Kokako population studies at Rotoehu Forest and on Little Barrier Island

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Abstract

We studied North Island kokako (*Callaeas cinerea wilsoni*) breeding attempts and their outcomes from 1989-90 to 1993-94 at Rotoehu Forest (Bay of Plenty) as part of a basic study of kokako biology in an unmanaged mainland New Zealand forest. These data, and others on pest and food abundance, were gathered to clarify whether predation and/or competition limit mainland kokako populations. We also examine kokako juvenile production on Little Barrier Island from 1990-91 to 1993-94. At Rotoehu, 61-77% of kokako pairs attempted to breed each year but most (83%) attempts failed, owing mostly to predation of eggs, chicks, and (rarely) adults by ship rats (*Rattus rattus*), possums (*Trichosurus vulpecula*), and kahu (*Circus approximans*). Predators were identified by time-lapse video cameras, a break-through technique for observing events at forest bird nests. In "good" fruit years (1990-91 and 1992-93), kokako made more breeding attempts but the proportion of pairs which attempted to breed remained the same. Some pairs never tried to breed, probably because both pair members were male. Male excess in the population was probably a consequence of the predation (especially by possums) of females while incubating. juvenile production was high each year from 1990-91 to 1993-94 on Little Barrier, where ship rats and possums were absent, consistent with evidence from nest video cameras that these are key pests on the mainland. However, the roles of mustelids and feral cats in mainland kokako decline remain unclear, since these species were also absent on Littler Barrier. Until these are clarified, management effort to recover mainland kokako populations should focus on the reduction of predation at nests by ship rats and possums.

1. Introduction

The North Island kokako *Callaeas cinerea wilsoni* (henceforth called "kokako") is an endangered endemic forest passerine which is declining throughout its range on the mainland but was translocated to Little Barrier Island where the population is apparently secure. To determine the cause of mainland decline, staff members of Landcare Research, Rotorua (now Hamilton) studied kokako breeding attempts at Rotoehu Forest from 1989-90 to 1993-94, with funding from the Foundation for Research, Science and Technology. The Science and Research Division of the Department of Conservation funded further objectives to help explain breeding outcomes, including nest predator identification, kokako diet, phenology of kokako plant foods, and predator (ship rat and possum) abundance. Research at Rotoehu was in practice collaborative between Landcare Research and the Department of Conservation (Rotorua). Landcare Research staff and contractors also surveyed kokako juvenile production on Little Barrier from 1990-91 to 1993-94 to examine breeding success in the absence of mainland predator species.

2. Background

Most previous research on kokako arose from logging controversies and looked at their habitat use (Hay 1981, 1984, Powlesland 1987, Best & Bellingham 1991, Rasch 1992), but research after 1990 focused on their breeding, since population declines occurred even in large unlogged forests. Kokako are long-lived (perhaps to 25 years), but their reported breeding success on the mainland is poor (0.1 young per female per annum: Hay 1981). Thirty-three accounts of kokako nesting to 1989 were reviewed by Innes & Hay (1995); predation was the most frequent cause of nest failure, although no predators were identified with certainty. Food shortage caused by competition with introduced browsing mammals, especially possums (*Trichosurus vulpecula*), was perhaps a contributing factor in the decline (Leathwich *et al.* 1983).

Two main research approaches were chosen in 1988 to clarify the cause(s) of kokako decline on the mainland. These were a manipulative programme of pest mammal control (so-called "research-by-management", at Mapara and Kaharoa) to see if kokako numbers would then increase, and an observational or basic study of kokako biology in an unmanaged mainland forest and on an offshore island. The basic research at Rotoehu and on Little Barrier focused on whether kokako pairs tried to breed or not, and the outcomes of their attempts. These data, and others on pest and food abundance, were gathered to clarify whether predation and/or competition limit kokako populations on the New Zealand mainland.

3. Objectives

- Under FRST funding, to investigate the proportion of Rotoehu kokako pairs which attempt breeding from 1990-91 to 1993-94, and the outcomes of those attempts.
- Under DoC funding, to identify predators at kokako nests.
- To determine kokako diet, kokako plant food phenology, and predator (ship rat and possum) abundance before and during the breeding season at Rotoehu.
- To determine kokako juvenile output on Little Barrier from 1990-91 to 1993-94.

4. Methods

4.1 BREEDING ATTEMPTS AT ROTOEHU AND THEIR OUTCOMES

We first colour-banded kokako and undertook a pilot study to trial radio transmitters (n=9) in the 1989-90 breeding season. Forty-five adult kokako were colour-banded during the next four breeding seasons, and 35 transmitters were attached to birds to assist individual identification, territory mapping, and the location of nests. Transmitters were made by Sirtrack Ltd, Havelock North; they weighed about 10 g each, including a harness which incorporated a thread weak link (Karl & Clout 1987) to enable the transmitter to shed if it tangled in vegetation or in due course after the batteries failed. Kokako without transmitters were located by listening for their singing at dawn. Twelve to 15 kokako pairs were followed for at least a half hour once per week throughout the four breeding seasons (November up to March) from 1990-91 to 1993-94 inclusive, to see if pairs attempted breeding and to resolve the outcome of each attempt. If an attempt failed, we tried to climb to the nest as soon as possible to diagnose why.

4.2 IDENTIFICATION OF PREDATORS AT KOKAKO NESTS

Only Moors (1978, 1983) and McLennan & MacMillan (1985) have published accounts of attempts to identify New Zealand mainland predators to species, on the basis of sign left at nests, footprint tracking, triggered movie cameras, poisoning and exclosures. We designed and built a 24-hour, time-lapse VHS video recording system which recorded all events at kokako nests (Inner et al. 1994). The system was powered by three 12 volt batteries which were stored by the video recorder and were renewed each 72 hours, along with the video cassette. We filmed at 19 kokako nests for a total of 442 days and nights between December 1991 and February 1994. With one exception the camera was placed in a tree separate from the nest tree, and we did not visit the nest vicinity again after the camera was placed unless it was necessary to adjust the infra-red light source or the camera.

Most nests (47) were not filmed. To identify predators at unfilmed nests we carefully noted sign left at or near all nests and compared this with the sign left at filmed nests where the predator was known.

4.3 KOKAKO DIET

We determined kokako diet at Rotoehu by time-sampling in (1658 observations, August 1991 to February 1992, and 396 observations, November 1992 to

February 1993), or by occasional observation (365 observations, January-March 1991). Too few observations (72) were taken in 1993-94 to be worth reporting. Time sampling consisted of recording kokako behaviour, including diet, at 1-minute intervals when birds were followed and observed. This method was used also by Hay (1981), Powlesland (1987) and Best & Bellingham (1991).

4.4 VEGETATION PHENOLOGY

We scored the abundance (subjective 6-step scale, 0-5) of 10 phenological stages (leaf buds, expanding leaves, new leaves, flower buds, expanding flower buds, flowers, petal fall, unripe fruit, ripe fruit, dehisced fruit) on 10-15 marked individuals of 10 important kokako food species, at monthly intervals before and during each of the four breeding seasons at Rotoehu.

4.5 RODENT AND POSSUM ABUNDANCE

We assessed indices of ship rat and mouse abundance by snap-trapping and footprint-tracking. Thirty-five rat and mouse traps were placed under covers at 50 m intervals and set baited with peanut butter for three nights at about 3-monthly intervals (method of Fitzgerald 1978) during the kokako breeding season, in January and March 1991, October 1991, January and October 1992, January, April, and November 1993, and February 1994. Results were expressed as rats trapped per 100 trap-nights (TN), corrected for sprung traps as per Nelson & Clark (1973). Also, 100 tracking tunnels using the chemical system of King & Edgar (1977) were set in a long line at 50 m spacing. They were set baited with peanut butter for one night once (in April) in the 1990-91 season but each 6 weeks during the next three breeding seasons. Results were expressed as the percentage of tunnels tracked by each species, excluding those tunnels rendered unavailable after disturbance by, for example, possums.

Possum abundance was assessed by leg-hole trapping with gin traps set on ramps in a method which has become standard in kokako research-by-management (RbM) blocks. raps were set unlured at 25-30 m spacing for three nights; 50 traps were set in 1991-92 and 100 in the two following breeding seasons. For any one index, traps set were nos 1-10, 21-30, 41-50, etc.; this was to ensure that the results were comparable with those from poisoned blocks where the intervening traps (11-20, 31-40, etc.) would be wet for the post-poison assessment. Possum abundance was not assessed in 1990-91, since at that stage Rotoehu was not part of the RbM programme. All possums were killed when captured.

4.6 FLEDGING SUCCESS, LITTLE BARRIER

On Little Barrier, kokako pairs were followed at the end of each breeding season during 1990-91 to 1993-94 to see if they were accompanied by juveniles. Standard criteria for accepting field records of juveniles as used by the Kokako Recovery Group in RbM studies (J. Innes, unpubl. report) were applied. After visiting the island twice in 1992 (14-29 January and 24 March - 7 April) to check for late nestings, we reduced the survey to one visit in 1993 (23 February - 10 March) and 1994 (9-21 March) because nesting seemed to be synchronous, and there were no or few late nestings.

5. Results

5.1 BREEDING ATTEMPTS AND OUTCOMES, ROTOEHU

At Rotoehu from 1990-91 to 1993-94, 61-77% (n=12-15) of monitored pairs attempted to breed each year, but only 17% (11/65) of attempts were successful (Table 1). The number of attempts made by breeding pairs varied significantly between years (ANOVA, p = 0.016), although the proportion of the population which attempted to breed did not vary significantly from year to year. The 1990-91 and 1992-93 seasons were "good" (2.0, 2.2 attempts per pair, respectively); 1991-92 was a "poor" year (1.0 attempt per pair), and 1993-94 was "intermediate" (1.7).

TABLE 1 KOKAKO BREEDING ATTEMPTS AND OUTCOMES AT ROTOEHU FOREST, 1990-91 TO 1993-94.

	1990-91	1991-92	1992-93	1993-94	TOTAL
No. pairs monitored	12	13	15	14	54
No. pairs attempting (%)	8 (67)	8 (61)	11 (73)	10 (71)	37 (70)
No. breeding attempts	16	8	24	17	65
Mean no, attempts per pair	2.0	1.0	2.2	1.7	1.8
No. successful attempts (%)	2 (12)	1 (12)	5 (21)	3 (18)	11 (17)
No. possum predations (%)	3 (19)	0	3 (12)	4 (23)	10 (15)
No. ship rat predations (%)	5 (31)	2 (25)	4 (17)	2 (12)	13 (20)
No. kahu predations (%")	0	1 (12)	2 (8)	2 (12)	5 (8)
No. deserted (%)	0	2 (25)	3 (12)	3 (18)	8 (12)
No. unknown predator (%)	1 (6)	0	1 (4)	2 (12)	4 (6)
Failed, cause unknown (%)	5 (31)	2 (25)	6 (25)	1 (6)	14 (21)

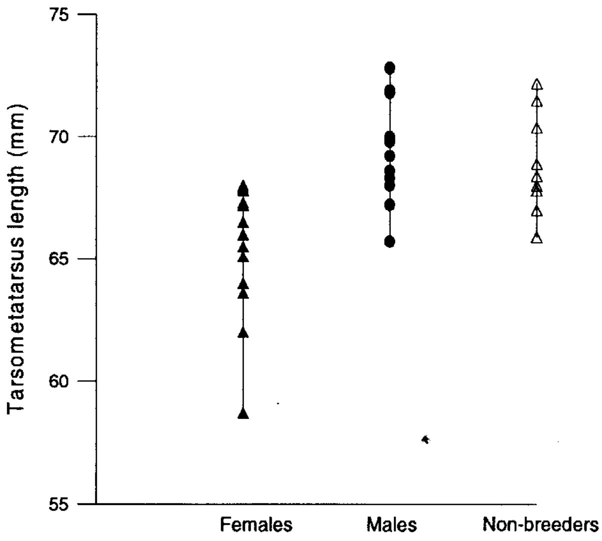

FIGURE 1 TARSOMETATARSUS LENGTH FOR KNOWN FEMALES, KNOWN MALES, AND BANDED MEMBERS OF NON-BREEDING PAIRS.

Of the 65 breeding attempts monitored, only 11 (17%) were successful; 13 (20%) were ended by predation attributed to rats, 10 (15%) by possums, 5 (8%) by kahu (Australasian harrier, *Circus approximans*), and 4 (6%) by unknown predators; 8 (12%) suffered desertion, and 14 (21%) failed for unknown reasons since the nests could not be reached. There were no significant differences in failure causes between years (chi t, p = 0.72). About half of the nests failed at the egg stage, and a further half of the surviving nests failed at the chick stage. Two sitting females were killed by predators (probably possums) during the study period. In January 1991 "Tracy" was preyed on while incubating. The head was missing and back and flight muscles were eaten; there were regurgitated feather pellets on the corpse which are diagnostic of possum feeding (Brown *et al.* 1993). In December 1992 "Baldrick" had been incubating when she was found with a broken leg and feather loss on one side of her body, indicating an encounter with a large predator, most plausibly a possum. We could not reach the nest to look for diagnostic sign there.

Pairs which attempted to breed one year always attempted to breed the next year if they were still together, and all pairs which did not attempt breeding in any year also did not attempt the following year (Appendix 1). Five of the 11 pairs which did not attempt to breed in any year had both members of the pair banded, and dissection (one bird) or tarsometatarsus measurements taken at banding (nine birds) showed that all 10 birds were possibly males (Figure 1).

Two of the five pairs subsequently split up, so that one member became part of a pair which did attempt breeding; in both instances ("Tease" and "Squirm") the bird was confirmed as male because its mate incubated.

The mean weight of kokako which attempted to breed in any season (229.2 g, S.D.=21.4, n=24) did not differ significantly (p=0.26, unpaired t-test) from that of birds which did not (223.2 g, S.D.=12.2 g, n=18). However, only one known female ("Wissel" in 1989-90) was found to not attempt breeding in any season, so the weight data fro non-breeding birds may be mostly from males. The plumage of "Wissel" was brownish in 1989-90 and she weighted only 197 g, so was perhaps a subadult which fledged the previous season.

Several deserted eggs and a dead chick recovered from nests were lodged as specimens with the Auckland Institute and Museum.

5.2 NEST PREDATOR IDENTIFICATION AND BEHAVIOUR

Evidence from video cameras

Events recorded by the video cameras at filmed nests included predation of eggs by ship rats, and of eggs and chicks by kahu and possums. To our surprise, ship rats and possums also visited some nests WITHOUT predation occurring; they were either beaten off by the sitting female or did not prey on kokako chicks while they had the chance to do so. Ship rats scavenged at two nests which had suffered predation by kahu, and a kahu returned to scavenge at a nest where it had previously killed a chick (Table 2).

TABLE 2 EVENTS RECORDED AT KOKAKO NESTS BY TIME-LAPSE VIDEO. SEVERAL EVENTS WERE SOMETIMES RECORDED AT ONE NEST.

SEASON	1991-92	1992-93	1993-94	TOTAL
No. of nests	2	9	8	19
Preyed on by: *Ship rat*		I		I
Possum		1	3	4
Kahu	1	2	2	5
'Visited" by: *Ship rat*	1	5		
Possum		2		2
Scavenged by: *Ship rat*		2		2
Kahu		I		1
Deserted	1	2	1	4
Fledged		1	2	3

Sometimes several events occurred at the same nest. At one nest, over a 1-month period, we filmed seven rat visits (all fought off by the female), then a possum visit (did not eat young chicks, for unknown reasons), then two more rat visits, then a kahu predation in which one chick was eaten and another jumped out of the nest and later died on the ground. There were then two scavenging visits by rats the night after the predation and a second scavenging visit by the kahu the day after.

Six of 19 kokako nests were visited by ship rats, usually once per night by one rat for about 90 seconds, although on one occasion two rats together threatened a sitting female. Each rat ran about the nest within 30 cm of the female, which responded by flapping its wings and pecking at the rat. Rat predation occurred mostly in the first 10 days of incubation, perhaps because females were less committed to nest defence at this early stage of incubation. No rats were filmed preying on chicks.

Sitting females approached by possums at night left the nest when the possums came within 30-200 cm, although once a female remained sitting and defended the nest by pecking at the possum, which then retreated.

On one occasion a late-stage chick leaped from the nest when a rat approached. The chick was found alive and being fed by its parents on the ground the following day, and subsequently survived. At another nest, a chick approx. 15 days old leaped from a nest during a kahu predation and died on the ground. Four predations by kahu were of older chicks in exposed nests, and one was of eggs. Sitting or brooding females always fled the nest without defending it against the kahu. The mean height above ground of nests preyed on by kahu was 11 m (n=5), and some were definitely in the forest understorey, showing that these aerial predators were not just hunting the forest canopy. Kahu usually took chicks away to eat them (minimum time at nest was 5 seconds), but one killed and ate a chick in 75 minutes at the nest.

No mustelid (stoat *Mustela erminea*, ferret *Mustela furo*, weasel *Mustela nivalis*), feral cat (*Felis catus*), magpie (*Gymnorhina tibicen*), or myna (*Acridotheres tristis*) or ruru (*Ninox novaeseelandiae*) was videoed at any kokako nest.

All predator species sometimes left characteristic sign. Clean removal of eggs or chicks was impossible to allocate to species. Ship rats generally made a hole in eggs sufficient to get access to the contents, leaving one or two large shell fragments with jagged margins (but very few incisor marks) and numerous small (approx. 1 cm) fragments (**Plate la**, end of report). They also often left faeces in the nest bowl or on the nest rim. Kahu either took chicks cleanly away from the nest to eat them elsewhere or (on one occasion) plucked and ate a chick in the nest, scattering feathers widely around the nest area, as they do when plucking prey on the ground. Only one kahu predation on eggs was filmed. The kahu left only large shell fragments with clean shell break margins (**Plate lb**). Regurgitated feather pellets characteristic of possums were found on a kokako killed while incubating in January 1991. These were the same as others produced by possums in feeding trials (**Plate 2a**) (Brown *et al*. 1993). We also found eggshell "pellets" after filmed possum predations of kokako eggs (**Plate 2b**). Characteristic features were that no very large shell fragments remained, and that the shell margins were grossly broken (rather than nibbled) and infolded. Both ship rats and possums "snuffled" the nest bowl lining, so that small shell fragments ended up 3-4 cm under the nest lining. In three filmed encounters between possums and kokako chicks, possums killed but hardly ate chicks on two occasions, and on the third the possum did not touch the chick at all. In one predation the possum ate only the head and emerging primary quills of the chick.

Evidence from all predations

Using the descriptions of characteristic sign outlined in the final paragraph above, we attributed 29 of 33 predations to a likely culprit species (Figure 2).

Eighty percent of nest failures from known causes (n=41) were attributable to predation, mostly by ship rats (14), possums (10), and kahu (5).

Most desertions (4/7) occurred after treefern fronds disrupted nests built in treefern crowns.

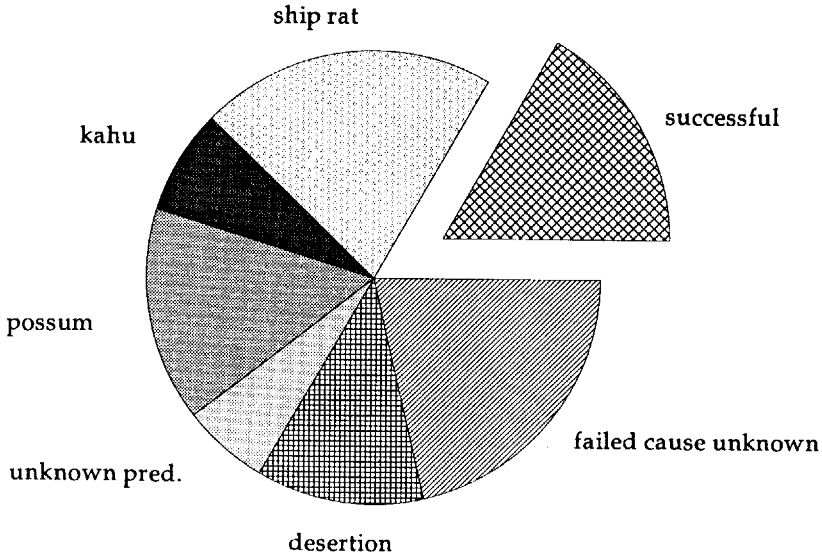

FIGURE 2 FATE OF KOKAKO BREEDING ATTEMPTS, 1989-94 (N=66), DERIVED BY DETERMINING CHARACTERISTIC PREDATOR SIGN FROM FILMED NESTS AND EXAMINING UNFILMED NESTS FOR SIGN.

5.3 KOKAKO DIET, ROTOEHU

Kokako ate more fruit and less leaf and flower in 1990-91 and 1992-93, when more breeding attempts were made, than in 1991-92 when fewer attempts were made (Figure 3).

Only in 1991-92 were sufficient minute-sampling data (1658 observations) collected to allow comparisons of behaviour (including diet) between breeding and non-breeding kokako pairs. Between August 1991 and February 1992, major foods were rewarewa flowers (11.8% of feeding observations), asplenium leaf (10.6%), scale insect (9.4%), pigeonwood fruit (8.7%), *Myrsine australis* fruit (5.4%), mangeao fruit (3.7%), puka leaf (3.6%), supplejack fruit (3.3%), and hound's tongue fern leaf (3.1%). Eighty other food items made up the remaining 40% of diet. There were no significant differences between kokako pairs which attempted to breed and those which did not with regard to time spent feeding, or in any other activity, nor in food type eaten (Appendix 2).

FIGURE 3 KOKAKO DIET, 1900-91 TO 1992-93.

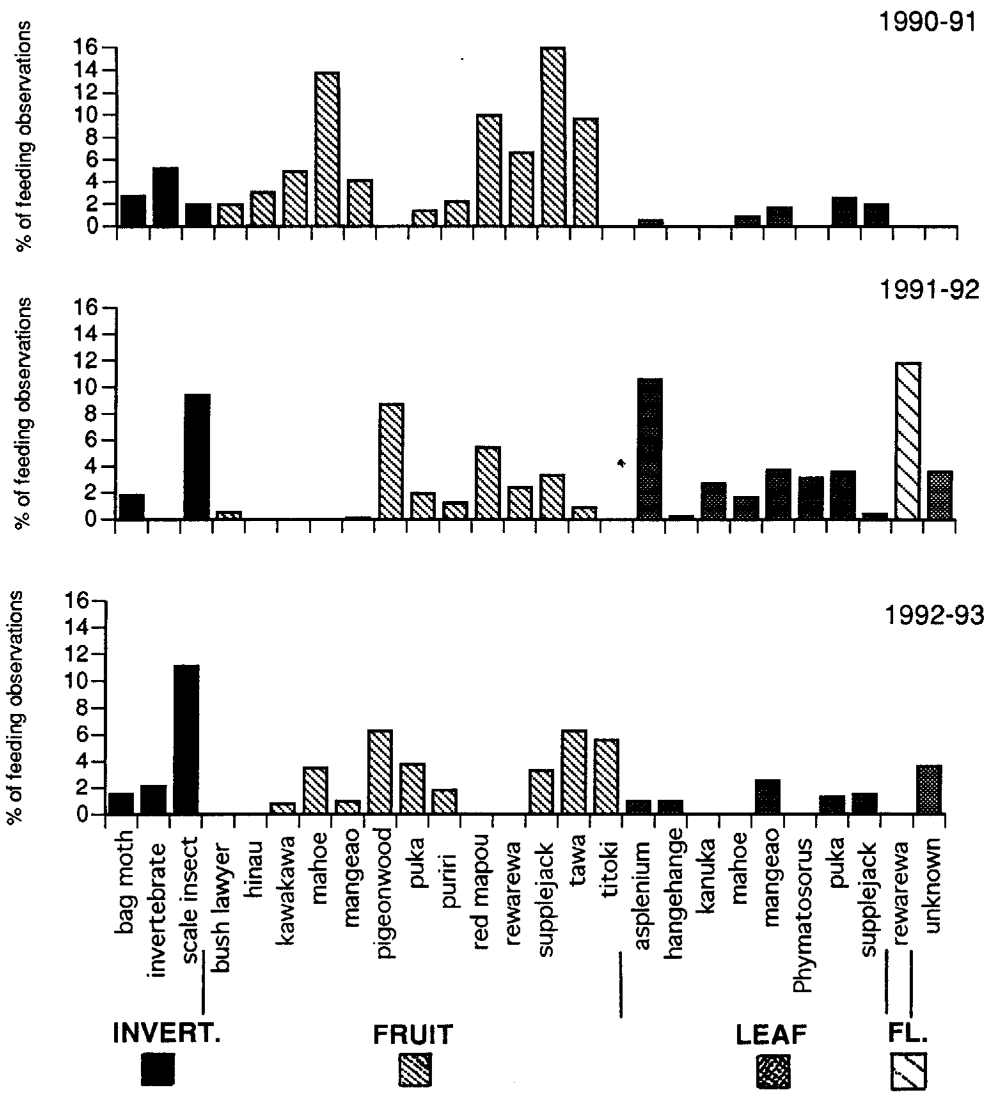

FIGURE 3 KOKAKO DIET, 1900-91 TO 1992-93.

5.4 PHENOLOGY OF FOOD PLANTS, ROTOEHU

Ripe fruit of pigeonwood, kohekohe, hinau, rewarewa, mahoe, and tawa were most abundant in 1992-93 (Appendix 3). Supplejack and bush lawyer fruit were most abundant in 1993-94. Formal phenology data were not gathered until January 1991, although field staff noted that before then there were large crops of rewarewa *(Knightia excelsa)* flowers, and of fruit of mahoe *(Melicytus ramiflorus),* taws *(Beilschmiedia tawa)* and bush lawyer *(Rubus cissoides).*

5.5 RODENT AND POSSUM ABUNDANCE, ROTOEHU

Ship rats were moderately abundant in all breeding seasons according to indices from both trapping (2-13 rats /100 TN) and tracking (12-43% papers tracked), although indices from the two systems had different trends during the 1992-93 season, and there was no overall coherent relationship between them (Figure 4).

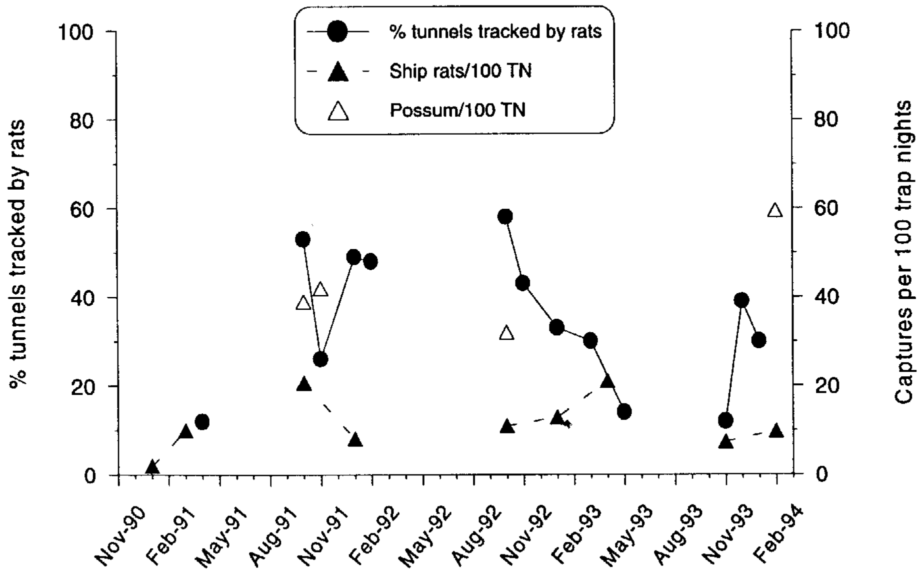

FIGURE 4 ABUNDANCE INDICES OF SHIP RATS AND POSSUMS AT ROTOEHU, NOV. 1990 TO FEB. 1994.

This may have been due to the differing lengths and locations of the two lines. The tracking tunnel line was 5 km long, and was placed as a square through the entire study area; the trapping line was 1.75 km long, and was in the middle of the square of tunnels.

Mice were always rare (0-3 per 100 TN; 0-3% tracking).

Possums were consistently abundant (32-58 per 100 TN) when indexed from 1991-92 to 1993-94.

5.6 TERRITORIALITY, PAIR-BONDING, ADULT MORTALITY, AND JUVENILE DISPERSAL, ROTOEHU

Mean territory size of pairs which were followed at least five times in a season was 9.0 ha, 11.9 ha, 14.4 ha, and 11.6 ha in 1990-91 to 1993-94 respectively (n = 15, 15, 13, 8) calculated by the minimum convex polygon method (Mohr 1947). Overall, the mean number of "follows" per pair per season which contributed to these territory calculations was 13.8. Mean territory size of pairs which attempted to breed in any year (10.8 ha, S.E. = 5.5 ha, n = 31, range 2.5-24.7 ha) did not differ significantly from that of pairs which never attempted to breed (13.4 ha, S.E. = 7.6 ha, n = 16, range 4.4-29.5 ha) $p>0.2$, $t=1.214$, 45 d.f.). Too few "follows" were made of single kokako through a season to permit comparison of the size of territories between single and paired birds.

Kokako whose territories were adjacent to exotic forest compartments used the exotic trees as a natural part of the territory, although only one bird ("Dale's Bird") lived exclusively in a pine compartment (Calder & Innes 1987). One successful nest was in a *Pinus strobus* tree, and an unsuccessful nest in a treefern was constructed mostly of redwood *(Sequoia sempervirens)* foliage.

Pairs which remained together for more than one season (n=13) always occupied virtually the same territory each year. Five pairs had their territory in the same location for three consecutive years.

Eleven (85%) of 13 territorial kokako which were single for at least 30 days were definitely (by observation of their nesting behaviour, n = 4) or probably (by leg measurement, n = 7) males, implying that there was an excess of males in the population.

Twenty-one (48%) of the kokako pairs we monitored in any year from 1989-90 to 1992-93 were intact the following year; 19 (43%) had broken up, and for four of the pairs we could not tell since they were unbanded. No pair remained intact for the entire duration (4 years) of the study. Closer examination of the patterns of the break-ups showed that there were examples of both males and females moving to a new mate or disappearing, but that only females were known to have died (two of three deaths were at nests). This may reflect a bias towards being able to locate corpses at nests rather than elsewhere, but many birds of both sexes bore radio transmitters, which should have enabled us to find dead birds away from nests if deaths were at all frequent. No females were left as singles, although on seven occasions known males (paired with an incubating mate) or probable males (by leg measurement) remained single for several months after the pair split up, further suggesting an excess of males in the population.

An estimate of adult mortality is possible by considering disappearance rates of banded birds, although the estimate assumes that kokako which disappeared (i.e., were not located in the study area) had died. This is unlikely to be true, since the study area is surrounded by forest which was searched less by workers, and on at least two occasions banded birds disappeared for 1-2 years and then reappeared. There were 1078 band-months (89.8 band-years) in total; 16 banded birds disappeared in this time, i.e., 0.18 per bird-year. The estimate of adult mortality of 18% is likely to be excessive.

Six juveniles banded in nests were later relocated as paired adults, three ("Moon" has bands metal-YW, "Pooh" has m-WB, "Velcrow" has m-GB) after 9-12 months and three ("Gossamer" has m-B, "Raucous" has m-WR, "Sycamore" has m-W) after 21-25 months. They moved on average 1.7 km (n=6, S.D.=0.5; Figure 5).

juvenile kokako apparently dispersed through exotic forests at Rotoehu, suggesting that fast-growing pines are an effective way to rapidly establish links between kokako populations in adjacent separated native forest areas.

5.7 FLEDGING SUCCESS, LITTLE BARRIER

On Little Barrier, at least 75-83% of monitored pairs fledged young each year, indicating that most pairs attempted to breed and were successful (Table 3). The actual percentage of young fledging may have been even higher in some years, since most "follows" did not reach the 2-hour minimum time used on the mainland as a criterion of satisfactory effort. Each year, all juveniles were at a similar development stage, indicating fairly synchronous breeding by pairs.

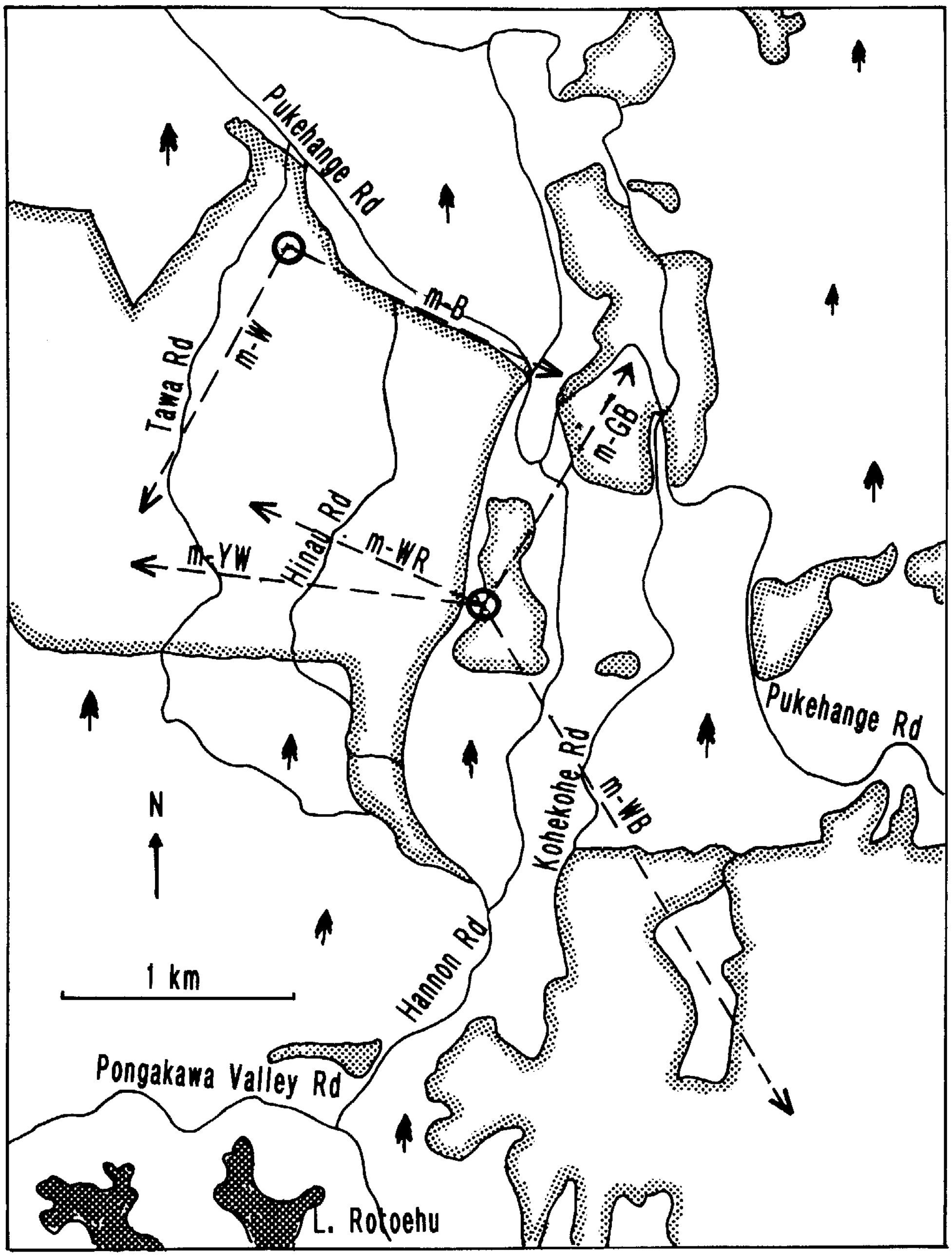

FIGURE 5 NEST SITES (CIRCLES) AND DISPERSAL DISTANCES (DASHED LINES) OF RELOCATED JUVENILE KOKAKO AT ROTOEHU FOREST. THE KOKAKO ARE IDENTIFIED BY COLOUR BAND COMBINATION. NATIVE FOREST AREAS HAVE A DOTTED MARGIN.

TABLE 3 KOKAKO BREEDING SUCCESS ON LITTLE BARRIER ISLAND, 1991-94.

	1990-91	1991-92	1992-93	1993-94
No. pairs surveyed	9	13	12	12
No. pairs fledged chicks (%)	7 (78)	10 (77)	10 (83)	9 (75)
No. fledged chicks	9	12	12	13

6. Discussion

6.1 KOKAKO BREEDING ATTEMPTS AND THEIR OUTCOMES

Each season, most kokako pairs attempted breeding at Rotoehu but failed to fledge young, mostly because of predation. Kokako made more breeding attempts in 1990-91 and 1992-93 when ripe fruit was more abundant, and kokako ate more fruit in those years. More leaf and flower were eaten in 1991-92, when fewer breeding attempts were made. However, if all breeding attempts had succeeded and only one clutch were raised, the "good" fruit years would have made no difference to the number of chicks fledged since the same proportion of the population attempted to breed in all years. We never observed a kokako pair to attempt nesting again after successfully fledging a first clutch, as occurred with many pairs at Mapara (King Country) in the 1994-95 season (I. Flux & P. Bradfield, unpubl. data).

The most likely reason why some pairs consistently did not attempt to breed is that both members were male, and that there was an excess of males in the population. Evidence for this is that the leg measurements of non-breeding kokako were consistent with (although not always diagnostic of) those of known males; that non-breeding pairs sometimes split up and members were subsequently confirmed as males; that single territorial kokako were invariably males, and that females from breeding pairs which split up found new mates rapidly although males did not. These observations, plus data showing that neither weight nor diet of breeding birds differed from those of non-breeders, and that no non-breeding pairs became breeders in phenologically "good" years, together suggest strongly that the failure of 23-39% (n=12-15) of pairs to attempt breeding in any season at Rotoehu was an outcome of predation (resulting in male-male pair bonds), not competition (food shortage).

Predation of females while incubating at nests is the most likely cause of the gender imbalance. During the 4-year study two females were killed while incubating, during 65 breeding attempts by 24 breeding pairs. Population modelling is required to explore whether this rate of female loss is adequate to explain why so many mainland kokako populations end up with many single territorial birds, probably males (Rasch 1992). No females were reported killed from 1880 to 1989 at 33 kokako nests reviewed by Innes & Hay (1995). Alternatively or additionally, females may face extra risk of predation or some other cause of mortality away from nests. This study produced no evidence that such a mechanism is likely, although we followed 35 kokako with radio transmitters during 5 years. In fact, the survival rate of banded adults was high (minimum 82% per annum), and six of seventeen banded juveniles were resighted as adults despite the lack of explicit searches of surrounding forest for them.

The high (approx. 80%) chick output on Little Barrier Island suggests that most kokako pairs on the mainland will attempt to breed, and will succeed each year if predators and competitors are adequately controlled.

These results from Rotoehu expand those of a decade earlier by Rod Hay and others with the Forest Bird Research Group, who first studied kokako breeding attempts and their outcomes in unmanaged mainland forests at Rotoehu, Mapara and Pureora (Hay 1981, 1984). Hay observed pairs which apparently never attempted breeding, and all seven nests he located failed after predation. Chicks in at least one nest were eaten by a possum, although at that stage the characteristic feather pellets produced by possums (Brown *et al.* 1993) were unknown, and the culprit was suspected but not confirmed.

Predation of nesting female kokako probably explains the excess of single kokako in remnant populations, such as at Coromandel (4/4 were singles; H. Speed *et al.,* 1988 unpublished Department of Conservation report), Hunua (20 of 26-28 were singles; Greene 1994), and Tatanaki (21/31 were singles; J. Molloy, 1989 unpublished Department of Conservation report). Populations at this stage inevitably collapse rapidly in the absence of management. Kokako declined also on Great Barrier Island where possums and mustelids (but no ship rats) are absent. Six of 12 kokako located there in late 1984 were singles (Hay *et al.* 1985) and only two single birds remained in April 1993 (H. Speed, S. Boyd, P. Jansen, 1994 unpublished Department of Conservation report).

6.2 NEST PREDATORS, SCAVENGERS, AND DISTURBERS

Ship rats, possums, and kahu were confirmed as predators at Rotoehu nests. We found no evidence that ship rats killed chicks, although they scavenged at two nests where kahu had killed chicks previously. We verified that scavenging can result in misleading sign being left at nests after predation, but could not determine the likely full extent of this since we retrieved nests quickly after predation occurred. There are some useful differences in sign diagnostic of different predator species, although culprits cannot yet be identified in all instances. Also, we filmed no predation by stoats, and damage by stoats to hens' eggs can be indistinguishable from that of rats (E. Spurr, pers. comm.). Diagnostic sign described by Moors (1983) and used subsequently by McLennan & MacMillan (1985) is simplistic, since at Rotoehu possums produced verified sign fitting that which Moors described as characteristic of rodents; and possums and kahu (this study), ship rats (Major 1991, Brown 1994), and ruru *(Ninox novaeseelandiae:* Brown 1994) are all known to take eggs or chicks cleanly, which Moors suggested was diagnostic of mustelids.

Possums may be the most significant kokako predator on the mainland because they prey on adults and chicks as well as eggs. They are ubiquitous in kokako habitats, and each kokako nest will probably be within the home range of at least one possum. Possums approached six of 19 nests we filmed at. On two occasions we filmed female kokako letting possums approach to within 30 cm of their nest at night; on one of these the kokako refused to leave the nest and pecked at the possum, which then departed. However, if the possum had pressed an attack, the female would surely have been extremely vulnerable to serious injuries, consistent with those we observed in two other instances where females died. Observed correlations between possum spread and kokako decline (Leathwick *et al.* 1983) may have been due to possums as predators rather than browsing competitors.

We could detect no obvious relationship between nest predation rates and abundance indices of ship rats and possums. In the absence of any management, both predator species seemed to be similarly abundant each year; nor were the causes of nest failure significantly different between years. This suggests that there are not particular years when predator control is especially needed, nor particular years when kokako benefit more from predator control than in other years.

Predators of mobile subadults or adults remain unknown, other than from one anecdotal account of a karearea (*Falco novaeselandiae*) killing a kokako in the Pikiariki Ecological Area, Pureora Forest Park. New field techniques are badly needed to give researchers reasonable methods for determining the causes of death of mobile birds (Innes 1995). Kokako females did not defend nests against kahu, probably because they were themselves at risk of death. Predations by kahu were always in more exposed nests, suggesting that the kahu hunt mainly by sight. Several aspects of kokako nesting, such as nest-building under dense overhead cover, probably evolved in response to diurnal avian predation in pre-human times (Innes & Hay 1995). Kahu should not be regarded simply as predators of open country, where they are most conspicuous. This research suggests that they are important predators of kokako chicks and eggs, and that their control in the vicinity of important kokako management areas would improve kokako population recovery. This is of course contentious, since they are themselves protected native birds.

Predator-kokako interactions are complex, with outcomes depending at least partly on how the female kokako behaves. Risks from introduced mammals include disturbance (late-stage chicks leaping from nests), which could ultimately be fatal for the chick although it is not strictly "predation". Learned reactions of individual kokako to mammalian predators may be an important component of kokako population survival in both managed and unmanaged habitats.

The identification of possums and ship rats as important kokako predators at Rotoehu is consistent with the high kokako nesting success observed in RbM blocks at Kaharoa (H. Speed, unpublished report, Department of Conservation) and Mapara (Flux *et al.* 1995; Flux *et al.*, unpubl. data) when these species were intensively managed, and at Little Barrier Island where they were absent. The role of mustelids and feral cats in kokako decline remains equivocal, however, since they were also controlled at Kaharoa and at Mapara but not at Rotoehu, and are absent from Little Barrier Island. Video camera studies at Rotoehu suggest that mustelids and feral cats are not important predators at kokako nests (n=19 nests), although these results should be considered preliminary until more nests are filmed. Kerry Brown (1994) also filmed no mustelids or cats at 27 nests of robin (*Petroica australis*) or tomtit (*Petroica macrocephala*) in tawa-broadleaf forest at Kaharoa, Bay of Plenty.

6.3 THE TIME-LAPSE VIDEO TECHNIQUE

The time-lapse video system is a break-through technique for recording not only predator identity but also the behaviour of predators, scavengers, disturbers, and the kokako themselves (Innes *et al.* 1994, Brown 1994). The resulting images are permanent, can be viewed repeatedly, and display the time at which they were recorded, to the second. This provides accurate data on the timing, duration, and sequence of events. In our study the research technique produced its own communication opportunities through the video format, which has been invaluable for anti-pest and pro-kokako public advocacy. Predation sequences recorded in this study have appeared' on television in New Zealand, Australia, and Germany.

The video system described here has some advantages over previous techniques. It has no need for triggers, tracking papers, flashlights or cameras to be placed near the nest, such as those used by Moors (1978), McLennan & MacMillan (1985), and Major (1991). It should not "run out of film", and is silent, unlike most reflex and movie camera systems. There was no obvious behavioural evidence that either kokako or predators were aware of the camera during any sequences filmed from adjacent trees. Although it is known that some birds (e.g., hummingbirds) have some vision in the near-ultraviolet, bird colour vision does not extend beyond about 750 mm in the red under normal conditions (Bowmaker 1980), about the same as humans. It is therefore unlikely that kokako could see the IR light we used (830-850 mm), just as we could not detect it. Furthermore, unlike ultraviolet, IR light does not penetrate ocular fluids well so that the eye itself protects the retina from damage by IR. However, a small amount of visible light was produced by the LEDs and the laser. This was apparent to our eyes as faint and small orange and red glows from the two sources respectively, which would have been visible to birds and predators at night. Regardless of the detection of IR light, the cameras themselves may have attracted or deterred predators (especially kahu) in the daytime. The fledging rate at filmed nests (3/19 = 16%) was the same as that at unfilmed nests (8/46 = 17%), consistent with no disturbance effect. Further research is needed to explore whether either birds or predators are damaged or disturbed by, or attracted to, the surveillance equipment we used.

6.4 KOKAKO TERRITORIALITY AND PAIR-BONDING

Most aspects of kokako territoriality and pair-bonding at Rotoehu agree with results from Mapara, where pest control has been undertaken for 6 years and nearly all kokako are now banded (Flux *et al.* 1995; Flux *et al.*, unpubl. data). One interesting difference is that territories at Rotoehu (average 9-14 ha during 1990-91 to 1993-94) were twice as large as those at Mapara (average 4.6-5.9 ha during 1992-93 to 1993-94). If this is due to better food supply at Mapara after several years of intensive possum and goat control, then territory sizes may decrease at Rotoehu during the forthcoming years of pest control there.

7. Conclusions

Most kokako pairs attempted to breed each year but failed, owing primarily to predation of eggs, chicks, and (rarely) adults by ship rats, possums, and kahu. In "good" fruit years (1990-91 and 1992-93) kokako made more breeding attempts, but the proportion of pairs which attempted to breed remained the same. The most likely reason why some pairs never tried to breed is that both members were male. This was probably a consequence of the predation of females while they were incubating, especially from possums. Ship rats and possums were abundant each year. The causes` of nest failure did not differ significantly from year to year, suggesting that pest control cannot usefully be confined to particular years.

Time-lapse video systems are a break-through technique for identifying nest predators, scavengers, and disturbers. Interactions between kokako and potential predators are complex. Kokako often defend their nest against ship rats, and occasionally against possums, but not against kahu, which may kill the adult kokako.

Juvenile production was high each year from 1990-91 to 1993-94 on Little Barrier Island, where ship rats and possums are absent, supporting mainland evidence that these may be key pests. However, the role of mustelids and feral cats in mainland kokako decline remains unclear. These species too are absent on Little Barrier Island, and were reduced in RbM blocks (Mapara and Kaharoa, where kokako numbers increased) at the same time as ship rats and possums.

8. Recommendations

1. Management effort to recover kokako populations on the mainland should focus on the reduction of predation at nests by possums and ship rats.
2. Research should be intensified into the causes of death of mobile adult and subadult kokako. This will clarify the pest status of mustelids and feral cats.
3. Kokako populations should be modelled to determine the scale, intensity and frequency of effort required to maintain or enhance mainland kokako populations.
4. The outcomes for predators and kokako of mainland predator control should be monitored to continually refine its effectiveness and efficiency, thus maximising the area of estate over which control can be undertaken.

9. Acknowledgements

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11. Appendix 1

BREEDING ATTEMPTS OF KOKAKO PAIRS AT ROTOEHU FOREST, 1989-90 TO 1993-94.
A ZERO INDICATES THAT THE PAIR WAS MONITORED BUT DID NOT ATTEMPT.
FEMALES IDENTIFIED BY INCUBATION ARE ITALICISED.

PAIR	1989-90	1990-91	1991-92	1992-93	1993-94
Mad-E & Scuttlemania		3	1		
Kawi & Bema		3			
Uppill & Downdill		2			
Hika & Tikka		1	1		
Wissel & Warble		1			
Barry & Jacinda		0	0	0	
Mad-E & Samburr	1			1	
Sonyam & Wissel	0		1	3	1
Tease & Taunt	0				
Wriggle & Squirm	0	0	0		
Tu & Fro		3	1	1	
Trevor & Tracy		2			
Pop & Tringle		0			
Eco & Bio		1			
Ron & Eff		0			
Bee & Caspar			1		
Kawi & Trevor			1	2	2
Magus & Goblin			0		
Merlin & Downdill			1	2	
Nel & Malcolm			1	1	
Eco & Baldrick				2	
Chev & Zodiac				4	3
Mark & Judy				3	
Ron & Raucous				3	2
Blue & Mini				2	1
Homer & Marge			0	0	0
Gawdnose & Wobble			0		
Frodo & Pippin				0	

PAIR	1989-90	1990-91	1991-92	1992-93	1993-94
Zig & Zag				0	
Uppill & Frodo					0
Tease & Merlin					I
Goblin & Hoggle					I
Hika & Squirm					2
Eco & Mad-E					2
Samburr & Frot					2
Wobble & Tracy II					0
Shika & Dika					0
PAIRS ATTEMPTING	1/4	8/12	8/13	11/15	10/14

12. Appendix 2

APPENDIX 2A. MEAN PERCENTAGE OF TIME SPENT ON MAJOR ACTIVITIES BY BREEDING (N=9) AND NON-BREEDING (N=3) PAIRS OF KOKAKO AT ROTOEHU FOREST, AUGUST 1991 TO APRIL 1992. DIFFERENCES BETWEEN CATEGORIES WERE TESTED WITH ANOVA.

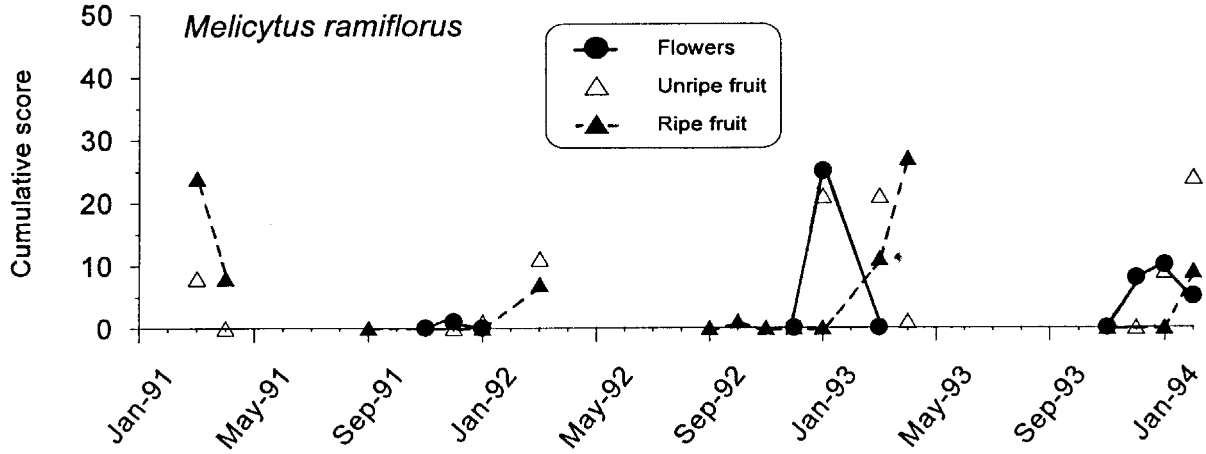
ACTIVITY	NON-BREEDING	BREEDING	P VALUE
feed	24.6	22.3	0.76
mew	3.7	2.8	0.88
move	35.8	29.9	0.43
preen	10.6	8.7	0.08
roost	10.5	12.0	0.63
sing	7.3	13.7	0.37
took	6.4	6.1	0.08
No. observations	2035	6118	

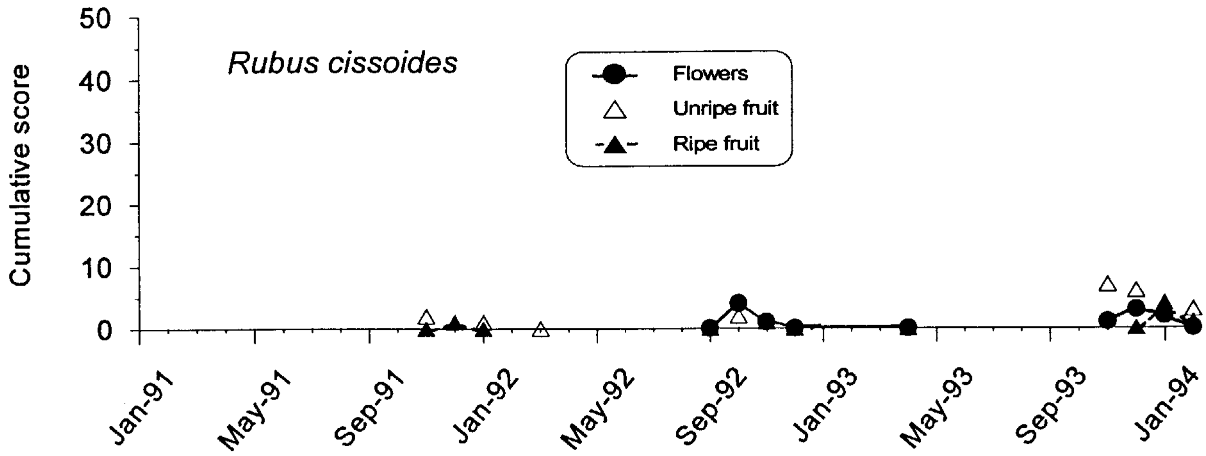
APPENDIX 2B. MEAN PERCENTAGE DIET BY MAJOR FOOD TYPE OF BREEDING (N=9) AND NON-BREEDING (N=3) PAIRS OF KOKAKO AT ROTOEHU FOREST, AUGUST 1991 TO APRIL 1992. DIFFERENCES BETWEEN CATEGORIES WERE TESTED WITH ANOVA.

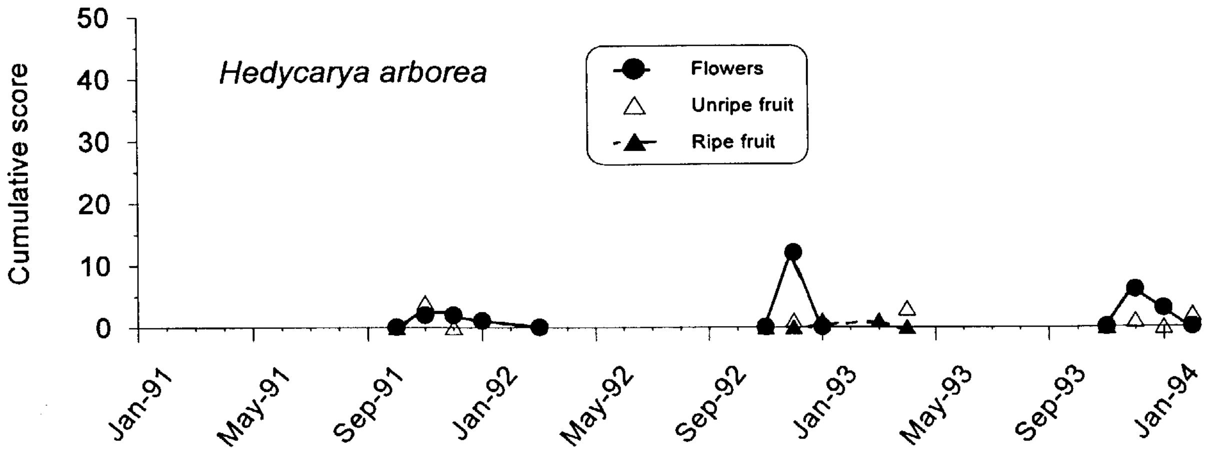
ACTIVITY	NON-BREEDING	BREEDING	P VALUE
flower	15	14.3	0.77
fruit	14	25	0.43
insect	16	11	0.19
leaf	29	30	0.76
unknown	25	19	0.15
No. observations	498	1358	

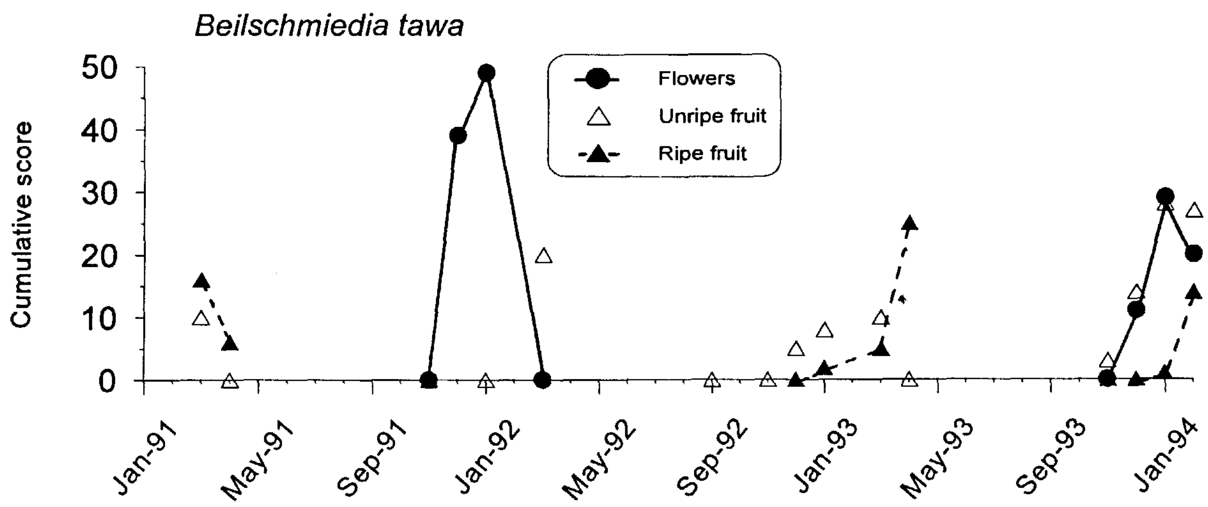
13. Appendix 3

CUMULATIVE PHENOLOGY SCORE, REFLECTING THE ABUNDANCE OF FLOWERS, UNRIPE FRUIT, AND RIPE FRUIT OF MAHOE (*Melicytus ramiflorus*), BUSH LAWYER (*Rubus cissoides*), PIGEONWOOD (*Hedycarya arborea*), KOHEKOHE (*Dysoxylum spectabile*), SUPPLEJACK (*Ripogonum scandens*), KAWAKAWA (*Macropiper excelsum*), TAWA (*Beilschmiedia tawa*), HINAU (*Elaeocarpus dentatus*) AND REWAREWA (*Knightia excelsa*) FROM JANUARY 1991 TO JANUARY 1994.


Melicytus ramiflorus
Flowers
Unripe fruit
Ripe fruit
Cumulative score
50
40
30
20
10
0
Jan-91
May-91
Sep-91
Jan-92
May-92
Sep-92
Jan-93
May-93
Sep-93
Jan-94


Rubus cissoides
Flowers
Unripe fruit
Ripe fruit
Cumulative score
50
40
30
20
10
0
Jan-91
May-91
Sep-91
Jan-92
May-92
Sep-92
Jan-93
May-93
Sep-93
Jan-94


Hedycarya arborea
Flowers
Unripe fruit
Ripe fruit
Cumulative score
50
40
30
20
10
0
Jan-91
May-91
Sep-91
Jan-92
May-92
Sep-92
Jan-93
May-93
Sep-93
Jan-94


Beilschmiedia tawa
Cumulative score
Flowers
Unripe fruit
Ripe fruit
Jan-91
May-91
Sep-91
Jan-92
May-92
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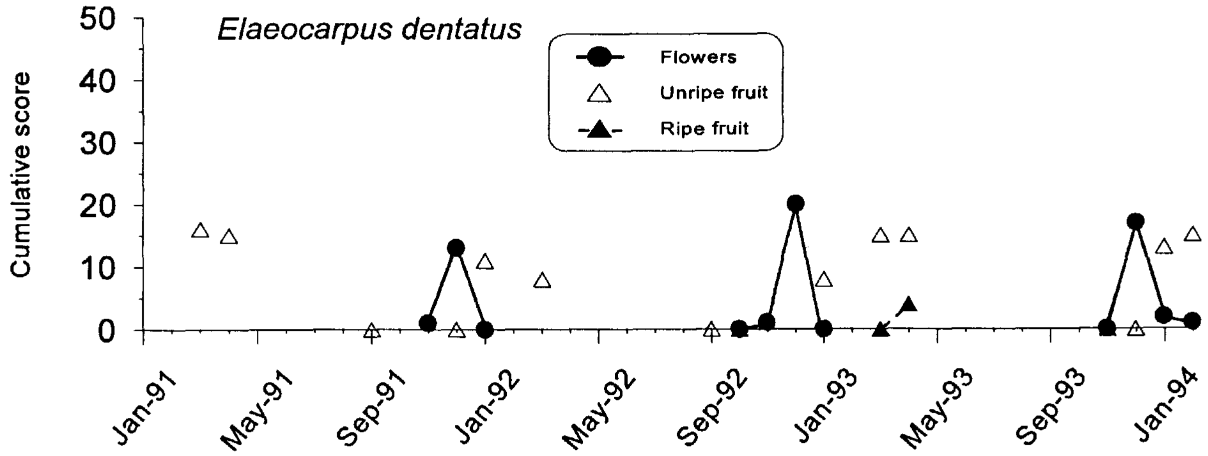
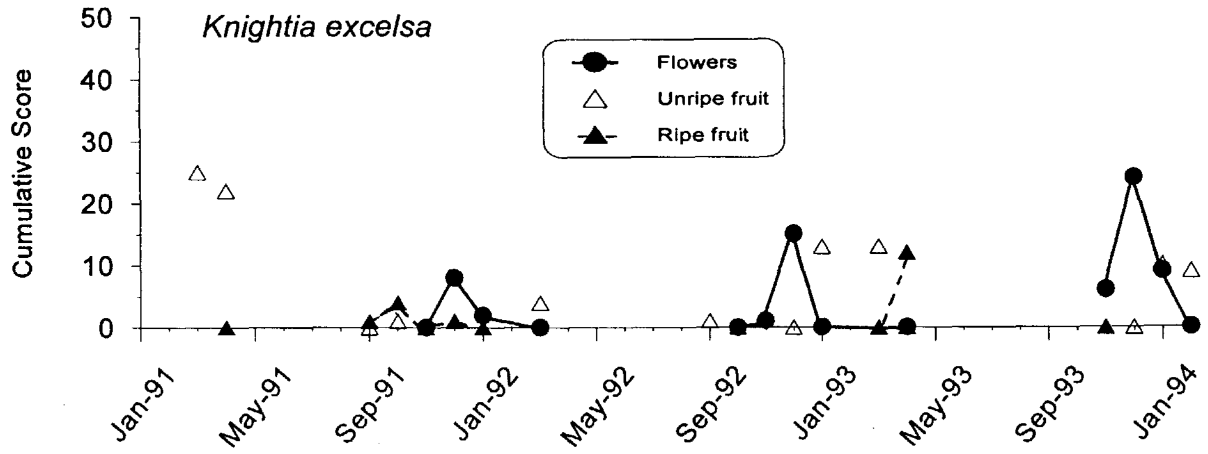
Jan-93
May-93
Sep-93
Jan-94


Elaeocarpus dentatus
Cumulative score
Flowers
Unripe fruit
Ripe fruit
Jan-91
May-91
Sep-91
Jan-92
May-92
Sep-92
Jan-93
May-93
Sep-93
Jan-94


Knightia excelsa
Cumulative Score
Flowers
Unripe fruit
Ripe fruit
Jan-91
May-91
Sep-91
Jan-92
May-92
Sep-92
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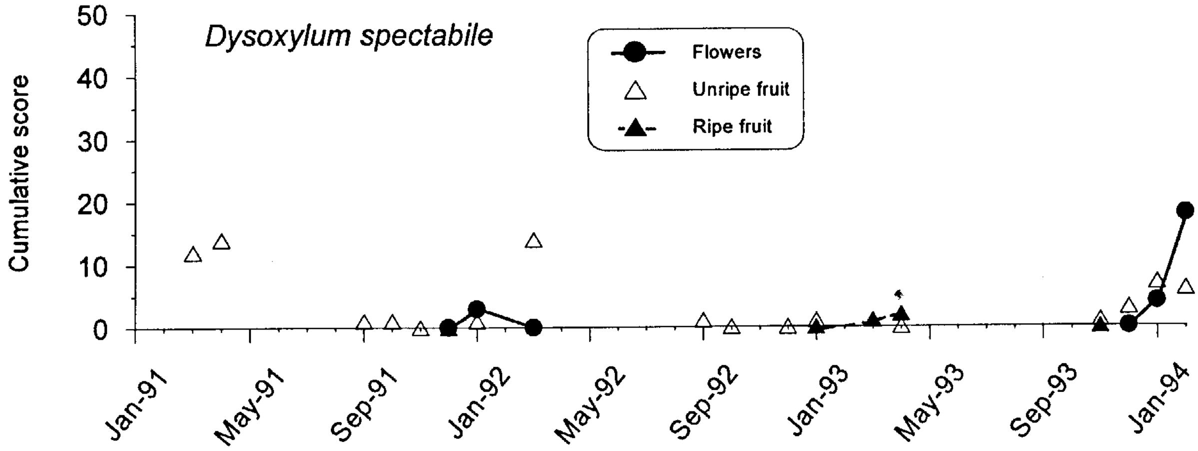
May-93
Sep-93
Jan-94


Dysoxylum spectabile
Cumulative score
Flowers
Unripe fruit
Ripe fruit
50
40
30
20
10
0
Jan-91
May-91
Sep-91
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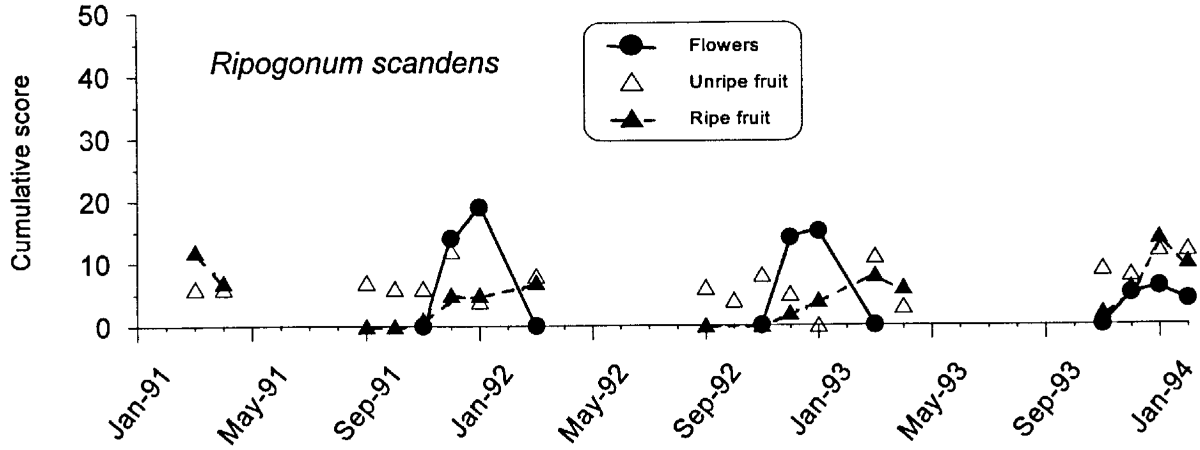
Jan-93
May-93
Sep-93
Jan-94


Ripogonum scandens
Cumulative score
Flowers
Unripe fruit
Ripe fruit
50
40
30
20
10
0
Jan-91
May-91
Sep-91
Jan-92
May-92
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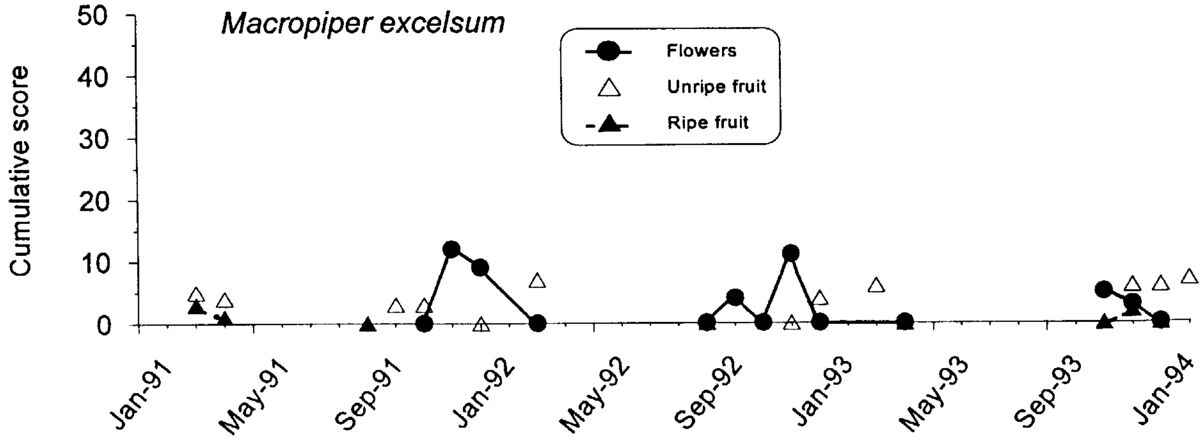
Jan-93
May-93
Sep-93
Jan-94


Macropiper excelsum
Cumulative score
Flowers
Unripe fruit
Ripe fruit
50
40
30
20
10
0
Jan-91
May-91
Sep-91
Jan-92
May-92
Sep-92
Jan-93
May-93
Sep-93
Jan-94

14. Appendix 4

COLOUR PLATES

PLATE IA KOKAKO EGGS AFTER SHIP RAT PREDATION. NOTE LARGE SHELL REMNANTS WITH JAGGED MARGINS, AND NUMEROUS SMALLER SHELL PIECES.

PLATE 1B KOKAKO EGGS AFTER FILMED KAHU (HARRIER) PREDATION. NOTE LARGE SHELL FRAGMENTS WITH CLEAN MARGINS AND THE ABSENCE OF SMALL SHELL PIECES.

PLATE 2A A REGURGITATED FEATHER AND BONE PELLETS FOUND ON A KOKAKO KILLED ON A NEST AT ROTOEHU FOREST, RECOVERED JANUARY 1991. B FEATHER AND BONE PELLETS REMAINING AFTER A STARVED CAPTIVE POSSUM FED ON A ROAD-KILLED GREENFINCH (Carduelis Chloris), NOVEMBER 1991.

PLATE 2B KOKAKO EGGS AFTER FILMED POSSUM PREDATION. NOTE ABSENCE OF A LARGE SHELL FRAGMENTS AND THE INFOLDED, PELLET-LIKE SHELL REMAINS.