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Mortality and behaviour of hihi, an endangered New Zealand honeyeater, in the establishment phase following translocation

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Abstract

We analysed mortality and behaviour of hihi, an endangered New Zealand honeyeater, in the first three months after translocation to 135 ha Mokoia island. Our aims were to assess: (1) whether mortality and behaviour were affected by the translocation process or post-release management, and (2) whether the fate of birds during this establishment phase affected the viability of the population. Forty hihi were translocated from the wild population on Little Barrier Island, released immediately in three different locations, and provided with sugar water feeders. Many of the birds suffered leg injuries due to the bands initially used, and up to 7 birds may have died from these injuries. Nevertheless, the mortality rate over the first three months was similar to the average rate over the first 3 years. Therefore, except for the bands used, there was no evidence of post-release mortality associated with translocation stress. Most hihi discovered the feeders quickly. However, feeder use varied greatly among birds and there was no evidence that access to feeders reduced mortality. Access to feeders also did not affect overall time spent foraging. However, birds using feeders allocated most of their foraging effort to invertebrate feeding, whereas birds not using feeders foraged mostly on flowers and fruits. Hihi dispersed quickly after release, and moved all over the island. Transmitters increased re-sighting rates over the first 3 weeks, but intensive observation during that period provided no useful information relevant to subsequent survival and reproduction. There was a slight tendency for birds to settle closer to their release sites than expected by chance, but there was no tendency for birds released together to form breeding pairs. We conclude that the viability of this population was not affected by any problems in the establishment phase. However, the population has had a consistently high mortality rate over the first 3 years, and its long-term viability appears poor. Our subsequent research is, therefore, addressing the factors that might be limiting the population in the long-term. © 1999 Elsevier Science Ltd. All rights reserved.

Keywords: Translocation; Reintroduction; Hihi; Stitchbird; Mortality; Dispersal

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1. Introduction

There have been frequent calls for increased monitoring and research following translocations (Chivers, 1991; Kleiman et al., 1994; Armstrong and McLean, 1995; Hein, 1997; IUCN, 1998). While research is clearly needed, it also needs to be effectively targetted. The factors determining the success of translocations can be divided into two categories: those that affect the survival and behaviour of the founder group during the establishment phase, and those that affect the long-term dynamics of the population. The first category includes the number of founders, the composition of the founder group, the methods and timing of the translocation, pre- and post-release training, and post-release provisioning. The second category includes the habitat, predators, competitors, and pathogens at the release site. Different types of research are needed to address these two categories of factors, hence it is important to know which category is most important for any translocation programme. To do this, it is necessary to assess whether problems are occurring during the establishment phase or later on.

Where translocated populations have been carefully monitored, they often have a period of high mortality after release (Kurzejeski and Root, 1988; Slough, 1989;

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Lovegrove, 1992; Wilson et al., 1992: Musil et al., 1993; Armstrong, 1995). This may mean that the population is unlikely to survive or that large numbers need to be translocated to compensate for this mortality, impacting on the source population. In either case, research would need to target this initial mortality. It is therefore important to estimate mortality during the establishment phase, and distinguish this from the long-term background level of mortality. This information is also needed for improving comparative analyses on the effect of founder group size. Otherwise, it is unclear whether the tendency for small founder groups to be unsuccessful (Griffith et al., 1989; Wolf et al., 1996) is due to demographic stochasticity (Ludwig, 1996) or simply due to a die-off immediately after release.

In addition to monitoring mortality, it may be important to monitor the initial movements and behaviour of the animals, and assess how these are affected by translocation methods and post-release management. Initial movements and behaviour can potentially explain patterns of mortality, and can also affect the subsequent social structure, reproduction, and genetic relationships.

This paper reports the results of intensive monitoring of a hihi (stitchbird, *Notiomystis cincta*) population immediately after translocation, and assesses the importance of this period to the long-term viability of the population. The hihi is a cavity-nesting honeyeater (Meliphagidae) endemic to New Zealand. Hihi were originally found throughout the North Island of New Zealand and on at least three offshore islands. However, they declined following European colonisation, and by the 1880s were extinct everywhere except a single offshore island, 3083 ha Little Barrier (Buller, 1888). This decline is attributed to predation by ship rats (*Rattus rattus*), habitat destruction, and disease (Mills and Williams, 1979). Several other mammalian predators (brush-tailed possums *Tricohosurus vulpecula*, ferrets *Mustela furo*, stoats *Mustela erminea*, and weasels *Mustela nivalis*) have subsequently been established on the main islands. Consequently, efforts to improve the status of hihi have involved translocations to offshore islands without predators thought to threaten hihi. Since 1980, there have been 12 translocations of hihi from Little Barrier to other islands, including Hen (1980, 1981), Cuvier (1982, 1985), Kapiti (1983, 1984, 1990, 1991, 1992), Mokoia (1994) and Tiritiri Matangi (1995, 1996) (Rasch et al., 1996).

The initial translocations to Hen, Cuvier and Kapiti had little monitoring. However, all three populations declined, and the Hen and Cuvier populations are probably now extinct. When further hihi were translocated to Kapiti Island in 1991–1992, Castro et al. (1995) monitored post-release survival and compared alternative translocation strategies. They found substantial (37%) mortality in the first 4 weeks after release. They also found that: (1) birds held in an aviary for 2 weeks before release had higher mortality than birds released immediately, and (2) birds held and released in groups of two (one male, one female) had similar survival to birds in groups of 12 (six male, six female), but females in groups of two received a lot a aggression. When hihi were translocated to Mokoia Island in 1994, Castro et al.'s (1995) results were followed in that: (1) birds were released as soon as possible after arrival on Mokoia, and (2) birds were held in groups of 8–12 on Little Barrier and transported in groups of 6–7, with males and females separate in both cases. However, hihi were still held up to 12 days on Little Barrier before translocation to Mokoia.

We analysed mortality and behaviour of hihi during the first three months after translocation to Mokoia, and addressed the following questions:

1. Was the post-release mortality rate significantly higher than the mortality rate over the next three years?
2. Did provision of supplementary food lower mortality and/or lower the amount of time hihi spent foraging?
3. Did birds carrying transmitters have higher mortality, and were transmitters important for following birds?
4. Did the distribution of birds among release sites affect settlement locations and/or breeding partners?
5. Did initial movements of birds indicate where they would breed and/or who would breed?

2. Methods

2.1. Study site

Mokoia (Fig. 1) is a 135 ha island in Lake Rotorua, in the North Island of New Zealand (38°06′S, 174°55′E). The island was occupied and farmed by the Te Arawa iwi for several hundred years, but has been largely unoccupied for 40–50 years. It is now covered with regenerating broadleaf forest, which has regenerated more rapidly since rats, goats and sheep were eradicated in 1989. The youth of the vegetation means that there are no natural nesting cavities suitable for hihi (Rasch, 1985), hence artificial nest boxes were provided (see below). Hihi would definitely have inhabited Mokoia in the past, hence the translocation was a reintroduction rather than an introduction.

2.2. Translocation

Forty hihi (20 male, 20 female) were caught in mistnets on Little Barrier over a period of 10 days starting

24 August 1994, and were released on Mokoia on 5 September 1994. After initial capture birds were weighed, measured, banded (metal and colour), and had blood samples taken. Birds were then released into one of two aviaries. One aviary ultimately had 10 males and 8 females, and the other had 12 males and 10 females. In both aviaries the males and females were kept separate by shadecloth dividers. Birds had access to ad libitum Wombaroo® lorikeet and honeyeater food, which is a complete diet for honeyeaters. The food was presented in hummingbird feeders (Perky Pet Products No. 212-P, 1.4 l capacity). The same feeders were later used in the field.

On the evening of 4 September, the birds were caught using a hand net and put into three wooden transfer boxes (Lovegrove and Veitch, 1994), with 6–7 males and 6–7 females in each (a partition kept males and females separate). Before being placed into the boxes, 20 birds (10 male, 10 female) had transmitters glued to their backs. One female's transmitter fell off in transit, so 19 had transmitters on release. We used Biotrack SS-2 transmitters with Ag410 cells. The total weight of each transmitter package was about 1.3 g (3–4% of body weight). Birds were carried by helicopter from Little Barrier to Auckland, by light aircraft to Rotorua, by car to the wharf, then by boat to Mokoia. On arrival, the birds were given a powhiri (welcome) by representatives of the Mokoia Island Trust board. The three boxes were then taken to three different sites (Fig. 1) and the birds released.

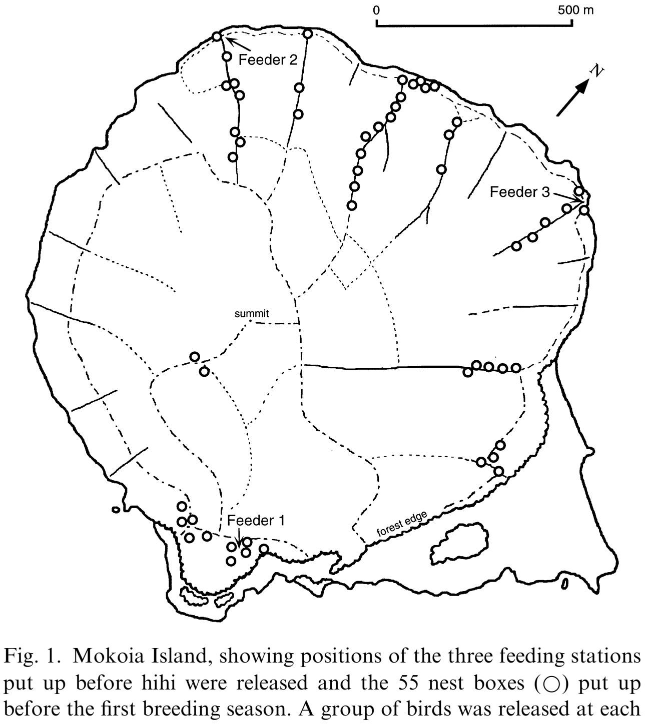

Fig. 1. Mokoia Island, showing positions of the three feeding stations put up before hihi were released and the 55 nest boxes (○) put up before the first breeding season. A group of birds was released at each feeding station. The island is covered by regenerating native forest except for the portion at the bottom right which is mainly grass and blackberry. Solid lines within the forested portion show gullies, and broken lines show walking tracks.

2.3. Provision of feeders and nest boxes

Permanent feeding stations were erected at each of the three release sites (Fig. 1). The permanent stations consisted of a plywood roof and plastic-covered plywood base connected by four steel rods, with the whole unit supported by a steel pole. A feeder was suspended from the roof of each station. In the first week we hung up three additional feeders near each station to attract birds. We also initially put feeders in other locations where we saw birds, then moved these toward the stations once birds began using them. The feeders initially held sugar water (220 g sugar per l, or 20% W/W). When hihi began breeding, we switched this to Wombaroo (220 g sugar per l, plus protein, fat, vitamins, and minerals). Feeders were available continuously for the first 3 weeks, then taken down for 12 days to begin an experimental test of carbohydrate limitation (Armstrong and Perrott, in press). However, this experiment was delayed by leg injuries caused by the bands used (see below). Consequently, feeders were available continuously from 8 October 1994 until 10 January 1995. Feeders were changed and disinfected every 2–4 days when sugar water was used, and daily when Wombaroo was used.

Fifty-four hihi nest boxes were erected, usually about 1.5 m from the ground (Fig. 1). The boxes were 34 × 25 × 20 cm, made of 2.5 cm tanalised pine, with 4 × 5 cm entrance holes.

2.4. Monitoring

At least three people monitored continuously over the first 2 weeks, and for 3 days during the third week. We walked around the island separately, searching for hihi and scanning for each transmitter frequency (using two Telonics TR4 receivers and one Telonics TR2 receiver). We also observed each feeder for 30 min/day for the first 2 weeks. We subsequently monitored for at least 3 days every 2 weeks, during which we recorded all birds seen, recorded behavioural data from those birds, and observed feeders for at least 4 h (1 h early morning, late morning, early afternoon, and late afternoon). To ensure broad coverage of the island, we walked over all the tracks and major gullies (Fig. 1) during each survey. Whenever a bird was sighted at least 50 m from a feeder, we observed it for as long as possible up to a maximum of 20 min, recording time budget data continuously into a hand-held microcasette recorder. At feeders, we recorded the number of seconds feeding by each bird during each feeding bout. We continued this regime until November 1995, and continued doing population surveys and recording feeder use every 6 weeks until November 1997. However, in this paper we only report data collected during the first 3 months after the release, except for the population surveys which were used to estimate the long-term mortality rate. We have also done intensive research on hihi mating behaviour and reproduction from about November–February in each of the first 4 years (Castro et al., in prep.).

2.5. Mortality

We used MARK 1.2 (White, 1998; Cooch and White, 1998) to estimate survival between surveys and test whether survival was significantly higher in the 3 months after translocation. The re-sighting data are treated as "recaptures only" by MARK. The encounter histories file went from the release data until November 1997, and included data for the 40 released birds plus 104 birds that fledged on Mokoia during the first 3 years (all juveniles were colour-banded, hence birds could always be individually identified). Birds fledged on Mokoia were considered to be "released" on the survey closest to their fledging date, and were considered to be juveniles for their first 3 months after fledging (the parameter index matrix was coded to estimate separate parameters for adults and juveniles). The original birds would have all been at least 5–6 months old when released, hence are considered to be adults.

We initially used a saturated model, which gave unconstrained estimates for survivorship and re-sighting rates for each time interval for adults and juveniles. We then created a design matrix that coded each survival parameter according to the bird's age, the year, and the season. The years ran from September–September, corresponding to the release date, hence there were three complete years plus one additional survey (which was included so that mortality could be estimated for the final interval of the third year). We recognised four seasons: September–November, December–February, March–May, and June–August. We excluded several of the surveys done in the first year to make the data set manageable. We included surveys at 3, 6, 9 and 12 weeks after the release, but otherwise included only two surveys per season. We progressively simplified the model, comparing Akaike weights and doing likelihood ratio tests for pairs of nested models. Finally, we added two additional terms to the best fitting model to determine if survivorship was significantly different 0–6 weeks after translocation and/or 6–12 weeks after translocation. We used the logit link function and 2nd part variance estimation, except for the saturated model which used the sin link function.

2.6. Effect of supplementary food

There was no scope to compare survival rates for bird that had and had not discovered feeders (see results). We used ANOVA to test whether the amount of feeder use was significantly different between birds that survived the period from 3–15 weeks after release and birds that died during that period. We measured feeder use as seconds of feeding per hour of observation, and initially calculated this separately for each bird on 26 September, 23 October and 7 November. We initially used two-way ANOVA (with individual and date as factors) to get the least squares estimate of feeder use by each bird (we couldn't just take the average between the three dates because some birds were not alive on all three dates). We then used two-way ANOVA to test whether feeder use varied according to the bird's sex and whether it survived or died.

To relate feeder use to energy budgets, we calculated the rate of energy intake while feeding and the energy requirements of hihi. We calculated energy intake from the amount of sugar water (20% $W/W = 16.5$ kJ/g) removed per feeding time. We calculated energy requirements of hihi based on Collins and Newland's (1986) equation derived from measurements on brown honeyeaters *Lichmera indistincta*. The average weights of the hihi were 37 g for males and 31 g for females. With a 13°C day temperature and 9°C night temperature, the predicted requirement is 68 and 60 kJ/day for males and females respectively. Hihi foraged for about 10 h of the day, hence males would have needed to obtain about 6.8 kJ/h while foraging and females about 6.0 kJ/h.

We used ANOVA to test for effects of feeders on foraging time. For each bout of observations on a bird, we calculated: (1) the proportion of time spent feeding, and (2) the proportion of feeding time spent foraging for carbohydrates (nectar or fruits, rather than invertebrates). We measured carbohydrate foraging as a proportion of feeding time so that measures 1 and 2 would not be directly influenced by one another. We did arcsin square root transformations on both proportions, then used two-way ANOVA to test for the effects of: (1) the individual, and (2) whether it had discovered the feeders. We usually considered each bout to be an independent observation, but combined bouts together if an individual was observed more than once in a day. We rejected observation sessions less than 60 s, but otherwise weighted all observation sessions equally.

2.7. Effect of transmitters

We used a *t*-test to compare re-sighting rates for birds that did and did not have transmitters. We calculated a re-sighting rate for each bird over the first three weeks, which was the number of days the bird was seen divided by the number of days searched (for birds with transmitters, searching was considered to stop when the transmitter fell off or stopped working).

2.8. Movements and settlement

We developed permutation tests (Crowley, 1992), written in SYSTAT BASIC, to determine whether birds' release sites affected where they settled or who they mated with. Birds' release sites and settlement sites were recorded on a Cartesian plane (birds were considered "settled" when $>50\%$ of their sightings were within a 100 m radius, excluding visits to feeders). To assess whether settlement sites were closer to release sites than expected by chance, we re-shuffled the data 1000 times, assigning release sites to birds at random without replacement (so the number released at each site was the same as in the real data set). On each run, the program measured the distance between the release and settlement site for each bird. We then compared the real distribution of distances to those generated by the permuted data.

We noted the release site of the male and female for each pair formed during the first set of breeding attempts (hihi do not necessarily breed in pairs, but there was always a dominant male associated with each female). To assess whether birds from the same release site paired more often than expected by chance, we randomised the release sites 1000 times for males and females separately (i.e. the number of males and females released at each site was the same as in the real data set). On each run, the program tallied the number of times that the male and female at a nest were from the same release site.

We used a randomisation test (Crowley, 1992) to assess whether birds' early movements were related to the places where they later settled and bred. We noted where each bird was seen most frequently in the first three weeks, and measured the distance between that location and the nest box where the bird had it's first breeding attempt (some males attended more than one box, but all had a primary box). The locations where birds were most frequently seen in the first 3 weeks all had nest boxes (Figs. 1, 4). Therefore, the randomisation test involved assigning nest boxes to birds at random (each of the 55 boxes having equal chance of being assigned to any bird). On each run, the program measured the distance between the randomly assigned box and the real box for each bird. We ran the program 1000 times, and compared the observed distribution of distances to that generated by the program.

3. Results

3.1. Mortality

All 40 birds survived the first 5 days after release, 38–39 survived the first 3 weeks, and 37–38 survived the first 6 weeks (Fig. 2). A female was apparently killed by a predator (probably a ruru owl, *Ninox novaeseelandiae*) on day 6 (we found her transmitter on the ground and a piece of wing nearby). A male died between days 22 and 25, and his body was found intact. His weight had dropped 12.5% in the 3 weeks following release, suggesting malnutrition or infection. A third bird (a female) was last seen 10 days after release. Loss of 2–3 birds equates to 5–7.5% mortality over the first 6 weeks, which would extrapolate to 36–49% annual mortality if continued over a year. This is lower than the annual (September–September) mortality estimated by MARK for 1994/1995 (63%), 1995/1996 (62%), and 1996/1997 (58%).

Mortality was higher for the period 6–12 weeks after release. However, this was due to injuries caused by the split-type colour bands initially used. Colour bands placed above metal bands caught on the upper part of the tarso-metatarsus, causing swelling and loss of movement. The split-type bands were removed after 6

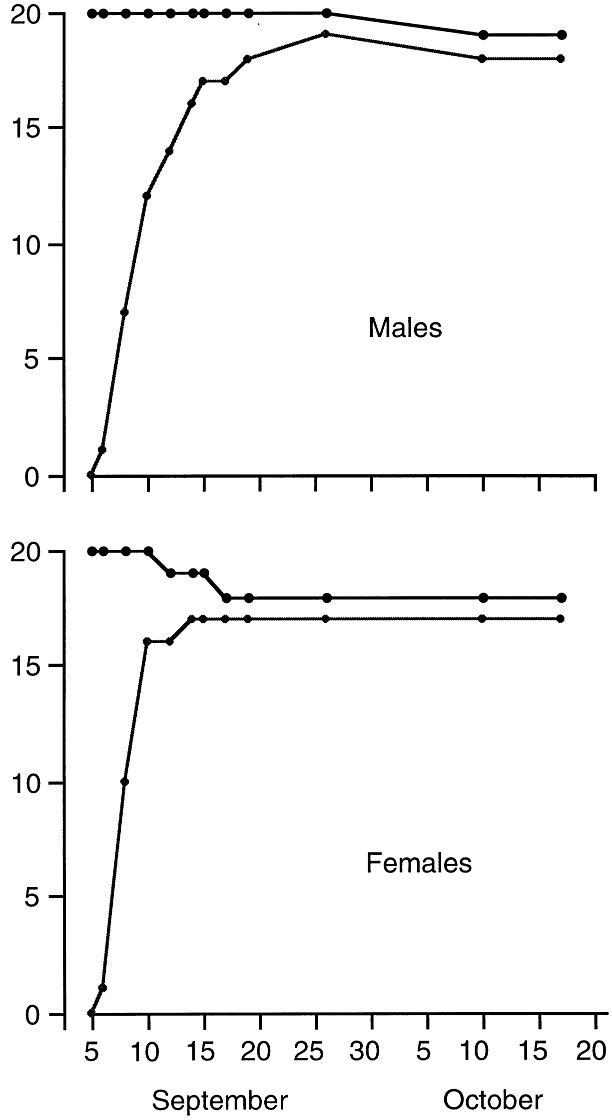

Fig. 2. Discovery of feeders by hihi on Mokoia Island following their release on 5 September 1994. The number of birds known to have discovered feeders (lower lines) is shown in comparison to the number known to be alive.

Table 1
A series of models fit to hihi re-sighting data using MARK 1.2, listed in the order tested

Model[b]	Factors[a]	QAICc	Weight	#Par	Deviance	LRT[c]	p[c]
1	Saturated	1430.28	0.00	79	533.94		
2	Y*S+A	1384.31	0.00	45	567.86	1-2	0.472
3	Y+S+A	1374.88	0.01	39	571.79	2-3	0.686
4	S+A	1501.66	0.00	38	700.78	3-4	<0.001
5	Y+S	1373.29	0.03	38	572.41	3-5	0.432
6	Y+A	1370.08	0.16	36	573.59	3-6	0.614
7	Y	1367.56	0.55	34	575.45	6-7	0.395
8	Y+T1+T2	1397.56	0.00	34	605.45	7-8	****
9	Y+T1	1370.60	0.12	36	574.11	7-9	0.513
10	Y+T2	1370.46	0.13	36	573.98	7-10	0.479

[a] "Factors" show the factors affecting survival parameters in each model (Y = year, S = season, A = age, T1 = 0–6 weeks after release, T2 = 6–12 weeks after release, and * shows an interaction between two factors).

[b] All models were saturated with respect to re-sighting parameters.

[c] LRT and p show likelihood ratio tests comparing pairs of models. The simpler model was always accepted unless $p < 0.05$, hence "year" is the only factor retained in the best model (7). No p value is calculated for models 7–8 because the same number of parameters were estimated for both models.

weeks, and replaced by wrap-a-round bands. Of the 37 birds known to be alive at 6 weeks, 14 males and 6 females lost at least partial use of one leg due to the bands. Seven of the males were last seen 6–18 weeks after release, and had crippling injuries when they were last seen. One of the females disappeared without recovering, but had subsequently suffered a broken tarsometatarsus that was probably unrelated to the initial injury. Two birds (1 male, 1 female) survived for at least 15 months with permanent injuries, and the other 10 birds recovered from their injuries. If all birds are included, a maximum of 6 (16%) birds died 6–12 weeks after release. MARK also estimates 16% mortality, which would extrapolate to an annual rate of 78%. However, if we discount the males that probably died due to band injuries, the maximum mortality over that period was 7% (2/30) which is below the average rate (see above).

When we modelled the factors affecting mortality from 1994–1997 using MARK, the only factor that had a significant effect was the year (Table 1). Mortality did not vary significantly between seasons or between adults and juveniles, and removing these factors improved the fit of the model. The mortality rate was not significantly different 0–6 weeks after release or 6–12 weeks after release, even though the injured birds were included in the data set.

3.2. *Effect of supplementary food*

Feeder 2 (Fig. 1) was discovered on the day after the release, and 28 of the hihi used this feeder in the first 5 days. The other two feeders were discovered after 6–7 days. By three weeks, 36 of the 38–39 birds still alive had used one or more feeders (Fig. 2). Consequently, there is no scope to compare survival rates for birds that had and had not discovered feeders. However, the amount that they used feeders varied greatly among birds (Fig. 3), and we could test whether this was correlated with subsequent mortality. We calculated that birds obtained about 86 J of sucrose energy per second of feeding time. Based on this and the predicted energy requirements for hihi, we estimate that about 16% (6/38) of birds were obtaining more than 100% of their energy requirements from feeders and about 45% (17/38) were obtaining less than 50% of their requirements from feeders (Fig. 3). Of the 38 birds alive 3 weeks after release, 13 (8 males, 5 females) were last seen over the next 12 weeks and probably died during that period.

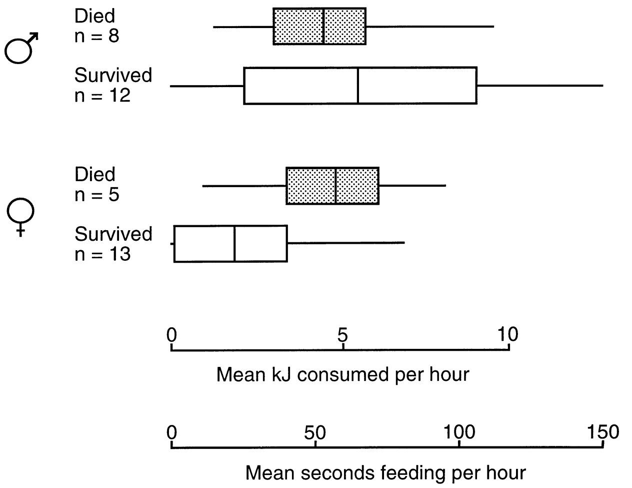

Fig. 3. Use of feeders by hihi, and whether they survived the period from 3 to 15 weeks after release. The time at a feeder includes time standing up to swallow the solution in addition to the time actually licking at the solution. The feeder use for each bird is a least squares estimate of its mean use on 26 September, 23 October and 7 November. Box plots show the median rates, plus quartiles and ranges. The estimated energy requirements are 6.8 kJ/h for an average male, and 6 kJ/h for an average female (see Methods).

There was no overall difference in feeding rates between birds that died or survived, or between males and females (ANOVA; $p > 0.5$), but the interaction term ($F_{1,34} = 3.070$, $p = 0.089$) suggests the sexes should be considered separately. Feeding rates were similar for males that died and males that survived ($t_{18} = 0.77$, $p = 0.451$), but tended to be higher in females that died than those that survived ($t_{16} = 1.91$, $p = 0.075$) (Fig. 3).

We only analysed time budget data for the first 2 weeks, as this was the only period when there were several birds that hadn't discovered feeders. We recorded 67 observation sessions from 32 hihi (18 male, 14 female) in this period, totalling 6.1 h of observation. Birds spent 29% of this time perching, 34% foraging for natural carbohydrate sources, 36% foraging for invertebrates, and 1% doing other behaviour. The carbohydrate foraging was on flowers of *Pseudopanax arboreus* (63%), *Fuchsia excorticata* (22%), and *Albizia lophanta* (3%), and on fruits of *P. arboreus* (7%) and *Schefflera digitata* (5%). Invertebrate foraging was mostly leaf gleaning, with occasional hawking flights.

The percent time foraging varied among birds ($F_{31,34} = 1.865$, $p = 0.039$), but was not significantly different for birds using feeders vs birds not using feeders (two-way ANOVA: $F_{1,34} = 0.007$, $p = 0.935$; Table 2), but did. While feeders didn't affect overall foraging time, they affected whether birds foraged for carbohydrates or invertebrates. Birds not using feeders mostly foraged for nectar or fruit sources, whereas birds using feeders mostly foraged for invertebrates (two-way ANOVA: $F_{1,28} = 8.485$, $p = 0.007$; Table 2). These data were recorded away from feeders, hence don't include time at feeders as a component of the time budget. However, this makes little difference to the proportions. Birds that had discovered feeders spent 82 sec/h (±9 sec) at feeders on average, which is 2.2% of their time. If this is added to the time budgets, birds using feeders spent an average of 3% of their foraging time at feeders, 30% on nectar and fruit sources, and 67% on invertebrate sources.

3.3. Impact and effectiveness of transmitters

Transmitters were removed after 6 weeks if they hadn't already fallen off. Only 2–3 birds had died by then, so transmitters could not have had a significant impact on mortality (2/19 birds with transmitters and 1/20 birds without transmitters). The average re-sighting rate was 0.70 for birds with transmitters and 0.42 for birds without transmitters ($t_{38} = 4.9$, $p < 0.001$). Feeders also affected re-sighting rates, particularly for birds without transmitters. For birds that discovered feeders in the first three days, the average sighting rate in the first week was 0.70 ($n = 11$, sd $= 0.14$) for birds with transmitters and 0.36 ($n = 6$, sd $= 0.08$) for birds without transmitters. For birds that did not use feeders in the first week, the average sighting rate was 0.58 ($n = 4$, sd $= 0.12$) for birds with transmitters and 0.09 ($n = 8$, sd $= 0.13$) for birds without transmitters.

3.4. Movements and settlement

The hihi moved extensively after release (Fig. 4). Even on the afternoon of the release, 5 of 14 birds seen had already moved about 1 km. A few locations became obvious centres of activity in the first 2 weeks, but the birds spread out more when they began breeding (Fig. 5). Settlement locations could be established for 26 birds (Fig. 5). Some birds settled immediately, whereas the last birds to settle did so in mid-December, by which time most surviving females had started nesting. The other birds either died before the breeding season (10) or remained floaters during the breeding season (4).

Table 2
Effect of feeders on percent of time spent foraging by hihi, and on percent of foraging time spent foraging for fruits or flowers

	Time feeding (%)		Percentage of feeding time on fruits or flowers	
	n	Mean[a]	*n*	Mean[a]
Using feeder	52	70 ± 6	45	31 ± 6
Not using feeder	5	79 ± 9	14	84 ± 8

[a] Means are given ± standard error, treating each observation session as an independent sample.

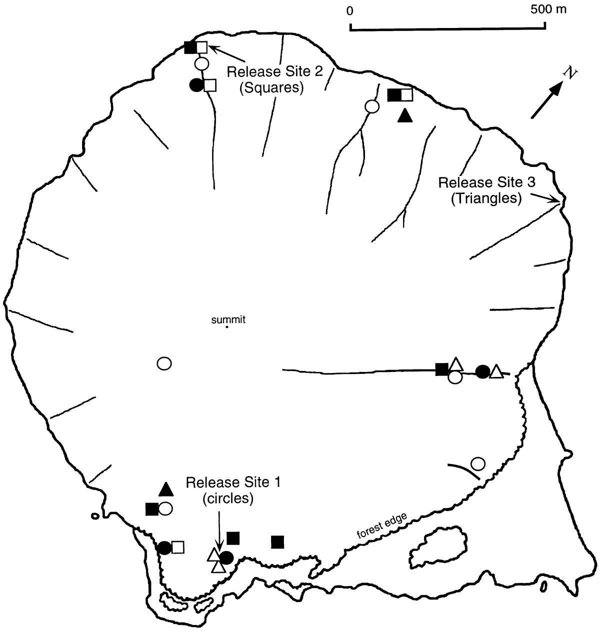

Fig. 4. Locations of hihi 17–19 September (2 weeks after release). Different symbols show birds' release sites (as indicated in parenthesis at each release site) and sexes (black = male, white = female). If a bird was recorded at more than one location, the most frequent location is shown. The positions are accurate within 200 m. Birds from the same release site are grouped together at each location for ease of comparison.

Despite the extensive movements, there was some tendency for birds to settle closer to their release sites than expected by chance. The median distance between release and settlement site was 606 m, and 923 of the 1000 permuted data sets had a median higher than this (i.e. $p = 0.077$ with a one-tailed test). Twelve birds settled within 500 m of their real release site, whereas 8.6 birds on average settled within 500 m of their randomly assigned release sites. Male and female hihi shared the same release site for only 3 of 14 nests. This is less than the expected value of 5.1 generated by the permutations, but not significantly lower ($p = 0.193$ that $n \leqslant 3$).

For 6 of the 26 birds that settled, the settlement site was within 100 m of their most frequent location in the first three weeks after release. This is a small proportion, but more than expected by chance ($p = 0.008$). On average, 1.85 of the randomised locations fell within 100 m of the real locations. The distance was within 500 m for 9 birds, which is not greater than expected by chance ($p = 0.351$).

4. Discussion

4.1. Mortality

The mortality rate for the first 6 weeks after release was no higher than the long-term mortality rate for the first 3 years. Mortality was slightly (but not significantly) higher for the period 6–12 weeks after release, but this was attributable to injuries caused by leg bands. Except for the effect of the bands, we conclude that capture, holding, and transport of hihi had no effect on post-release mortality. We cannot reject the possibility that the translocation affected longer-term mortality, either by spreading disease among birds or stressing birds so that disease could become established (most dead birds found have had extensive *Aspergillus* infections). However, the mortality rate did not reduce much over three years (63% in 1994/1995, 62% in 1995/1996, 58% in 1996/1997), and has been just as high in birds fledged on Mokoia as it was for the translocated birds).

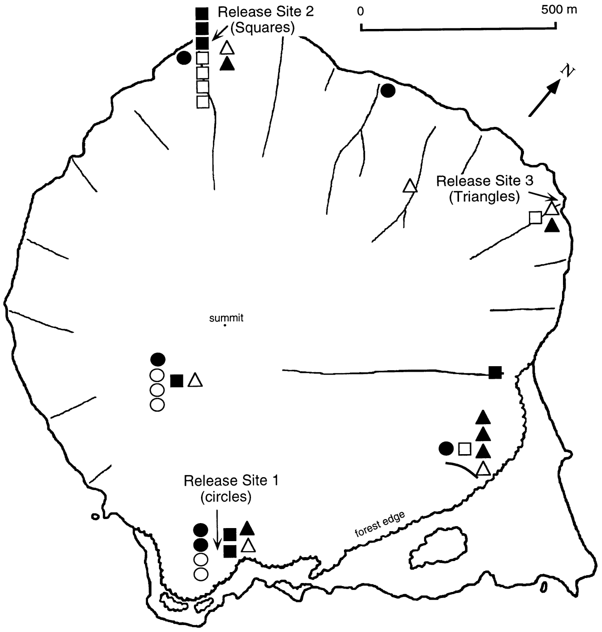

Fig. 5. Locations of hihi in mid-December, when most females had started nesting. Different symbols indicate birds' release sites (as indicated in parentheses at each release site) and sexes (black = male, white = female). If a male's symbol is touching that of a female, then he is the dominant male at her nest.

In contrast to the Mokoia translocation, other hihi translocations that have been monitored have had elevated mortality after release. For the 1992 translocation to Kapiti, this can partially be attributed to the higher mortality in birds that had delayed release. Disregarding these birds, there was 32% mortality (23/71) in the 4 weeks after release in 1991 and 1992. This would extrapolate to an annual mortality rate of 99.4%, whereas the annual mortality on Kapiti is usually about 50% (Castro, 1995). Post-release mortality was even higher on Tiritiri Matangi—55% (22/40) were never seen after the 1995 release, and 69% (9/13) were never seen after the 1996 release. Disregarding the 6 weeks after release, the annual mortality on Tiritiri Matangi in 1995/1996 was only 36% (8/22) (Ewen, 1996).

We can only speculate about the differences in post-release mortality between islands. However, separation of sexes could be important, as males usually harass females. Males and females were kept separate for the Mokoia translocation, whereas they were held together in aviaries before the translocations to Kapiti and the first translocation to Tiritiri Matangi. They were also held together on transit to Kapiti. Post-release harassment by bellbirds *Anthornis melanura* could also be important. Bellbirds are another honeyeater which are present on Kapiti and Tiritiri Matangi but not Mokoia, and which are known to be dominant over hihi (Rasch and Craig, 1988). Weather may have been a factor in the Tiritiri Matangi translocations, as the island was hit by a storm after the 1995 release and in 1996 birds were captured in rainy weather on Little Barrier. The habitat on Tiritiri Matangi may also be important, given that hihi are rarely seen outside three forest patches that have a total area of about 20 ha. This may cause additional stress during establishment, particularly in 1996 when there were already hihi present.

4.2. Effect of supplementary food

Supplementary feeding is common after translocations (Bertram and Moltu, 1986; Jeffries et al., 1986; Kleiman et al., 1986; Zwank and Wilson, 1987; Carbyn et al., 1994; Bright and Morris, 1994; Castro et al., 1995; Brown et al., 1995; Southgate, 1995), and can be a way of achieving a "soft release" (Scott and Carpenter, 1987). However, it is usually unclear whether this actually benefits the animals. We couldn't deliberately provide food to some hihi and not others to test the effect of the food, because they moved all over Mokoia after release. However, there were 12 birds that never discovered feeders in the first week. Only one of these died, and this was attributed to predation. Of the 38 birds that survived the first three weeks, all but one survived the subsequent 12 day period when we removed the feeders. The bird that died was already in poor condition when feeders were removed, despite having discovered a feeder within the first 3 days. We had planned to continue removing feeders on a regular basis, but delayed this until 1995 due to the injuries caused by the leg bands. The experiment conducted in 1995 showed that there was no time of year when hihi lost weight when feeders were taken away, and that mortality was not signicantly higher when feeders were absent (Armstrong and Perrot, in press).

The data comparing degree of feeder use among birds also gave no suggestion that supplementary food was needed for survival. Birds that used feeders little were not more likely to die, even though they probably obtained only a small portion of their daily energy requirements from feeders (Fig. 3). It's possible that the birds that used feeders extensively were those that needed to do so, and would have died otherwise, but there's no evidence to support this. Our later supplementation experiments (Armstrong and Perrott, in press) showed that extensive use of feeders does not necessarily imply that the feeders are needed for survival. Among females, the amount of feeder use was actually higher for the five birds that subsequently died than for the 13 that survived to breed. This could be because they were in a poor condition hence needed to use feeders. However, the average weights from 27 September to 7 November were similar for females that survived (mean = 31.5 g, sd = 2.0) vs those that died (mean = 30.5 g, sd = 2.0), and the average weight gain since capture was also about the same (mean = 0.5 g, sd = 1.5 vs mean = 0.0 g, sd = 1.7). Another possibility is that females using feeders had higher risk of forced copulations, and these resulted in mortality. Male hihi frequently attempt forced copulations, and do so quite violently (Castro et al., 1996). Four of the females disappeared after the start of the breeding season, and three of them were building nests when they disappeared.

While there is no indication that feeders improved survival, they changed birds' foraging behaviour. Birds using feeders concentrated on invertebrate foraging, and would therefore have been obtaining more protein, lipid, vitamins and minerals than birds concentrating on nectar foraging. This could be important in preparation for breeding.

The one clear benefit of the feeders was that they made birds easier to find so that we could closely monitor survival. Feeders could be useful for this purpose in any translocation of nectar-feeding birds. However, there is also some risk of damaging populations by using feeders. As noted above, female hihi may put themselves at risk by visiting feeders during the breeding season due to forced copulations. The other potential risk with feeders is disease, either from close contact among birds or from the food itself. However, microbiological tests of our feeders showed no contamination by bacteria or fungi.

4.3. *Effect of transmitters*

Transmitters increased re-sighting rates, and had no apparent ill effects on birds. However, they were expensive, required extra handling of birds, and lasted only 3–5 weeks. For our objectives, we did not consider the benefits of the transmitters to be worth the cost. Transmitters would have been more beneficial on a larger island (Castro et al., 1995) or the mainland, or if there had been no feeders.

4.4. *Movements and settlement*

The settlement sites of a few birds were probably affected by their release sites. Nevertheless, release sites did not have a major effect on birds' distributions, with the majority (14/26) settling more than 500 m from their release sites. Again, these results may depend on the scale of the release area. Release sites also had no effect on who mated with whom. The only factor that clearly affected where hihi settled and bred was availability of nest boxes. It is probably unimportant to spread birds out, except to avoid places where there are existing hihi (Castro et al., 1995). There was no obvious aggression among hihi immediately after release on Mokoia, and birds seemed to be attracted by other hihi. Like the release sites, movements of hihi over the first 3 weeks predicted the settlement locations of more birds than expected by chance, but only a small proportion of the population.

The importance of release sites will vary according to the species and circumstances. The quality and distribution of release sites is obviously critical for plants (Maunder, 1992), and less mobile animals such as some invertebrates (Meads, 1995; Sherley, 1995) and herptiles (Dodd and Siegel, 1991). With birds, extensive and rapid dispersal seems to be typical after release, even in normally sedentary species (Kurzejeski and Root, 1988; Allen et al., 1993; Musil et al., 1993; Armstrong et al., 1995; Clarke and Schedvin, 1997).

Nevertheless, release sites are probably more important for many other birds than they are for hihi. Tieke were also translocated to Mokoia, in 1992, and were released at two sites. Even though these sites were only 750 m apart, and the tieke dispersed over the whole island, the release sites had a clear effect on the distribution of birds (Armstrong and Craig, 1995). There was also a statistically significant trend for birds to mate with other birds released at the same site. With toutouwai *Petroica australis* released on similar-sized Tiritiri Matangi, there was also extensive dispersal from release sites. However, some release sites had much higher dispersal than others, and birds released at low-dispersal sites had higher survival (Armstrong, 1995). Movements immediately after translocation may also be more relevant in sedentary species such as tieke and toutouwai than they are for hihi.

5. Conclusions

There is no evidence that there was a critical establishment phase for the Mokoia hihi population. Mortality was no higher immediately after translocation than it was later on. Therefore, there is no obvious need to improve the translocation methods, except that split-type bands should be avoided with hihi. Hihi seemed to forage successfully immediately after release, and there was no evidence that they needed the supplementary food provided. Intensive observations on movements and behaviour during the first three weeks provided no useful information relevant to subsequent survival and reproduction.

While that were no apparent problems associated with establishment, the population has had a consistently high mortality rate over the first three years. The population has so far remained fairly consistent in size, but it’s long-term viability appears poor (Armstrong et al., 1997). Our subsequent research is addressing the factors that might be limiting the population, including food supply (Armstrong and Perrott, in press), effects of habitat on the mating system (Castro et al., in prep.), and effects of pathogens and disease. Other translocated populations of hihi have had a significant die-off immediately after release. Nevertheless, all the translocated populations have survived for many years and the initial die-off was probably irrelevant to the long-term viability of the populations. The key to the hihi recovery programme is to understand the factors causing long-term declines of the translocated populations rather than those affecting survival and behaviour during the establishment phase.

The establishment phase may be critical to the success of some translocations. Consequently, there have been several studies in recent years testing effects of alternative translocation strategies on post-release survival and behaviour (Davis, 1983; Zwank and Wilson, 1987; Bright and Morris, 1994; Soderquist and Serena, 1994; Armstrong et al., 1995; Castro et al., 1995; Fancy et al., 1997; Wauters et al., 1997). However, the perceived causes of translocation failure usually involve factors such as habitat quality or predation (Wolf et al., 1996). We suspect that that research should focus mainly on factors affecting long-term dynamics of translocated populations rather than those affecting survival and behaviour during the establishment phase. Nevertheless, it is important to do enough monitoring at all stages to determine which category of factors is most important.

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