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At what age should brown kiwi (*Apteryx mantelli*) eggs be collected for artificial incubation?

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Abstract We recorded the fate of brown kiwi (*Apteryx mantelli*) eggs collected from Northland forests for artificial incubation at Auckland Zoo. The hatchability of eggs of different ages were combined with known rates of egg losses in the wild to derive models which predicted that optimal hatching success (>64%) was when the oldest egg in a brown kiwi nest was 41-57 days old at the time the eggs were collected. Collection before this interval risked egg failure resulting from unknown developmental problems associated with artificial incubation of freshly-laid eggs, whereas later collection of clutches risked failures in the wild before the eggs were collected.

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INTRODUCTION

Kiwi (*Apteryx* spp.) populations are declining rapidly on the New Zealand mainland, with stoat (*Mustela erminea*) predation of chicks up to about 6 months old being identified as the critical factor in most populations (McLennan *et al.* 1996). "Operation Nest Egg", the collection of eggs or young chicks from the wild, and the release of subadults back to the wild once they are big enough to survive in the presence of stoats, was successfully developed to circumvent this problem (Colbourne *et al*. 2005). Generally, eggs are collected from the wild, transferred to incubators at a captive-rearing institution, and the resultant chicks are either raised in captivity or, preferably, in a predator-free wild environment such as on an island or in a predator-proof enclosure. Subadults are then released to the wild, usually when over 1200 g (at 6-8 months old), but sometimes at a younger age at some sites where stoats are controlled intensively.

Brown kiwi (*Apteryx mantelli*) have a long egg-laying season (Jun - Dec), during which each pair normally produce 2 clutches of 1-2 eggs (Heather & Robertson 2000). In Northland, the eggs are laid 18-25 days apart, and are incubated for 75-91 days (H. Robertson, unpubl. data). Colbourne (2002) noted that incubation is only intermittent until the 2nd egg is laid, and so the chicks hatch out only 1-2 weeks apart. Hatching rates in the wild (30-60%) are relatively low, with the main causes of egg failure being desertion, embryo deaths, infertility, predation, or accidental breakage (McLennan *et al.* 1996).

In this paper we investigate the relationship between the age at which eggs are collected from the wild and their hatchability, and we combine these data with observed daily failure rate of eggs

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in the wild to determine an optimum range of ages at which a clutch of eggs should be collected from the wild.

METHODS

Eggs were collected during a study of the population dynamics of radio-tagged brown kiwi under various forms of pest management in the Purua–Riponui area of central Northland, 20-25 km northwest of Whangarei (see Robertson *et al.* 1999). In total, 124 eggs were taken to Auckland Zoo, 150 km to the south, as part of the development and running of "Operation Nest Egg" between 1996 and 2003.

Eggs ranging from freshly-laid to 82 days old were removed from nests during daytime. Eggs were collected by reaching under the incubating adult male and gently withdrawing each egg, or by firstly removing the male and then collecting the eggs. They were measured, weighed and then placed in an insulated bin filled with shredded paper, and transported to Auckland Zoo by car, usually within 8 h of collection. Very occasionally, eggs were held overnight in Whangarei in a portable incubator at 36ºC, and taken to the zoo the following day. At Auckland Zoo, the eggs were managed according to a regime that closely matched the normal incubation patterns (temperatures and temperature gradients, egg turning, and humidity) observed in the central Northland population (Colbourne 2002).

The fate of each egg was recorded and related to its approximate age at collection; this was determined by a combination of the history of radio-tracking observations of birds associated with each nest, and the length of time each egg was held in captivity before hatching. We did not attempt to determine the age or viability of eggs by candling before collection.

The hatchability of kiwi eggs was related to age at collection by a logistic regression equation incorporating a log transformation of the age (+1 day) of each egg. The single day was added simply to allow fresh eggs (day 0) to be log-transformed and so be included in the sample.

The daily failure rate of eggs laid in the study area was determined using the Mayfield technique (Mayfield 1961, 1975; Johnson 1979). This assumes a constant rate of failure, and an exponential decline in the number of viable eggs in the wild. A confidence interval for this rate was calculated assuming a binomial distribution of daily failure. Most failures in our study area were attributed to nest desertions from unknown causes, and predation of eggs probably by possums (*Trichosurus vulpecula*), ferrets (*Mustela furo*), and possibly stoats and hedgehogs (*Erinaceus europaeus*).

These 2 models, giving failure rate in the wild up to date of collection, and hatchability in relation to date of collection, were combined to assess the ages at collection of an egg which give optimal productivity. This was extended to the normal case where the nest had 2 eggs of different ages.

RESULTS

Most eggs arrived at Auckland Zoo in good condition. Over the final 3 seasons of this study, when particular note was taken of the condition of eggs on arrival, 6 (10%) of 62 eggs were cracked, and 1 (2%) had a mal-positioned embryo; however, the cracked eggs were sealed with glue, and all 7 abnormal eggs hatched successfully. Field staff believed that most cracked eggs were already cracked in the nest, but a few were damaged while the egg was being collected, and none was damaged during transportation to Auckland Zoo (Pat Miller, Sue Bell, pers. comm.).

Despite specific attempts to replicate the natural incubation patterns observed in the wild right from laying (Colbourne 2002), only 1 (8%) of 13 eggs aged less than 11 days old hatched successfully, and this was estimated to be about 9 days old at the time of collection (Table 1). Most of these freshly-laid eggs were fertile, and the embryo developed initially, but died during incubation or, once, during the process of hatching. The percentage of eggs that hatched increased rapidly through the 11-30 day old range, and remained high thereafter, so that a total of 100 (81%) of the 124 eggs hatched (Table 1). Of the 12 older eggs that failed to hatch, most did so for reasons outside the control of Auckland Zoo, such as infertility (6), or the embryo being dead at the time of collection (3).

The hatchability of kiwi eggs was related to age at collection by a logistic regression (Fig. 1), which gave a good fit visually, and a 1 degree goodness of fit test (Hosmer et al. 1997) provided a satisfactory result ($P = 0.06$).

Although the hatchability of eggs increased over time, they were constantly at risk of desertion or predation in the wild, and so the longer they were left the greater the risk of failure. Over the 10-year study, the daily egg failure rate was 0.65% (95% CI 0.59%-0.71%; 407 failures of 946 eggs in 62,675 eggs at-risk days). When this exponential decline of survival of eggs in the wild was combined with the egg hatchability data, then the optimum time to collect eggs could be calculated by estimating the age at which maximum success rate was achieved for 1- and 2-egg clutches (Fig. 2).

Table 1 Number of brown kiwi (*Apteryx mantelli*) eggs of different estimated ages (days) at collection which hatched or failed.

	Egg age at collection (days)								
Egg age (days)	0-9	10-19	20-29	30-39	40-49	50-59	60-69	70-82	Total
Failed	12	2	-	2	4	1	3	-	24
Hatched	1	4	13	15	20	19	13	15	100

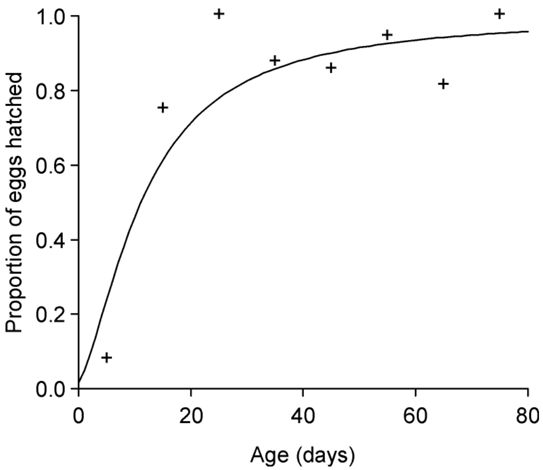

Fig. 1 The proportion of brown kiwi (*Apteryx mantelli*) eggs hatched against days since laid (grouped into 10-day age intervals), with logistic curve fitted to the raw data given in Table 1. The estimates (with standard errors) for the intercept and ln(age +1) was -4.12 (±1.2) and 1.65 (±0.35) respectively, giving an equation:

$\ln(p/(1-p)) = -4.12 + \ln[1.65*(1 + age)]$

equivalent to

$p = 1 - [1/(1 + 0.0162(1 + age)^{1.65})]$.

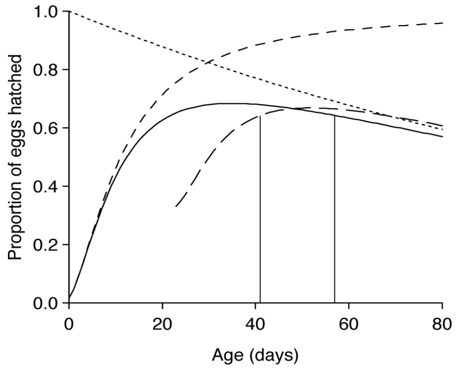

Fig. 2 Fitted models showing hatching success of brown kiwi (*Apteryx mantelli*) eggs through time. Success in the wild was based on a constant daily loss rate of 0.65%, with an equation $p = \exp(-0.0065*days)$. ONE success rate from given age at collection is as in Fig. 1. These 2 equations were combined by multiplication to give success for a single nest. The 2-egg-nest model involved average success based on the single combined curve and a similar curve delayed by a 22-day gap to account for the normal interval between eggs. Dotted line: egg success in the wild to a given age of collection; short dashed line: ONE success rate of eggs of a given age at collection; solid line: combined success rate for 1-egg nests; long dashed line: combined success rate for 2-egg nests. The vertical lines indicate the age of nest (41-57 days from 1st laying) where modelled success was greater than 64% regardless whether there are 1 or 2 eggs in the nest.

Given that there were variances associated with the equations, we present an optimum range of ages rather than precise ages. The optimum range to maximise hatching success (for at least 64% modelled success rate) of the 40% of single egg clutches was when the egg was 22-57 days old. For 2-egg clutches this optimum range was when the older of the 2 eggs was 41-68 days old, and so the younger egg was about 19-46 days old (assuming a 22-day gap: H.A. Robertson unpubl. data). Because the clutch size is generally not known in the wild until eggs are collected, our models suggests that success rate should be over 64% if brown kiwi eggs are collected 41-57 days after the 1st egg was laid, regardless of whether the nest has 1 or 2 eggs. It is most important to avoid collecting too early, as this has the biggest impact on the success rate (Fig. 2).

DISCUSSION

"Operation Nest Egg" has proven to be a very successful and effective method of rapidly restoring dwindling or locally extinct kiwi populations, through bypassing predation of the very vulnerable chicks in their first 6 months of life (Colbourne *et al.* 2005).

The artificial incubation of kiwi eggs is a fine art, improved recently by integrating scientific field data on natural incubation patterns

(Colbourne 2002) with the extensive knowledge of artificial incubation of captive-laid eggs. Despite this, no institution has consistently been able to hatch freshly-laid kiwi eggs successfully because many of the embryos suffer from developmental problems, or are mal-positioned and so fail to hatch successfully. The low hatching success of freshly-laid eggs means that conservation workers have shied away from collecting fresh eggs, but further experiments aimed at replicating natural patterns of incubation/ attendance of freshly-laid eggs should help to develop special protocols to enable captive institutions to routinely hatch these eggs. This would reduce the recommended age at which eggs could be collected, and so reduce the risk of egg losses in the wild before collection, and perhaps also allow the kiwi to lay more clutches during a season.

For logistical reasons, some projects collect mainly young chicks for immediate transfer to a captive institution or to a predator-free environment. Our model suggests that the overall productivity of chicks under this approach will be lower than through collecting eggs, because some nests fail late in incubation. Additionally, the wild-hatched chicks will be subjected to diseases and ectoparasites that can be avoided in well-maintained captive facilities, if only eggs are collected.

We have shown that collecting kiwi eggs at the most appropriate age, rather than randomly, can increase kiwi productivity and so add to the pace of kiwi recovery efforts. At sites where egg losses in the wild are lower than in central Northland, then the optimum age of collection would be slightly greater than recommended here, while in sites where egg hatchability is lower or where only 1-egg clutches are laid, then eggs should be collected at a younger age. As a general rule, kiwi eggs should be collected at about mid-term incubation to maximise productivity.

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