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Habitat loss drives population decline and reduced mass of Rakiura tokoeka (*Apteryx australis australis*, Stewart Island brown kiwi,) at Mason Bay, Stewart Island/Rakiura

HUGH A. ROBERTSON*
ROGAN M. COLBOURNE
Biodiversity Group, Department of Conservation, PO Box 10420, Wellington, New Zealand

Abstract: Between 1993 and 2018, the number of Rakiura tokoeka (*Apteryx australis australis*, Stewart Island brown kiwi) territories in 125 ha of retired farmland near Island Hill Homestead, Mason Bay, declined from 17 to 12 at a mean rate of 1.43% per year, and the minimum number of adults declined by 1.39% per year. These rates triggered a New Zealand conservation status of 'Nationally Endangered' for the subspecies assuming that they were typical of the whole of Stewart Island/Rakiura. Feeding habitat for tokoeka has been lost as the study site reverts from rough pasture to flax (*Phormium tenax*) and scrub; the mean mass of adult birds has decreased by 7.5% over 30 years despite a 30% decline in population density. Key predators of adult kiwi are absent, and predation of Rakiura tokoeka by feral cats (*Felis catus*) is known but is likely to be insignificant. With a conservative population estimate of 15,000–20,000 adults, and with the decline likely localised at Mason Bay, the conservation status of Rakiura tokoeka is more appropriately classified as 'At Risk – Naturally Uncommon'. This research highlights the risks of extrapolating results from a single study, in this case with a limited geographical extent rather than a limited duration.

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Keywords: kiwi, population dynamics, predation, habitat loss, mass, conservation status

INTRODUCTION

Conservation biology has historically placed a strong emphasis on measuring changes in the populations of threatened species and determining the causes for both negative and positive changes. The quantitative measures and rates of change underpin threat classification systems such as the IUCN Red List (IUCN 2012) and the New Zealand Threat Classification System (Townsend *et al*. 2008) and, in turn, these are used by conservation planners and managers to determine priorities for the investment of conservation funds.

Predation by introduced mammals, including humans, has been the primary agent of decline and current limitation of New Zealand native forest birds (Innes *et al*. 2010). Because New Zealand's avifauna evolved with avian rather than mammalian predators, the extinction of 54 bird species since human settlement in New Zealand *c*. 800 years ago (Robertson *et al*. 2021) was driven primarily by predation by introduced mammals, but habitat loss was undoubtedly a contributing factor driving population decline and extinction

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*Correspondence: *hrobertson@doc.govt.nz*

risk to New Zealand birds (Holdaway 1989; Innes *et al*. 2010). Globally, habitat loss is regarded as the main driver of population decline and extinction in birds (Collar *et al*. 1994; BirdLife International 2018), especially for those species that are habitat specialists and/or have small body sizes (Owens & Bennett 2000).

The Stewart Island brown kiwi (hereafter called Rakiura tokoeka) *Apteryx australis australis* (Scofield *et al*. 2021, Checklist Committee (OSNZ) 2022), is widespread and common throughout Stewart Island/Rakiura (Harper 2009), and they are also present on adjacent Ulva and Pearl islands. Rakiura tokoeka often live in family groups, with multiple juveniles, subadults, and adults sharing a burrow, hollow log, tree stump or clump of dense foliage, and fiercely defending their territory (Guthrie-Smith 1914; Colbourne 1991). Up to seven adults have been recorded in a single territory (Robertson *et al*. 2019b). Subadult and adult helpers assist the 'alpha' pair to incubate the one-egg clutch and to brood recently hatched chicks. Adults and helpers of both sexes develop well-defined brood patches (Colbourne 1991, 2002). Unlike other kiwi taxa, Rakiura tokoeka are renowned for feeding and occasionally calling in daylight (Colbourne & Powlesland 1988), especially females that have incubated all night, and males soon after their eggs have hatched (Colbourne 1991).

The Rakiura tokoeka was long regarded as the least threatened of all kiwi taxa because it had a large population of *c*. 20,000 birds on Stewart Island/Rakiura (Heather & Robertson 2005). The island is still largely cloaked in forest and natural shrubland communities, and the tokoeka there are not exposed to any predation by mustelids (stoat [*Mustela erminea*], ferret [*M. furo*], or weasel [*M. nivalis*]), and the few dogs (*Canis familiaris*) present are confined to a small area in and around the only settlement at Oban on the north-eastern side of the island. Apart from common brushtail possums (*Trichosurus vulpecula*), which occasionally compete for burrows (Morrin 1989), disturb nests and eat kiwi eggs (McLennan *et al*. 1996), and very rarely kill adult kiwi (Robertson *et al*. 2011), the only mammalian predators present are feral cats (*Felis catus*). They are known to prey on kiwi chicks (<50 days old), juveniles (50 days to 6 months old), subadults (6 months to 4 years old), and very rarely adult kiwi (McLennan *et al*. 1996; Robertson *et al*. 2011; Isabel Castro, *pers. comm*.). Without the other mammalian predators of kiwi on Stewart Island, the impact of predation was considered likely to be relatively minor and the population was expected to be stable.

Despite kiwi feathers having a distinctively simple structure, with a single rachis and unlinked barbs (Heather & Robertson 2015), Karl & Best (1982) did not detect any tokoeka feathers in the 44% of 229 feral cat scats that contained bird remains, collected mainly from southern Stewart Island/Rakiura, in areas where Rakiura tokoeka were present (e.g. Colbourne & Powlesland 1988). Although Harper (2005) did not always attempt to distinguish the species of bird from feathers found in 27% of 219 feral cat scats from central Stewart Island/Rakiura, small native and introduced passerines were most commonly found, and remains of tokoeka were not identified. Evidence of consumption of tokoeka by feral cats on Stewart Island/Rakiura has been found in the form of tokoeka DNA in feral cat scats collected at Mason Bay (Danielle Middleton, Manaaki Whenua Landcare Research, *pers. comm*.), but whether the tokoeka was killed by the cat or eaten as carrion is unknown.

Our preliminary data on the decline of the study population at Mason Bay (46°55'S, 167°48'E) between 1993 and 2008 were influential in Miskelly *et al*. (2008) classifying Rakiura tokoeka as 'Nationally Vulnerable' according to the New Zealand Threat Classification System criteria (Townsend *et al*. 2008). This assessment was accompanied by the qualifier 'Recruitment Failure' because of concerns that predation by cats could have been a driver of the observed decline in the number of adult birds and territories. In 2008, we proposed that the population decline at Mason Bay may have been driven by habitat loss as rough farmland reverted to communities of New Zealand flax/harakeke (*Phormium tenax*), red tussock (*Chionochloa rubra*), and mānuka (*Leptospermum scoparium*)-dominated scrub, following the removal of sheep in the mid-1980s (RMC & HAR *unpubl. data*). These observed, but unquantified, habitat changes have provided good cover and daytime shelters for tokoeka, but have reduced feeding opportunities, particularly in areas dominated by dense swards of flax that build up an impenetrable mass of tough dead leaves at ground level. Like other kiwi species, Rakiura tokoeka feed by walking about and probing their long bill into the soil or leaf litter layer to catch a wide variety of invertebrates, including earthworms, beetles (Coleoptera) and their larvae, spiders, wētā (Orthoptera), Lepidoptera larvae, centipedes, and cicada (Hemiptera) nymphs (Colbourne & Powlesland 1988).

To assess whether the decline was localised to Mason Bay or was more widespread, a second population monitoring site was established in 115 ha of mature forest habitat at Port Adventure (47°03'S, 168°11'E) on the eastern coast of Stewart Island/Rakiura where feral cats are also present. In January 2011, our initial monitoring, including searches with trained kiwi conservation dogs, found only one recently hatched chick but no juvenile or subadult tokoeka among the 21 birds

caught. This suggested that poor recruitment due to cat predation may have been skewing the age structure heavily in favour of adults (Robertson *et al*. 2019b).

The expert panels assessing the conservation status of New Zealand birds in 2012 (Robertson *et al*. 2013) and 2016 (Robertson *et al*. 2017) designated the conservation status of Rakiura tokoeka as 'Nationally Endangered'. The observed decline up to 2008, and then through to 2013 at Mason Bay, together with low numbers of young kiwi detected at Port Adventure in 2011, suggested that the population may be declining at >70% in three generations, which would trigger 'Nationally Critical'. Because there was uncertainty whether the decline at Mason Bay was typical of the whole population, and because the Port Adventure data were based on a single visit, a lower threat category was designated, pending the collection of further data. The designation was accompanied by the qualifiers 'Data Poor', 'One Location', and 'Recruitment Failure' (2012 assessment only). These qualifiers indicated the lack of knowledge about the cause and extent of the population decline of this essentially single-island endemic subspecies, and the belief in 2012 that recruitment failure was a likely significant driver of the population decline at Mason Bay and the reason for the lack of young tokoeka caught at Port Adventure in 2011.

Habitat loss is one of the key threats to birdlife globally (Collar *et al*. 1994). It can lead to individuals moving to alternative feeding and breeding sites, or have an impact on the individual fitness (survival, body condition, or fecundity) of those that remain (Goss-Custard *et al*. 1995; Burton *et al*. 2006), and ultimately lead to a new lower population limit or carrying capacity at a site (Newton 1998). In this paper, we assess whether the decline in the population size of Rakiura tokoeka at Mason Bay was driven by predation by cats and/or by habitat loss as the study area reverts from rough farmland. A measure of mass change of the adult birds could distinguish between these hypotheses; bird mass would be stable or higher with decreasing population density if the decline is driven by predation, but stable or lower with decreasing population density if habitat loss has reduced the carrying capacity of the site.

METHODS

Study area

Stewart Island/Rakiura is the smallest (174,600 ha) and least modified of the three main islands of New Zealand. Mason Bay, on the western coast of Stewart Island/Rakiura, lies in the path of the prevailing westerly winds which bring frequent rainfall, cool temperatures in winter, and generally mild conditions in summer. From approximately 2.5 km inland from the beach, an attempt was made to farm sheep on the stable ancient linear sand dunes and the flats between them. The 2,000-ha Island Hill Run was established in 1884 and the drier land was burned and converted to rough pasture, some swamps were drained in an effort to make more land suitable for grazing, and in the 1970s an airstrip was cleared and used by aircraft to bring superphosphate fertilizer to spread on the better pasture, and to fly out possum skins and live deer (Cervidae). Commercial farming ceased in 1985 and the farm was finally destocked in 1987 (Peat 2010), allowing the rough pasture to revert naturally to New Zealand flax/harakeke, red tussock, and scrub dominated by mānuka.

We mapped the territories of Rakiura tokoeka in a 125-ha area to the north and east of the Island Hill Homestead (Fig. 1), approximately centred on the western end of the old airstrip (46°55′S, 167°48′E).

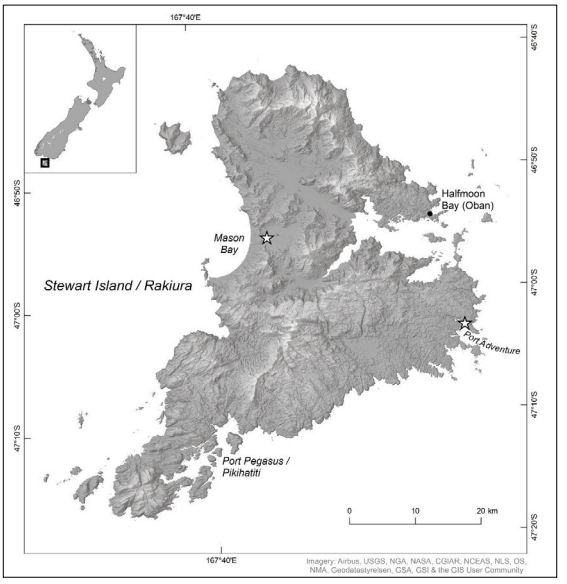

Figure 1. Map of Stewart Island/Rakiura, New Zealand, showing the location of the Mason Bay and Port Adventure study areas.

Catching and handling birds

Rakiura tokoeka were caught using a variety of methods described in the Kiwi Best Practice manual (Robertson & Colbourne 2017). Most were caught by hand or in hand nets when we found them feeding at night, often when a trained and muzzled conservation dog indicated their presence nearby. We also used conservation dogs to indicate their presence in a burrow or under dense vegetation by

day, and caught birds by hand when they shared a daytime shelter with a radio-tagged family member. We occasionally used playback to attract adults at night. Each bird captured or re-captured was measured, sexed, aged, mass determined, and body condition scored, according to the methods described by Robertson & Colbourne (2017), except that we discovered during this study that Rakiura tokoeka were still growing, and hence still classified as subadults, up to about 6 years old (see results). Every bird handled was permanently marked with a uniquely numbered fish fingerling tag inserted in the patagium of the wing, or banded with a uniquely numbered metal band which had a combination of colours of reflective tape added to allow individual identification at night. Radio-transmitters (Sirtrack™ two-stage, 25 g or, more recently, 11 g) were temporarily strapped to the tarsus with a single soft plastic hospital identification bracelet according to the method described by Miles & McLennan (1998).

Territory mapping

Long-term monitoring of Rakiura tokoeka started in November 1993, to take advantage of the many birds living in 11 territories that had been banded during an ecological and behavioural study conducted in 1988–1991 (Colbourne 1991, 2002). In 1993, the original study area was expanded from 80 ha to 125 ha by including six additional territories largely to the north and east of the original scientific study area. The monitoring surveys were done approximately every five years; the first two surveys were done in November and the last four surveys (from 2003) in February; the entire study spanned 24.25 years from November 1993 to February 2018.

Based on records of captures, daily checks of the location of radio-tagged birds, occasional sightings of birds with and without coloured reflector bands, and projected locations of transmitter signals and calls at night, we mapped the approximate boundaries of each territory. Rakiura tokoeka were strongly territorial with very little apparent overlap of neighbouring territories. Territory boundaries were often streams or swamps, although some territories spanned these features on some visits. Many adults remained faithful to a particular territory for decades. We used the 'fieldworker's estimate' (Macdonald *et al*. 1980) by starting with a maximum convex polygon of locations, and then modified the shape to exclude overlap of territories and include adjacent suitable habitat bounded by the same geographical features (i.e. major streams), with the assumption that these sites would have been used if we had more daily location data.

Because each territory of Rakiura tokoeka can be occupied by multiple adults and subadults, the daily checks usually involved sighting the radio-tagged bird to determine if any extra birds were with it, even after a pair of adults had been caught and radio-tagged in a territory.

Table 1. The number of Rakiura tokoeka (*Apteryx australis australis*) captured during six approximately 5-yearly surveys at Mason Bay, Stewart Island/Rakiura. The minimum number of birds and minimum number of adult birds known to be alive is based on captures, sightings, projected calls, and recaptures of birds in subsequent surveys, with the assumption that birds did not leave and then re-enter the study area between surveys. The number of territories was calculated using the 'field worker's estimate' method by mapping all the above records and observing that territories are not overlapping and assuming that small spaces between known locations of birds are not occupied by additional birds.

	Year					
	1993	**1997**	**2003**	**2008**	**2013**	**2018**
Adult female	9	14	13	12	9	9
Adult male	12	18	10	18	12	11
Chick (in nest)	1	0	0	0	0	0
Juvenile (<6 months)	0	0	0	1	1	1
Subadult (>6 months)	2	2	5	2	3	6
Total captures	**24**	**34**	**28**	**33**	**25**	**27**
Percentage young	13	6	18	9	16	26
Minimum # birds alive	42	45	38	36	35	38
Minimum # adult birds	39	43	33	33	30	30
# Territories	17	16	14	13	11	12
Min # adults/territory	2.29	2.69	2.36	2.54	2.73	2.50

RESULTS

Population change

Over the six surveys at Mason Bay from 1993 to 2018, we caught 79 different Rakiura tokoeka a total of 171 times. At first capture, 26 were adult females, 30 were adult males, one was a chick in a nest, three were juveniles (<1 kg and therefore assumed to be < 6 months old), and 19 were subadults (Table 1). The chick was not seen again. One of the two juveniles that were caught before 2018 (and hence capable of being recaptured on a subsequent survey) was recaptured on the two subsequent surveys (once as a subadult, and then as an adult) still in its natal territory. Six (43%) of 14 subadults caught before 2018 were recaptured as adults within the study area during subsequent 5-yearly surveys.

In November 1993, there were 17 occupied territories containing a minimum of 42 birds, of which 39 were adults. Over the 24.25 years to February 2018, the estimated number of adults in the 125-ha study area declined at an average rate of 1.39% per year (Figure 2) while the actual number of territories declined from 17 to 12 at an average rate of 1.43% per year (Figure 2, Figure 3). If the mean generation time (the average age of female parents) of Rakiura tokoeka is assumed to be 20–25 years, then over three generations (60–75 years), this would result in a 57–65% decline in the number of adults and a 58–66% decline in the number of territories.

The mean territory size has increased 42% from 7.4 ha in 1993 to 10.4 ha in 2018, and the density of adults has declined 30% from one adult per 3.2 ha to one adult per 4.2 ha. The number of adults per territory has varied over the six surveys (Table 1), with a weak linear increase over the 25-year period (r = 0.62, P = 0.19), but the actual increase may be greater because our experience from 5-yearly visits to Mason Bay is that we usually underestimate the number of extra adults alive in a few territories.

We detected simple pairs in territories 58% of the time, but the other territories were occupied by up to five adults (three males and two females). In the 31 instances where three adults were present in a territory, there were significantly more trios with two males (23) than with two females (8) (Binomial test, z = 2.69, P = 0.007), but in the three territories with four adults there were two of each sex in one territory and one male and three females in the other two territories. At least some of the additional adults in territories were offspring from that territory; e.g. a 680 g juvenile female that was wing-tagged in Territory 4 in February 2008 was still in the same territory 10 years later, along with her putative parents.

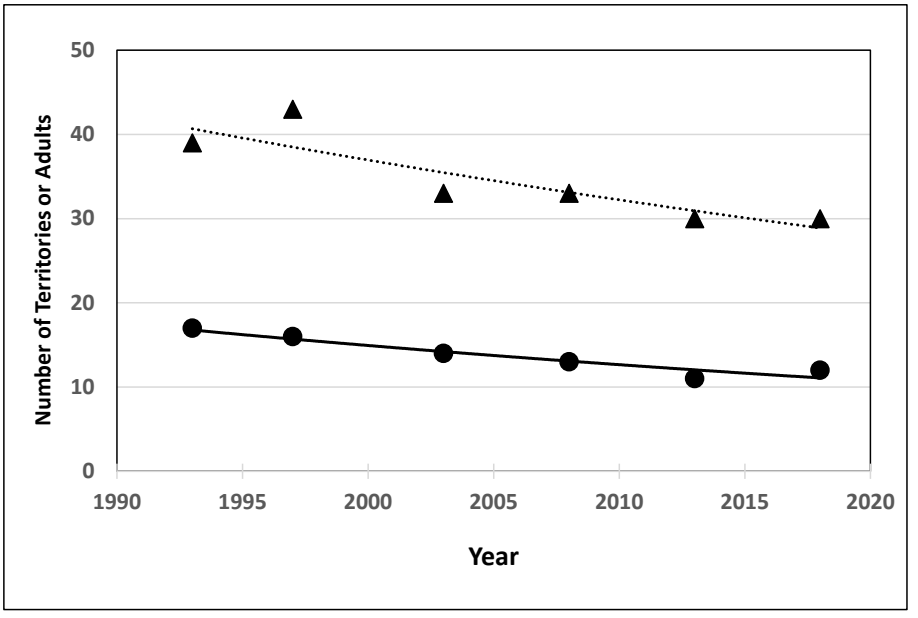

Figure 2. Exponential decline in the minimum number of adult Rakiura tokoeka (*Apteryx australis australis*) (triangles and dotted line) in 125 ha at Mason Bay, Stewart Island/Rakiura between November 1993 and February 2018 (y = $40.46e^{-0.014x}$, r = -0.885, P = 0.019). The number of territories (circles and solid line), which was known exactly, declined from 17 to 12 over the same period.

Figure 3. Maps showing the approximate boundaries of territories of Rakiura tokoeka (*Apteryx australis australis*) in the 125-ha study area at Mason Bay, Stewart Island/Rakiura (see Fig. 1), at approximately 5-year intervals from 1993 to 2018. Territory boundaries are shown as bold lines, the former boundaries at the previous assessment are shown as faint lines.

Morphometrics

Including unpublished data from the 1988–1991 scientific study, the averaged measurements of 74 adult Rakiura tokoeka caught at Mason Bay are given in Table 2. At this site, tokoeka have had their mass determined during only a limited part of the year, from 12 October to 21 February, mainly in late January or early February, and so the annual mean mass is likely to be higher than those we recorded because kiwi gain mass as their condition improves through autumn and winter in the lead-up to the breeding season (e.g. McLennan 1988).

In February 2008, a *c.* 3-month-old juvenile female (bill length 57.2 mm, mass 680 g) was captured, wing-tagged and released. It was recaptured in the same territory five years later (bill length 147.8 mm, mass 2,890 g), but when again recaptured in the same territory in February 2018, its bill length had grown a further 5.4 mm to 153.2 mm, and its mass had increased to 3,120 g. This female probably did not stop growing until it was about six years old, at the upper end of the usual 5–6 year growth period of kiwi (Beale 1991; Bourdon *et al*. 2009).

Table 2. Measurements of Rakiura tokoeka (*Apteryx australis australis*) at Mason Bay, Stewart Island/Rakiura taken using the methods described by Robertson & Colbourne (2017). Up to nine repeated measurements of each individual taken between 1988 and 2018 were averaged and then these were used to calculate the overall mean, standard deviation (SD) and extremes of all averaged measurements, except for mass, where the actual extreme measurements are presented.

Female	**Mean**	**SD**	**n**	**Minimum**	**Maximum**
Bill length (mm)	142.7	5.8	35	133.4	156.4
Tarsus width (mm)	13.9	0.7	32	12.0	15.8
Tarsus depth (mm)	19.6	1.1	32	17.9	22.2
Tarsus length (mm)	96.5	3.6	32	88.3	104.5
Mass (g)	3,264	269	35	2,780	4,120
Male	**Mean**	**SD**	**n**	**Minimum**	**Maximum**
Bill length (mm)	105.1	4.1	38	97.5	118.0
Tarsus width (mm)	13.2	0.7	36	11.5	14.5
Tarsus depth (mm)	18.4	0.8	36	16.9	20.0
Tarsus length (mm)	91.5	3.5	36	84.4	98.3
Mass (g)	2,657	192	38	2,200	3,170

The mass of adults recorded in late January or in February during research work in 1988 and 1990 (RMC *unpubl. data*), and during territory mapping from 2003 to 2018, showed some variation from year to year; however, both adult females and adult males had a similar and highly significant linear decrease in mass over the 30 years (r = -0.33, P = 0.017 and r = -0.34, P = 0.005, respectively, Figure 4). Adult female body mass decreased by a mean of 8.5 g per year, and adult males were on average 7.1 g lighter per year. Over the 30 years, these equated to losses of 255 g or 7.5 % of mean body mass for females, and 213 g or 7.5% of mean body mass for adult males.

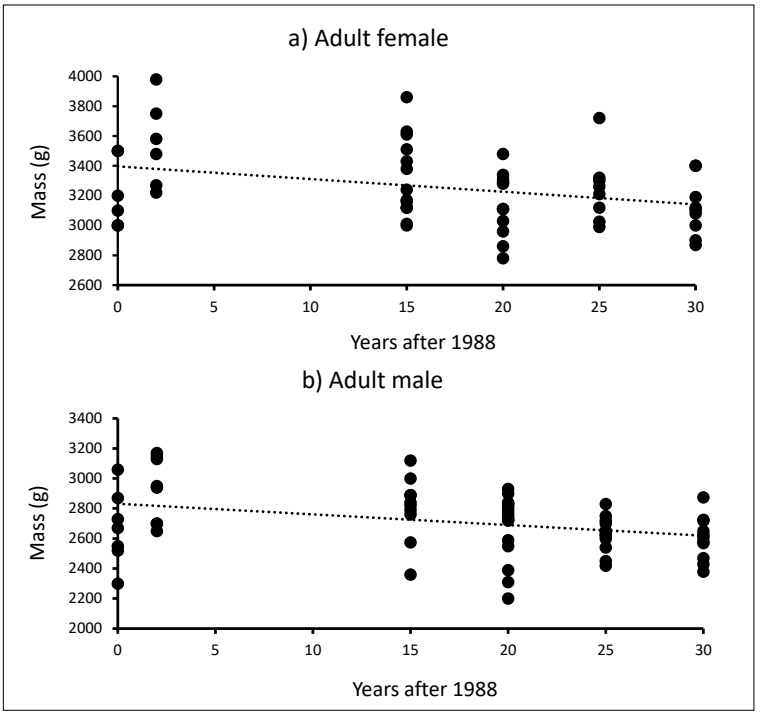

Figure 4. Mass of adult Rakiura tokoeka (*Apteryx australis australis*) at Mason Bay, Stewart Island/Rakiura recorded between 26 January and 20 February in 1988, 1990, 2003, 2008, 2013, and 2018. The mean decrease in mass of 8.5 g per year for females (a) was significant (r = -0.33, n = 53, P = 0.017), as was the mean decrease of 7.1 g per year for males (b) (r = -0.34, n = 65, P = 0.005).

DISCUSSION

Two possible mechanisms were suggested for the serious decline in the number of territories of Rakiura tokoeka at Mason Bay: recruitment failure through predation of young tokoeka by feral cats, or habitat loss following the retirement of farmland reducing the carrying capacity of the study site.

The dominant year-round prey of feral cats on Stewart Island/Rakiura is rats (Karl & Best 1982; Harper 2005) and although feral cats ate more birds as rat abundance declined, they did not prey-switch to specialise on birds when rat abundance was low (Harper 2005). Given the lack of kiwi feathers detected in a total of 448 feral cat scats from Stewart Island/Rakiura (Karl & Best 1982; Harper 2005), it seems likely that predation of Rakiura tokoeka by feral cats is infrequent and insignificant. Predation rates may vary from year to year, and from site to site; for example, in contrast to catching or detecting only one chick at Port Adventure in 2011, during the next visit to the site in February 2017, one chick and four juveniles hatched in the 2016/17 breeding season and three subadults hatched in earlier years were caught or seen (Robertson *et al*. 2019b). The following year, we caught three subadults at Mason Bay (mass of 1,425–1,875 g) that likely hatched in the 2016/17 breeding season. This suggests that 2016/17 was a particularly productive year for Rakiura tokoeka and/or that feral cat predation on young Rakiura tokoeka was low at both sites that particular year. Compared with kiwi species, such as North Island brown kiwi (*Apteryx mantelli*), that have young that become independent from <2 months old (Heather & Robertson 2015), the social system of Rakiura tokoeka may afford better protection of chicks and juveniles from predation by feral cats because chicks are not left unattended in the nest, and juveniles often share daytime dens with subadults or adults.

Habitat loss often refers to situations where natural communities are destroyed or become fragmented when forests are logged, shrubland communities are cleared, wetlands are drained or filled, or cities expand. Habitat loss resulting from slow habitat change during seral succession clearly affects bird communities as shown, for example, by changes in the abundance of bird species in different habitat guilds during vegetation restoration programmes (e.g. Munro *et al*. 2011; Graham *et al*. 2013), but the mechanisms underlying population declines during seral succession or vegetation restoration have received little attention compared with species that have benefitted from such processes.

Carrying capacity, the maximum population of a species that a site can sustain, is an often-quoted concept but is very difficult to estimate or measure accurately because resource limits vary in both space and time, and such variations can be temporary in nature, such as during a severe drought (Robertson *et al*. 2019a). The carrying capacity of a site is often estimated from observed population densities in apparently stable populations in similar habitat elsewhere (e.g. Colbourne & Robertson 1997), but changes in physiology (e.g. mass, levels of stress hormones), feeding behaviour, breeding productivity, immigration/emigration, and survival can provide greater insights into the mechanisms underlying demographic changes in populations close to or beyond carrying capacity. The direction of changes in these parameters are generally predictable; for example, as the carrying capacity of a site is approached or exceeded, time spent foraging increases and reproductive effort decreases (Morris & Mukherjee 2007).

If habitat loss has been the primary driver of the observed population decline at Mason Bay, then predation by feral cats would have been insignificant because any Rakiura tokoeka killed would have been part of the 'doomed surplus'.

Our data indicate that reduced food availability, likely caused by a loss of short grassland habitat which is easy for birds to forage in, has been the main driver of the observed population decline at Mason Bay. The mean mass of adult birds decreased by 7.5% over a 30-year period of habitat change, despite a 30% decrease in the density of adults over the last 25 years of that period. If predation had been the main driver of population decline, we would have expected the body mass of adults to have been stable or to have increased as the population density declined.

We note that even with a 42% increase in the mean territory size at Mason Bay from 7.4 ha to 10.4 ha, they are still smaller than the mean territory size (14.4 ha) recorded in 115 ha of mature forest at Port Adventure (Robertson *et al*. 2019b). The density of one adult per 4.2 ha at Mason Bay is also higher than the one per 5.0 ha recorded at Port Adventure despite more adults per territory (mean 2.88) at Port Adventure in 2017 (Robertson *et al*. 2019b). The number of adults per territory at Mason Bay showed a non-significant increase over the last 25 years but, because some additional adults in territories are usually missed during our surveys, it is likely that over time an increasing number of young tokoeka delay leaving their natal territory and remain as helpers well into adulthood. An example of delayed dispersal was the 10.25-year-old female that was found in her natal territory with her putative parents in 2018, some 6 years after most other kiwi species start breeding (Robertson & de Monchy 2012). We expect that there will have been other behavioural changes over the same period that have led to mortality and/or emigration

exceeding recruitment and/or immigration, but we have not been able to measure these during our few brief but regular visits.

It may seem counterintuitive that densities of the endemic Rakiura tokoeka at Mason Bay have declined as the habitat reverts from rough farmland dominated by exotic grass and legume species to more natural communities dominated by native species. We do not know the quantity of fertilizer that was applied to the pasture in the study area before our research, but this may have led to artificially high soil fertility and density of soil invertebrates at the start of our studies.

We believe that the main habitat change affecting tokoeka since the cessation of farming has been a considerable increase in the ground surface covered by New Zealand flax/harakeke, red tussock, mānuka scrub and, in places by bracken fern (*Pteridium esculentum*), umbrella fern (*Sticherus cunninghamii*), and rank exotic grasses. Although historical aerial photographs with sufficient resolution to quantify habitat changes are lacking from this remote site, the main loss of feeding habitat appears to have been caused by the rapid spread of flax, which now forms dense monocultural stands of 0.5 ha or more (Fig. 5). Flax is a tall perennial monocotyledonous tussock-herb that has fan-like tufts of fibrous, stiff and sword-like leaves that fall to the base of the plant when they die (Wehi & Clarkson 2007). It is native to Stewart Island/Rakiura, but some plants almost certainly represent introductions of high-quality races (Wilson 2009) because of their economic importance for weaving, ropemaking, and to act as windbreaks. Flax provides very good cover and daytime shelters for tokoeka, but the dense accumulated mass of tough dead leaves at ground level makes foraging slow and difficult for tokoeka.

Figure 5. Dense swards of flax (*Phormium tenax*) have replaced large areas of open grassland at Mason Bay, Stewart Island/Rakiura. Photograph: Sabine Bernert.

Interestingly, between our surveys in 2013 and 2018, there was a major die-off of flax from an unknown disease with characteristics akin to 'yellow-leaf disease'. This disease of northern New Zealand is caused by a phytoplasma bacterium and it led to the widespread die-off of flax and the closure of the flax fibre industry in New Zealand (Beever *et al*. 1996). Isolated flax bushes and those on the periphery of stands seemed to be the most affected in 2018. If the outbreak of this unknown disease continues, it may provide a natural test of our thesis that the decline of Rakiura tokoeka at Mason Bay has been driven primarily by the rapid spread of flax and consequent decreased foraging opportunities and loss of body mass of the tokoeka.

Based on densities we have encountered on Stewart Island/Rakiura, we conservatively estimate the population to be 15,000–20,000 adults. Given that the decline appears to be driven by habitat changes localised to Mason Bay, it appears likely that the overall population is close to stable (i.e. ±10% in three generations), and so the conservation status of Rakiura tokoeka should be classified as 'At Risk – Naturally Uncommon'. Using data from a draft of this paper, the bird assessment panel accepted that Rakiura tokoeka should be re-classified as 'At Risk – Naturally Uncommon' pending an assessment of whether the total population is above or below 20,000 mature birds (Robertson *et al*. 2021). This new classification carries the qualifier 'Conservation Dependent' in recognition of the need for ongoing biosecurity measures to keep Stewart Island/Rakiura free of mustelids. If the population is stable and actually greater than 20,000 adult birds, then this subspecies would be classified as 'Not Threatened', which is a far cry from the 'Nationally Critical' classification that our Mason Bay data initially pointed to. This research highlights the risks associated with extrapolating results from a single study, in this case with a limited geographical extent rather than duration, because valuable conservation funds could have been spent addressing what is likely to be only a localised problem.

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