Research and monitoring plan for the kiwi sanctuaries

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CONTENTS

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ABSTRACT

Five areas were established as 'kiwi sanctuaries' in 2000 as part of the New Zealand Biodiversity Strategy. The areas were chosen to include significant populations of rowi (*Apteryx rowi*) and Haast tokoeka (*Apteryx australis* 'Haast'), the most endangered taxa of kiwi; and sample populations of three of the four varieties of brown kiwi (*Apteryx mantelli*), the species suffering the greatest rate of decline. This plan recommends research and monitoring actions needed to establish the effectiveness of management within the five kiwi sanctuaries. It especially concentrates on the development of site-specific population models based on data derived from monitoring radio-tagged kiwi of all ages. Understanding the effect on target and non-target species (both pests and protected fauna) of management to protect kiwi, especially the large-scale control of stoats (*Mustela erminea*), is also important if kiwi are to be considered as just one part of the functioning ecosystem that makes up each kiwi sanctuary.

Keywords: *Apteryx* spp., kiwi, population dynamics, population models, monitoring methods, mustelid control, predator-prey dynamics, New Zealand.

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1. Introduction

Most kiwi (*Apteryx* spp.) populations on the mainland of New Zealand are declining rapidly, due to predation by stoats, cats, ferrets and dogs (McLennan et al. 1996). Without predator control, less than 5% of kiwi chicks survive their first 6 months, mainly because of predation by stoats and cats. Experimental work undertaken by Bank of New Zealand Kiwi Recovery, at the scale of hundreds of hectares, has shown that intensive control of predators, or the temporary removal of eggs and young chicks from risk in the wild (Operation Nest Egg), can turn the tide and allow kiwi populations to stabilise or recover. Predator control offers the prospect of managing kiwi over areas of tens of thousands of hectares, whereas Operation Nest Egg may be more applicable for managing the rarest taxa, for rapidly restoring depleted populations, or for establishing new populations.

Following a campaign by the Royal Forest & Bird Protection Society, for the government to establish 11 kiwi sanctuaries, each of 10 000–20 000 hectares, five kiwi sanctuaries were established in 2000 as part of the New Zealand Biodiversity Strategy (Department of Conservation 2000). The Kiwi Recovery Group chose five populations to manage in order to recover the most critically endangered taxa, and to best maintain the overall genetic diversity of kiwi. These included sample populations of three of the four varieties of brown kiwi (*A. mantelli*) and significant populations of rowi (*A. rowi*) and Haast tokoeka (*A. australis*, 'Haast') and are as follows:

- Whangarei area, Northland—for brown kiwi (Northland)
- Moehau/Kuaotunu, Coromandel—for brown kiwi (Coromandel)
- Tongariro Forest, King Country—for brown kiwi (Western North Island)
- South Okarito Forest , West Coast—for rowi
- Haast Range, South Westland—for Haast tokoeka

Management in the five sanctuaries varies slightly, but each aims primarily to increase survivorship of young kiwi so that it more than balances adult mortality. Within the 5-year timeframe of this project, it will be important to be able to demonstrate whether the experimental management, mainly through the extensive and continuous trapping of stoats, has allowed kiwi populations to recover, and whether the targets set at the start of the project are met. In the longer term, the Department of Conservation (DOC) will need to be able to quickly and accurately monitor the status of each managed kiwi population, without the costly requirement of having many birds radio-tagged. Therefore, during the intensive management phase it will be necessary to test whether remote monitoring by systematically recording call rates or by carrying out regular surveys of banded adults will provide an accurate tool for recording the number of birds in the populations.

Management aimed at recovering kiwi populations will have other costs and benefits to other protected wildlife and unwanted pests living in each Kiwi Sanctuary. Part of the overall funding from the New Zealand Biodiversity Strategy is to be spent on elucidating the effects of pest management for kiwi on other biota within the sanctuaries.

This document sets out the background to a series of recommendations about research and monitoring within the five kiwi sanctuaries; however, many of the principles will be applicable to other sites where kiwi are being studied or managed as part of their ecosystem (e.g. in the 'mainland islands').

1.1 LINKAGE TO THE KIWI RECOVERY PLAN

The management of the five Kiwi Sanctuaries contributes directly to the objective of Topic 4 of the Kiwi Recovery Plan 1996–2006 (Robertson 2003), i.e. representative populations of mainland kiwi are stabilized or increasing, and specifically to Actions 4.1 and 4.2:

> Action 4.1: Maintain intensive management of Okarito brown kiwi/rowi in the wild and increase population to 200 birds or more by 2006; and
>
> Action 4.2: Develop programmes to secure representative wild kiwi populations resulting in the IUCN and DOC threat classification status of all presently recognized kiwi taxa being either maintained or improved by 2006.

The work being undertaken in the Kiwi Sanctuaries will also contribute to several other objectives of the Kiwi Recovery Plan 1996–2006 (Robertson 2003), namely:

- Iwi are involved at all levels of kiwi research and management in an interactive way and in a way appropriate to all parties' commitments and expectations under the Treaty of Waitangi, taking particular note of the Ngai Tahu Claims Settlement Act 1998.
- Communities are empowered to protect kiwi by the sharing of knowledge and best management practices among all individuals and organisations concerned with this protection.
- Secure island locations are found for threatened taxa of kiwi.
- Tools are developed to maximise productivity of wild-laid eggs in captivity.
- Captive institutions produce surplus kiwi progeny for release.
- Population trends of all taxa are monitored.
- The agents of decline for each taxon have been determined and the effectiveness of management assessed.

The main research and monitoring effort needed in the sanctuaries over the 5-year timeframe available is to assess the effect of management in each sanctuary for the kiwi population and for other biota living there. The main priority areas for research will be to:

- Model growth rates of each kiwi population, especially concentrating on establishing survival rates of kiwi up to 1000 g, because this is the most critical stage where management can make a difference.
- Monitor concurrent changes in call rates.
- Assess effects of pest control on other biota.
- Increase our understanding of the way pest control operations work so that more cost-effective and sustainable control methods can be developed.

There will be many other research opportunities in the sanctuaries, provided by having a large sample of birds captured, handled and radio-tagged each year. An important criterion when assessing research proposals in the sanctuaries is that these extra activities do not impinge on or compromise the main research activities listed above. For example, investigation of the cause of blindness which is quite common in rowi should be done outside the breeding season, or with non-breeding birds, and birds should not be removed from the forest for this investigation.

2. Population models to show whether management is making a difference

To justify the ongoing management of the five kiwi sanctuaries, and ultimately to extend this method of focal species management to other kiwi taxa and populations, it will be critical to be able to show that kiwi populations have increased, or are at least stable, in the managed areas after 5 years of management. In the timeframe available, this will have to be done through the application of population models because censuses or other indices of abundance (such as call rates) are too coarse or slow to change to provide a firm basis for judgments.

Research on different kiwi populations has shown that population dynamics are highly variable between taxa, between populations of the same taxon, and within a population in different years. This variation is due to a combination of different, fixed, intrinsic features of each taxon such as clutch size and number of clutches laid each year, and variable extrinsic features such as the impact of particular predators and competitors at each site, and at different times.

In the 5-year timeframe of the kiwi sanctuaries, all data needed for site-specific population models will not be obtainable. However, for some less variable parameters, assumptions can be made from data collected during other long-term studies of kiwi populations.

The key elements of kiwi population models are:

- Initial population size
- Adult sex ratio
- Adult survival rate
- Number of eggs laid/pair/year
- Hatching success
- Chick survival (0–180 days old)
- Subadult survival (180 days–adulthood)
- Age at first breeding
- Immigration rate
- Emigration rate

2.1 INITIAL POPULATION SIZE

Although this parameter is not important in terms of building models to measure the growth rate of the population, politicians and the public expect the outcome to be reported in terms of the change in numbers of individuals within each sanctuary. Making this estimate is of lower priority than obtaining good estimates for the factors involved in determining the rate of population change. In most cases, a coarse estimate of population size can be obtained by plotting the known distribution of pairs or singletons, and then extrapolating this density to other comparable areas in which birds are not marked. Call count surveys can establish the general distribution of birds within each sanctuary, and so determine if it is valid to extrapolate known density to the whole block. For Haast tokoeka, rowi, and brown kiwi in the Coromandel, it would be useful to check and verify records beyond the sanctuary boundaries to better estimate the overall population size of each taxon, and so determine what portion of the entire taxon is under conservation management.

2.1.1 Recommendations

- The kiwi population in each sanctuary (except in high density parts of Whangarei) should be estimated by plotting the known distribution of birds, and extrapolating to the entire sanctuary (assuming that unsolicited call counts done throughout the sanctuary are linearly related to density). In high density parts of Whangarei Kiwi Sanctuary the territories of radio-tagged birds should be plotted to estimate density, and call counts can be related to known densities.
- Listening surveys should be used to search nearby areas to verify the presence of birds outside the sanctuaries, and estimate numbers (based on the assumption that unsolicited call rates are linearly related to density).

2.2 ADULT SEX RATIO

The sex ratio needs to be considered in population models because the productivity per bird may be much lower than the productivity per paired bird if there is a surplus of one gender in the population. It is theoretically possible that sex biases could occur in kiwi populations through physiological or behavioural differences, e.g. female chicks grow faster than males (H. Robertson, pers. obs) making them vulnerable to stoat and cat predation for a shorter period; adult females may be less vulnerable to ferret attacks than smaller, adult males (see Section 2.7); and males call more frequently than females, potentially disclosing their whereabouts to predators; however, egg peritonitis contributes to an increased mortality rate of females in captivity. There may also be sex-related differences in juvenile dispersal from protected natal areas.

Despite claims by Taborsky & Taborsky (1999) of biased sex ratios in kiwi populations, in no population studied to date has the sex ratio of adults been significantly different from even. Claims of sex ratio biases may have resulted from chance; possible misidentification of juvenile females as adult males; or more likely, from different capture probabilities of males and females (for example, males are more readily caught because they respond better to playback, and are more easily found at night because they call about three times more frequently than females). Because no consistent sex ratio bias has been found in kiwi populations, it is probably reasonable to assume that for every male identified during call counts, a female will be present in the population.

Massey University has developed an accurate test to determine the gender of kiwi, based on extracting DNA from the bases of feathers (Huynen et al. 2003). As long as sufficient DNA material is present, and as long as samples are not contaminated (e.g. feathers are collected from the bird and placed in a labelled and sealed plastic bag immediately, rather than collected from clothing or nets and held where they could be confused with another sample) there is a greater than 95% chance that the determination will prove correct.

2.2.1 Recommendations

- Record the gender of all kiwi handled, and check to see if there is any bias in the sex ratio of young or adult kiwi. Record the method of first capture for each individual (e.g. called to tape recorder, found with radio-tagged partner, found by dog).
- Collect feather samples (especially pin feathers) from all young kiwi handled and determine the gender by DNA analysis.
- Record weights of young kiwi each time they are handled, and plot growth rates of males and females to determine how long each gender takes to reach 1000 g.

2.3 ADULT SURVIVAL RATE AND LIFE EXPECTANCY

Information on the survival of radio-tagged individuals is free from many of the biases inherent in capture-recapture models for banded birds. Not only can annual survival rate and life expectancy be calculated, but the cause of each mortality event can often be determined from field and/or subsequent laboratory evidence.

Research has shown that the annual survival rate of adult kiwi varies considerably from site to site around New Zealand, mainly due to the presence or absence of particular predators, especially dogs and ferrets. A long-term study in central Northland, with 44 deaths of kiwi in about 537 bird-years of radio-telemetry data, has shown that mortality events are often episodic, due to the effect of individual ferrets or dogs that visit the study sites (H. Robertson, pers. obs). Males and females appear to have similar survival rates, e.g. in the Northland study the crude annual survival of females is 91.7% (9 deaths in 108 bird-years), and 91.8% for males (35 deaths in 429 bird-years).

The crude life expectancy of an adult kiwi can be calculated as $1/m$, where m is the annual mortality rate. The estimate assumes that mortality is more or less constant with age once adulthood has been reached (and most studies for many years to come will primarily deal with adult kiwi of unknown age). The annual mortality rate (m) is simply calculated by dividing the number of bird-years of radio-tracking by the number of deaths. For example, in Northland a total of 44 deaths in 537 bird-years gives a mortality rate of 44/537 = 8.2%, a survivorship of 91.8% (100%-8.2%) and a life expectancy of 12.2 years (1/8.2).

Sound estimates of survival rates depend not only on the number of years that birds are followed, but the number of deaths recorded. Kiwi are exceptionally long-lived birds and this means that many years of radio-telemetry data are needed to get accurate estimates of adult survival—until the variance in survival estimates is stabilised, so that the chance death or non-death of an individual makes little difference (< 5%) to the overall estimate of life expectancy. The reason why this is so important is that a small change in the survival estimate of such a long-lived bird can be greatly magnified during subsequent calculations of life expectancy and life-time productivity of adults, and hence estimates of the survival of eggs, chicks and subadults required to maintain a stable population. H. Robertson and I. Westbrooke (unpubl. data) recommend that, for reasonable accuracy of mortality/survival/life expectancy estimates, the product of the number of radio-tracking years and deaths should exceed 500, e.g. 10 deaths in 50 bird-years of data, 5 deaths in 100 bird-years, etc.

H. Robertson and I. Westbrooke (unpubl. data) have also developed a set of standard rules to follow for including or excluding records, so that results between different sites are comparable. They include sample Excel sheets for the storage of data, set in a format where it can be simply used in Excel or imported into SPSS for Kaplan-Meier survival models. They also show how to make comparisons between groups (e.g. by gender) and produce graphical representations of the survival curves.

2.3.1 Recommendations

- The survival rate of adult kiwi in each kiwi sanctuary should be primarily measured from radio-telemetry data from ordinary or mortality transmitters.
- The interpretation of data and analysis should follow the methods proposed by H. Robertson and I. Westbrooke (unpubl. data) so that results are comparable between sanctuaries.
- As many males and females as possible should be radio-tagged (with a minimum of 30 adult birds) so that adult survival data in each sanctuary is accumulated rapidly. Having transmitters on females helps to accumulate adult survival data, and should the transmitter on a male fail, then there is an increased probability of relocating him when he shares a daytime den with his radio-tagged partner.
- Both males and females should be checked monthly, to determine if the signal is in normal or mortality mode, or moving at night, but females need only be precisely located and recaptured at 6-month intervals to change transmitters or to check transmitter attachment, or to identify their partners. When a signal goes missing, the date it was first searched for and not found should be noted.
- Where the sample of radio-tagged birds is too great to handle logistically, then randomly selected pairs should be dropped and/or transmitters should be removed from females, and the survival of both genders assumed to be equal.

2.4 ANNUAL EGG PRODUCTION BY PAIRS

Because male kiwi do all the incubation in brown kiwi, and are in attendance at the nest during daytime in rowi and Haast tokoeka, it is simplest to concentrate the analysis on the number of eggs attended by each adult male in the population each year, as a measure of the number of eggs laid/pair/year.

It is important to try to record the number of eggs in each clutch, and to determine the fate of all eggs laid. Exclusion of nests that are not detected because they failed in early incubation will increase the apparent hatching success of those that are detected, but will be balanced by a decrease in the numbers of eggs/male/year.

What is probably more important to the overall calculations is that all non-breeding adult males (e.g. unpaired, helpers in a parental territory, or simply in an unproductive partnership) are kept in the sample and their lack of productivity is taken into account in the calculations. When the annual percentage (and its variation) of unproductive adult males in the population is confidently known, then it is permissible to remove their transmitters and to add a correction figure into subsequent calculations. In some bird species, the incidence of senescence (non-breeding and increased mortality) increases with increasing age. In all kiwi populations on the mainland, the agents of decline (introduced predators) have been present for 3–10 kiwi generations, so the age structure will have now stabilised with a higher percentage of older birds present. Except for sites where the population has declined to the point where birds can't locate potential mates (Allee effect), populations will not comprise mainly very old birds.

Handling of birds in the months leading up to the breeding season may disturb birds sufficiently to put them off attempting to breed, and so consistently unproductive birds should be monitored as remotely as possible. In Northland, we know that kiwi are discerning in selecting a new partner following loss of a partner—in one instance a widower remained unpaired for an entire season despite the presence of three widows living within 400 m of him; on the other hand, some birds re-pair very rapidly following loss of a partner.

2.4.1 Recommendations

The productivity of a population should be measured as the number of eggs incubated per adult male per year. Attempts should be made to determine the clutch size of each nesting attempt, and to record all nesting attempts each year. For purposes of calculations where clutch size is uncertain, the mean clutch size of that pair should be assumed or, if those data are lacking, the mean clutch size of the population.

- Males that are fully grown and/or > 3.5 years old, but who have not yet found a partner, should be included as adult males for the purposes of these calculations.
- Transmitters should be kept on all adult male kiwi, even those in consistently unproductive partnerships, until the percentage (and its annual variation) of unproductive adult males is accurately known.

- Consistently unproductive birds or pairs should be approached cautiously, and handling of either partner should be avoided in the 2 months before the start of the usual breeding season of that taxon (e.g. May in brown kiwi in Northland, July in rowi).

2.5 HATCHING SUCCESS

Hatching success of kiwi (at 45%–60%) is quite low among birds, especially since relatively few eggs are lost directly to predators. McLennan et al. (1996) identified microbes as a major 'predator' of kiwi eggs, with a high number of eggs becoming rotten during the course of incubation. This may be a result of the damp, humid nest conditions, the prolonged incubation period and, in some taxa, the regular cooling and warming of eggs due to discontinuous incubation. Disturbance at nests by humans or other mammals (e.g. possums) may contribute to egg losses through accidental damage to the egg, or desertion. The effect of human disturbance can be minimised by treating each check of an adult male during the breeding season as though he may be on a nest. By recording the behaviour of birds during and following each nest visit, the tolerance of each adult male in the population can be ascertained — some males desert whenever a nest is approached within 5 m, others will tolerate handling and a transmitter change while incubating. Expert analysis of the age of death of embryos may indicate whether egg failures/nest desertions coincided with nest inspections by researchers.

2.5.1 Recommendations

The hatching success of each egg laid should be determined as far as possible by checking the location of all radio-tagged adult males at least once each month, and then inspecting the supposed nest if he is away from it—carefully looking for traces of egg shell and the dried shell membranes.

- Each nest should be inspected after the eggs should have hatched but before its chicks should have permanently left the nest (at as little as 10 days old for the younger chick in a 2-egg nest of a brown kiwi). Failed eggs can be buried in the nesting material, and adult kiwi sometimes eat the entire shell of a hatched egg.
- All failed eggs and eggs in abandoned nests should be retrieved, and all intact eggs initially treated as being potentially viable. A bird may be temporarily away from the nest (even for whole days in the early stages of incubation), or disturbed by the checker's approach to the nest, so a cautious approach to declaring abandonment is advised. Each egg should be candled to determine the stage of development, and well-developed eggs (> 40 days old) should be checked for movement.
- Eggs that are potentially viable should be left in the nest for 2–3 h to give the male a chance to return. They should be removed for artificial incubation if the male has not returned within 2–3 h, if he has a history of not returning after disturbance, or if the nest was clearly abandoned before checking.
- Dead eggs should be refrigerated, packaged carefully and couriered to Dr Murray Potter, Massey University, for determination of the fertility of the egg, and approximate age of embryo death.

2.6 CHICK SURVIVAL RATE

McLennan et al. (1996) found that survival of young brown kiwi from hatching to 6 months old was the critical factor affecting the viability of kiwi population on the mainland. Without predator control, < 5% of kiwi chicks survived their first 6 months, mainly because of predation by stoats and cats. Chicks (still in the nest by day, or < 60 days old) and juveniles (independent of the nest, or > 60 days old, but < 180 days old) are particularly vulnerable to predators, but their mortality risk slowly declines as they become larger, faster, and less naïve, so that at about 6 months old, or 1000 g in weight, they are largely safe from stoats and cats.

Samples of at least 20 radio-tagged chicks are needed in each kiwi sanctuary each year to be able to properly assess the effectiveness of management on the survival rate of young kiwi. This figure of 20 chicks is a minimum, not a target; the greater the number of chicks followed, the better the estimates of survival and measures of relative importance of various causes of death. The abundance of predators (especially stoats) varies considerably from year to year, mainly in response to the population levels of their main prey (rodents), and this annual variation is especially pronounced in or near beech forests, tussock grasslands, or masting podocarps.

Predation of kiwi chicks is thought to be largely incidental to the standard diet of the predators, and highly opportunistic. However, there is growing evidence that some individual predators may learn to tackle and kill kiwi chicks, while others may ignore them; therefore, deaths of kiwi chicks are not necessarily random events. The samples of chicks radio-tagged should, where possible, be spread out geographically through the study areas so that the influence of one individual predator is not unduly large, so that samples are not weighted towards or away from natural access points for predators moving into the kiwi sanctuaries, and so different habitats are fairly represented. Radio-tagged samples should also be a chronologically representative sample of chicks each year, rather than just the first 20 chicks to hatch, because there is a marked peak in stoat dispersal in December and January as young stoats become independent and move away from their natal areas. Chicks that hatch early in the season (August to September) are well grown by the time stoat abundance increases, and so have a better chance of survival than those hatched in November to December. Similarly, those chicks that hatch after the peak of stoat abundance has passed also have a better chance of survival.

2.6.1 Recommendations

- Sufficient nests need to be monitored in each kiwi sanctuary to ensure that at least 20 chicks, preferably more, are radio-tagged each year.
- The sample of radio-tagged chicks should be spread geographically through the kiwi sanctuaries, with no undue bias towards nests near or away from the forest edge or other natural entry points for predators. Different habitats in the sanctuaries should be fairly represented.
- The sample of chicks should be spread chronologically throughout the whole hatching season, with no undue bias towards early-, mid- or late-hatching chicks. From known hatching chronology and estimates of the number of

chicks that should hatch in a season in each kiwi sanctuary, the monthly number of nests in which chicks are to be radio-tagged should be decided in advance to ensure that samples are stratified according to season.

- Where one chick in a nest with two chicks is to be radio-tagged, a coin should be tossed to decide which is to be radio-tagged.
- Although it is ideal to check to see if chicks are alive each week, so causes of deaths can be more accurately determined, excessive disturbance and handling of chicks should be avoided as this may affect their growth rate, behaviour and vulnerability to predators. In some sites, where radio-tracking is difficult, fortnightly checks to see if a chick is dead or alive are probably more realistic without greatly increased staffing. Monthly checks of each chick are an absolute minimum, otherwise valuable data on the causes of death are lost, and too many chicks disappear or lose their transmitters between checks.

2.7 SUBADULT SURVIVAL RATE

At about 180 days old, brown kiwi, rowi and tokoeka weigh about 1000 g, although there is much variation depending on gender (females grow faster), time of year, and fitness or health of the individual. Although a 1000-g kiwi is not immune to stoat or cat predation, few birds of this weight are tackled and killed, either because they appear physically too big to tackle, or because they are sufficiently adept at escaping and fighting off the predators. The largest kiwi known to have been killed by a stoat weighed about 1200 g. Ferrets seem to be more able to kill smaller (< 2200 g) kiwi (subadults and adult males) than adult females (> 2200 g). In general, subadults (being smaller) are more vulnerable to predators than adults. Subadults are mobile as they disperse to seek new territories, and this also brings them into contact with a greater range of natural hazards (rivers, territorial kiwi) and anthropogenic hazards (roads, dogs, cattle stops) as they sometimes have to disperse across inhospitable habitats (e.g. open farmland, rivers). In some areas, subadults have to compete for limited territories, and are found eking out an existence in suboptimal habitats, or in small gaps between established territories.

McLennan et al. (1996) reported few data on subadult survival, mainly because few birds reach this stage in unmanaged populations, and contact with radio-tagged birds is often lost once they have left a study area. This data deficiency still persists, especially for wild-raised subadults, but preliminary data from Northland and Lake Waikaremoana, based on small samples with high variances, suggests that survival rates of subadults are highly variable between sites, mainly due to the presence or absence of ferrets and dogs, and perhaps kiwi population density. Annual mortality estimates for subadults are cubed over the 3-year period from 6 months to mean age of first breeding. In Northland, < 50% of subadult birds survive the 3-year journey to adulthood; whereas at Lake Waikaremoana, survival is higher, and > 50% of subadults survive through that 3-year stage (J. McLennan pers. comm.).

2.7.1 Recommendations

- Acquisition of radio-telemetry data on the survival and dispersal of subadult kiwi is a very high priority in all kiwi sanctuaries. Subadults should be fitted with mortality transmitters and checked monthly, but only need to be approached closely if the mortality mode is triggered, to change transmitter or transmitter attachment, to see if the bird is with a partner, or to collect morphometric data for determining growth rates.
- It should be possible to determine the gender of subadults from their final adult size, although females can be identified once they have exceeded the male dimensions. As a precaution, a feather sample (preferably pin feathers) should be collected at first capture, and stored in a well-labelled container; if necessary, the gender can later be determined by DNA analysis.
- The weight and bill length of subadult kiwi should be recorded each time they are handled, to provide data to better develop growth curves, and increase the ability to age subadults of unknown provenance. The growth rates of known-age, known-gender kiwi, can be used to estimate the ages of any subadults discovered during the course of kiwi sanctuary work.

2.8 AGE AT FIRST BREEDING

Throughout the history of kiwi research in the wild, very few known-aged birds have been recorded breeding for their first time. This is mainly because few individuals survive long enough to breed, especially in unmanaged populations, but also because many birds disperse away from study areas and contact with them is lost. For population models, the median age at first breeding is a useful definition of the start of adulthood. Studies on other birds suggest that females usually start breeding earlier than males (although with role reversal in many aspects of their ecology, the opposite might apply in kiwi) and breeding starts earlier at low population density, where there is little competition for resources. However, at exceptionally low densities, birds may have trouble attracting mates and so, on average, breed later than normal.

Kiwi have exceptionally slow growth rates for birds, and are still growing at 3–5 years old, while their weight may not stabilise until 4–6 years old. Bones in the skull do not become finally fused until birds are about 5 years old. It is not uncommon for birds to start breeding while they are still growing and, from limited Northland data, an age of about 3.5 years seems to be a reasonable median age of first breeding. (This is based on five Operation Nest Egg birds in low population density areas that have bred at 2–3 years old, several wild and Operation Nest Egg birds in high density populations that have bred at 3–5 years old, and one wild-reared individual that was 9 years old before attempting to breed; H. Robertson, unpubl. data.) The situation may be different in those kiwi taxa in which young birds remain in their parental territory for some or many years after hatching. On Stewart Island, a known-aged tokoeka was still in his parental territory at 4.5 years old, but had acquired a territory by 7.5 years old (R. Colbourne, pers. comm.); at Okarito, two wild-reared birds have yet to breed at 4 years old, and one is still with its parents (C. Rickard, pers. comm.)

2.8.1 Recommendations

- A sample of 20 subadult kiwi should be caught and radio-tagged at each sanctuary, including birds that had been followed as chicks. They should carry a mortality transmitter so that the bird does not need to be physically checked until the transmitter or its attachment needs to be checked or replaced. A bird whose bill has grown > 1.5 mm between measurements at least 6 months apart should be classified as a subadult, unless subsequent measurements show that the second measurement was inaccurate.
- The age of first breeding should be recorded wherever possible. For a young female brown kiwi, this information will probably have to be obtained by finding and radio-tagging her mate, and then following him until he has bred, and then confirming that the birds are still a pair.

2.9 IMMIGRATION RATE

Although kiwi chicks can move several kilometres a few weeks after leaving the nest, most long-distance dispersal happens when subadults are over 9 months old. Radio-tagged subadults have been known to travel at least 25 km (T. Herbert and N. Coad, pers. comm.), and rivers prove not to be major obstacles (C. Speedy, pers. comm.). In most cases, the rate of immigration into the kiwi sanctuaries is likely to be negligible, because either the whole range of the taxon is being managed, or because very few subadults are produced in areas not under management. An exception to this generalisation may occur where there is high variability in productivity and/or juvenile survival in different habitats and these 'source' habitats occur near to a sanctuary. For example, in Northland, it is possible that juveniles survive better in nearby hilly, partly scrub-covered, farmland than in the forested reserves being managed as part of the Whangarei Kiwi Sanctuary, because there is less predation pressure in farmland habitats than in the forest patches.

2.9.1 Recommendation

- Researchers should assume that immigration is negligible. However, juvenile kiwi in some nearby modified habitats may survive better than in native forest habitats because of reduced predation pressure.

2.10 EMIGRATION RATE

The rate of emigration from kiwi sanctuaries into nearby unmanaged areas will be measured incidentally during the course of radio-tracking young kiwi after they leave the nest, or radio-tracking subadult kiwi found during the study. All kiwi in the sanctuaries must be permanently marked (banded, wing-tagged or transpondered) rather than simply radio-tagged, because transmitters will eventually fall off. Transponders and wing-tags should be used for small kiwi only, and bands should be applied once the young reach about 1200 g, so that the identity of the bird is unquestionable. This will allow future researchers or members of the public who encounter the bird to report it to the National

Museum (the address on New Zealand bands) or to DOC. Although no outstanding dispersal records have yet been established through banded birds, some important longevity records have been obtained from banded kiwi (e.g., a rowi banded at Okarito in 1979 is still alive; C. Rickard, pers. comm.), two brown kiwi banded at Waitangi in 1981 are still alive (R. Colbourne, pers. comm.), and many adult little spotted kiwi (*A. owenii*) banded in the early 1980s were still alive in 2002 (H. Robertson, pers. obs.).

The rate of emigration is likely to be density dependent, and so change over time; and to vary considerably between sanctuaries. In the initial phases of kiwi sanctuary management, it is likely that there will be many gaps available for new birds to establish territories, but as the population approaches the carrying capacity of the area the rate of emigration is likely to increase, so population growth in the sanctuary ceases. At this point, management of the sanctuary may either have to change to encompass a larger area with less intensive management, or accept that the sanctuary is going to be a continuous source of birds that will have low breeding success in sink areas nearby.

2.10.1 Recommendations

- All subadult kiwi weighing >1200 g should be banded, to increase the probability of obtaining data on long-distance dispersal.
- Determined efforts, including aircraft use, should be made to try to locate birds that disappear from the kiwi sanctuaries. If possible, retain transmitters on birds that leave the area until they have settled and started to breed.
- The natural pattern of dispersal should not be disrupted by returning dispersing birds back into the managed area (although they sometimes return themselves)—even if the birds seem to have moved into a dangerous habitat (e.g. near a house with dogs).
- The age and gender of all young birds that disappear without trace, and those known to have dispersed, should be recorded to see if there is any pattern in the timing and gender of birds that emigrate.

3. Measuring the effectiveness of call counts to assess changes in kiwi populations

With intensive work being undertaken in each sanctuary with individual kiwi or pairs of kiwi carrying radio-transmitters, and population changes estimated from the above population model, it should be possible to measure the effectiveness of call counts as a tool for indirectly measuring changes in kiwi populations. In Northland, Pierce & Westbrooke (2003) found a close correlation between changes in call counts over time and the level of management (predator control and/or advocacy): in well managed sites, call counts remained more or less constant, whereas in unmanaged sites they decreased over the 8-year period.

If call counts accurately measure changes in populations on the ground, with or without a lag effect, then there will be no need to have birds radio-tagged in any of the managed areas in the long term.

Baseline data have been gathered in each sanctuary as part of the Nationwide Kiwi Call Count Scheme (Robertson & Colbourne 2003), or during specific surveys. Details are summarized below.

Northland

As part of the Nationwide Kiwi Call Count Scheme, call rates of kiwi have been measured at three relevant listening stations (Marlow, Rarewarewa and Purua) for 8 h listening at each station every May–June since about 1996. In 2001 and 2002, many new listening sites were added at both Motatau and Whangarei Heads (including Bream Head, Tauikura, Manaia, The Nook and Kauri Mountain), so that each of the two clusters now has a complement of six or more listening stations.

Coromandel

Nationwide Kiwi Call Count Scheme stations in the Coromandel included two stations within the sanctuary: Port Charles (survey station 178) and Kuaotunu Hill). A total of 150 h of listening was conducted at these stations over the winters of 1994–1996. In 2000, before management started in the sanctuary, an extensive call count survey was conducted at 80 listening stations for up to 6 h per site (Stewart et al. 2000). This was partly to identify 'hot-spots' where birds could be caught for radio-tagging, but will prove to be a valuable baseline against which to measure changes in call rates over time.

Tongariro

Miles (1995) measured the seasonal and nightly changes in call rates of kiwi in part of Tongariro Forest in the early 1990s. A total of 180 h of listening was then conducted at five listening stations in 1994–1997 as part of the Nationwide Kiwi Call Count Scheme. Call rates at these five stations were re-measured over 50 h in autumn 2002. The five stations used for the baseline sample were clustered in an existing study area, and did not cover the range of habitats or situations available in the whole of the 16 000-ha Tongariro Kiwi Sanctuary.

Okarito

Nationwide Kiwi Call Count Scheme stations were established in 1994. However, as call rates were consistently well below the suggested minimum threshold of 3 calls/h (McLennan 1992) they were discontinued after 2 years. In 1996–1997, an alternative monitoring method was established by listening at 84 stations spread through the whole 10 000-ha area occupied by rowi. At each site, listening was conducted for 2 h. Natural call rates were recorded in the first hour, and then taped calls broadcast in the second hour were used to entice resident birds to call, and to approach close enough to be caught by hand. The first hour of listening at each site provides an index of kiwi abundance, from which changes can be measured.

Haast

As part of the Nationwide Kiwi Call Count Scheme, call counts of Haast tokoeka were measured at five sites for a total of 182 h in 1994–1997. The listening stations were all above the bushline, which does not accurately represent the distribution of birds now determined from more extensive survey work. These five sites were revisited in autumn 2002, and 49 h of listening were completed.

3.1 RECOMMENDATIONS

- Whangarei Kiwi Sanctuary should settle on a minimum of 12 listening sites in two clusters of six listening sites, one covering the Whangarei Heads area where kiwi populations are being restored, and one covering main kiwi research blocks being managed as part of the sanctuary. The latter includes long-standing listening stations at Marlow, Rarewarewa Barn, northern Purua, and Motatau Access Road, but at least two further listening sites should be selected covering the southern side of Purua or the northern side of Rarewarewa, and another independent site at Motatau. Listening should be conducted for 2 h per station for 4 nights in late May–June, preferably at the current annual rate for the rest of Northland. The expectation is that in the Whangarei Heads area, where management commenced in 2000, the call rates may initially be well below the 3 calls/h threshold recommended, but pest management and the addition of Operation Nest Egg birds should soon see call rates increase.
- Coromandel Kiwi Sanctuary should add at least three more listening stations in or near to the Moehau Kiwi Sanctuary, and one or two more listening sites in the Kuaotunu area. The sites should preferably have call rates above 3 calls/h, but some may be below this initially. Suggested stations that could be used at Moehau, based on the numbers of birds detected during the survey by Stewart et al. (2000), accessibility, and to give a wide geographical spread within the managed area include: nos 127, 139, and 120 or 155. To establish a firm baseline of call counts, a minimum of 2 h listening for 4 nights is needed at the four new sites (and preferably at the two existing stations in the managed areas) for the next 2 years, at the same time of year as the existing Nationwide Kiwi Call Count monitoring has been done on the Coromandel Peninsula. All six stations (the two existing stations and the four new stations) in the managed areas should be resurveyed in another 4 years. On a broader scale, all 80 stations (or a stratified sample of 40 stations, based on numbers of birds detected) covered in the 2000 survey should be resurveyed in 2005 at the same time of year, and with the same methods as the initial survey to establish if there is any measurable change in the distribution and numbers of calling birds.
- Tongariro Kiwi Sanctuary should replace the listening stations at 'The Pond' and 'The Slipway' (one site with a low call rate, and one too close to another to be truly independent) with new stations established in the northern part of the Sanctuary. Some survey work may be needed to select stations with a good listening coverage and a moderate density of birds, preferably giving a minimum of 2–3 calls/h.

- The extensive survey and capture-recapture work at Okarito should be completed in 2003 or 2004, and then repeated at 5-year intervals.
- At least two new listening stations should be established in the lowland areas, or on the toe of the slopes of the Haast Kiwi Sanctuary. Stations at Lake Greaney and either Mimim Mere or Camp Site should be dropped during the next 5-year repeat of the Nationwide Kiwi Call Counts. In the meantime, a minimum of 2 h listening for each of 5 nights is needed at the two new stations for the next 2 years, at the same time of year as the existing Nationwide Kiwi Call Count monitoring is done elsewhere in the sanctuary.

4. Assessing the wider ecosystem effects of mustelid control in kiwi sanctuaries

It is hoped that the extensive stoat trapping, and/or periodic 1080 (sodium monofluoroacetate) operations to control possums, being undertaken in most of the kiwi sanctuaries will provide wider ecological benefits to the communities in which the kiwi live, and that kiwi might serve as an umbrella species at these sites. The removal of many stoats will almost certainly affect the food webs and predator-prey dynamics in these areas. In New Zealand forests the main prey of stoats are rodents, so trapping large numbers of stoats may release predation pressure on rodents sufficiently to allow a build-up in their populations, which could in turn be detrimental to populations of their prey, or competitors. On the other hand, it is hoped that the reduction in predator pressure from stoats will directly benefit many native species, especially those which are not prey or competitors of rodents. Periodic control of possums by aerial 1080 operations may result in the poisoning (primary or secondary) of rats, mustelids and cats, providing a window of opportunity for a pulse of kiwi chicks to reach a ‘safe’ size, and ultimately be recruited into the breeding population, as well as boosting recruitment of other native species.

The ecological consequences of mustelid control to benefit kiwi, and especially the interactions with other pest species, are the subject of a research investigation by DOC (I. Flux, pers. comm.). Core elements of this study include:

- Monitoring the changing abundance of mammalian pests (mustelids, possums and rodents) in each kiwi sanctuary, during trapping operations or following aerial 1080 operations, and comparing pest abundance indices with those in non-managed controls nearby.
- Monitoring the change in abundance of forest birds from a series of 5-min counts in managed and unmanaged areas.
- Recording the breeding success of tree-nesting fantails (*Rhipidura fuliginosa*) and/or tits (*Petroica macrocephala*) in managed areas.

4.1 RECOMMENDATION

- All kiwi sanctuaries should support research aimed at assessing the ecological consequences of mustelid control to benefit kiwi.

5. Studying landscape-scale predator control dynamics

Large-scale monitoring of stoat management operations has never been attempted before, and much is still to be learnt about stoat dynamics in order to find more cost-effective and sustainable approaches to their control. The kiwi sanctuaries in which landscape-scale stoat trapping is being undertaken provide an opportunity to study the geographical and temporal patterns of stoat captures in relationship to kiwi chick survival in the same landscapes. This might lead to modifications to the principles behind national protocols for running stoat trap networks so that, for the same effort, the trapping is better targeted at common access points for stoats so they are intercepted before they can kill kiwi chicks. It is important not to modify stoat trapping effort in kiwi sanctuaries simply to react to local conditions shown up by the geographical pattern of mortality of kiwi chicks, because in most situations there will not be radio-tagged chicks to guide our management practices.

The Stoat Technical Advisory Group (STAG) has commissioned a GIS-based study by Jenny Christie and Ian Westbrooke (DOC Science & Research Unit, Christchurch) on the factors affecting the capture of stoats in traps, especially those related to timing, baits, terrain, habitats, and distances to landscape features (eg. edges, rivers, ridges, houses). At least some of the initial feasibility study is using data from the Haast and Moehau Kiwi Sanctuaries, and ultimately it would be very useful to also include data from Whangarei and Okarito Kiwi Sanctuaries.

5.1 RECOMMENDATIONS

- Efforts should be made to ensure that stoat trapping data is collected in a systematic way throughout all sanctuaries, and particularly that the geographical location of each animal trapped is recorded; and that these data are stored in a format that can be integrated nationally.
- All Kiwi Sanctuaries should contribute to the STAG-commissioned research project on the factors affecting trap capture rate of stoats.
- Any modifications to the 'standard' stoat trapping methodologies in the Kiwi Sanctuaries must be on the basis of recommendations to the way stoat trapping is done nationally, rather than as a response to local observations of the geographical pattern of kiwi chick mortality.

6. Conclusions

The 5-year experiment in the five kiwi sanctuaries provides an ideal opportunity to gain crucial information on the population dynamics of kiwi and other biota in large areas under intensive pest (especially stoat) management. Armed with this information, conservation decision-makers will decide the future direction of kiwi management, and conservation managers should be confident of the outcome of their management actions without the need for close-order monitoring of kiwi that is crucial at this initial stage of the recovery efforts.

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