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Monitoring grey-faced petrels *(Pterodroma macroptera gouldi)* in a restoration project on Motuora Island, Hauraki Gulf

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Abstract Motuora is a highly modified island in the Hauraki Gulf that is currently being re-vegetated. It is envisaged that the island will eventually be restored to a native forest system with strong seabird influences. The island retains a small breeding population of grey-faced petrels (*Pterodroma macroptera gouldi*). In 2005 a survey of the accessible areas of the coastal margin was carried out to estimate the current size of the population. The survey located 406 active burrows and it was estimated that approximately 260-280 burrows contained incubating pairs. There was some evidence that active burrow numbers had increased at established breeding areas since the last survey in 1995, but differences between survey methods made comparisons difficult. Fixed monitoring plots were put in place in 2005 to provide a standardized measure of changes in burrow activity. Between 2005 and 2007 no change in the number of active burrows was discernible in the fixed plots. Longer term monitoring will be required to determine the population dynamics of the Motuora grey-faced petrels as evidence from other locations indicates that growth (if it occurs) will be slow. Consequently, seabird numbers (and associated nutrient inputs) on Motuora are likely to be below pre-disturbance levels for many decades. These results highlight the challenges of ecosystem restoration in highly modified habitats.

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Keywords: Seabirds; grey-faced petrel; *Pterodroma macroptera;* restoration; Motuora

INTRODUCTION

Seabirds can have extensive impacts on the terrestrial ecosystems where they nest because they disturb soil (especially burrowing species), modify surface and canopy vegetation, and link terrestrial and marine ecosytems through the deposition of guano, carrion, egg remains and food scraps (Mulder & Keall 2001, Bancroft *et al*. 2005, Hawke & Holdaway 2005). The marine-derived nutrients introduced into terrestrial systems by seabirds can have strong positive effects on plant growth, invertebrate abundance and reptile abundance (Polis & Hurd 1996, Stapp *et al.* 1999, Barrett *et al.* 2005). At high densities however, seabirds can also reduce vegetation cover and inhibit plant growth (Mulder & Keall 2001). In New Zealand, seabirds were widespread and abundant on both the mainland and offshore islands (Worthy & Holdaway 1993, 1995, 2000; Holdaway & Worthy 1994), but most species are now restricted to offshore islands as a result of anthropogenic impacts (Taylor 2000a).

As the roles of seabirds in New Zealand terrestrial ecosystems have become better understood there has been increasing inclusion of seabirds in restoration projects (Miskelly 1997, Miskelly & Taylor 2004). One such project is the community-led restoration currently underway on Motuora (36°30'S, 174°48'E), a highly modified 80 ha island in the Hauraki Gulf. The goal of the Motuora restoration is to re-establish a fully functioning native forest ecosystem with strong seabird influences (Gardner-Gee *et al.* 2007). Prior to human disturbance it is likely that the island had a diverse seabird fauna, with perhaps up to 7 species of burrowing seabirds in the coastal forest (McCallum *et al.* 1984, Gardner-Gee *et al.* 2007). Currently blue penguins (*Eudyptula minor*) utilise beaches and accessible inland locations around the island, and black backed gulls (*Larus dominicanus*) nest on an exposed spur at the northern end of the island. However, the only forest-breeding seabird remaining on Motuora is the grey-faced petrel

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(*Pterodroma macroptera gouldi*), a common endemic sub-species that breeds around the upper half of the North Is, with large colonies (20,000-95,000 pairs) present on Whale and Hongiora Is in the Bay of Plenty (Taylor 2000b, Heather & Robertson 2000, Imber *et al.* 2003). In the Hauraki Gulf area most offshore islands have tens to hundreds of grey-faced petrel breeding pairs, although more than 5,000 breeding pairs are thought to be present on each of the following islands: Hen, Lady Alice and Whatupuke Is in the Hen and Chickens group, on Burgess and Fanal Is in the Mokohinau group, on Red Mercury, Stanley and Double Is in the Mercury group, and on Ruamahuanui and Ruamahuaiti Is in the Aldermen group (Taylor 2000b).

Grey-faced petrels begin breeding at *c.* 7 years old and lay only 1 egg season^{-1} (Heather & Robertson 2000). This is typical for procellariids as their life history strategy involves delayed sexual maturity and low reproductive rates, accompanied by high adult survival (Warham 1996). Consequently, even when undisturbed breeding habitat is available, intrinsic population growth rates are low (Ainley *et al.* 2001, Jiguet *et al.* 2007). For example, a long-term study of 2 small protected grey-faced petrel colonies on the Auckland west coast has recorded slow growth at both sites, with 1 population increasing from 50 to 100 breeding pairs and the other increasing from 200 to 300 pairs over an 18 year period (G. Taylor, *pers. comm.*). Introduced predators, competitors, or habitat disturbance at breeding sites can severely reduce seabird breeding success (Warham 1996, Taylor 2000a, Rayner *et al.* 2007a). However, it appears that as long as adult mortality remains low, breeding success can increase rapidly once disturbances have been mitigated. For example, rat predation on grey-faced petrel eggs and chicks reduced fledgling production to negligible levels during the 1970s on Whale Is (Imber *et al.* 2000, 2003). After the eradication of rats in 1986, fledgling production increased and the number of occupied burrows more than doubled in a decade (Imber *et al.* 2000, 2003).

Like other procellariids, grey-faced petrels return at night to breeding areas to dig or renovate burrows and this can occur some months prior to egg laying. Studies that assess procellariid population trends or population size typically rely on burrow counts as the nocturnal burrowing habits of the birds makes direct counts impractical. Two types of burrow counts ("active burrow" and "occupied burrow" counts) are used that provide information about different aspects of the breeding activity of the study population. Active (or "used") burrows are generally defined as burrows that have been excavated or renovated to a functional state and have sign of recent occupancy such as faeces, feathers or tracks (Gaze 2000, Dunlop *et al.* 2002, Rayner *et al.* 2007b). Experienced breeders, novice breeders, non-breeders and young pre-breeding birds can all use burrows during the breeding season and hence the number of active burrows can indicate the potential breeding population using an area (Dunlop *et al.* 2002). After mating and a period of feeding at sea, birds return to the breeding area and females lay their eggs. Occupied burrows are generally defined as burrows in which an egg is laid during the breeding season (Hamilton 1998, Dunlop *et al*. 2002). Direct examination of the breeding chamber with miniature video camera systems (burrowscopes) or inspections holes is the most reliable method of determining occupancy (Hamilton 1998, Cuthbert & Davis 2002). Direct assessment of occupancy is needed to determine the reproductive output of a population as the number of occupied burrows does not necessarily correspond to the number of burrows excavated earlier in the year or the number of active burrows during the incubation period (Dunlop *et al*. 2002, Cuthbert & Davis 2002).

Before our study, relatively little was known about the state of the grey-faced petrel population on Motuora. A burrow survey had been conducted by the Ornithological Society of New Zealand (OSNZ) in 1995 (Hawley & Buckton 1997). However, substantial restoration work has been undertaken on the island since then and this was expected to have improved breeding conditions for grey-faced petrels. In particular, repairs to the perimeter fence have protected the coastal margin from stock damage for at least a decade and natural regeneration plus re-planting has increased native forest cover. In 2005, a seabird research programme was initiated as part of the Motuora restoration project and this paper reports on: i) the results of an island-wide burrow survey in 2005 to determine the population size and distribution of the grey-faced petrel population, and ii) preliminary results from fixed plot monitoring begun in 2005 to assess changes in active grey-faced petrel burrow numbers across time.

METHODS

Motuora burrow survey

Active burrows numbers and occupancy rates were recorded to ascertain the size and distribution of the grey-faced petrel population on Motuora. A burrow survey was conducted over 4 days in Jun and Aug 2005. During the survey, teams of 2 to 4 people moved through the accessible areas of the coastal margin in a loose line (approximately 5-10 m apart) and recorded each active petrel burrow encountered. Burrows were counted as active if they were deeper than 50 cm with obvious signs of recent activity (e.g. excavated soil, footprints,

Table 1 Number of active burrows recorded at grey-faced petrel established breeding areas in 1995 and 2005 on Motuora Is. A question mark indicates that the number of burrows was difficult to determine because the boundaries of the breeding area were unclear.

Name of established breeding area	1995	2005
Coromandel Valley	6	4?
Big North	30	22?
Big South	20	41
Ewe Paddock	12	25
Still Bay	20	26
Headland	26	15
Snake Gully	10	9
South	3	11
Total number of active burrows	127	153

feathers, guano). Active burrows were marked with stick gates to identify them as counted and their locations (or the locations of aggregations of very close burrows) recorded using hand-held GPS (Global Positioning System) units. All burrow co-ordinates were entered into a GIS (Geographic Information System) database. Total search time amounted to 54 person hours.

Burrow occupancy was examined during the grey-faced petrel incubation period on 14 Aug 2005. Using information available from previous studies we defined 2 types of breeding area. Established breeding areas were defined as areas where grey-faced petrel burrows have been present for at least 2 decades (Dowding 1988, Hawley & Buckton 1997). Peripheral areas were defined as burrowed areas of unknown age that were at least 10 m away from established breeding areas. Occupancy was measured in both areas as it was thought the areas could contain different ratios of experienced to novice/pre-breeding birds. Twenty four burrows were randomly selected from established breeding areas and another 20 were randomly selected from peripheral areas. The 44 surveyed burrows were checked using a burrowscope fitted with a video monitor. Burrows were regarded as occupied if an egg was observed in the burrow.

To investigate long-term trends in the Motuora grey-faced petrel population, we compared our burrow survey results against those of the OSNZ 1995 survey (Hawley & Buckton 1997). The 1995 survey counted the number of active burrows in 8 established breeding areas (Table 1). However, the 1995 survey did not record search area (m^2), location or search effort in detail, so it was not possible to replicate the 1995 survey method. Instead we used the 2005 survey data to estimate the number of active burrows in the main dense aggregation in each established breeding area (Table 1).

Fixed plot monitoring

Fixed plots were created to enable more consistent measures of burrow numbers at established breeding areas. Fixed plots were put in place at 9 established breeding areas (the 8 sites surveyed in 1995 as listed in Table 1 plus "Home Bay", an additional site identified in Dowding (1988)) between Jun and Aug 2005. At each site a rectangular plot was positioned to enclose the main aggregation of accessible burrows present. Plot corners were marked with wooden pegs and tags, and the numbers of active burrows within the plots were counted. The average area of the established plots was 174 m^2 but ranged from 72 m^2 to 483 m^2. To monitor petrel activity in peripheral areas 9 more plots were marked in adjacent areas. The peripheral plots were positioned at least 10 m from established breeding areas and included at least 1 active burrow when established. Peripheral plots were approximately 10 m x 10 m. All plots were revisited in late May 2006 and 2007, and active burrows counted. Repeated measure ANOVAs were used to test for change in burrow numbers between years. As the assumption of sphericity was violated, Huynh-Feldt adjusted numerator and denominator degrees of freedom were used to determine *P*-values.

RESULTS

Burrow survey

A total of 406 active burrows were located in the 2005 survey of the coastal margin of Motuora (Fig. 1). Most (72%) were concentrated on the north-eastern side of the island between Still Bay and Coromandel Valley. Burrows typically were found scattered individually or in small groups. Large dense aggregations (20 plus burrows, > 0.05 burrows per m^2) only occurred at established breeding areas and these areas contained 35% of all active burrows located. Almost all burrows were found within the naturally regenerating coastal forest, with many occurring under the roots of large remnant pohutukawa (*Metrosideros excelsa*). A few were found beneath gorse (*Ulex europaeus*) or in grass, but no burrows were detected in the areas of planted forest.

The overall burrow occupancy rate was 70%. The occupancy rate for active burrows sampled from the established breeding area was 83% (n = 24), while occupancy rate in peripheral areas was 55% (n = 20). Using the overall occupancy rate of

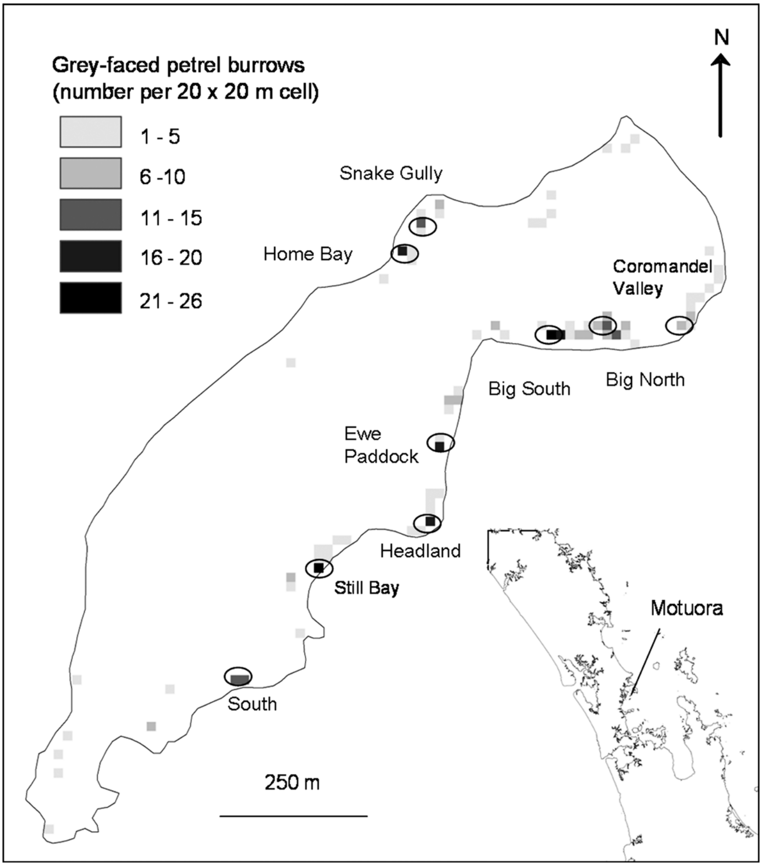

Fig. 1 2005 distribution and density of active grey-faced petrel burrows on Motuora. Each square represents a 20 m by 20 m GIS cell and the shade of the square indicates the number of active burrows recorded in the cell. Ovals indicate the locations of established breeding areas.

70%, it was estimated that there were 284 occupied burrows on Motuora. Using the rates for each type of area, a slightly lower total of 263 was reached (0.83 x 143 active burrows in established areas plus 0.55 x 263 burrows in peripheral areas). Hence it is estimated that approximately 260-280 pairs of grey-faced petrel were breeding in 2005 in the accessible areas of the coastal margin on Motuora.

Comparisons between the 1995 and 2005 surveys provided some evidence that active burrow numbers had increased at established breeding areas (Table 1). In 2 areas (Big North and Coromandel Valley), no spatially distinct aggregations were discernible which made estimates difficult for these sites. At the remaining 6 established breeding areas, reasonably distinct aggregations were present and burrow numbers here were compared with counts from the same areas in 1995. The total number of burrows counted at these 6 areas was 40% higher in 2005 than in 1995. However, no significant differences were found when paired t-tests were used to examine whether, on average, burrow numbers have changed at these 6 sites across the decade (paired t-test $t = -1.32$, $df = 5$, $P = 0.24$).

Fixed plot monitoring

The mean change in burrow numbers in fixed plots between 2005 and 2007 was -2.38 ± 1.43 ($x \pm se$) in the established breeding areas and -0.71 ± 0.47 in the peripheral areas (Fig. 2). In both types of area the change in burrow numbers between years was not statistically significant (Repeated measures ANOVA $F = 2.64$, $P = 0.11$). There was also no significant interaction between plot type (established or peripheral) and year (Repeated measures ANOVA $F = 0.90$, $P = 0.40$).

DISCUSSION

Despite a long history of habitat modification, a small population of grey-faced petrels has managed to persist on Motuora. This study estimated that approximately 260-280 pairs of grey-faced petrels were breeding on Motuora in 2005 in accessible coastal areas. Some additional burrows may be located in inaccessible cliff-face areas so the total number is likely to be slightly higher. The burrow occupancy rate in established breeding areas on Motuora (83%) is comparable with occupancy rates (73% and 87%) that have been reported for Whale

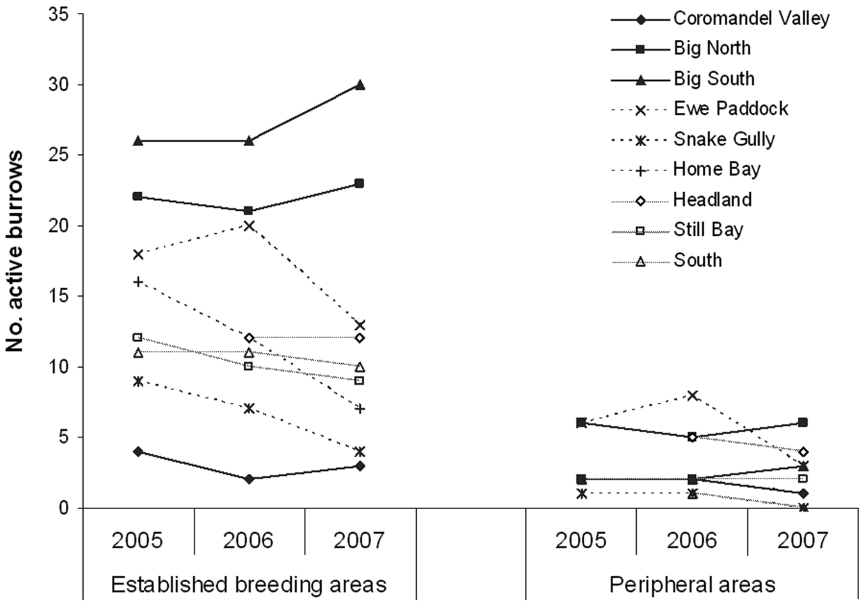

Fig. 2 Number of active grey-faced petrel burrows in fixed plots at nine established breeding areas and 9 peripheral areas on Motuora.

Island grey-faced petrel colonies (Imber *et al.* 2003). In our study, a reduced occupancy rate (55%) was recorded in peripheral areas. It is possible that this difference is simply due to sampling error, and more extensive sampling is planned in the future to improve current occupancy estimates.

If the increased protection of breeding areas on Motuora over the past several decades has allowed more pairs of grey-faced petrel to establish burrows and fledge young, this would presumably result in increased recruitment of young birds into the breeding population. Accordingly, annual increases in active burrow numbers could be expected until the population becomes limited by other factors. However, we found no clear evidence of increased burrow numbers on Motuora. Although the total number of burrows at 6 established breeding areas increased by 40% between 1995 and 2005, the average number of burrows at these sites had not changed significantly across the decade. We were also unable to detect any increases in burrow numbers in the fixed plot monitoring. It is possible that population growth is not occurring because other factors (e.g. interaction with other colonies, food supplies at sea) are slowing growth or limiting population size. Although petrels generally return to breed at their natal site, movement between sites does occur (Warham 1996). In the Hauraki Gulf, the larger colonies on outer islands may attract petrels hatched from Motuora, slowing or preventing Motuora population growth. Human impacts (e.g. fishing) and climate variability at feeding grounds can also prevent population growth or cause population declines in some seabirds (Taylor, 2000a). Grey-faced petrels feed in pelagic water beyond the continental shelf and to date there has been little research on either human-induced or climate-induced changes to their food resources (Taylor, 2000b).

Alternatively, it is possible that population growth has occurred on Motuora but was not detected because of the monitoring methods used. Differences between the 1995 and 2005 survey methods make it difficult to assess population change across the decade with confidence. Annual counts of active burrow numbers in fixed plots should generate more reliable data in time. Active burrow counts are rapid and require no specialised equipment or skills. This makes the method attractive for seabird monitoring in community projects such as the Motuora restoration. However the value of the method has been questioned because activity signs can be difficult to detect even if a bird is using a burrow, and because observers can have different opinions about what burrows are active (Hill *et al.* 1996, Gaze 2000, Cuthbert & Davis 2002). On Motuora, the team of people checking burrows has been consistent since 2005 which should minimise observer variability between years. Variability between observers within a year is currently unknown and should be investigated to ensure results are as reliable as possible. Differing weather conditions may also make it more difficult to detect activity signs in some years than in others. In particular, long dry periods prior to a burrow count may mean few tracks are visible, and burrow entrances readily fill with dry soil and leaf litter. However, is unlikely that discrepancies between observers or weather conditions would be enough to mask large changes in active burrow numbers over time.

Even assuming that there has been some growth in the breeding population of grey-faced petrel on Motuora, the small size of the current population and the reduced seabird diversity on the island means that total seabird densities and associated inputs will be below likely pre-disturbance levels for many more years. Studies from the Chicken Is and Stephens Is provide some indication of what the pre-disturbance ecosystem on Motuora may have been like. The Chickens Is group lies in the outer Hauraki Gulf and contains similar sized islands to Motuora. These islands have experienced fewer disturbances than Motuora and have retained a diverse burrowing seabird fauna, with 3 to 7 species occurring on each island (McCallum *et al.* 1984). Typically 2 to 3 species are common, and thousands of burrows are present on each island (McCallum *et al.* 1984). Total seabird density on the more southern Stephens Is (150 ha) is estimated to be 5000-11,000 ha^{-1} and fairy prion burrow densities in remnant forest patches on Stephens Is can be as high as 3 m^{-2} (Mulder & Keall 2001, Markwell & Daugherty 2002). In contrast, seabirds are absent from most of Motuora Is, and existing breeding areas are small with relatively low densities. As a result, the current impact of seabirds on Motuora is likely to be both limited and localized.

In conclusion, this study confirms that grey-faced petrel are continuing to breed on Motuora but further monitoring is required to determine the long term trajectory of this population. Evidence to date indicates that ongoing population growth (if it occurs) will be slow. Consequently, seabird numbers (and associated nutrient inputs) on Motuora are likely to be well below presumed pre-disturbance levels for many decades. These results highlight the challenges of ecosystem restoration in highly modified habitats.

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