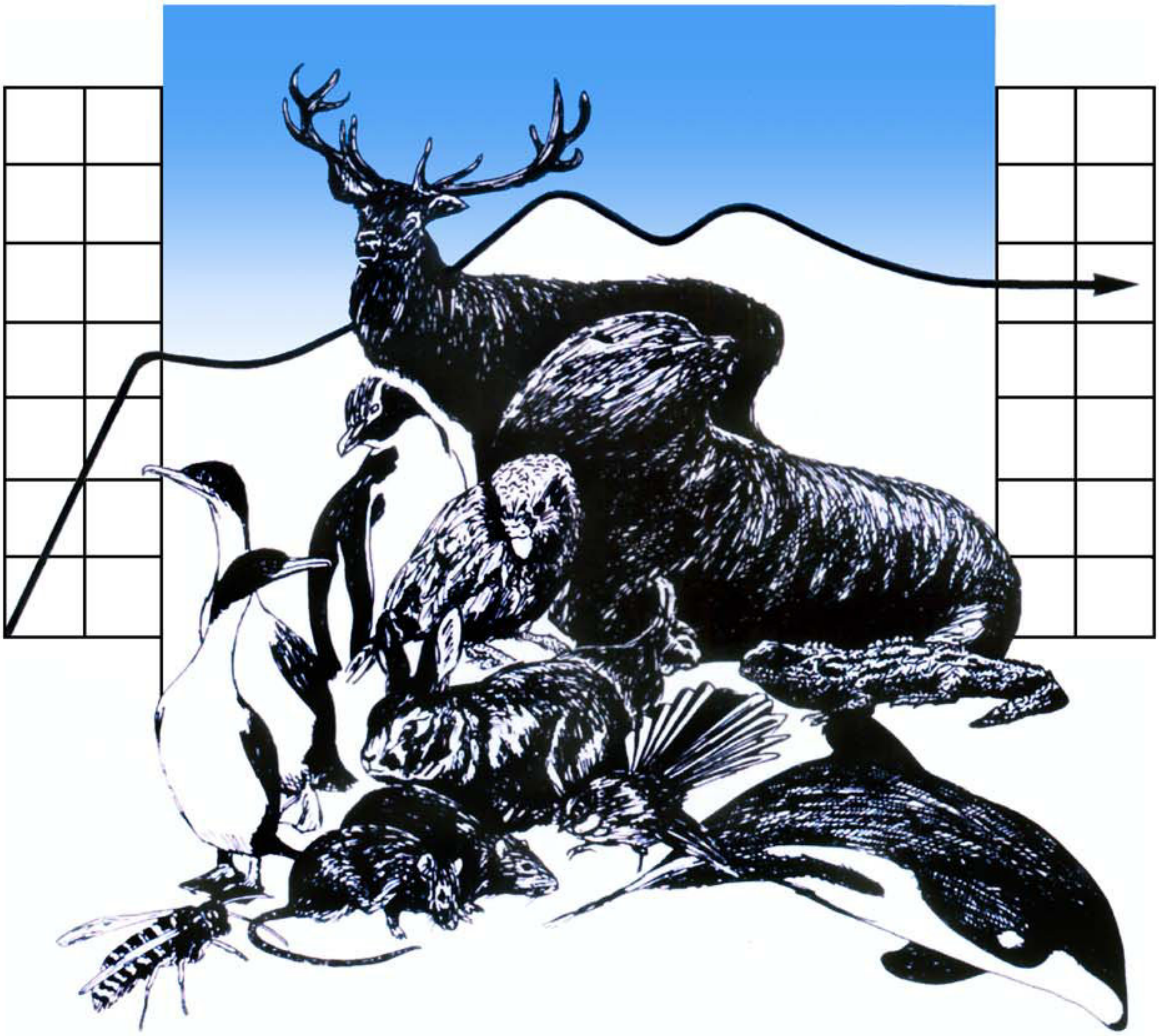
UNIVERSITY of OTAGO

Te Whare Wānanga o Otāgo

NEW ZEALAND

DEPARTMENT OF ZOOLOGY



WILDLIFE MANAGEMENT

Point transect distance sampling to determine male hihi (Notiomystis cincta) density and abundance within the Southern Enclosure of Maungatautari Ecological Island, New Zealand.

Rebecca Moyle

A report submitted in partial fulfilment of the
Post-graduate Diploma in Wildlife Management

University of Otago

2012

University of Otago
Department of Zoology
P.O. Box 56, Dunedin
New Zealand

WLM Report Number: 263

Point transect distance sampling to determine male hihi (Notiomystis cincta) density and abundance within the Southern Enclosure of Maungatautari Ecological Island, New Zealand.

Rebecca Moyle

Contents

Abstract

Estimation of population density and abundance is an important aspect of post-release monitoring following a reintroduction. This study aimed to use point transect distance sampling to estimate the density and abundance of male hihi (stitchbird, Notiomystis cincta) in the Southern Enclosure of Maungatautari Ecological Island, New Zealand.

Data collection was carried out over three weeks at 29 point locations. 74 observations were recorded and the data was analysed using Distance v6.0 Release 2 software. This resulted in an estimated density of 1.642 male hihi per hectare and an estimated abundance (95% CI) of 103 (72-148) male hihi.

The estimated abundance is considerably higher than the number of known territories in the Southern Enclosure, and is also higher than can be accounted for by birds moving into the Southern Enclosure from other parts of the mountain. This higher estimate could be connected to the timing of the survey relative to breeding in this population, and also the location of supplementary feeding stations. It is interesting, however, that biases are noted in other studies evaluating point transect distance sampling.

Care needs to be taken when implementing any survey method, and perhaps especially with the point transect distance method. Under the conditions that this method was applied, very poor estimates were produced.

Introduction

Reintroduction is the attempt to re-establish a species within its historical range, from which it has been extirpated or become extinct (IUCN 1998). Reintroduction is increasingly being used as a management strategy to re-establish populations of endangered or threatened species (Seddon 1999). In response to reintroduction becoming a common practice, the International Union for the Conservation of Nature (IUCN) published 'Guidelines for Reintroductions' in 1998 in an attempt to improve reintroduction success. One of the guidelines outlined in this document stresses the necessity of post-release monitoring (IUCN 1998).

Post-release monitoring has now been recognised as an important part of reintroduction biology, as it helps determine the long-term success of a reintroduction (Seddon et al. 2007; Sutherland et al. 2010). In addition, post-release monitoring can provide information which can be used both to assess the feasibility of future comparable reintroduction programs and to improve their success (Sarrazin and Barbault 1996). Depending on the extent to which post-release monitoring is carried out, this information can include, but is not limited to, the short- and long-term survival of individuals, the reproductive rate of the population, and changes in population abundance (Sutherland et al. 2010). The information gained from post-release monitoring allows the assessment of the methods used during the reintroduction process by enabling the timing and causes of success and failures to be assessed (Sarrazin and Barbault 1996; Sutherland et al. 2010)

An indication of long-term population trends following the reintroduction of a species is of particular importance to conservation managers. This can be achieved by estimating population density and/or abundance between years in order to determine whether the reintroduced population is increasing, decreasing, or remaining stable (Greene et al. 2008).

Hihi (stitchbird, Notiomystis cincta) are an example of a species which been reintroduced numerous times for conservation management. Hihi were once widespread throughout the North Island, but declined to a single remnant population on Little Barrier Island following the introduction of non-native predators (Taylor et al. 2005). Hihi have since been reintroduced to a number of offshore islands and to sites on the North Island (Ewen et al. 2011).

One of the sites to which hihi have been reintroduced is Maungatautari Ecological Island, a mountain situated in the central Waikato in the North Island of New Zealand (38°02'S, 175°57'E). The mountain is forest-covered with the predominant forest type being native podocarp-broadleaf (Speedy et al. 2007). Most mammalian pests have been eradicated from the 3,255ha Maungatautari Ecological Island (Ewen et al. 2011). Since 2006, the mountain has been completely surrounded with 47 kilometres of Xcluder™ pest-proof fence (Speedy et al. 2007). The 63ha Southern Enclosure is one of two smaller enclosures initially constructed as a pilot for the fencing of the entire mountain (Speedy et al. 2007).

The reintroduction of hihi to Maungatautari Ecological Island involved the release in 2009 of 79 hihi from Tiritiri Matangi Island and Little Barrier Island (Ewen et al. 2011). All hihi were released within the Southern Enclosure. A closed mark-recapture analysis based on a 15-day survey indicated that 19 to 52% of the hihi that were released survived the first year, and breeding has since been observed (Ewen et al. 2011).

Point transect distance sampling has been used annually since 2005 to determine the density of hihi on Little Barrier Island (Toy 2010). The objectives of the work carried out on Little Barrier Island are to identify changes in population density and to understand the source population from which birds may be taken for translocations (Toy 2010). Unlike count methods, which assume that all the objects in an area are detected, distance sampling methods have the advantage of accounting for the objects which are present but are not detected by the observer (Buckland et al. 2001). The use of distance sampling methods also allows for comparisons between sites, and for comparison between years at the same site, even if the observer changes from year to year (Buckland 2006). Distance sampling methods have the following three assumptions:

1) Objects on the point are always detected
2) Objects are detected at their initial location
3) Distance measurements are exact

Point transect distance sampling involves an observer measuring the radial distance from a point to the object of interest either over the course of a set time period, or at a predetermined time from the observers arrival at the point (called the 'snapshot' method). Various detection functions are then used to model the distance data and the model with the best fit is used to generate density and abundance estimations (Greene et al. 2010). Point transect distance sampling has been developed almost exclusively to estimate the density of avian communities (Cassey et al. 2007). However, point transect methods have been known to overestimate the density of some populations (e.g. Cassey et al. 2007; Peak 2011).

The aim of this study was to estimate the density and abundance of male hihi within the Southern Enclosure of Maungatautari Ecological Island, using point transect distance sampling and to compare this to the known density of male hihi at the site.

Methods

Study species

The hihi is a small, sexually dimorphic passerine species that is endemic to northern New Zealand (Ewen et al. 2011; Taylor et al. 2005). Hihi are classified as ‘Nationally Endangered’ under the Department of Conservation’s ‘Threat of Extinction’ classification system (Taylor et al. 2005).

Hihi feed on nectar, fruit and invertebrates (Taylor et al. 2005). Reintroduced populations often rely on food supplementation, especially when the availability of other food sources is low. Supplementary feeding has been shown to increase the survival and the reproductive rate of reintroduced hihi (Ewen et al. 2011). Hihi are known to travel several kilometres to visit artificial feeders (Taylor et al. 2005).

Hihi are often display social monogamy, however the mating system also includes various types of polygamy (Low 2005; Taylor et al. 2005). Extra-pair copulations are common, with 80 to 82% of all clutches being found to have extra-pair young and 35 to 46% of all chicks resulting from extra-pair copulations (Ewen et al. 1999; Castro et al. 2004). Male hihi defend a breeding territory and demonstrate paternity guarding behaviour during the September to March breeding season (Low 2005).

Field methods

Pest tracking lines run from north to south within the Southern Enclosure and are situated roughly 50 metres apart. On each tracking line, tracking tunnels are placed roughly every 50 metres (Figure 1). For this study every third tunnel location on every third tracking line was used as a sampling point, resulting in 29 points that were roughly 150 metres apart.

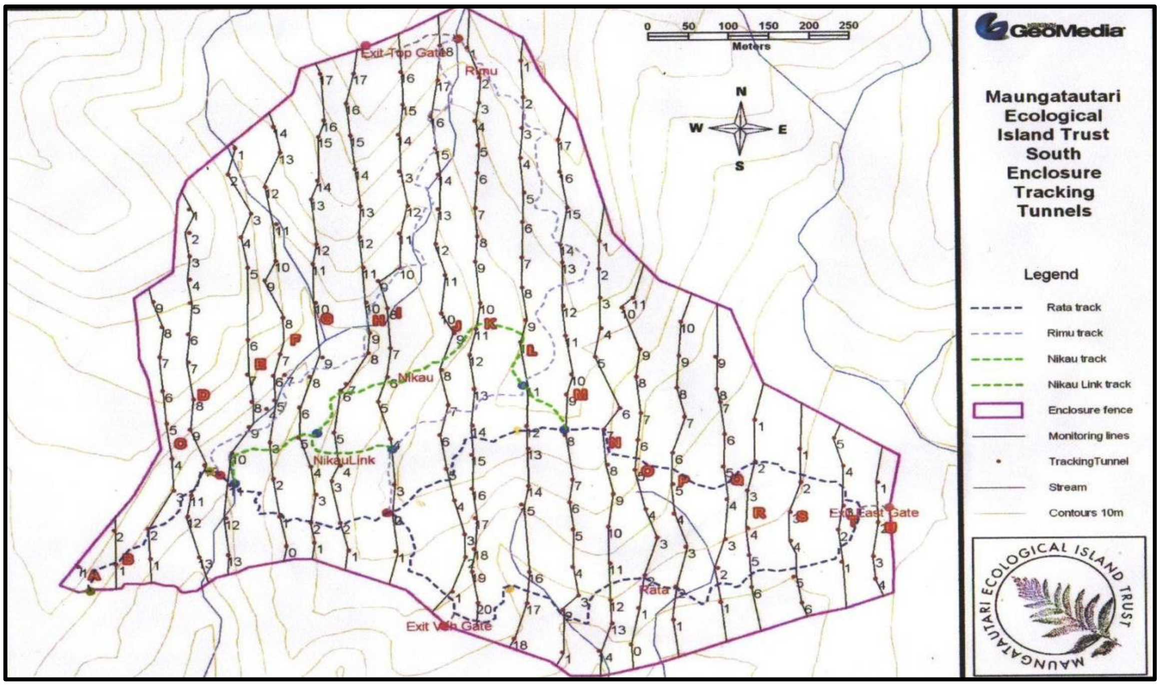


Figure 1: Map of the Southern Enclosure at Maungatautari Ecological Island showing tracking tunnel lines and locations. Every third tracking tunnel location on lines B, E, H, K, N, Q and T was used as a sampling location.

The methods used to carry out the point transect distance sampling were similar to those which have been used to determine the density of hihi on Hauturu (Toy 2010). Distance sampling was carried out over a period of three weeks, between the times of 7:00am and 4:00pm. Each point was visited 15 times, at varying times of the day, in order to achieve the minimum of 60 observations recommended for analysis (Buckland et al. 2001). However, no point was visited twice in the same day. One of the main differences between this study and the one carried out on Little Barrier Island is the time of year the sampling took place. This study was carried out between the 21st of November and the 10th of December, whereas on Little Barrier Island sampling took place between September and October (Toy 2010).

A 'snapshot' survey approach was used, with the distance of hihi from the point at exactly 4 minutes after the arrival of the observer being recorded. If the bird could be heard at 4 minutes but not seen, the observer could move away from the point to try and pinpoint the location of the bird. Only if the hihi's location at 4 minutes could be confidently determined would a measurement be recorded. If the hihi was thought to have moved since the 4 minute 'snapshot' time, it was not included in the data set. The observer was unaware of the positions of the known territories within the Southern Enclosure at the time of data collection.

For consistency, distance measurements were taken from a point 0.5 metres north of the base of the tree which was marked with the tracking tunnel number, and were taken using a tape measure. Distances less than 6 metres were recorded to the nearest 0.1 metre, while distances 6 metres and over were recorded to the nearest metre. Only male hihi were recorded. This was because female hihi are less detectable than males at the time of year in which the study took place. Combining data for both male and female may have resulted in a detection function that was difficult to model (Buckland 2006). If two or more male hihi were clearly interacting (that is, fighting), they were recorded as a cluster, with the average distance between the birds and the point being taken.

Weather, cloud cover, and rain were also recorded. Recording did not continue if light or heavy rain persisted, or if the wind persisted at Beaufort Wind Force Scale 3 or more (small twigs in motion).

Analysis

The data was analysed using Distance v6.0 Release 2 software (Thomas et al. 2009). The data was truncated at 10% (28 metres), as recommended for point transects by Buckland et al. (2001). After an initial examination of the data, a ‘filter’ was used to achieve a more ideal distribution. The cut points of 0, 3, 5, 8, 13, 15, and 28 metres were used.

The fit of six models (half-normal cosine, half-normal hermite, uniform cosine, uniform simple polynomial, hazard-rate simple polynomial, and hazard-rate cosine) to the ‘filtered’ data was examined. The fit of the models was determined using χ^2 goodness-of-fit and the models were compared using Akaike’s Information Criterion (AIC).

The software produced a density estimate based on the chosen model. The software also calculated hihi abundance by multiplying the density per sampling area by the size of the total area.

Results

The distance measurements were recorded for 74 observations of male hihi. Following the truncation of the data 67 distances were analysed. The model with the half-normal key function with the cosine series expansion had the best fit (Figure 2).

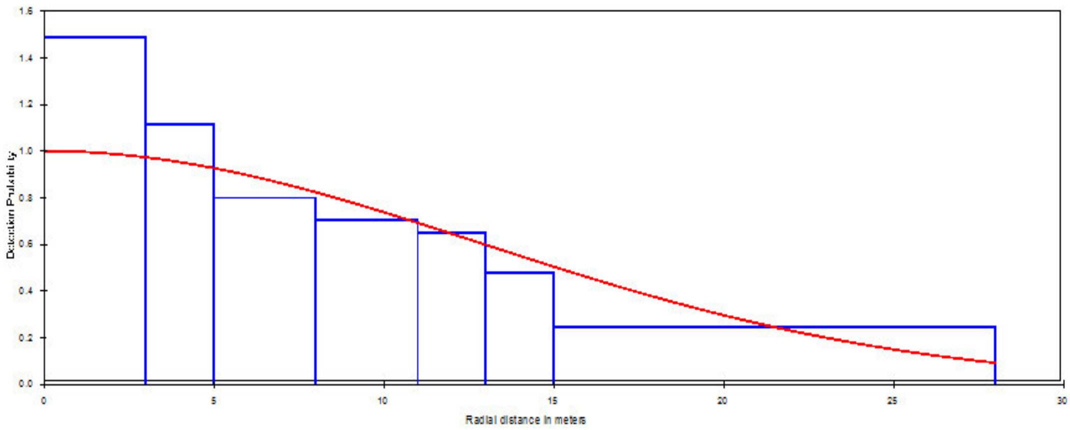


Figure 2: The detection function of male hihi in the Southern Enclosure of Maungatautari Ecological Island, showing the arrangement of data into selected cut points and truncation at 28 metres (10%). The model is a half-normal cosine.

The half-normal key with the hermite polynomial expansion had the same AIC value as the selected model (Table 1). However, it ran with the warning that parameters were very highly correlated.

The estimated density of male hihi within the Southern Enclosure of Maungatautari is 1.642 per hectare, resulting in an estimated abundance (95% CI) of 103 (72-148) male hihi (Table 1).

Table 1: The estimation of the density (D) per hectare and the total population (N) of hihi in the Southern Enclosure of Maungatautari Ecological Island for each model used, including the corresponding confidence intervals (CI) and coefficient of variation (CV). The AIC value and goodness-of-fit χ^2 p-value for each model are also shown.

Model	GOF χ^2 p-value	AIC	%CV	D	D 95% CI	N	N 95%
Half-normal cosine	0.97	220.08	17.98	1.6424	1.1505 – 2.3446	103	72-148
Half-normal hermite polynomial	0.97	220.08	17.98	1.6424	1.1505 – 2.3446	103	72-148
Hazard-rate cosine	0.96	221.91	42.80	1.9654	0.86646-4.4581	124	55-281
Hazard-rate simple polynomial	0.96	221.91	42.80	1.9654	0.86646-4.4581	124	55-281
Uniform simple polynomial	0.89	220.84	14.05	1.4151	1.0706-1.8705	89	67-118
Uniform cosine	0.97	220.13	14.53	1.5992	1.1985-2.1337	101	76-134

Discussion

The abundance estimate of 103 (72-148) male hihi that this study produced for the Southern Enclosure is considerably higher than could be expected from the number of males currently known to be holding territories in this area. It is currently thought that 9 male hihi hold territories in the Southern Enclosure (K. Richardson pers. comm.).

The population of male hihi in Southern Enclosure is not a closed population. As a result, male hihi visiting the Southern Enclosure from other parts of the mountain may have contributed to the biased density estimate. Male hihi frequently enter the territories of other males to seek extra-pair copulations with fertile females (Low 2005). The timing of this study coincides with the September to March hihi breeding season. Therefore it is likely that male hihi are visiting the Southern Enclosure from other parts of the mountain to seek extra-pair copulations.

Male hihi from other parts of the mountain have been also been observed visiting the Southern Enclosure to use the feeding stations (K. Richardson pers. comm.). There are six feeding stations supplying a sugar water solution within the Southern Enclosure of Maungatautari Ecological Island.

It would be expected that these ‘visiting’ males have contributed to the higher estimate of male hihi than the number of known territories within the Southern Enclosure would suggest. However, even when this is taken into consideration, the density and abundance estimates resulting from this study still appear to be an overestimate when it is considered that only 42 male hihi are known to be present on the whole mountain.

Point transect sampling has been known to result in overestimates of density. Peak (2011) found that point transect distance sampling abundance estimates produced for golden-cheeked warblers (Dendroica chrysoparia) were greater than abundance estimates derived from intensive territory monitoring. Similarly, Buckland (2006) found that abundance estimates produced for Great Tits (Parus major) from point transect distance sampling was more than double the estimate produced from territory mapping. Gottschalk and Huettmann (2011) compared distance sampling and territory mapping for a range of bird species in Germany and came to the conclusion that distance sampling is especially likely to result in overestimation if the population is sparse. Point transect distance sampling estimates were also found to exceed the known nesting populations in forested habitats of Venezuelan parrot species (Casagrande and Beissinger 1997). Cassey et al. (2007) compared line transect and point transect distance sampling of saddleback (Philesturnus carunculatus rufusater) on Tiritiri Matangi Island, New Zealand with the actual saddleback density. It was found that point transect methods significantly overestimated the density of saddleback in two separate locations. Line transect distance sampling, in which the perpendicular distance between a transect and the object is measured, could be an alternative approach to try in the future, as it has been found to generate lower bias and higher precision than point transect distance sampling (Buckland et al. 2008; Cassey et al. 2007). Line transect distance sampling has not been used to estimate hihi density to date due to concerns about the effect that difficult terrain would have on the safety of the observer and on the ability of the observer to detect birds whilst walking (Marsden 1999).

Because the detectability of a species can vary in relation to the time of year (Gottschalk and Huettmann 2011; Powlesland and Barraclough 2001), the timing of a distance sampling study may have an influence on the accuracy of the results (Simon et al. 2002). Toy (2010) stated that the density estimates of hihi on Little Barrier Island may have been higher for the north-east sector of the island than the south-east sector due to the sampling in the north-east sector being later in the breeding season. The sampling for the study at Maungatautari was carried out later in the breeding season than the sampling on both sectors of Little Barrier Island. If the study had been carried out earlier in the breeding season hihi would have been more conspicuous (K. Richardson pers. comm.), perhaps increasing the accuracy of the results. Furthermore, increased detectability would have made it easier to exceed the minimum number of detections and may have resulted in a detection function that was easier to fit.

It is important to consider whether the overestimated density and abundance were a result of the assumptions of distance sampling not being held. The first assumption, that the objects on the point are always detected, may not have held as an examination of the data revealed that very few birds were recorded as on or near the point compared with other distances. However, this is unlikely to have contributed to the substantial overestimate in density and abundance. Failing to detect birds on a point results in an underestimate of density (Buckland et al. 2008; Greene et al. 2010).

The second assumption is that the objects are detected at their initial location. While random movement does not affect the accuracy of the density estimates, responsive movements do (Hutto and Young 2003). Responsive movements can be difficult to detect and as such, Hutto and Young (2003) believe that it would be naïve to assume that responsive movements are not occurring simply because there is no evidence of it. One reason for density estimates based on distance data being overestimated can be that the studied animal or bird is attracted to the observer (DiTraglia 2007). On first examination of the ungrouped data, it appears that the opposite (that is, evasive movement) is the case. Evasive movement can be seen in distance sampling data as a ‘spike’ at intermediate distances from the point (Thomas et al. 2010). Evasive movement cannot explain the overestimation in hihi density as it is known to cause underestimation. However, Granholm (1983) stated that a spike in bird numbers at intermediate distances from a point could have resulted from either avoidance behaviour or the movement of birds to points within the detection range. It is therefore equally possible that the ‘spike’ is as a result of birds moving in from a further distance as a result of the observer’s presence, a factor which would result in an overestimation in hihi density (Buckland et al. 2008; Hutto and Young 2003). As hihi have been known to approach people, this could be considered a likely cause of overestimation. It is possible that the length of time before the ‘snapshot’ moment needs to be adjusted to prevent this from being a problem.

The third assumption is that that the distance measurements are exact. Density estimates (and therefore abundance estimates) can be highly affected by the accuracy of the measurements, especially when birds are detected aurally (Buckland 2006). Abundance is biased high if the measurements are underestimated (Buckland et al. 2008), and errors in measurements are even more of a problem with point transect sampling as opposed to line transect sampling. This is because any errors made are squared in density calculations (Marsden 1999). However, the observer discounted any hihi whose location could not be determined with complete certainty. While the use of a laser range finder is recommended by Buckland (2006), I am confident that the use of the tape measure provided accurate measurements.

While the use of the ‘snapshot’ method prevented individuals being recorded twice at the same point, some birds were thought to have been detected at successive points. If the bird has arrived at the next point independently of the observer, this is not considered to be a problem. Buckland (2006) found that detecting birds at more than one point caused a minimal bias of less than 1% in bird density. However, if the bird has been flushed to the next point by the observer and is recorded at both points (termed 'double counting'), it can cause serious bias (Marsden 1999). While all birds thought to be recorded at successive points seemed to have left the first point before the observer, this cannot be confirmed with complete confidence. Likewise, while some birds were already present at the point on arrival, some arrived after the observer but before the 4 minute 'snapshot' time. It is therefore a possibility that 'double-counting' could be partially responsible for the overestimate in hihi density.

One other factor which needs to be considered is the sample size. In situations where a species is rare or sparsely distributed, distance sampling methods can perform poorly due to a small number of observations (Norvell et al. 2003). The sample size was above the minimum sample size of 60 recommended by Buckland et al. (2001). However, a small sample size can affect the precision of density estimates (Marsden 1999; Smolensky and Fitzgerald 2010). It is possible that a longer study period was needed to gain more observations and therefore improve the precision of the estimate.

Under the conditions in which they were implemented in this study, the point transect sampling method generated density and abundance estimates of male hihi that were hugely biased. Care must be taken when implementing any survey method. However, the results of this study and the other studies mentioned earlier in the discussion suggest that the point transect distance sampling method needs to be applied with more care than most.

Acknowledgements

Firstly, I would like to thank the Maungatautari Ecological Island Trust for allowing me to carry out my placement at Maungatautari. Everyone made me feel extremely welcome and I thoroughly enjoyed my time there. I would also like to thank John Ewen and Kate Richardson for their helpful advice during the course of this project, and for suggesting distance sampling as a suitable project to carry out. Thank you to Kate and Lydia Doerr for making me welcome in the Trust house, for providing me with general information about hihi, and for introducing me to the Southern Enclosure. Finally, thanks to Michelle Goh for introducing me to hihi on Tiritiri Matangi Island.

References

Buckland, S.T. (2006). Point transect surveys for songbirds: robust methodologies. The Auk **123**, 345-357.

Buckland, S.T., Marsden, S.J., and Green, R.E. (2008). Estimating bird abundance: making methods work. Bird Conservation International **18**: S91-S108.

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L., and Thomas, L. (2001). Introduction to distance sampling: estimating abundance of biological populations. Oxford University Press. 448 p.

Cassagrande, D.G., and Beissinger, S.R. (1997). Evaluation of four methods of estimating parrot population size. The Condor **99**, 445-457.

Cassey, P., Craig, J.L., McArdle, B.H., and Barraclough, R.K. (2007). Distance sampling techniques compared for a New Zealand endemic passerine (Philesturnus carunculatus rufusater). New Zealand Journal of Ecology **31**, 223-231.

Castro, I., Mason, K.M., Armstrong, D.P., and Lambert, D.M. (2004). Effect of extra-pair paternity on effective population size in a reintroduced population of the endangered hihi, and potential for behavioural management. Conservation Genetics **5**, 381-393.

DiTraglia, F.J. (2007). Model of random wildlife movement with an application to distance sampling. MSc Thesis, University of St. Andrews. 47p.

Ewen, J.G., Armstrong, D.P., and Lambert, D.M. (1999). Floater males gain reproductive success through extrapair fertilizations in the stitchbird. Animal Behaviour **58**, 321-328.

Ewen, J.G., Parker, K.A., Richardson, K., Armstrong, D., and Smuts-Kennedy, C. (2011). Translocation of hihi Notiomystis cincta to Maungatautari, a mainland reserve protected by a predator-exclusion fence, Waikato, New Zealand. Conservation Evidence **8**, 58-65.

Gottschalk, T.K., and Huettmann, F. (2011). Comparison of distance sampling and territory mapping methods for birds in four different habitats. Journal of Ornithology **152**, 421-429.

Granholm, S.L. (1983). Bias in density estimates due to movement of birds. Condor **85**, 243-248.

Greene, T., Jones, A., Dennis, G., and Sachtleben, T. 2010. Distance sampling to determine kaka (Nestor meridionalis septentrionalis) density within Waipapa Ecological Area. New Zealand Journal of Ecology **34**, 297-305.

Hutto, R.L., and Young, J.S. (2003). On the design of monitoring programs and the use of population indices: a reply to Ellingson and Lukacs. Wildlife Society Bulletin **31**, 903-910.

IUCN (World Conservation Union). (1998). Guidelines for reintroductions. IUCN/SSC Re-introduction Specialist Group, IUCN, Gland, Switzerland, and Cambridge, United Kingdom. 11p.

Low, M. (2005). Factors influencing mate guarding and territory defence in stitchbird (hihi) Notiomystis cincta. New Zealand Journal of Ecology **29**, 231-242.

Marsden, S.J. (1999). Estimation of parrot and hornbill densities using a point count distance sampling method. Ibis **141**, 377-390.

Norvell, R.E., Howe, F.P., and Parrish, J.R. (2003). A seven-year comparison of relative-abundance and distance-sampling methods. The Auk **120**: 1013-1028.

Peak, R.G. (2011). A field test of the distance sampling method using Golden-cheeked Warblers. Journal of Field Ornithology **82**: 311-319.

Powlesland, R.G., and Barraclough, R.K. (2001). Proceedings of a workshop on distance sampling, Wellington, May 2000. Conservation Advisory Science Notes No. 329, Department of Conservation, Wellington. 14p.

Sarrazin, F., and Barbault, R. (1996). Reintroduction: challenges and lessons for basic ecology. Tree **11,** 474-478.

Seddon, P.J. (1999). Persistence without intervention: assessing success in wildlife reintroductions. Tree **14**, 503.

Seddon, P.J., Armstrong, D.P., and Maloney, R.F. (2007). Developing the science of reintroduction biology. Conservation Biology **21**, 303-312.

Simon, J.C., Pratt, T.K., Berlin, K.E., Kowalsky, J.R., Fancy, S.G., and Hatfield, J.S. (2002). Temporal variation in bird counts within a Hawaiian rainforest. The Condor **104**, 469-481.

Smolensky, N.L., and Fitzgerald, L.A. (2010). Distance sampling underestimates population densities of dune-dwelling lizards. Journal of Herpetology **44**, 372-381.

Speedy, C., Day, T., and Innes, J. (2007). Pest eradication technology – the critical partner to pest exclusion technology: the Maungatautari Experience. Managing Vertebrate Invasive Species Paper 49. 13p.

Sutherland, W.J., Armstrong, D., Butchart, S.H.M., Earnhardt, J.M., Ewen, J., Jamieson, I., Jones, C.G., Lee, R., Newbery, P., Nichols, J.D., Parker, K.A, Sarrazin, F., Seddon, P.J., Shah, N., and Tatayah, V. (2010). Standards for documenting and monitoring bird reintroduction projects. Conservation Letters **3**, 229-235.

Taylor, S., Castro, I., and Griffiths, R. (2005). Hihi/stitchbird (Notiomystis cincta) recovery plan 2004-09. Threatened Species Recovery Plan 54. Wellington. 31 p.

Thomas, L., Buckland, S.T., Rexstad, E.A., Laake, J.L., Strindberg, S., Hedley, S.L, Bishop, J.R.B., Marques, T.A., and Burnham, K.P. (2010). Distance software: design and analysis of distance sampling surveys for estimating population size. Journal of Applied Ecology **47**, 5-14.

Thomas, L., Laake, J.L., Rexstad, E., Strindberg, S., Marques, F.F.C., Buckland, S.T., Borchers, D.L., Anderson, D.R., Burnham, K.P., Burt, M.L., Hedley, S.L., Pollard, J.H., Bishop, J.R.B., and Marques, T.A. (2009). Distance 6.0. Release 2. Research Unit for Wildlife Population Assessment, University of St. Andrews, UK.

Toy, R. (2010). Hihi, tui, and tieke density on Hauturu 2005-2010. DOCDM-676687. 50p.

Appendix 1: Raw Data

Table 1: Table of raw data showing data collection date, point location, the time at which the 'snapshot' survey was undertaken, the number of male hihi observed at this time, and the distance of observed hihi from the point.

Date	Point location	Snapshot time	Number of male hihi observed	Distance(s) (m)
21/11/2011	B2	8:04am	0	NA
	E13	8:29am	0	NA
	E10	8:50am	1	19
	E7	9:20am	0	NA
	E4	9:47am	0	NA
	E1	10:22am	0	NA
	H16	10:52am	0	NA
	H13	11:10am	0	NA
	H10	11:29am	1	22
	H7	11:49am	0	NA
	H4	12:23pm	0	NA
	H1	12:35pm	0	NA
	K20	1:53pm	0	NA
	K17	1:09pm	0	NA
	K14	1:22pm	0	NA
	K11	1:34pm	1	20
	K8	1:57pm	0	NA
	K5	2:06pm	0	NA
	K2	2:16pm	0	NA
	N2	2:35pm	0	NA
	N5	2:43pm	1	5.1
	N8	2:52pm	0	NA
	N11	2:59pm	0	NA
	N14	3:06pm	0	NA
	Q3	3:16pm	0	NA
	Q6	3:25pm	0	NA
	Q9	3:32pm	0	NA
	T4	3:43pm	0	NA
	T1	3:50pm	0	NA
22/11/2011	B2	7:47am	0	NA
	E13	8:15am	0	NA
	E10	8:34am	0	NA
	E7	8:53am	0	NA
	E4	9:10am	0	NA
	E1	9:43am	0	NA
	H16	10:06am	0	NA
	H13	10:21am	0	NA

Date	Point location	Snapshot time	Number of male hihi observed	Distance(s) (m)
	H10	10:35am	0	NA
	H7	11:07am	1	9
	H4	1:35 am	0	NA
	H1	11:46am	0	NA
	K20	12:01pm	1	4.8
	K17	12:27pm	0	NA
	K11	12:55pm	0	37
	K8	1:20pm	0	NA
	K5	1:31pm	0	NA
	K2	1:48pm	0	NA
	N2	2:07pm	0	NA
	N5	2:15pm	0	NA
	N8	2:24pm	0	NA
	N11	2:34pm	0	NA
	N14	2:43pm	1	26
	Q3	3:04pm	0	NA
	Q6	3:15pm	0	NA
	Q9	3:24pm	0	NA
	T4	3:35pm	1	4.1
	T1	3:45pm	0	NA
23/11/2011	E13	8:01am	0	NA
	E10	8:11am	0	NA
	E7	8:23am	0	NA
	E4	8:38am	0	NA
	E1	8:57am	0	NA
	H16	9:11am	0	NA
	H13	9:19am	0	NA
	H10	9:38am	1	26
	H7	9:47am	0	NA
	H4	9:57am	0	NA
	H1	10:05am	0	NA
	K20	10:14am	0	NA
	K17	10:24am	0	NA
	K14	10:32am	0	NA
	K11	10:42am	0	NA
	K8	10:53am	0	NA
	K5	11:19am	0	NA
	K2	11:33am	0	NA
	N2	11:53am	0	NA
	N5	12:02pm	0	NA
	N8	12:15pm	0	NA

Date	Point location	Snapshot time	Number of male hihi observed	Distance(s) (m)
	N11	12:24pm	1	27
	N14	12:43pm	0	NA
	Q3	12:56pm	0	NA
	Q6	1:06pm	0	NA
	Q9	1:15pm	0	NA
	T4	1:26pm	1	27
	T1	1:41pm	0	NA
	B2	2:07pm	0	NA
	Q6	12:56pm	0	NA
	Q9	1:00pm	0	NA
	N2	1:14pm	0	NA
	N5	1:33pm	0	NA
	N8	1:57pm	0	NA
	N11	2:09pm	0	NA
	N14	2:19pm	0	NA
	K20	2:40pm	0	NA
	K17	2:53pm	1	8
	K14	3:10pm	0	NA
25/11/2011	H16	8:11am	0	NA
	H13	8:19am	0	NA
	H10	8:28am	0	NA
	H7	8:37am	0	NA
	H4	8:45am	0	NA
	H1	8:55am	0	NA
	K20	9:06am	0	NA
	K17	9:16am	1	17
	K14	9:37am	0	NA
	K11	9:48am	1	38
	K8	10:03am	0	NA
	K8	10:03am	0	NA
	K5	10:12am	0	NA
	K2	10:23am	0	NA
	N2	10:40am	0	NA
	N5	10:40am	0	NA
	N8	10:57am	0	NA
	N11	11:12am	1	11
	N14	11:31am	0	NA
	Q3	11:45am	0	NA
	Q6	11:55am	0	NA
	Q9	12:03pm	0	NA
	T4	12:14pm	1	22

Date	Point location	Snapshot time	Number of male hihi observed	Distance(s) (m)
	T1	12:23pm	0	NA
	E13	12:55pm	0	NA
	E10	1:08pm	0	NA
	E7	1:21pm	1	22
	E4	1:41pm	0	NA
	E1	1:59pm	0	NA
	B2	2:17pm	0	NA
28/11/2011	K20	7:59am	1	29
	K17	8:17am	1	12
	K14	8:31am	0	NA
	K8	8:51am	0	NA
	K5	9:00am	0	NA
	K2	9:10am	0	NA
	N2	9:26am	0	NA
	N5	9:35am	0	NA
	N8	9:47am	1	21
	N11	10:03am	0	NA
	N14	10:11am	0	NA
	Q3	10:22am	1	15
	Q6	10:31am	0	NA
	Q9	10:40am	0	NA
	T4	10:55am	1	5.9
	T1	11:14am	0	NA
	B2	11:42am	0	NA
	E13	12:00pm	0	NA
	E10	12:12pm	0	NA
	E7	12:26pm	0	NA
	E4	12:41pm	0	NA
	E1	12:58pm	1	12
	H16	1:24pm	0	NA
	H13	1:31pm	0	NA
	H10	1:40pm	0	NA
	H7	1:49pm	0	NA
	H4	1:57pm	0	NA
	H1	2:06pm	0	NA
29/11/2011	N2	8:16am	0	NA
	N5	8:26am	0	NA
	N8	8:34am	1	25
	N11	8:47am	1	16
	N14	8:59am	0	NA
	Q3	9:11am	1	14

Date	Point location	Snapshot time	Number of male hihi observed	Distance(s) (m)
	Q6	9:21am	0	NA
	Q9	9:29am	0	NA
	T4	9:41am	1	3.3
	T1	9:55am	0	NA
	B2	10:21am	0	NA
	E13	10:34am	0	NA
	E10	10:44am	0	NA
	E7	10:57am	0	NA
	E4	11:11am	0	NA
	E1	11:31am	1	13
	H16	11:54am	0	NA
	H13	12:02pm	0	NA
	H7	12:19pm	0	NA
	H4	12:27pm	0	NA
	H1	12:37pm	0	NA
	K20	12:49pm	1	9
	K17	1:08pm	1	13
	K14	1:21pm	0	NA
	K11	1:30pm	0	NA
	K8	1:42pm	0	NA
	K5	1:54pm	0	NA
	K2	2:03pm	0	NA
30/11/2011	Q3	7:39am	1	28
	Q6	8:13am	0	NA
	Q9	8:21am	0	NA
	T4	8:32am	1	14
	T1	8:43am	0	NA
	B2	9:09am	0	NA
	E13	9:33am	0	NA
	E10	9:45am	0	NA
	E7	9:58am	0	NA
	E4	10:13am	0	NA
	E1	10:32am	1	1.9
	E1	10:32am	1	15
	H16	11:06am	0	NA
	H13	11:14am	0	NA
	H10	11:23am	0	NA
	H7	11:33am	0	NA
	H4	1:41am	0	NA
	H1	11:52am	0	NA
	K20	12:03pm	0	NA

Date	Point location	Snapshot time	Number of male hihi observed	Distance(s) (m)
	K17	12:17pm	1	18
	K14	12:36pm	0	NA
	K11	12:47pm	1	21
	K8	1:06pm	0	NA
	K5	1:16pm	0	NA
	K2	1:27pm	0	NA
	N2	1:52pm	0	NA
	N5	2:00pm	0	NA
	N8	2:09pm	1	19
	N11	2:17pm	0	NA
	N14	2:25pm	0	NA
31/11/11	B2	7:44am	0	NA
	E13	8:00am	0	NA
	E10	8:11am	0	NA
	E4	8:42am	0	NA
	E1	9:03am	0	NA
	H16	9:26am	0	NA
	H13	9:34am	0	NA
	H10	9:43am	0	NA
	H7	9:54am	0	NA
	H4	9:62am	0	NA
	H1	10:12am	0	NA
	K20	10:24am	1	9
	K17	10:37am	0	NA
	K14	10:51am	0	NA
	K11	11:00am	0	NA
	K8	11:21am	0	NA
	K5	11:31am	0	NA
	K2	11:38am	0	NA
	N2	11:56am	0	NA
	N5	12:05pm	0	NA
	N8	12:14pm	0	NA
	N11	12:22pm	0	NA
	N14	12:29pm	0	NA
	Q3	12:44pm	0	NA
	Q6	12:57pm	1	28
	Q9	1:09pm	1	NA
	T4	1:25pm	2	4.4, 11
	T1	1:38pm	0	NA
1/12/2011	B2	7:44am	0	NA
	E13	7:54am	0	NA

Date	Point location	Snapshot time	Number of male hihi observed	Distance(s) (m)
	E10	8:03am	0	NA
	E7	8:13am	0	NA
	E4	8:26am	0	NA
	E1	8:41am	0	NA
	H16	8:58am	1	23
	H13	9:15am	0	NA
	H10	9:22am	0	NA
	H7	9:29am	0	NA
	H4	9:36am	0	NA
	H1	9:43am	0	NA
	K20	9:51am	0	NA
	K17	9:59am	0	NA
	K14	10:14am	0	NA
	K11	10:22am	0	NA
	K8	10:33am	0	NA
	K5	10:42am	0	NA
	N2	11:03am	0	NA
	N5	11:10am	0	NA
	N8	11:16am	1	21
	N11	11:23am	0	NA
	N14	11:29am	0	NA
	Q3	11:37am	0	NA
	Q6	11:43am	0	NA
	Q9	11:49am	0	NA
	T4	11:57am	2	1.3, 10
	T1	12:05pm	1	NA
5/12/2011	B2	7:34am	0	NA
	E13	7:50am	0	NA
	E10	8:03am	0	NA
	E7	8:12am	1	8
	E4	8:29am	1	13
	E1	8:57am	0	NA
	H16	9:20am	0	NA
	H13	9:28am	0	NA
	H10	9:36am	0	NA
	H7	9:47am	0	NA
	H4	9:55am	1	21
	H1	10:04am	1	30
	K20	10:14am	1	7
	K17	10:25am	0	NA
	K14	10:40am	0	NA

Date	Point location	Snapshot time	Number of male hihi observed	Distance(s) (m)
	K11	10:53am	1	22
	K8	11:13am	1	10
	K5	11:24am	0	NA
	K2	11:35am	0	NA
	N2	11:56am	0	NA
	N5	12:06pm	0	NA
	N8	12:17pm	1	25
	N11	12:26pm	0	NA
	N14	12:38pm	0	NA
	Q3	12:55pm	1	6
	Q6	1:07pm	0	NA
	Q9	1:18pm	0	NA
	T4	1:36pm	2	27, 7
	T1	1:45pm	0	NA
6/12/2011	E13	7:57am	0	NA
	E10	8:08am	2	13, 11
	E7	8:31am	1	12
	E4	8:49am	0	NA
	H16	9:31am	1	6
	H13	9:39am	0	NA
	H10	9:50am	0	NA
	H7	9:59am	0	NA
	H4	10:07am	1	9
	H1	10:16am	0	NA
	K20	10:29am	1	14
	K17	10:40am	2	10, 7
	K14	10:58am	0	NA
	K11	11:08am	2	8, 21
	K8	11:30am	1	9
	K5	11:44am	0	NA
	K2	11:54am	1	13
	N2	12:08pm	0	NA
	N5	12:18pm	0	NA
	N8	12:27pm	0	NA
	N11	12:36pm	0	NA
	N14	12:54pm	0	NA
	Q3	12:03pm	0	NA
	Q6	1:14pm	1	28
	Q9	1:26pm	0	NA
	T4	1:38pm	1	0.9, 26
	T1	1:47pm	0	NA

Date	Point location	Snapshot time	Number of male hihi observed	Distance(s) (m)
	B2	2:10pm	0	NA
7/12/2011	B2	7:48am	0	NA
	E13	8:01am	0	NA
	E10	8:12am	0	NA
	E7	8:27am	0	NA
	E4	8:45am	0	NA
	E1	9:05am	1	15
	H16	9:26am	0	NA
	H13	9:35am	0	NA
	H10	9:44am	0	NA
	H7	9:54am	0	NA
	H4	10:02am	0	NA
	H1	10:11am	0	NA
	K20	10:21am	0	NA
	K17	10:31am	0	NA
	K14	10:51am	0	NA
	K11	11.03am	2	32, 8
	K8	11:21am	0	NA
	K5	11:36am	0	NA
	K2	11:46am	0	NA
	N5	12:12pm	0	NA
	N8	12:24pm	0	NA
	N11	12:30pm	0	NA
	N14	12:50pm	0	NA
	Q3	1:01pm	1	21
	Q6	1:16pm	0	NA
	Q9	1:25pm	0	NA
	T4	1:36pm	2	25, 10
	T1	1:47pm	0	NA
8/12/2012	K20	7:49am	0	NA
	K17	7:60am	1	14
	K14	8:11am	1	7
	K11	8:26am	2	30, 16
	K8	8:42am	0	NA
	K5	8:52am	0	NA
	K2	9:03am	0	NA
	N2	9:27am	0	NA
	N5	9:35am	1	21
	N8	9:44am	0	NA
	N11	9:54am	1	19
	N14	10:05am	0	NA

Date	Point location	Snapshot time	Number of male hihi observed	Distance(s) (m)
	Q3	10:17am	1	26
	Q6	10:39am	1	31
	Q9	10:54am	0	NA
	T4	11:07am	2	13, 28
	T1	11:17am	0	NA
	B2	11:30am	0	NA
	E13	11:40am	0	NA
	E10	11:49am	0	NA
	E7	12:02pm	1	20
	E4	12:17pm	1	15
	E1	12:43pm	0	NA
	H16	12:58pm	0	NA
	H13	1:05pm	1	14
	H10	1:14pm	0	NA
	H7	1:23pm	0	NA
	H4	1:34pm	0	NA
	H1	1:43pm	0	NA
10/12/2011	B2	10:17am	0	NA
	E13	10:32am	0	NA
	E10	10:42am	0	NA
	E7	10:52am	1	23
	E4	11:05am	0	NA
	H16	11:39am	0	NA
	H13	11:45am	0	NA
	H10	11:53am	0	NA
	H7	12:01pm	0	NA
	H4	12:08pm	0	NA
	H1	12:17pm	0	NA
	K11	12:25pm	1	43
	K8	12:43pm	0	NA
	K5	12:51pm	0	NA
	K2	1:01pm	0	NA
	T4	1:23pm	1	27
	T1	1:31pm	0	NA