The development of Operation Nest Egg as a tool in the conservation management of kiwi

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Cover: Operation Nest Egg kiwi chick being weighed.
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ABSTRACT

Without conservation management, less than 5% of kiwi chicks on the mainland of New Zealand survive to adulthood, mainly because of predation by stoats and cats in the first six months of life. To avoid this bottleneck, a programme was developed in which eggs or young chicks of brown kiwi (*Apteryx mantelli*) and rowi (*A. rowi*) are collected from the wild, raised in the safety of captivity or on predator-free islands, and the resultant subadults returned to the wild once they are big enough to survive successfully in the presence of stoats and cats. This programme is popularly known as 'Operation Nest Egg'. The success rate of this experimental programme has increased as more has been learned about the husbandry of eggs and chicks, and the age at which young kiwi should be returned to the wild. Most of the resultant young kiwi appear to be well adapted to life in the wild; the high initial post-release mortality of presumably maladapted subadults has been reduced by raising young kiwi on predator-free islands rather than in captivity. Operation Nest Egg is now a valuable tool for restoring critically endangered kiwi populations, for establishing populations in new sites, for restoring depleted populations, and for maintaining kiwi recruitment in years when conventional predator control, through trapping or poisoning, fails to give adequate protection of young kiwi. Operation Nest Egg is ecologically neutral, because there are no costs or benefits to other components of the ecosystems involved, whereas some other management techniques can have adverse effects, or upset the ecological balance of the ecosystems.

Keywords: kiwi, *Apteryx* spp., threatened species, incubation, translocation, captive management

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1. Introduction

The distribution and numbers of all five species of kiwi have declined substantially since human occupation of New Zealand, and all the species are classified as threatened with extinction (BirdLife International 2000). McLennan et al. (1996) showed that less than 5% of kiwi chicks survive to adulthood in unmanaged areas. The most critical factor affecting the long-term security of kiwi populations on the mainland of New Zealand was identified as predation by stoats (*Mustela erminea*) and, in some places, cats (*Felis catus*), of kiwi less than six months old.

Under the auspices of Bank of New Zealand Kiwi Recovery, several experimental management projects have been carried out to protect kiwi populations. These aimed to increase the productivity and survival of kiwi through trapping or poisoning the main predators of kiwi, especially stoats and cats. In this paper, we describe the development of an alternative method of protecting kiwi eggs and juvenile kiwi. Our approach, involving the removal of eggs and / or chicks from predation risk in the wild, was started in 1994, and is popularly referred to as 'Operation Nest Egg' or 'ONE'. The eggs are artificially incubated, and the resultant juvenile kiwi are reared in captivity, and / or in another predator-free environment, until they are large enough (usually when more than 6 months old) to be safely released back to the wild. Kiwi naturally lend themselves to this captive-rearing approach because their young are semi-precocial and first leave the nest within a week of hatching to secure their own food. In some species, such as brown kiwi (*Apteryx mantelli*), they become completely independent of their parents several weeks after hatching.

The release of captive-reared animals into the wild is a widely-used conservation management technique, both geographically and across taxa. Although kiwi have been held in captivity for many decades, the captive population has been barely self-sustaining, and no systematic attempt had been made to release captive-reared kiwi to the wild, either to establish new populations or to supplement existing wild populations. The incubation regime of brown kiwi and behaviour of their chicks was well known from captive studies (Robson 1950, Reid & Williams 1975; Rowe 1978), and eggs of brown kiwi had been artificially incubated in captivity over many years; however, Operation Nest Egg started from first principles by firstly determining the actual incubation patterns in the wild, rather than assuming that traditional captive management practices were the most appropriate.

This paper reviews the development of Operation Nest Egg as a tool in the conservation management of kiwi, outlines some of the early successes and failures of the developmental phase of the programme up to 30 June 2002, and identifies situations where Operation Nest Egg should be applied in the future. More detailed analysis of embryo development, growth rates of chicks, and comparisons of the productivity through Operation Nest Egg v. other management techniques will appear elsewhere.

2. Gathering background data

The first step towards developing the Operation Nest Egg programme was a phase of gathering basic information about kiwi incubation processes in the wild. Radio-tagged kiwi were monitored regularly and their incubation behaviour and nest conditions were noted at various stages during incubation.

2.1 NEST ATTENDANCE

The nest attendance patterns of most taxa of kiwi were determined at various stages through the incubation period (e.g. Colbourne 2002) by recording the timing of departure and return to nests of incubating birds, either with data-loggers recording the presence and absence from the nest of radio-tagged kiwi, or from timed video footage of movements of adult birds in and out of nests. In both cases, these observations were supplemented by visual inspections to see which bird was incubating, if more than one adult was in the nest.

2.2 EGG TEMPERATURE AND TURNING

A dummy egg was made by filling a kiwi egg shell with paraffin wax that had similar thermal properties to a normal egg (Varney & Ellis 1974). Embedded in the wax were five temperature-sensitive transmitters, four placed at different sites 1 mm under the shell, and one placed at the core of the egg (Colbourne 2002). The dummy egg replaced a normal egg in the nests of two brown kiwi at different known stages of incubation, while the incubating males were away from the nest at night. This egg was readily accepted, and a nearby scanning receiver and datalogger recorded the temperatures of the five transmitters. The original aim was to determine the temperature differential between top and bottom of an egg in natural nests; however, the dummy egg trial showed that, contrary to accepted wisdom (e.g. Rowe 1978; Deeming 2002), kiwi eggs were turned, and thus provided information on the temperature differentials and the rate and magnitude of egg-turning by kiwi in the wild (Colbourne 2002).

2.3 RATE OF WATER LOSS FROM EGGS

Four eggs in two nests, at various known stages of incubation, were weighed to the nearest 0.1 g on a portable Mettler balance, to measure the rate of weight (water) loss in the wild. These eggs lost 0.5–0.75 g/day at a steady rate throughout incubation, until a sudden increase in the rate of water loss once the egg shell was broken during the first stages of hatching.

3. Methods

3.1 PILOT STUDY

In 1994, 22 eggs and two young chicks (4 and 22 days old) were collected as part of a pilot study that led to the Operation Nest Egg programme. They were collected from brown kiwi study sites near Whangarei (see Robertson et al. 1999a for a description of the sites). This sample was supplemented by two eggs rescued by members of the public near Waitangi, Northland. These 26 eggs were incubated at a Department of Conservation office in Wellington, and at Wellington Zoo, and the resultant chicks were reared at Wellington Zoo, Whangarei Museum and Kiwi House, and at the Kaitaia Nocturnal Park.

3.1.1 Collecting eggs

Radio-tagged adult kiwi were tracked to their nests, and their eggs were retrieved during the day. The eggs were removed by simply reaching underneath the incubating male from the burrow entrance or from a small shaft in the roof of the nest if the burrow was long. In the field, eggs were candled to determine the position of the air sac. They were labelled and placed, air-sac uppermost, in a chilly bin filled with polystyrene beads, wood wool or shredded paper, and flown as soon as possible to Wellington by commercial aircraft. In some cases, the eggs were held overnight in an incubator, and transported the following day.

3.1.2 Incubation

On arrival in Wellington, any cracks or dents in eggshells were sealed with glue or nail varnish, or covered with extra egg shell to prevent rapid water loss through the opening. The eggs were gently washed in cool water to remove excess soil, and wiped with a weak solution of a disinfectant ('Virkon®', 'Incusan®', or 'Chicguard®'). They were then weighed to the nearest 0.1 g on an electronic balance, and again candled to determine the stage of embryonic growth and to check that the embryo was developing normally. The size and position of the air sac was drawn on the outside of the shell, and progressive changes were periodically drawn as incubation proceeded.

The eggs were placed in 'Brinsea Hatchmaster' incubators. Temperature, humidity and egg-turning regimes recorded in the wild were then approximately replicated in the incubator. The temperature was set at 36.5ºC at the top of the eggs, but temperature differentials from top to bottom of the egg could not be matched precisely, leaving the bottom of the egg warmer than in the wild. The rate of egg weight loss was regulated by altering humidity levels in the incubator through varying the amount of water in trays at the bottom of the incubator. This continued until the daily weight loss was in the range of 0.7–1.2 g; slightly higher than the 0.5–0.75 g observed in two nests in the wild (Colbourne 2002) because the wild eggs were, by chance, smaller than most eggs collected at this site for Operation Nest Egg (R. Colbourne, unpubl. data). The eggs were turned 90º one way, returned to upright, and then turned 90º the opposite way, and then returned to upright in every 24-hour period. Eggs were held away from the upright position for at least 1 hour each time. Once eggs started internal pipping, the temperature in incubators was reduced to 35ºC and eggs were not turned.

3.1.3 Kiwi chick rearing

After hatching, chicks were kept in clean wooden brooder boxes, with towelling on the floors to enable them to stand upright and move about. Natural foods such as earthworms were introduced after about 5 days, and if chicks had not started feeding by the time they were 10 days old, they were force-fed until they started feeding themselves. The chicks were gradually weaned off natural foods and onto standard captive diets of finely minced ox heart, rolled oats and vitamin supplements. The brooder temperature was maintained at 35ºC for the first day, then gradually reduced to 25ºC over 5 days. After about 4 weeks, the chicks were moved to outdoor pens and maintained on standard captive diets.

3.1.4 Release of subadult kiwi

To test whether these captive-reared chicks could make the transition from captivity to the wild without the complication of dealing with predators or other kiwi, they were released onto Motukawanui Island, a 380-ha island off the eastern coast of Northland. Two subadults, rescued as young chicks from a nest at Waipoua, Northland and raised at Otorohanga Kiwi House, were added to the sample. The ten subadults were released onto the island on 15 July 1995. Each bird had a 30-g transmitter attached to one of their tibias (Miles & McLennan 1998), and all were monitored daily for the first 10 days after release, and then at 1–2-month intervals for the next year, after which their transmitters were removed.

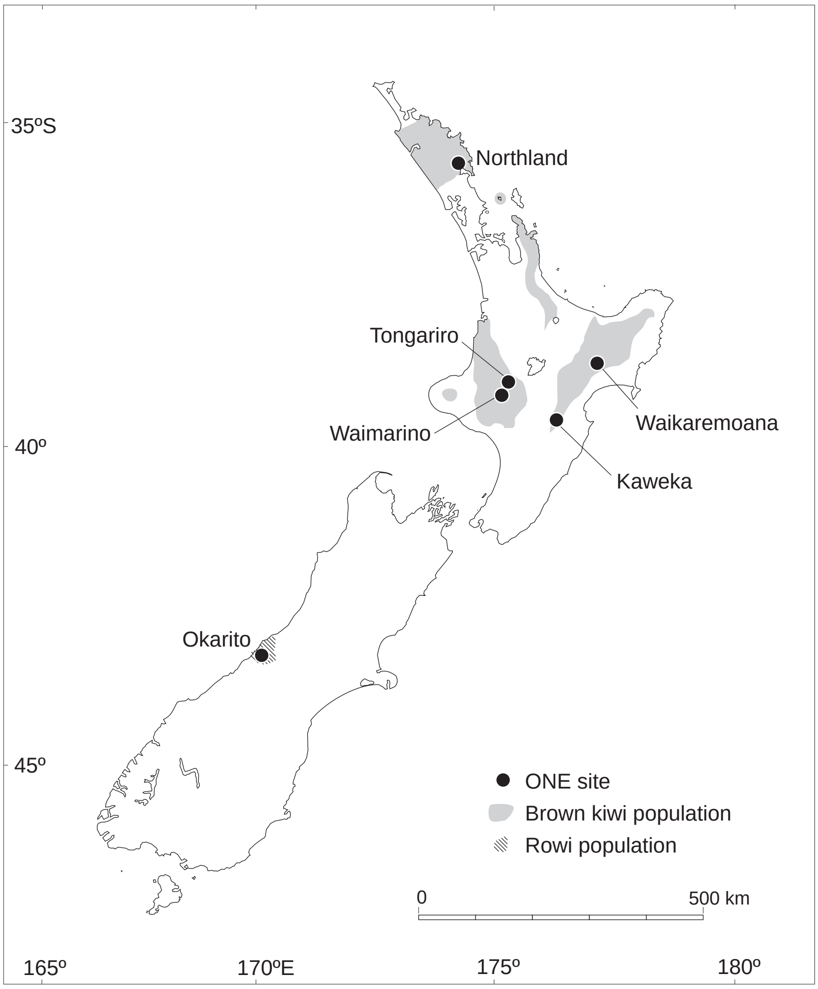
3.2 MAIN DEVELOPMENT PROGRAMME

Since 1995, eggs or young chicks have been systematically collected as part of the main development of Operation Nest Egg.

The egg collection and captive-rearing protocols are similar to those in the pilot study, except that they have been gradually refined through experimentation (e.g. Bassett & Potter 2001); in particular, to try to develop protocols for incubating freshly-laid eggs, and to raise subadults in predator-free environments (islands or fenced areas) rather than in captivity. For example, in 1997 eggs that were less than 30 days old (and generally less than 10 days old) were deliberately collected (from Northland) to try to develop protocols for the handling and incubation of freshly-laid eggs (at Auckland Zoo).

Since 1997, Motuara Island (59 ha) in the Marlborough Sounds has been used as a crèche site for young rowi, and since 1998, Motuora Island (85 ha) in the Hauraki Gulf has been used for brown kiwi chicks from Northland (Fig. 1). Initially, all young kiwi were radio-tagged before release on their crèche island, but after two of the first 15 young brown kiwi released on Motuora Island died from transmitter entanglement, all subsequent chicks, on both islands, have been released with only 'Trovan®' transponders for individual recognition. Once the chicks have become subadults, they are recaptured for release on the

Figure 1. Location of the six field sites used in the development of the Operation Nest Egg programme.



mainland, by radio-tracking, using trained kiwi dogs to locate them, or by attracting them by playing taped calls at night.

Slightly different chick-rearing methods have been developed to take into account variations in local climate at each of the four main institutions (Auckland Zoo, Rainbow Springs, Westshore and Hokitika) involved in the main development phase of Operation Nest Egg. For example, Westshore (near Napier) has lower humidity and a higher daily temperature range than Auckland.

The subadults released at mainland sites were radio-tagged before release, and their fate has been monitored (for as long as has been possible) to establish weight changes after release, causes of death, dispersal, and whether and when they bred.

We present mean ± standard deviation (range, sample size), unless otherwise stated.

3.2.1 Study areas

Eggs have been sourced from five sites in the North Island and one in the South Island—Purua in central Northland, Tongariro Forest, Waimarino Forest, Lake Waikaremoana and Kaweka Range for the endangered brown kiwi in the North Island; and Okarito for the critically endangered rowi (*Apteryx rowi*) in the South Island (Fig. 1).

Purua, central Northland

Egg collection at Purua started in 1994 as part of the pilot study, and has continued each subsequent year. Most eggs have been collected at Hodge's Bush, a privately owned 35-ha forest remnant; but since 1999, many eggs have been obtained from the southern side of the nearby 100-ha Purua Scenic Reserve. Some eggs were also collected from other nearby forest patches when nests were deserted during research on the productivity and survival of kiwi under different management regimes (see Robertson et al. 1999a, b).

Until 1998, most of the eggs and chicks were raised at Auckland Zoo, although the Whangarei Native Bird Recovery Centre, Whangarei Museum, Kaitaia Nocturnal Park, Mt Bruce National Wildlife Centre, and Wellington Zoo were also involved in some years. Since 1998, most chicks have been transferred to Motuora Island in the Hauraki Gulf from Auckland Zoo at 3–10 weeks old, but a few chicks were transferred directly to the island from Northland at 1–3 weeks old. Since 2001, some eggs have also been hatched at the Whangarei Native Bird Rescue Centre, and the chicks transferred to Limestone Island in Whangarei Harbour at 3–9 weeks old.

The resultant subadults have been returned to the wild on the mainland, either back at the Purua collection sites or, because kiwi densities were already very high there (c. 1 pair/4 ha), to (since 2000) the Whangarei Heads peninsula at Bream Head or at The Nook. Both areas have sparse natural populations of kiwi (< 1 pair/100 ha) and are being restored for kiwi as part of the Whangarei Kiwi Sanctuary.

Tongariro Forest

The Department of Conservation started collecting eggs in the Waione Stream area of Tongariro Forest Park in September 1995. All but the first egg (sent to Otorohanga Kiwi House), have been sent to Rainbow Springs in Rotorua and the resultant chicks raised entirely in captivity, apart from three reared in a 16-ha predator-free enclosure at Warrenheip, near Cambridge, in 2001/02. All subadults have been returned to Tongariro Forest near to where the eggs were collected. The kiwi density in the cutover podocarp forest was low (c. 1 pair/100 ha) and the total population was about 200 birds.

Waimarino Forest / Karioi Rahui

In September 1999, Whakamanu Wildlife Management Ltd started collecting eggs in exotic pine forest managed by Winstone Pulp International Ltd, and eggs were also collected from a kiwi pair living in scrub on a nearby farm. All eggs were sent to Rainbow Springs, and the chicks were raised entirely in captivity. The resultant subadults have been released into Karioi Rahui, an area of old-growth beech / podocarp forest on the southern flanks of Mt Ruapehu, about 30 km east of the egg collection site in Waimarino Forest. This programme aims to establish a self-sustaining population of kiwi in the Karioi Rahui, by supplementing the sparsely distributed remnant population with Operation Nest Egg birds, and then starting predator control once there are sufficient kiwi present to make it worthwhile.

Lake Waikaremoana

Manaaki Whenua Landcare Research NZ Ltd has studied the impact of predators on the breeding productivity and survival of kiwi, and dispersal of young kiwi on and near the Puketukutuku Peninsula (McLennan 1997). Since 1995, eggs or young chicks have been collected when nests were deserted naturally, or disturbed during research work; however, a concerted effort was made to collect eggs or young chicks in parts of the 1999 and 2000 breeding seasons when ongoing intensive trapping of stoats on the peninsula proved ineffective at protecting kiwi chicks. All eggs and chicks have been taken to Napier City Council's kiwi facility at Westshore, and raised entirely in captivity. The resultant subadults have been returned to the wild on the Puketukutuku Peninsula, mainly when they weighed about 800 g. One chick, raised in 2002, was released into a predator-proof pen on the peninsula.

Kaweka Range / Boundary Stream

The Department of Conservation is restoring Boundary Stream Scenic Reserve, inland from Lake Tutira, through intensive pest control by trapping and / or poisoning. In recent decades, the kiwi population has died out there, as they have in most forest patches in the Hawke's Bay hill country (McLennan & Potter 1992). Birds in the Kaweka Range, 35 km to the southwest, have been captured and radio-tagged, and eggs from their nests collected as part of Operation Nest Egg. Eggs were initially sent to Westshore, but in recent years have been sent to Rainbow Springs in Rotorua. All chicks have been reared entirely in captivity, and resultant subadults released into Boundary Stream Scenic Reserve.

Okarito

The Department of Conservation has studied and managed the critically endangered rowi population in South Okarito Forest, Westland National Park since 1992. The rowi is the rarest of the five kiwi species, with an estimated population of c. 200 birds in 2000 (Heather & Robertson 2000). In 1994, a sick chick was rescued from the forest, and from 1995 to 1998, young chicks were collected and taken to a specially constructed kiwi facility at Arahura, near Hokitika. In 1996 and 1997, three eggs were collected from the wild to trial hatching rowi eggs in captivity. In 1999, the decision was made to concentrate on collecting eggs rather than chicks, with the eggs being hatched in a dedicated Department of Conservation facility in Hokitika.

From 1994 to 1997, the chicks were reared entirely in captivity before release at Okarito Forest as subadults. Since 1998, chicks have been transferred at 1–22 weeks old from Hokitika or Arahura to Motuara Island in the Marlborough Sounds, and then returned to Okarito Forest as subadults.

4. Results

4.1 PILOT STUDY

Of the 24 eggs collected in 1994, four had already failed (two broken and two rotten) in the nest, and four were infertile. Eight (50%) of the remaining 16 viable eggs hatched after 2–58 days of artificial incubation. There was a positive correlation between mean age of the viable eggs at the time of collection and probability of hatching ($r = 0.764$, $P < 0.001$). As none of the six eggs younger than 20 days old hatched, this indicated that incubation conditions were probably not adequately replicating conditions in the wild.

Both chicks collected from the wild, and six of the eight chicks hatched in captivity survived to be released onto Motukawanui Island on 15 July 1995, at 235 ± 96 (160–436, $n = 8$) days old. The other two chicks contracted coccidiosis in captivity, and died at 20 and 30 days old.

Two subadults reared from chicks collected at Waipoua, Northland, 30 months earlier were released onto Motukawanui Island at the same time as the Operation Nest Egg subadults. All 10 birds survived at least 3 months; and although one transmitter failed after 25 days, this individual was recaptured in 2001 and again in 2004. After 104 days on the island, one of the birds died after its transmitter became entangled in *Muehlenbeckia complexa.* The two oldest birds, siblings from Waipoua, bred together during the first summer on the island. To minimise the risk of further entanglements, transmitters were gradually removed from all the birds so that the last two transmitters were removed in August 1996. In January 2001, two of the 10 birds were recaptured as fully-grown adults. In May 2004, these two were again recaptured, along with another original bird, an Operation Nest Egg bird put on the island in 1996, and four island-bred birds. In May 2004, the kiwi population on Motukawanui Island was estimated to be 50–60 birds (R. Colbourne & S. McManus, unpubl. data).

4.2 MAIN DEVELOPMENT PROGRAMME

The overall results for hatching, chick survival until release age, subadult survival post-release and number of breeding birds are given in Table 1 for each locality. A total of 357 eggs and 84 young chicks were brought into captivity as part of Operation Nest Egg (up to 2002). A total of 199 (70%) of the 286 viable eggs hatched. Of 283 chicks handled during the programme, 236 (83%) were released to the wild on the mainland or onto island crèches; two of the chicks were euthanased as part of the Ministry of Agriculture and Fisheries testing of the susceptibility of kiwi to rabbit haemorrhagic disease (RCD). A minimum of 101 released birds were known to be alive on the mainland on 30 June 2002, and probably another 20–30 were alive on crèche islands. Sixteen birds raised through Operation Nest Egg had bred in the wild by 30 June 2002, but most others were still too young to breed.

Because of the experimental nature of the programme, the success rate given above was lower than what might now be expected. Several factors have influenced the overall success rate of the programme at the various stages, and these are discussed in turn.

4.2.1 Age of eggs at time of collection

In the early years of the programme, eggs were collected at all stages of incubation, but it proved impossible to hatch any egg that was younger than 10 days old at the time of collection. In 1997, seven freshly-laid eggs (< 10 days old) were specifically collected in Northland to try to develop a successful incubation regime at Auckland Zoo using a variety of temperature and egg-turning regimes in the first month, but none of the eggs hatched. During the development phase of Operation Nest Egg, none of the 17 eggs from Northland that were less than 10 days old at collection hatched; however, Auckland Zoo has subsequently incubated and hatched two eggs that were collected, freshly

TABLE 1. SUMMARY OF OPERATION NEST EGG (1994–2002).

	NORTH-LAND	WAI-MARINO	TONGA-RIRO	KAWEKA	WAIKARE-MOANA	OKARITO	TOTAL
Eggs collected	174	22	64	28	36	33	357
Failed in wild / dead on arrival	24	8	24	7	8	0	71
Artificially incubated eggs	**150**	**14**	**40**	**21**	**28**	**33**	**286**
Eggs hatched	98	12	29	15	18	27	199
% hatched	65.3	85.7	72.5	71.4	64.3	81.8	69.6
Wild chicks collected	20	0	2	2	10	50	84
Artificially incubated eggs + chicks	170	14	42	23	38	83	370
Chicks	**118**	**12**	**31**	**17**	**28**	**77**	**283**
Deaths in captivity	19	0	7	4	6	4	40
Still in captivity	3	0	0	4	0	0	7
Released	**96**	**12**	**24**	**9**	**22**	**73**	**236**
Released direct to island	8	0	0	0	0	0	8
Released direct to mainland	31	12	24	9	22	18	116
Released to crèche island	57	0	0	0	0	55	112
Deaths on crèche	3					5	8
Missing on crèche	28					6	34
Released from crèche to mainland	26					44	70
Total to mainland	**57**	**12**	**24**	**9**	**22**	**62**	**186**
Deaths	22	3	9	2	3	17	56
Missing / Dispersed / Tx acc*	7	2	5	1	9	3	27
Returned to captivity	0	0	0	0	0	2	2
Alive in wild	**28**	**7**	**10**	**6**	**10**	**40**	**101**
No. that have since bred	**7**	**0**	**2**	**0**	**2**	**5**	**16**

* Transmitter accident

laid, from captive kiwi (A. Nelson, unpubl. data). Although eggs are rescued at any age after nests have been disturbed accidentally in the wild, the standard Operation Nest Egg protocol (H. Robertson & R. Colbourne, unpubl. guidelines 2003) for brown kiwi and rowi is now to avoid collecting eggs less than 20 days old. To balance the risk of predation or desertion of a clutch in the wild, and the ability to successfully hatch eggs in captivity, Robertson & Colbourne (unpubl. guidelines 2003) recommended that brown kiwi eggs should be deliberately collected only when the oldest egg is about 60 days old; the youngest egg in a two-egg clutch should therefore be at least 30 days old. Because rowi lay only one egg per clutch, egg collection is timed to take place 30–50 days after laying.

4.2.2 Egg collection

There was no difference in hatching rates of brown kiwi eggs between those collected primarily during the daytime (Purua, Tongariro, Waimarino, and Kaweka; 68%) and those collected mainly at night (Waikaremoana; 64%). Field operators collecting eggs in daytime reported that a few incubating males would lash out with their feet when eggs were being collected, and that this sometimes led to the eggs being punctured or cracked. A few eggs from Tongariro Forest were damaged beyond repair, but once the eggs arrived at the incubation facilities, most damage to shells could be repaired, and most damaged eggs hatched successfully.

Rowi pairs share incubation, so their egg is attended continuously (Colbourne 2002). To avoid egg damage, a taped call was played near the nest entrance to draw the incubating bird off the nest, and then the egg was collected.

4.2.3 Egg transport

Most eggs were transferred from the wild to the incubation facility within 8 hours of collection; although some were held overnight in emergency incubators, and delivered the following day. For rowi eggs, which are continuously incubated, hot water bottles were used in the transport container to prevent the eggs from cooling; however, brown kiwi eggs were allowed to cool during transportation. There was no evidence that eggs died during the time between collection and arrival at incubation facilities, apart from three of four eggs that were in a container that was dropped by airline staff somewhere between Whangarei and Wellington. All four eggs were found to be broken on arrival, and only one was repairable; however, the embryo died at the point of hatching.

The effects of jarring were tested on kiwi eggs collected in Tongariro and Waimarino Forests and transported to Rainbow Springs (Potter & Bassett 2001). These eggs were monitored with high-sensitivity shock data loggers, and this showed that maximum jarring occurred during transportation on quad bikes or while eggs were being carried in a chilly bin by hand, but the mean jarring was greatest during flights on chartered light aircraft. The mean level of jarring was found to be less than the levels of jarring that had no demonstrable effect on embryo development or hatching in emu *Dromaius novaehollandiae* (Potter & Bassett 2001).

Protocols have now been set for field operators when collecting eggs for Operation Nest Egg (H. Robertson & R. Colbourne, unpubl. guidelines 2003).

These stipulate that eggs must be transported to incubation facilities in chilly-bins lined with shredded paper to cushion shocks. Aircraft are now generally avoided because transport conditions are difficult to control, especially since commercial airline regulations prevent live animals (including eggs and chicks) from being carried in the passenger cabin.

4.2.4 Incubation conditions

Experimentation with egg temperatures within the range of 34–37°C has indicated that the optimum incubation temperature should be 36.5°C at the top of the egg. High incubation temperatures have been linked to the appearance of developmental problems in kiwi chicks, including splayed legs, and low temperatures can result in lethargic embryos, and prolonged incubation and hatching. For eggs incubated in facilities with naturally high humidity, dehumidifiers have to be used in the incubation room to achieve the desired daily weight loss of 0.7–1.2 g (a higher rate the larger the egg).

4.2.5 Hatching

Kiwi eggs hatch very slowly. For eggs incubated at Auckland Zoo, the time between the chick's bill piercing the internal air sac and the egg shell first fracturing was 2.3 ± 1.5 (0.5–7, $n = 24$) days, and between external pipping, when the first star-shaped upward dent appears in the shell, and hatching was 1.8 ± 0.9 (0.5–3.5, $n = 24$) days.

Most eggs hatched unassisted, but help was provided in some instances when chicks had difficulty freeing themselves from the shells. We do not know what role wild kiwi play in assisting their eggs to hatch, but very few wild chicks die during the hatching process, and so we can assume that some help is given, or that the chicks eventually manage to break free. Given the long period of time between internal pipping and hatching, some staff at incubation facilities may have intervened earlier than was necessary, but this early intervention didn't seem to cause any subsequent problems to chicks.

4.2.6 Chick management

Kiwi chicks hatch with a large external yolk sac which is gradually absorbed over their first 10 days of life. Chicks are semi-precocial and can stand upright at less than 6 hours old, and walk freely by 1–2 days old. They are never fed by their parents in the wild and survive entirely off the stored yolk until they first venture from the nest at 5–7 days old. In the wild, Northland chicks hatch at about 305 g, and their weight drops until about 10–20 days old when they are about 20–30% below their hatching weight (H. Robertson et al., unpubl. data). Weights of Northland Operation Nest Egg chicks hatched at Auckland Zoo showed a similar pattern, except that they hatched at significantly heavier weights than wild chicks (325 g cf. 305 g). Their weight dropped to a minimum at 12.3 ± 4.2 days old (8–28, $n = 39$), by which stage they were 83 ± 20.9 g (42–142, $n = 39$) or 25.6 ± 5.7% (12–38%, $n = 39$) below their hatching weight. Individuals regained their hatching weight by 20.5 ± 5.3 (14–37, $n = 37$) days old.

A special watch is now kept on the c. 25% of Operation Nest Egg chicks that do not start gaining weight by 15 days old, or which lose more than 30% of their hatching weight. Veterinary assistance was sought for the 10% of chicks that do not start gaining weight by 18 days old or which lose more than 33% of their hatching weight.

Early on, some brown kiwi and rowi chicks hatched with splayed legs. As previously mentioned, this has been linked to incubation temperatures being too high; however, other factors, such as poor nutrition, or the young bird being kept on a smooth surface (e.g. stainless steel) may also be involved. In brown kiwi, nutrition seemed unlikely to be a factor because chicks displayed the symptoms while feeding entirely off their yolk sac, and wild chicks from the same population did not exhibit this problem. Several wild-hatched rowi chicks had splayed legs when they arrived at Arahura Bird Rescue, and so the nutritional state of female rowi at laying may have contributed to their condition. The incidence of splayed legs in captive-hatched chicks has decreased since all institutions started placing chicks on paper or cloth towelling, or brooder matting, immediately after hatching, and since incubation temperatures have been kept at or below 36.5ºC. Early treatment, by loosely tying the legs together to prevent further splaying, generally resulted in the chicks assuming normal standing posture within a week.

Failure to completely absorb the yolk sac, and coccidiosis were the main causes of death of Operation Nest Egg chicks. The latter was virtually eliminated by implementing strict hygiene procedures, dosing chicks with 'Baycox®' when symptoms appeared, and by avoiding using incubation facilities or areas where birds have had this disease in the past. Screening of wild populations has shown that the parasite occurs naturally at low levels in wild kiwi populations (Jakob-Hoff 2001). A haemoparasite, *Babesia*, hitherto unknown in New Zealand, was initially detected in two lethargic and anaemic chicks taken to Auckland Zoo (Jakob-Hoff et al. 2000; Peirce et al. 2003); screening of wild kiwi has subsequently detected it in the source population, and in kiwi at several other sites in the North Island (Jakob-Hoff 2001).

Strict hygiene procedures are maintained at all Operation Nest Egg facilities to reduce the risk of captive-reared birds transporting diseases into wild populations. Hygiene requirements now include having purpose-built, dedicated and quarantined rooms for Operation Nest Egg eggs, and chicks in brooders. Staff use foot baths or dedicated footwear, and routine health screening (veterinary examination, blood tests and faecal examination) of all Operation Nest Egg chicks is carried out before they are released to the wild (H. Robertson & R. Colbourne, unpubl. guidelines 2003).

4.2.7 Release of kiwi chicks to crèche islands

In the wild, rowi chicks first venture from their nest at 5–7 days old, but they keep returning to the parental burrow for several years. Brown kiwi chicks also leave the nest for the first time at 5–7 days old, but only return to the nest for a few weeks. The first chick to hatch and its father usually return each morning for 4–6 more weeks, but the second chick to hatch usually leaves the nest permanently at about the same time as its older sibling, at 2–4 weeks old. In Northland, the youngest age recorded for a wild-hatched chick permanently leaving the nest was 10 days old (H. Robertson et al., unpubl. data). Based on these observations, chicks raised through Operation Nest Egg were usually transferred from brooders to outdoor pens or to crèche islands when 3–6 weeks old, and a few wild-hatched brown kiwi chicks were transferred to safe sites at 1–3 weeks old.

In 1997/98 and 1998/99, the first batches of captive-reared rowi juveniles were released onto Motuara Island. Their ages varied from 60 to 150 days old and they had good survival rates, so release age was subsequently successfully reduced to as little as 6 days old in the 1999/00 and 2000/01 seasons (Table 2). The 6-day-old rowi chick released on Motuara Island was captured and returned to Okarito 11 months later. Most brown kiwi juveniles were taken to crèche islands (Motuora and Limestone) at about 20–40 days old (Table 2), after they had regained their hatching weight. Some chicks were released onto crèche islands before they had reached their lowest weight—the youngest chick was estimated to be only 6 days old at release, but he was recaptured 14 months later and taken to Bream Head. Being able to successfully transfer chicks to crèche islands at less than 40 days old saves the cost of feeding birds in captivity, and taking them directly from sterile brooders to the wild, without using outdoor holding pens, greatly reduces the risk of disease.

4.2.8 Release of subadult kiwi on the mainland

In the wild, the mortality rate of young kiwi declines with increasing age, at least partly due to their increasing mobility and ability to escape from or fight-off predators. From about 6 months old, when subadult kiwi weigh 800–1200 g, mortality due to stoats and cats drops away to almost zero (McLennan et al. 2004).

Most Operation Nest Egg subadults were transferred from captivity or crèche islands to the wild on the mainland when they were at least 7 months (210 days) old and weighed over 1200 g, although some Tongariro and Karioi Rahui subadults were younger and lighter than this. There was high mortality of subadults in the first month after release; some birds used inappropriate daytime locations and thus were vulnerable to predators or bad weather or, in the case of rowi, some were killed by adult birds, perhaps because they behaved inappropriately. In Northland, eight (14%) of the 57 Operation Nest Egg subadults monitored died in the first month after release (three killed by dogs, one killed by a ferret, one died of hypothermia, one fell down a cliff, and two died

TABLE 2. AGE (DAYS) OF JUVENILE KIWI ON RELEASE.

SITE	MOVEMENT	MEAN	SD	MIN	MAX	*n*
Northland	Captivity to crèche	33	23	6	122	57
	Crèche to wild	437	207	233	1057	26
	Captivity to wild	291	114	164	525	31
Waimarino	Captivity to wild	160	32	114	215	12
Tongariro	Captivity to wild	271	107	125	526	24
Kaweka	Captivity to wild	109	12	96	125	7
Waikaremoana	Captivity to wild	95	35	23	138	22
Okarito	Captivity to crèche	77	51	6	167	55
	Crèche to wild	399	65	260	507	44
	Captivity to wild	361	106	182	587	18

of unknown causes 4–6 days after release). These eight deaths accounted for 42% of the 19 deaths of Operation Nest Egg subadults in Northland recorded in a total of 620 bird-months of radio-tracking data to 30 June 2002 (H. Robertson et al., unpubl. data). At Karioi Rahui and Tongariro combined, three (8%) of 36 released birds were killed in the first month after release (at least two were killed by stoats). At Okarito, eight (47%) of 17 deaths of all 62 Operation Nest Egg subadults happened in the first month after release (five killed by adults, one drowned, one died of dermatitis and one starved or died of hypothermia); another bird fell down a cliff and broke part of its bill within a month of release, and was returned to captivity. It is noteworthy that only two, possibly three, of the 155 subadults released at these four mainland sites were definitely killed by stoats after release; these birds were all lighter than 1200 g when released.

At Lake Waikaremoana and at Boundary Stream, the normal release weight of subadults was about 800 g (3–4 months old, Table 2). At both sites the birds were released into areas where the stoat density had been reduced significantly by intensive trapping. All three very young chicks (23–25 days old) released onto Puketukutuku Peninsula, Lake Waikaremoana, in November 1996 were killed by stoats before the end of December. Apart from a 53-day-old bird released into a predator-proof pen in June 2002, the other 25 subadult kiwi were released into these sites at over 83 days old, and none died in their first month after release.

Most captive-reared Operation Nest Egg subadults were in either very good or fat condition at release, and many lost 100–200 g weight in the first month after release to the wild, before slowly regaining their release weight. Despite this weight loss, lack of food apparently contributed to the deaths of only two birds, both of which were found wet and emaciated. Subadult kiwi released from crèche islands were in good to excellent condition and lost less weight than their captive-reared counterparts, probably because they used more appropriate behaviours from having already lived in the wild.

The initial mortality rate of island-reared subadults was lower than that of captive-reared birds. Field operators felt that most island-reared birds were better adapted to life in the wild than most captive-reared birds (Sue Bell and Chris Rickard, DOC, pers. comms). In Northland, the single death in the month after release out of ten subadult brown kiwi at The Nook or at Bream Head was due to a fall from a cliff. At Okarito, five (28%) of 18 captive-reared subadult rowi died in the month after release, whereas only three (7%) died in the first month after returning from Motuara Island. Though this latter difference is significant (Fisher Exact Test, $P = 0.04$), the release sites used were different to those used for the captive birds and this may have biased the results (see below).

Adult brown kiwi in the North Island tolerated the release of Operation Nest Egg subadults into their territories, even at high initial densities (e.g. 1 pair/4 ha at Hodges Bush, Northland). By contrast, 11 (65%) of the 17 deaths of released subadult rowi at Okarito have apparently been the direct result of physical aggression from adult rowi, despite a very low population density there (1 pair/ 100 ha). Six (33%) of the first 18 subadult rowi (all captive-reared) released between 1995 and early 1998 were killed by adult rowi, including five subadults in the first month after their release. Therefore, since late 1998, release sites were chosen away from territorial birds, generally at the edge of the species' range. Only five (11%) of the subsequent 44 subadult rowi released have been killed by adults, and only one in the first month after their release. In 1997/98, the first wild-hatched subadult rowi seen since research began in 1992 was actually discovered beaten to death in a burrow belonging to a radio-tagged pair known not to be its parents (Chris Rickard, DOC, pers. comm.). This phenomenon of infanticide seems, therefore, to be associated with the extreme territoriality of at least some members of the species, rather than because the Operation Nest Egg subadults are behaviourally maladjusted. From the few naturally-reared rowi juveniles studied at Okarito, it seems that they normally stay with their parents for 2–5 years before leaving the territory, a behaviour pattern shared with tokoeka (*Apteryx australis*) on Stewart Island (Colbourne 2002).

4.2.9 Assessment of success of the Operation Nest Egg programme

In Northland, a preliminary analysis has shown that hatching success of partially-incubated Operation Nest Egg eggs (62%) was significantly better than that in unmanaged nests (52%), even allowing for eggs lost to predators or nest abandonment before the eggs were due to be collected, and the four egg breakages during transport, but excluding the 17 freshly-laid eggs taken into captivity (H. Robertson et al., unpubl. data). The 81% survival to 6 months of brown kiwi in captivity or on island crèches far exceeds the 11% observed in unmanaged forest patches near to where the eggs and chicks were collected (H. Robertson et al., unpubl. data). It also far exceeds the c. 20% survival calculated to be necessary to maintain mainland populations of brown kiwi (McLennan et al. 1996). Although there was a high initial post-release mortality, the annual survival of Operation Nest Egg subadults to mean age of first breeding (3.5 years old) in Northland (74%) was similar to that of naturally-reared subadults (76%) (H. Robertson et al., unpubl. data). The overall Northland data showed that 21% of eggs collected for Operation Nest Egg survived to become breeding adults 3–4 years later, and this was far greater productivity than the 6.6% survival of eggs to adulthood that is required to maintain the population (H. Robertson et al., unpubl. data).

At Okarito, the rarest species of kiwi has received a boost through the release of 62 Operation Nest Egg subadults, of which 40 birds were known to be alive in the wild on 30 June 2002. Transmitters failed on a further three birds, and these individuals may still be alive. This was far better recruitment than that observed in unmanaged pairs, whose chicks were all lost to stoats within the first 3 months of their life. The 62/77 (81%) survival of rowi to 180 days in the Operation Nest Egg programme was also much better than the 6/37 (16%) survival to 180 days observed for wild-reared rowi chicks in 2001/02 and 2002/03 under an intensive stoat trapping regime. The addition of Operation Nest Egg subadults increased the total population of the critically endangered rowi by 25% from c. 160 to c. 200 individuals in the six breeding seasons from 1995 to 2000.

Similar success rates at all six study locations points to this method being able to 'turn the tide' for selected mainland populations of kiwi.

5. Discussion

Predation of juvenile kiwi by stoats is the key factor causing the decline of kiwi populations on the mainland of New Zealand; secondary factors affecting the rate of decline include predation of eggs by possums and mustelids, loss of eggs to microbes, predation of chicks by cats, and predation of adult kiwi by dogs and ferrets (McLennan et al. 1996). Operation Nest Egg was developed primarily as a method to improve the survival of kiwi chicks, by physically removing them from risk during the period in which they are most vulnerable to predation. By collecting mainly eggs, hatching success also improved in the absence of risk of nest desertion, predation or bacterial infection in the wild.

Operation Nest Egg is ecologically neutral, because the removal of eggs or young chicks and the return of subadult kiwi has few positive or negative effects on the functioning of the ecosystems involved. Other techniques to conserve kiwi populations can have huge positive or negative effects on other parts of the ecosystems. Extensive stoat trapping leads to a greatly reduced abundance of stoats and hence stoat predation on vulnerable species; however, it also appears to result in a greatly increased abundance of rats (I. Flux, DOC, unpubl. data). Increased abundance of rats is likely to have considerable impact on species that compete with rats, or are primarily preyed on by them. For example, there is likely to be an increase in competition for food between rats and kiwi (especially chicks), and the regeneration dynamics of forests may be affected by increased destruction of certain seeds favoured by rats. Large rat populations may, in turn, act as a 'magnet' for future invasions of stoats. Where toxins are used to control pests such as possums and rats, and there is secondary poisoning of stoats and cats, there may be accidental non-target deaths of protected species and other animals, including a risk to human health, and possible economic damage if toxin residues are detected in milk or the meat of farm, or wild game, animals.

Concerns about captive-reared birds lacking social adjustment to life in the wild may be unfounded. Much kiwi behaviour is clearly innate, because birds raised through Operation Nest Egg programmes in captivity and on crèche islands appear to behave as other young kiwi do; they give normal kiwi calls on island crèches where there are no adult kiwi to copy, and 16 have bred successfully with wild-reared or other captive-reared partners. Within a few days of release to the wild, most subadults used the same types of daytime shelters as adult birds, and only a very few appeared unable to find sufficient natural foods to survive. The age of first breeding of Operation Nest Egg birds in Northland appears to be similar to that of wild-raised subadults, although the data in both samples is still sparse (H. Robertson et al., unpubl. data). At Okarito, 5 of 13 Operation Nest Egg birds aged 5 years had bred by the end of the 2001/02 season, whereas the only wild-hatched subadult monitored to this age had paired but not bred. During the development of Operation Nest Egg, the territorial system of rowi at Okarito was discovered to be markedly different from that of brown kiwi in the North Island. The first Operation Nest Egg releasees were often killed by territorial adults. More recently, birds have been released away from territorial adults and appear to have integrated better with the wild population; however, the long-term effect, if any, of their not being raised within the parental territory is not known.

The concern that Operation Nest Egg is not economically sustainable as a method to manage kiwi in perpetuity over large areas of forest is correct. The method requires that adult birds be monitored by radio-telemetry so that nests can be found for egg or chick collection. It is possible to do this in small areas (< 10 000 ha), but there is little potential to expand this effort successfully over hundreds of thousands of hectares. On the other hand, trapping and / or poisoning programmes to control pests can potentially cover these larger areas.

The Operation Nest Egg programme so far has shown that it can be a particularly effective tool at rapidly recovering the populations of our rarest taxa of kiwi, as illustrated by the 25% increase in numbers of rowi at Okarito over a 6-year period. Other strengths are its use as a tool for re-establishing kiwi populations in areas where kiwi have died out (e.g. Boundary Stream), or for rapidly increasing localised populations that have declined to just a few individuals (e.g. Bream Head, Karioi Rahui), and for restoring larger populations (e.g. Tongariro Forest). At Lake Waikaremoana, Operation Nest Egg was successful as a tool to help restore a small population, but it was also able to ensure that some kiwi recruitment was guaranteed every year, including in those years when the constant re-invasion of stoats onto the 750-ha peninsula was sufficiently high that intensive stoat trapping failed to adequately protect wild-reared kiwi chicks.

Much has been learnt about the breeding ecology and behaviour of kiwi during the development of Operation Nest Egg. The discovery that kiwi eggs are turned during incubation has led to improved hatching success of salvaged wild eggs, and of kiwi eggs laid in captivity. The overall standards of captive husbandry and, especially, disease risk management have improved greatly. We now have a better health profile of kiwi, and knowledge of the diseases and parasites that affect them, and can now design health screens and interpret results better than we were able to before the development of Operation Nest Egg. Incubation facilities and captive-rearing institutions involved in the programme have gained satisfaction and recognition through contributing their expertise to a successful conservation management programme.

Perhaps the greatest contribution that Operation Nest Egg has made to kiwi recovery, beyond positive effects on the particular populations being managed, has been the way the programme has captured the imagination of the public of New Zealand. It has been an ideal vehicle for getting messages across to the public about the plight of kiwi and things that people can do to help in the conservation of kiwi. The Bank of New Zealand was able to demonstrate that an Operation Nest Egg cause-related promotion was picked up by more of its customers than an identical general offer, and this has helped to maintain the bank's involvement in supporting kiwi conservation in general (Kieron Goodwin, Executive Director, Bank of New Zealand Kiwi Recovery Trust, pers. comm.). The transfers of eggs to captivity, and subadults to the wild, provided excellent media opportunities, and also provided opportunities for iwi to be involved, and assert their interest in the conservation of their *taonga* or special species.

Now that the development phase of Operation Nest Egg is completed, the tool is now being applied to conserve or restore many other populations of threatened kiwi taxa. Clear prescriptions for 'best practice' have been written (H. Robertson & R. Colbourne, unpubl. guidelines 2003), but ongoing refinements are continuously being made to the programme, as more experience is gained. Monitoring of the fate and reproductive output of Operation Nest Egg birds is ongoing, and this may lead to further refinements to our handling and release protocols.

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