccessful)	G. Taylor, *unpubl. data* (2003)
Motukaha	13	10-20	Unknown	Towns & Atkinson (2004)
Ohinau	5543	5000-6000	Absent (kiore 2005, mice 2005, rabbit 2005)	Buxton (2010)
Red Mercury/Whakau	>5000	5000-10000	Absent (kiore 1992)	Taylor (2000)
Red Mercury/Whakau	Chicks present	20	Absent (kiore 1992)	Fogarty & Douglas (1972)
Needle Rock	Several large burrows	1-10	Absent	Taylor (1995)
Hongiora/Flat	13800	2829-28070	Absent	Whitehead *et al.* (2014)

Appendix 1. Continued.

Hongiora/Flat	20000-50000	20000-50000	Absent	Taylor (2000)
Middle Chain	20730	4230-43240	Absent	Whitehead *et al.* (2014)
Ruamahuaiti	18240	3517-3580	Absent	Whitehead *et al.* (2014)
Ruamahuanui	19640	3577-37150	Absent	Whitehead *et al.* (2014)
Motunau/Plate	< 5000	3000-5000	Absent	Taylor (1987a)
Moutohora/Whale	69330	10590-128300	Absent (cat 1954, goat 1977, Norway rat 1986, rabbit 1987)	Whitehead *et al.* (2014)
Moutohora/Whale	>95000	95000-100000	Absent (cat 1954, goat 1977, Norway rat 1986, rabbit 1987)	Imber *et al.* (2000)
Moutohora/Whale	109000	99000-119000	Absent (cat 1954, goat 1977, Norway rat 1986, rabbit 1987)	Imber *et al.* (2003)
Moutohora/Whale	2000	670-940	Absent (cat 1954, goat 1977, Norway rat 1986, rabbit 1987)	Harrison (1992)
Moutohora/Whale	1036	810-1260	Absent (cat 1954, goat 1977, Norway rat 1986, rabbit 1987)	Harrison (1992)
Moutohora/Whale	3000	1830-4140	Absent (cat 1954, goat 1977, Norway rat 1986, rabbit 1987)	Harrison (1992)
Moutohora/Whale	2000	1400-4140	Absent (cat 1954, goat 1977, Norway rat 1986, rabbit 1987)	Harrison (1992)
Moutohora/Whale	Several hundred pairs	300	Absent (cat 1954, goat 1977, Norway rat 1986, rabbit 1987)	Croxall & Millener (1971)
White/Whakaari	< 75	50-75	Kiore	P. Livingstone, *pers. comm.* (2013)
White/Whakaari	Common	50	Kiore	Clarkson & Clarkson (1994)
Portland	< 50	30-50	Mouse	H. Jonas, *pers. comm.* (2013)
Whangaokeno/East	2760	2760	Absent (kiore 1997, goat 1960)	A. Kirk, *pers. comm.* (2013)
Whangaparaoa	35	35-50	Absent	Taylor (1987b)