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Assessing minimum population size of Kermadec parakeets (*Cyanoramphus novaezelandiae cyanurus*) on Macauley Island, Kermadec Islands

TERRY C. GREENE*
IAN M. WESTBROOKE
DEREK BROWN
PETER J. DILKS
Science and Technical, Department of Conservation, Private Bag 4715, Christchurch 8140, New Zealand

JOHN W. BARKLA
Department of Conservation, PO Box 5244, Dunedin 9058, New Zealand

RICHARD GRIFFITHS
Department of Conservation, PO Box 32026, Devonport 0744, New Zealand

Abstract The minimum population size of Kermadec parakeets (*Cyanoramphus novaezelandiae cyanurus*) is reported for Macauley Island in the southern Kermadec Islands group. To minimise population impacts of any accidental parakeet deaths the confirmed presence of a minimum population of 3,000 parakeets was required prior to the attempted eradication of Pacific rats (*Rattus exulans*) from Macauley Island. Eight pre-defined vegetation strata were identified and 4 count methods ranging from simple counts to distance sampling were assigned to each strata depending on sampling conditions. As the resultant point estimate of 3,484 parakeets during the 29 June to 1 July 2006 survey period was greater than the minimum threshold the rat eradication was able to proceed. The potential impacts of changes in the vegetation on the population dynamics of Kermadec parakeets and recommendations for future monitoring of this species on Macauley Island are discussed.

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INTRODUCTION

The Kermadec Islands rise from the Kermadec sub-oceanic ridge midway between New Zealand and Tonga. They are comprised of a chain of widely scattered active and extinct volcanic cones between latitudes 29°S and 32°S (Veitch *et al.* 2004; Greene *et al.* 2014). Only 6 islands exceed 5 ha in area and all are young (< 2 million years) with consequent low levels of floral and faunal endemism (Veitch *et al.* 2004).

The introduction of goats (*Capra hircus*), rats (*Rattus* spp.) and cats (*Felis catus*) to the Kermadec Islands over the previous 2 centuries has had a profound detrimental impact on the birds of this isolated island archipelago (Veitch *et al.* 2004). Following the successful removal of goats from Macauley Island by 1970 and from Raoul Island by

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

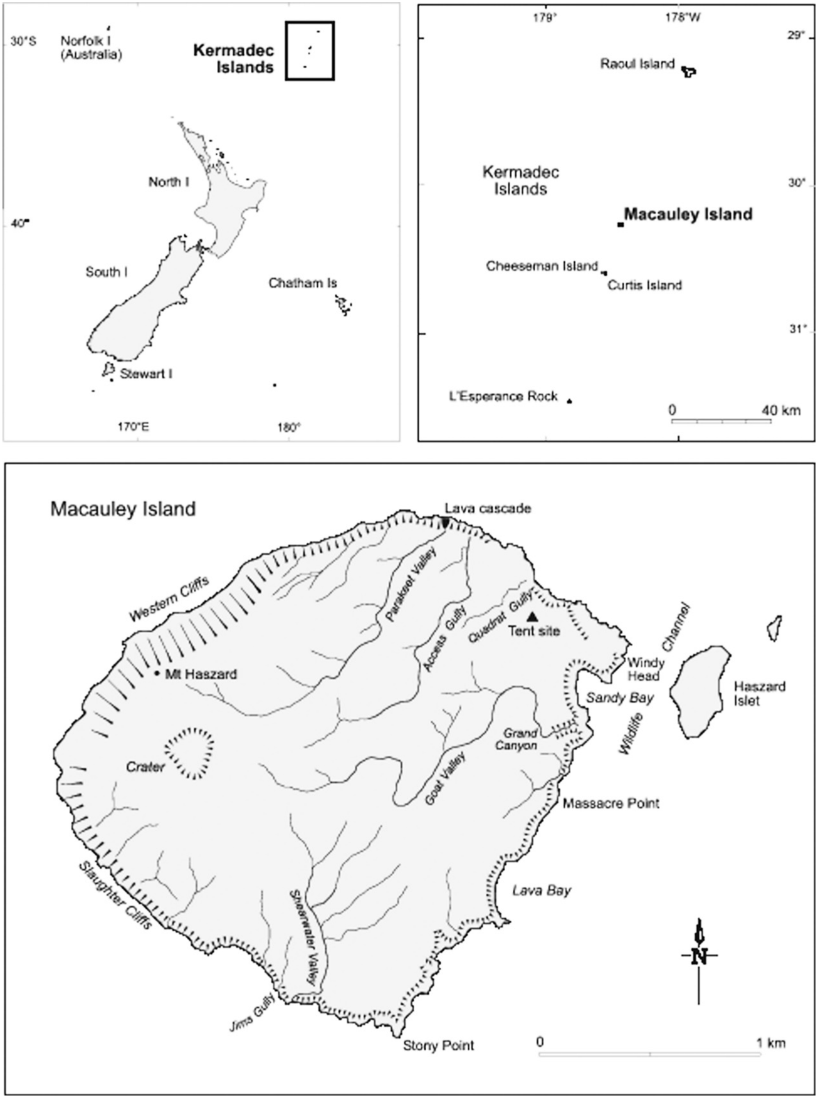

Fig. 1. Location and significant geographic features of Macauley Island.

1985, the eradication of cats, Norway rats (*Rattus norvegicus*) and Pacific rats (*Rattus exulans*) from Raoul Island and Pacific rats from Macauley Island was scheduled for the winter months of 2002. However, concerns about the risk posed to Kermadec parakeets (*Cyanoramphus novaezelandiae cyanurus*) by aerially spread rat-baits containing the second generation anticoagulant brodifacoum (20 ppm) resulted in the postponement of rat eradication on Macauley Island to allow time for a more formal risk assessment. Accordingly, Macauley Island was visited for 4 days in July 2002 where the risk of rat eradication to the parakeets was assessed and determined to be minimal (Greene *et al*. 2004). The New Zealand Department of Conservation subsequently reapplied for resource consent (required by the NZ Resource Management Act 1991) to eradicate Pacific rats in July 2006. Consent was granted subject to several conditions (M. Ambrose, *pers. comm.*). The most significant of these in terms of risk to the project was the requirement that a minimum population of 3,000 parakeets be confirmed inhabiting Macauley Island before rat eradication could proceed. At the time the Macauley Island population of Kermadec parakeets was the most significant in the Kermadec group and this condition was therefore imposed to minimise the long-term population impacts of any mortality on this species.

Historical population estimates for Kermadec parakeets inhabiting Macauley Island vary markedly. Estimates range from a minimum of >1,000 birds in 1966 (Taylor 1985) to 17,000-20,000 in September 1988. This was followed within 2 months by an almost immediate decline to 5-10% of the preceding estimate (Veitch *et al.* 2004). Seasonal drought, food shortages, and successional changes in the plant communities on Macauley Island over the last 40 years have all been identified as potential significant drivers of these highly variable population estimates (Taylor 1985; Greene *et al.* 2004; Veitch *et al.* 2004; Greene *et al.* 2014). Additionally, the absence of a consistent and robust sampling design and survey methodology has also hampered the accuracy and precision of population estimates (G. Taylor, *pers. comm*.; Greene *et al.* 2004).

During 2002, parakeet numbers on Macauley Island were estimated using distance sampling methods (Greene *et al*. 2004). However, the short duration of the visit (4 days) and the need to complete other priority tasks required that sampling effort was low and biased toward areas of greatest floristic diversity and high parakeet density easily accessible to observers. Thus, the calculated population estimate of between 8,000 and 10,000 parakeets was probably a significant overestimate (Greene *et al.* 2004). A more robust sampling design was clearly required to detect with confidence the presence of sufficient parakeets to allow the Macauley Island rat eradication to proceed. In this study we report on the objectives, sampling design and survey methodologies used to determine the minimum population size for Kermadec parakeets on Macauley Island.

METHODS

Study site

Macauley Island (30° 13’S, 178° 33’W) is the 306 ha remnant of an extinct basaltic volcano (Fig. 1). The island is bounded on all sides by vertical coastal cliffs and comprised of a sloping plateau which climbs from relatively low eastern cliffs about Windy Point to Mt. Haszard (238 m) in the northwest. The plateau is dissected by numerous erosion gullies, some of which have developed into vertical sided ravines where they exit through the coastal cliffs. Vegetation is dominated by tall and dense *Hypolepis dicksonioides* fernland and *Cyperus insularis* (Sykes 1977 as *Cyperus ustulatus*) sedgeland. More detailed examinations of the geology, climate and vegetation of Macauley Island can be found in Veitch *et al.* (2004), Greene *et al.* (2004), Barkla *et al.* (2008), Greene *et al.* 2014 and de Lange (*in press*).

Sampling methods

Selection of sampling methods was dictated by 2 objectives. First, there was a need to provide a robust point estimate with acceptably narrow confidence intervals (*i.e.*, CV ≤ 25%; Greene *et al.* 2004) of the minimum number of parakeets on Macauley Island immediately prior to the attempted rat eradication and second, to establish a baseline population estimate and sampling methodologies suitable for future monitoring programmes.

Previous visits to Macauley Island strongly suggested that Kermadec parakeet distribution and density was largely determined by the predominant vegetation communities (Greene *et al.* 2004). High densities of parakeets were noted in areas of *Scaevola gracilis*, *Cyperus insularis*, within the few remaining remnant stands of ngaio (*Myoporum rapense subsp. kermadecense*) and vegetation adjacent to coastal cliffs. Parakeets occured at much lower densities in areas dominated by the fern *Hypolepis dicksonioides* (Greene *et al.* 2004; Greene *et al.* 2014). In addition, the time limits imposed for the visit to Macauley Island (<7 days) and the difficulties of moving about the island suggested that a simple randomised or systematic sampling design imposed equally over all habitats would be an inefficient means of rapidly assessing the abundance of parakeets. Intensive sampling of habitats with low densities of parakeets was likely to waste time when the principle objective was to simply determine whether or not a minimum population of 3,000 parakeets was present.

A more efficient alternative was to concentrate on those habitats, or strata, known to hold higher densities of parakeets and that were relatively easy to survey. That is, those habitats with highest densities of parakeets and the greatest ease of access were sampled first and most intensively using the most appropriate standardised sampling methodology to maximise abundance estimates as quickly as possible. The most important pre-requisite for this type of stratified sampling approach is prior knowledge of the location and extent of the various habitats. These habitats can then be allocated as accurately as possible to sampling strata so that sampling effort can be apportioned prior to fieldwork thereby avoiding sampling inefficiencies and resultant problems associated with data interpretation. Seven sampling strata were defined *a priori* using a combination of satellite imagery (panchromatic and multispectral imagery obtained from Digital Globe 2005), recent oblique aerial photographs (RNZAF 2006) and observations of parakeet distribution derived from our previous visit in 2002 (Fig. 2; Greene *et al.* 2004). Each of these strata (Table 1) was sampled in priority order (high to low parakeet density, accessibility and sampling intensity). A further stratum comprising extensive patches of *Solanum nodiflorum* was defined on the island immediately following our arrival once this habitat and its significance was identified.

Count methodologies

Having defined the sampling strata of interest we then selected the most appropriate count

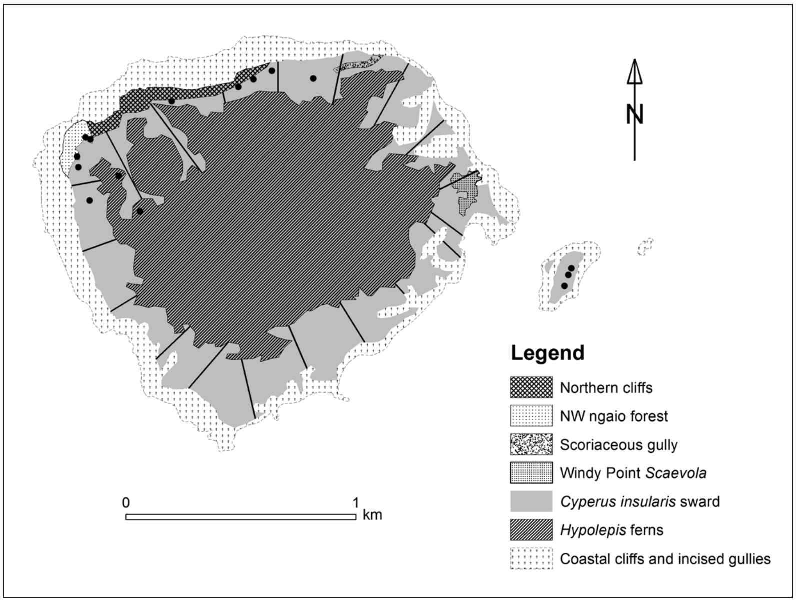

Fig. 2. Significant vegetation communities and sampling strata used on Macauley Island. Solid black lines represent distance sampling transects within the *Cyperus* stratum and solid dots the location of large trees (predominantly ngaio). Spatial extent of *Solanum* stratum could not be accurately quantified.

methodology. The application of specific count methods and sampling effort was dependent on the strata being sampled. Four methods were used:

Simple counts
Basic counts of parakeets either seen or heard in a given area with no expectation that all birds present were counted. These counts were restricted to the northern cliffs where access was poor and often dangerous. Our inability to traverse this area (counts had to be conducted from the cliff edge) and the significant amounts of dense vegetation growing on these steep slopes meant that counts of parakeets were likely to be considerable underestimates.

Total counts
Complete counts (effectively a census) of all birds within a stratum were only possible for small areas where visibility was good and detection probability was high such as the open areas of *Scaevola gracilis*. All parakeets seen or heard were counted by observers moving systematically through the defined area. This provided a minimum number of parakeets in the area and was considered a conservative estimate. This method was used for 4 of the defined strata (Fig. 2, Table 1).

Plot sampling
The total numbers of parakeets within a stratum was derived by simple extrapolation from the number encountered within sampled plots (quadrats, strips or circular plots) of known size. Appropriate variance estimates can also be calculated using the variation between sample counts. This method was only applied within small areas dominated by *Solanum* within the *Hypolepis* stratum (Fig. 2, Table 1).

Distance sampling
Estimates of parakeet density and abundance were derived from perpendicular distance measurements from transect lines to individuals or clusters of perched parakeets, or to the point from which birds were flushed using laser rangefinders (Nikon Forestry 550). Line transects were used to maximise sampling efficiency in the relatively narrow but extensive *C. insularis* habitat which was thought likely to contain the majority of the parakeet population (Greene *et al.* 2004). Prior to visiting Macauley Island, 53 potential transects were defined (start point, finish point and approximate length) using available satellite imagery and GIS. All transects were oriented at right angles from the coastal edge of the predefined *Cyperus* stratum. Of these, 19 (approximately every third one) were sampled to ensure adequate sampling effort, sample unit independence and even coverage probability (Buckland *et al.* 2001) within the *Cyperus* stratum (Fig. 2). Line length was entirely dependent on the width of the stratum for any given transect and ranged from 50-380 m. Navigation to start and finish points for each transect was accomplished using a GPS and/or compass.

Every effort was made to meet the 3 principle assumptions of distance sampling (Thomas *et al.* 2010): first, that all parakeets perched on or directly above each line were detected with certainty ($g(0)=1$); second, that survey objects are detected at their initial location and do not move in response to the observer prior to detection; and third, that distances from the line or point to the survey object are measured accurately. Parakeets flying into or over the count area were either ignored or, if recorded, excluded from the analysis. All distances were measured to

Table 1. Sampling strata used for sampling Kermadec parakeets on Macauley Island.

Strata name	Area (ha)	Sampling method used
1. *Cyperus insularis* sward	71.8	Distance sampling
2. Northern cliffs	4.3	Simple counts
3. Scoriaceous Gully (Access Gully)	0.6	Total count
4. Windy Point *Scaevola*	1.4	Total count
5. Remnant ngaio trees	–	Total count
6. NW ngaio forest	1.7	Total count
7. *Hypolepis* fernland	115.5	Distance sampling
8. *Solanum nodiflorum* patches	6.0	Plot sampling

the nearest metre to a maximum of 50 m and cluster size was also recorded. A minimum of 80 distance measurements to individual or clusters of parakeets were targeted in an attempt to maximise the precision of the detection function (Buckland *et al.* 2001). Each transect was traversed by a pair of observers working together to optimise the number of detections and the accuracy of distance measurements.

RESULTS

Stratum 1: *Cyperus insularis* sward

A total of 3796 m from 19 transect lines was sampled in the *C. insularis* habitat. Within this strata, 265 distances to individuals or clusters of parakeets within 50 m of either side of the line were recorded. Because of the difficulties of moving around the island, 3 days (29 June–1 July 2006) were required to complete coverage of this stratum.

Data were analysed using the free software DISTANCE 5 (Thomas *et al.* 2006). Distance data was truncated by 5% to remove outliers, reduce over-dispersion and improve model fit and estimate precision (Buckland *et al.* 2001, Thomas *et al.* 2010). Data were left ungrouped during analysis and histograms of the perpendicular distance measurements were constructed and detection functions ($\hat{g}\ (x)$) derived using several models and appropriate expansion functions (Buckland *et al.* 2001). Two models were found to fit the data well. Uncertainty around selection of the most appropriate model was addressed using the model averaging procedure outlined by Burnham and Anderson (1998). Point estimates for parakeet density and abundance and their associated confidence intervals within the *Cyperus* stratum are shown in Table 2. We estimated there were 1770 parakeets in this stratum (Table 2).

Stratum 2: Northern cliffs

Counting parakeets within this stratum was extremely difficult given its steepness, general inaccessibility and the cover provided by rapidly regenerating shrubs and trees – particularly ngaio. Simple counts could only be made from the cliff edge looking down onto the top of vegetation where observers were reliant on seeing perched or flying birds or counting the number of calling birds. Where we could access this stratum many more parakeets were found to be out of view beneath the low canopy. Considerable habitat suitable for parakeets below that visible from the summit ridge was also noted during helicopter flights following commencement of the rat eradication programme. Our perception was that counts in this area were substantial underestimates with more than half of the available habitat unable to be surveyed. The number of parakeets recorded (248) was therefore doubled (a conservative multiplier in our view) to a total of 496 parakeets in an attempt to provide a more accurate estimate.

Stratum 3: Scoriaceous gully

A total count of parakeets in this gully was made by all 4 observers walking line-abreast down the true right side of the gully. This count is likely to have been conservative as periods of heavy rain at the time the count was undertaken sent many birds into neighbouring large ngaio trees and the heavily vegetated slopes on the much steeper left side of the gully. A total of 53 parakeets (mostly foraging on *Disphyma* spp. and *Bidens pilosa*; Greene *et al.* 2014) were counted in this small area.

Stratum 4: Windy Point *Scaevola*

A total count of all parakeets present within the relatively small areas of *Scaevola gracilis* (~1.4 ha) near Windy Point was conducted on 29 June 2006. Parakeets were counted by all 4 observers walking line-abreast through all identifiable areas of this stratum. Although a total of 87 parakeets were counted, considerable movement into and out of these patches of vegetation was noted throughout the count period.

Stratum 5: Remnant ngaio and Kermadec poplar trees

Total counts of parakeets within 4 large ngaio trees in areas away from the northern cliffs were

Table 2. Density and abundance estimates for Kermadec parakeets in *Cyperus insularis* habitats on Macauley Island.

Model	ΔAIC	%CV	$\hat{D}_i$*	†	95% CI	‡	95% CI
Hnorm+cos.	0	12.6	25.1	24.7	18.5-30.8	1770	1119-2421
Unif+cos.	1.45	12.1	23.8				

**Estimated density (ha^{-1})
†Model averaged Density estimate (ha^{-1})
‡Model averaged Abundance estimate

conducted at varying times throughout the trip. These consisted of single isolated trees and a small patch of stunted trees on the western coast. Also included within these counts were birds seen perched in the large Kermadec poplar (*Homolanthus polyandrus*) located to the south of the crater (Barkla *et al.* 2008). Despite these large trees being isolated and rare, large numbers of parakeets were often associated with them. The dense networks of branches within the leafy exterior were particularly popular parakeet perches and 153 parakeets were counted within these relatively few trees.

Stratum 6: NW ngaio forest
This was the most extensive area of trees on Macauley Island and numerous parakeets were seen foraging for ngaio flowers and fallen seeds. Although 3 observers attempted a total count of the area, parts of the forested area were difficult to reach and were not checked for parakeets. The density and height (up to 5 m tall) of much of the forest made counts difficult and the estimate of 106 parakeets is likely to have been a significant underestimate.

Stratum 7: *Hypolepis* fernland
Time did not permit rigorous sampling within the extensive areas of fern habitat. It was apparent, however, that the density of parakeets was much lower in this habitat compared to other parts of the island and appeared similar to that seen in 2002. A rough estimate of the possible number of parakeets inhabiting this stratum was made using the encounter rate calculated in 2002 (~15% of that seen in areas of *Cyperus*; Greene *et al.* 2004). A rough density estimate of 3.7 parakeets ha^{-1} for *Hypolepis* fernland stratum was calculated.

Stratum 8: *Solanum* patches
Since 2002 several small areas of the *Hypolepis* stratum had experienced significant die-back (up to 1 ha) and had been invaded by dense patches of *Solanum nodiflorum* (the tops of which had in turn died back) (reported in Barkla *et al.* 2008 as *Solanum americanum* subsp. *nutans*). These areas (~5% or 6 ha of the *Hypolepis* stratum) supported very high densities of parakeets. Flocks of 50 or more could often be seen flying overhead or foraging on the abundant fruits and flowers. Sampling of 4 large plots (0.32-0.60 ha) in these areas suggested an average density of 67.8 (95% CI = 54.5-81.0) parakeets ha^{-1}.

Total estimate of parakeet population size
Point estimates of parakeet abundance computed from each stratum were added to provide a figure of overall parakeet abundance for the area sampled. Where variance estimates were able to be computed, overall precision was calculated by taking the square-root of the sum of the variances for the *Cyperus* and *Solanum* strata. The point estimate for the total population of Kermadec parakeets on Macauley Island was at least 3,484 (95% CI = 2772-4196) birds. As approval to discharge rat baits on Macauley Island required a minimum population of 3,000 parakeets, the Pacific rat eradication operation proceeded as planned on 3 July 2006.

DISCUSSION
The counts of parakeets on Macauley Island in 2006 represent the most robust population estimate for the species to date. However, the estimates recorded in Table 1 are conservative and, for at least 2 of the strata (*i.e.*, northern cliffs and NW ngaio forest), considered to be a substantial underestimate of the parakeet population. Simple counts of parakeets on the northern cliffs were particularly rudimentary. Similarly, access to all parts of the small patch of ngaio forest in the north-west (in addition to the unexpected height and density of this vegetation) made accurate counts impossible and undoubtedly underestimated the numbers of parakeets in both these areas. Although low abundance figures in these strata may have been offset to some degree by double counting of parakeets elsewhere (*e.g.*, those flying about in flocks over *Scaevola* or *Solanum*), observers were aware of this problem and were able to adjust counts accordingly. Despite the limitations imposed by the need for rapid assessment of population size and even if the most pessimistic estimates are used (*i.e.*, the lower 95% CI estimates for the *Cyperus* and *Solanum* strata) the Macauley Island parakeet population was still very close to the target of 3,000 birds and the decision to proceed with the rat eradication justified.

Although we were unable to monitor the parakeet population beyond the 48 hours immediately following the first application of rat

Table 3. Density and abundance estimates for Kermadec parakeets on Macauley Island.

Stratum	Area (ha)	Density ($\hat{D}$ ha^{-1}) (± 95% CI)	Abundance ($\hat{N}$) (± 95% CI)
Cyperus insularis sward	71.8	24.7* (18.5-30.8)	1770* (1119-2421)
Northern cliffs	4.3	115.3	496
Scoriaceous Gully	0.6	88.3	53
Windy Point *Scaevola*	1.4	62.1	87
Remnant ngaio trees	–	–	153
NW ngaio forest	1.7	62.4	106
Hypolepis fernland	115.5	3.7	412
Solanum patches	6.0	67.8	407* (327-486)
Total Parakeets			3,484 (2772-4196)

*Point estimate used

baits, observations of parakeets within this period showed no evidence that parakeets were consuming baits even where both bait and parakeet density was particularly high (*e.g.*, the loading site). Similar rodent eradications undertaken in the presence of other *Cyanoramphus* parakeets strongly suggest that any non-target impact would have been minor and short-lived (McFadden & Greene 1994; Empson & Miskelly 1999; Graeme & Veitch 2002; Towns & Broome 2003; Greene & Dilks 2004; Greene *et al.* 2004). Subsequent brief visits to Macauley Island in September 2006 and May 2011 (de Lange, *in press*) have confirmed the continued presence of a large parakeet population although numbers of birds may have declined again following Tropical Cylone Bune in 2011 (de Lange, *in press*).

Despite the obvious issues with the use of simple counts and total counts in more marginal habitats all of the assumptions associated with the more formal plot sampling and distance sampling methods were easily met. Kermadec parakeets are brightly coloured and readily detectable within the low vegetation (≤1 m) found in these strata. In addition, the parakeets on Macauley Island have had little if any previous contact with humans and thus did not flee when approached by an observer. Consequently, all parakeets on or close to transect lines and within plots were readily located and accurate distances obtained. The count methodologies employed within the various strata and the stratification applied should be altered particularly if the period available for counts increases (*e.g.*, greater use of distance sampling within the *Hypolepis* fernland) and as the structure and extent of the various vegetation communities continue to change (de Lange, *in press*). A robust but flexible approach to future monitoring of parakeets on Macauley Island is clearly required.

This population estimate confirms the status of Kermadec parakeets on Macauley Island as locally abundant and by far the most common terrestrial bird species on the island (Greene *et al*. 2014). Numbers of parakeets were significantly lower than the 10,000 estimated in 1980 and 2002 and substantially less than the 17,000 and 20,000 recorded in 1988 (Greene *et al*. 2004; Veitch *et al*. 2004). Although the processes driving these substantial fluctuations remain unknown it seems highly likely that the significant changes in vegetation observed on Macauley Island since 1988 (Barkla *et al.* 2008; Greene *et al.* 2014) has had a significant impact on food availability.

Since the removal of goats from Macauley Island in 1970 (Veitch *et al*. 2004) successional change in the dominant vegetation communities has been rapid. The *Microlaena* grassland that dominated the plateau in the 1960s and 1970s (Sykes 1977) and was still a significant component (~30%) of the flora in 1988 had completely disappeared by 2002 (Greene *et al.* 2004). This grassland was largely replaced by a *Cyperus insularis* sedge community by 1988 (~70% coverage) but by 2002 the extent of this species had been reduced by 45% to a peripheral band surrounding the island. Approximately 70% of the island is now covered by the large fern *Hypolepis dicksonioides* (Greene *et al.* 2004; Barkla *et al.* 2008).

Kermadec parakeets rarely feed on *H. dicksoniodes* (Higgins 1999) so it is likely that this fern's spread has significantly reduced both the foraging opportunities for more preferred seed and fruit producing species, particularly *C. insularis* and *S. nodiflorum* (Higgins 1999; Greene *et al.* 2014), and the ability of parakeets to increase or maintain their numbers at the more elevated levels observed in the past. Nevertheless, despite the reduction of historically preferred food species, considerable suitable habitat is likely to persist with some elements increasing again as further regeneration of woodier shrub and tree communities occurs particularly following the probable eradication of Pacific rats in 2006 (de Lange, *in press*).

The recolonisation of Raoul Island by Kermadec parakeets from adjacent pest-free islands following the eradication of cats (*Felis cattus*) and rats (*Rattus norvegicus* and *R. exulans*) in 2002 has been rapid and their expansion throughout forested areas extensive (Ortiz-Catedral *et al.* 2009; W. Beggs, *pers. comm*.). Given the relative size of both islands (Raoul Island 2938 ha) it is likely that the Macauley Island parakeet population has since been superseded as the largest population of this species in the Kermadec group. However, the Macauley Island population of parakeets remains significant particularly as questions about the potential for genetic differentiation between the 2 populations remain unanswered (Veitch *et al*. 2004) and the medium-term impacts of the very dynamic nature of vegetation succession (particularly following the presumed removal of rats) on the terrestrial and seabird fauna of Macauley Island is also uncertain. Further monitoring of the population status and trends of Kermadec parakeets should note the limitations of the current population estimates but continue to build on the robust unbiased sampling methodologies and sampling design reported here for all future visits to Macauley Island.

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