ECOLOGY AND CONSERVATION OF KOKI (*Prosopeia tabuensis*) IN TONGA

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of the requirements for the degree of
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MINOR AMENDMENTS

Abstract: Para 2 line 3 should read: "Highest koki density estimate was about 0.19 per hectare, and the average about 0.15 per hectare, suggesting about 1 koki per 6.6 hectares in 'Eua Plantation Forest".

Page 4: Delete the final sentence.

Tables 2.2, 2.4, 2.8: Read all mean values to one decimal place.

Page 47 last para: Read all mean values to one decimal place.

Page 50 last sentence should read: "Thus disturbances by people may limit the detectability and distribution of koki,....Chapter 3".

Tables 3.24; 3.25: Add to the Captions: "Fruit bats included for completeness"

This thesis is dedicated to my loving parents,

Sione Kiteau and Meliame Saafi

Photograph by E.Minot

Pea folofola 'a e 'Otua ......ke puna 'a e manupuna 'i he funga fonua moe mata 'o e langi. Pea na'e fakatupu 'e he 'Otua......mo e manupuna 'oku kapakau 'o fakafa'ahinga, pea na'e 'afio ki ai 'a e 'Otua kuo lelei. Pea na'e tapuaki'i kinautolu 'e he 'Otua 'o pehe........ke tokolahi 'a e manupuna 'i he fonua (Senesi 1: 20 – 21).

ABSTRACT

The population of Koki *Prosopeia tabuensis* on 'Eua, Tonga, was studied from August 1999 – November 2000. Line Transect and Point Count methods were used to estimate Koki density and abundance in 'Eua Plantation Forest and analyzed by distance sampling techniques. The density estimates derived by the two methods were compared.

Population estimates along six transect lines established in different forest types showed that the Point Count method tended to overestimate Koki density compared with the Line Transect method. Highest Koki density was 0.193 per hectare, and the average density was 0.153 per hectare, suggesting about 1 Koki per 6 hectares in 'Eua Plantation Forest.

The 'Eua Plantation forest was divided into four principal forest types and Koki density in each forest types was estimated using the Line Transect and the Point Count methods. Again, the Line Transect method better represented Koki density in these four forest types. Highest Koki density and abundance was associated with Native Forest, closely followed by *Pinus caribaea* Forest. It is estimated that there were approximately 620 Koki in the 'Eua Plantation Forest in 1999 - 2000.

Thirteen other birds were present at the 'Eua Plantation and they did not appear to compete with Koki for the same food sources.

Koki flying over the 'Eua National Park were calling when flying longer distances. The mean interval between calls for Koki calling while flying was 6.79 (95% C.I. = 5.78 – 7.99) seconds. The mean distance travelled by Koki flying and calling over the National Park was 134.50 (95% C.I. = 96.73 – 187.02) meters.

Koki fed on a variety of wild fruits and seeds including pinecones and pawpaw. Pinecones appeared to be a major food item in Koki diet at the 'Eua Plantation Forest. Eight Koki nests were found in the year 2000 breeding season. The eight nest trees suffered considerable damage by locals, removing the Koki chicks for sale. The implications of the research findings for future monitoring and conservation of Koki are discussed.

ACKNOWLEDGEMENTS

'Eiki lelei, teu kei fakafeta'ia mo fakamalo'ia aipe 'a e ngaahi tapuaki kuo ke faka'inasi'aki 'a 'eku nge'esi mo'ui ni. Sisu ke ke ma'u ma'au 'a 'eku ngaahi me'a kotoa, pea ke kei 'o 'ou 'a e kololia moe langilangi 'o lauikuonga.

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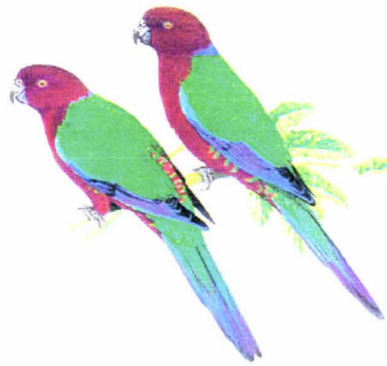


CHAPTER 1

GENERAL INTRODUCTION

1.1 KOKI

The Koki (Red Shining Parrot) (*Prosopeia tabuensis*) belongs to the family of parrots and lories known as Psittacidae. Within the Psittacidae there are four subfamilies. The Koki is a member of the subfamily Psittacinae (Forshaw and Cooper 1973). According to Forshaw and Cooper (1973), there are 271 species in 64 genera of Psittacidae and 261 species in 61 genera of Psittacinae. Different authors have used different forms of classifications of parrots within the Psittacidae. Higgins (1999) identified four subfamilies in the family Psittacidae but the subfamily Platycercinae is used in the place of Psittacinae. Close relatives of *Prosopeia tabuensis* include the Masked Shining parrot (*Prosopeia personata*) of Fiji, *the* Norfolk Island parakeet (*Cyanoramphus cookii*), the Antipodes parakeet (*Cyanoramphus unicolor)* of New Zealand and the endangered Orange-bellied parrot (*Neophema chrysogaster*) of Australia (Higgin 1999).

The Koki obtained its name from the local people of Tonga naming it according to the sounds it makes, which was *ko-ki-ko-ki* (Moala 1994). Rinke (1987) describes the voice of Koki as a dry rattle or variety of raucous squawks and screeches. However, Juniper and Parr (1998) characterizes the Koki voice as a harsh, loud *nea nea* and a grating *arrrrr* repeated in bursts and also a *ra-ra-ra-ra,* a dry bill rattle, various other hoots, squawks and screeches and distinctive *tok* when it approaches the nest.

A large, long tailed parrot the Koki has a bright green back and rump. A broad blue collar extends down the lower neck to the primary feathers of the wings and the ends of the tail feathers. The head and underparts are red/maroon (Forshaw and Cooper 1973, Watling 1982, Juniper and Parr 1998). Forshaw and Cooper (1973), Watling (1982) and Juniper and Parr (1998) all give the length of Koki as 45cm. Wing, tail, bill and tarsus measurements can be found in Forshaw and Cooper (1973) and Juniper and Parr (1998). No information on Koki longevity is available but there are records of captive parrots living for between thirty and fifty year (Forshaw and Cooper 1973). In the wild a female Kaka (*Nestor meridionalis)* is known to have lived for at least 27 years on Kapiti Island in New Zealand (Moorhouse and Greene 1995).

Currently five subspecies of Prosopeia tabuensis are recognized: *P. t.atrogularis, P.t.koroensis, P.t.taviuensis, P.t.tabuensis* and *P.t.splendens* (Watling 1982). Of the five subspecies *P.t. tabuensis* is the only subspecies found on 'Eua, Tonga. The other subspecies are found only in Fiji (Forshaw and Cooper 1973,Watling 1982, Juniper and Parr 1998). Watling (1982) identified the subspecies found in Tonga, as a variate in adult colouring, which is intermediate between *P.t. atrogularis* and *P.t.koroensis*. The change of plumage colouring is believed to be a result of introducing two or more subspecies to Tonga (Forshaw and Cooper 1973).

The sexes are morphologically very similar, although females have narrower upper mandibles than males (Rinke 1987, Juniper and Parr 1998). This difference can be easily seen in Koki nestlings as early as three weeks old (Rinke 1995). At one nest in Rinke's 1987 study where a female and a male nestling were weighed, the male nestling weighed 260g and the female nestling weighed 205g (Rinke 1987). All incubation and feeding of the young while they are in the nest is carried out by the female (Rinke 1987). On one occasion, however, in Rinke's work both parents were seen feeding the fully-feathered nestling at the entrance of the nest cavity.

Watling (1982) and Rinke (1987) found that in Tonga the Koki breeds during the cool and dry season, which lasts from May to October. Rinke (1987) recorded Koki nests in tree cavities where they lay two to three eggs at intervals of two days. The incubation period is 24 days and the young Koki stays in the nest for seven weeks before fledging (Rinke 1987).

Koki build nests in cavities of trees that grow in the remaining native forests on 'Eua, and occasionally in trees growing in plantations (Rinke 1987). Rinke (1987) found that the birds use a number of tree species including tavahi *(Rhus taitensis)*, ngatata *(Elattostachys falcata)* and salato *(Laportea harveyi)*.

The parrots feed on a variety of fruits and seeds (Watling 1982), including mango *Mangifera indica*, pawpaw *Carica papaya*, guava *Psidium guajava*, bananas *Musa spp* and kotone *Myristica hypargyraea* (Juniper and Parr 1998). Rinke (1995) shows Koki feeding on the cones of *Pinus caribaea*.

1.2 THE STATUS OF KOKI IN TONGA

The loss of birdlife in the tropical Pacific is accelerating and represents a 20 percent worldwide reduction in the number of species of birds. This accelerating reduction is mainly due to human impacts in recent centuries (Steadman 1995). The colonization of numerous islands by Polynesian settlers caused the first wave of impact on Pacific Island birdlife, and a second wave was initiated by the arrival of Western people (especially Europeans) in the Pacific (Rinke 1987).

Most Pacific islands, particularly large ones like Hawaii and New Zealand, supported rich avifaunas until the arrival of humans (Steadman 1995). On 'Eua, Tonga where the current research took place, bone deposits pre-date human arrival by tens of thousand of years (Watling 1982, Low 1994). At least 27 species of land birds lived on 'Eua in pre-human times, but only six of these have survived the past two centuries (Steadman 1995). Steadman (1995) also states that the toothbilled pigeon *(Didunculus)*, regarded as endemic to Samoa, once lived on 'Eua, as did the megapode *Megapodius pritchardii*, believed to be endemic to Niuafo'ou.

The Koki occurs naturally on the islands of Fiji and was first introduced to Tonga in the eighteenth century through trading activities between Tonga and the Fiji (Watling 1982, Low 1994). It was once widespread throughout the main islands of Tongatapu and 'Eua but, due to human collection, habitat loss from clearance of forests for agricultural purposes, and predation by species such as rats *(Rattus exulans)* and owls *(Tyto alba)*, the Koki is now found naturally only on 'Eua in Tonga (Rinke 1987).

The Koki population on 'Eua was estimated in 1988 to be between 700 and 1000 birds (Juniper and Parr 1998) – a much smaller population than previously. The main cause of the marked decline of the Koki is local people hunting the bird for food, pets, and the much prized maroon/red feathers to decorate fine mats and handicrafts (Watling 1982, Low 1994). The second major cause of the decline of Koki population is loss of habitat resulting from clearance of native forest for agricultural purposes (Watling 1982, Juniper and Parr 1998). Native forest provides habitat and nesting sites for Koki which nest in cavities in mature trees (Rinke 1987). Rinke (1987) also found that the entrance to such cavities is usually from a branch that has broken off, leaving a nest cavity with an inner diameter of at least 15cm, and a depth varying from less than 0.5m to more than 5m. The existence of old, established native forest is, therefore, a significant resource for breeding Koki seeking nest sites.

A small part of the decline of the Koki population is due to predation by the Polynesian rat *(Rattus exulans)* and barn owls (*Tyto alba)* feeding on the eggs (Rinke 1987). Overall, the sharp decline of the Koki now classes it as an endangered bird in Tonga (Rinke, 1995). It is illegal to hunt and trade the Koki in Tonga but unfortunately such activities still exist (unpublished observations). The Koki population on 'Eua was estimated in 1988 to be between 700 and 1000 birds (Juniper and Parr 1998).

1.3 'EUA

The Kingdom of Tonga consists of more than 150 islands. 'Eua island is the third largest island of the Tongan archipelago, lying within tropical latitudes (21°17'–21°27', S 174°55'W) in the southwest Pacific Ocean (Rinke 1987). 'Eua lies 20km south west of the main island Tongatapu, (Figure 1.1) (Bellingham and Fitzgerald 1997). The nearest land to the Tongan archipelago is Viti Levu, Fiji, 800km to the northwest, and Savaii Samoa 800km north. 'Eua also lies about 3300km east of Queensland, Australia and 1800km north northeast of Auckland New Zealand (Rinke 1987), and stands on the western edge, of the Tongan Trench.

'Eua is a high island approximately 81km² (Hoffmeister 1932), however recent studies estimated 'Eua to be 88km² (Bellingham and Fitzgerald 1997). Wilde and Hewitt (1983) estimated the island to be 19km long and up to 7km wide occupying 8100ha. A census by Bellingham and Fitzgerald (1998) showed that 'Eua has a population of 5000 in about 800 households. In all there are 15 villages on 'Eua, situated along the western side of the island. The main village on 'Eua is 'Ohonua, where the commercial center and Nafanua wharf is located (the only dock for all sea transport) (Figure 1.2). The most northern village is Houma and the most southern village is Ha'atu'a. The main form of transport from 'Eua to the main island Tongatapu is by ferry a 1 to 1½ hour journey. Plane flights from Kaufana Airport in the village Fata'ulua to Tongatapu takes 7 minutes.

'Eua rises from west to east along a series of raised terraces to high cliffs above its eastern coast (Bellingham and Fitzgerald 1997). The high eastern ridge reaches a maximum elevation of 312 m a.s.l. (Hoffmeister 1932, Drake 1996). Hoffmeister (1932) mapped five physiographic provinces on 'Eua. Figure 1.3 shows the five physiographic provinces described by Hoffmeister: 1) the eastern terraces and coastal regions, 2) the eastern ridge, 3) western slope of the eastern ridge, 4) the western ridge and central valley and 5) the western slope terraces and coastal region.

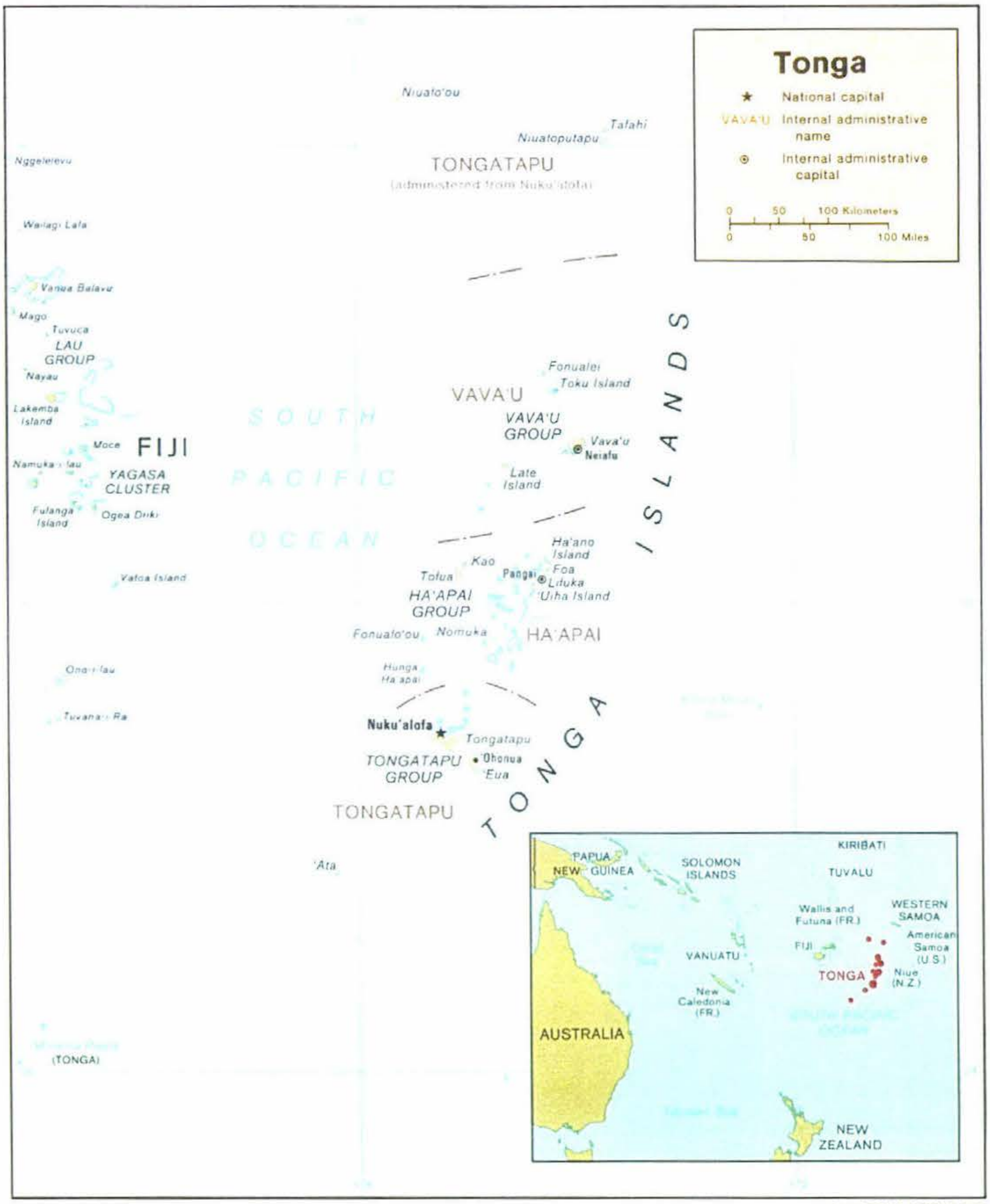


Figure 1.1 Map of the Tongan group of islands. From 'The Perry-Castañeda Library Map Collection, (http://pidp.eastwestcenter.org/pibn/countries/tonga.htm).

‘Eua Island

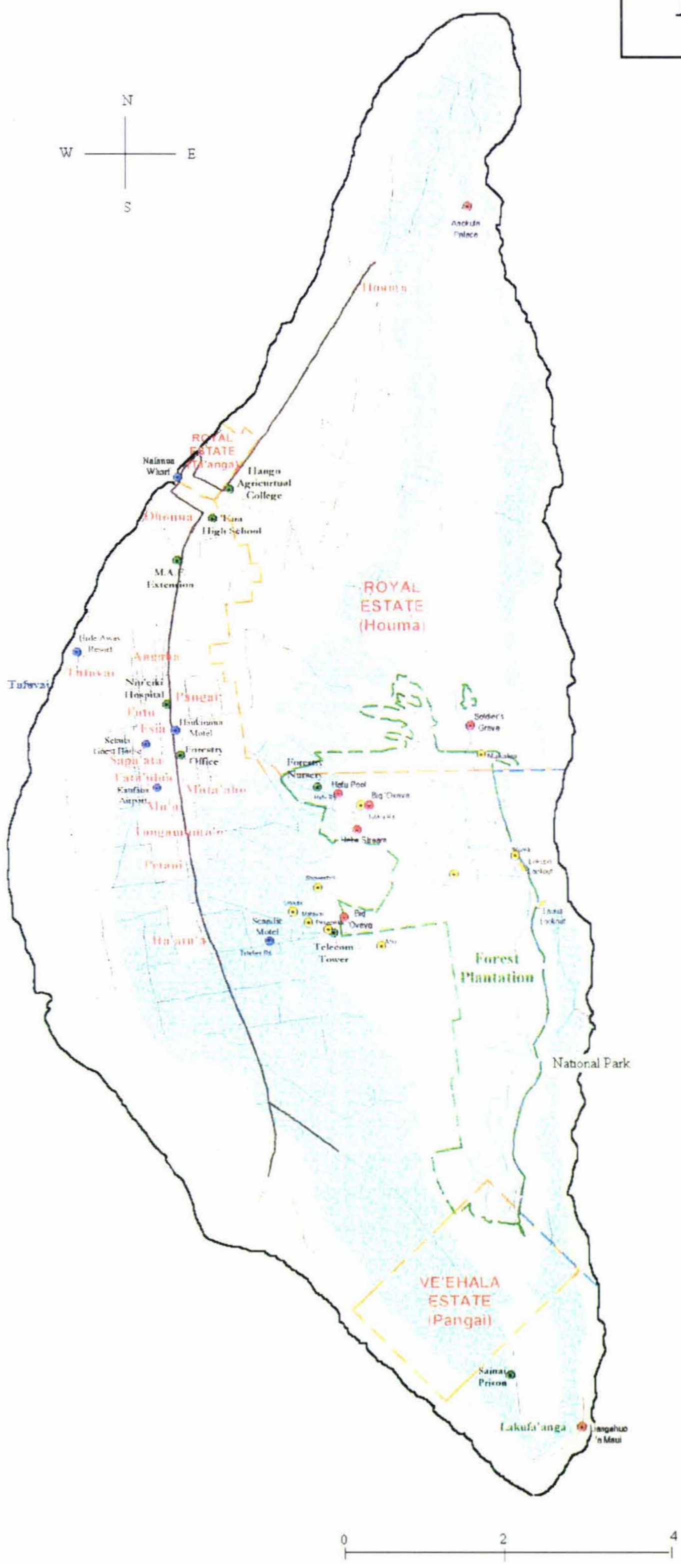


Figure 1.2 Map of ‘Eua Island.

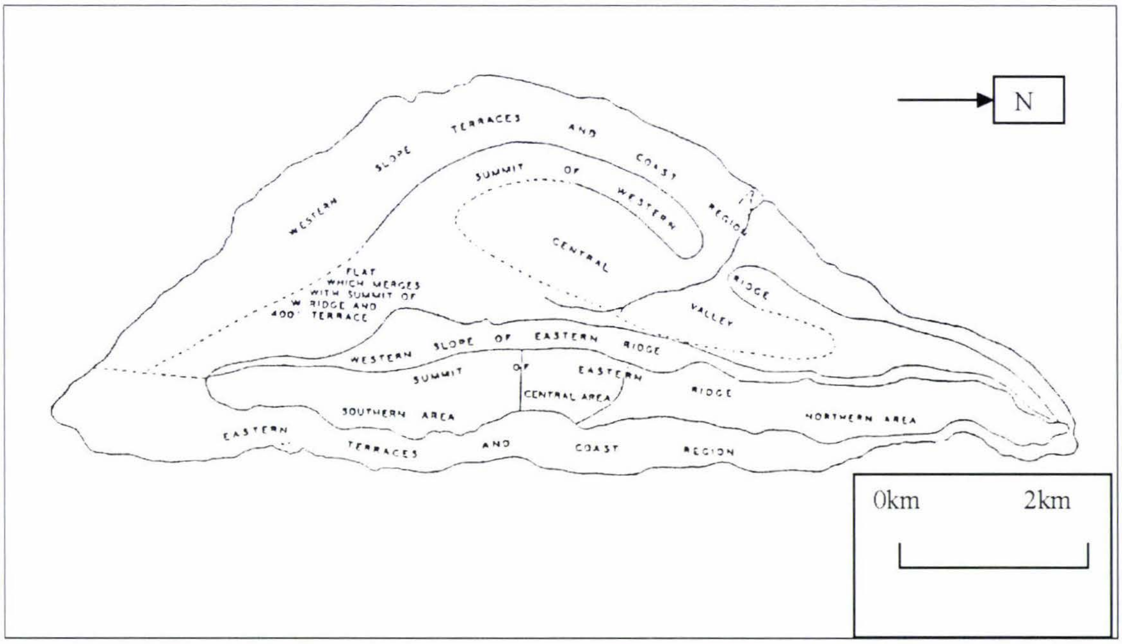


Figure 1.3 Map of the five physiographic provinces of 'Eua. From Wilde and Hewitt.

The 'Eua land surface is covered by limestone with a core of volcanic rocks (Drake 1996). The eastern side of the island is mostly steep cliffs, in some places falling 120m directly to the sea and in other places dropping 30-60m to the sea (Hoffmeister 1932). On the western side of the island, however, the cliffs are lower (6-10m high) falling to broader and more numerous beaches (Hoffmeister 1932).

'Eua lies in the south-east tradewind zone (Drake 1996), where the wind blows from the east to south-east from April to November i.e. three quarters of the year. (Bellingham and Fitzgerald 1997). The dry season runs from May to October and the wet season from November till April. The average annual rainfall is 2,700mm and 66% (c 178mm) falls during the wet season (Thompson (1986) cited in Drake (1996). During heavy rainfall periods some forest tracks are impassable with vehicles.

'Eua supports the most unique forest in the Tongan group (Drake 1996), comprising predominantly tropical and subtropical species (Wilde and Hewitt 1983). Many factors contribute to the uniqueness of the 'Eua forest. Plant taxa in the Pacific region decrease with increasing distance from the Malesian source area as quoted in Stoddart 1992

(Drake 1996). The combination of limestone substrate, and elevation leads raised islands such as 'Eua to have distinctive floras (Stoddart 1992). Wilde and Hewitt (1983) found that the presence of limestone is reflected by the vegetation, which is also influenced by the southeast trade winds atlitude and angle of the slopes (Wilde and Hewitt 1983). Plant composition on 'Eua is differs from that found in the more northern Vava'u island group, where the plant species composition did vary greatly with elevation (Drake 1996).

As agricultural practices developed the of 'Eua has gradually changed, for instance areas of forest have been cleared to plant crops. The remaining forests are now found on the steep slopes of the eastern coast (Bellingham and Fitzgerald 1997) and are protected as the 'Eua National Park (refer to Figure 1.2). There are other types of sparse forest on the coastal area of the island, which are either not, or scarcely, found in the National Park. For example on the highest point of the island, feto'omaka *Garcinia myrtifolia,* is the common plant and on other coastal forest, pekepeka *Maniltoa grandiflora,* is the common species (Bellingham and Fitzgerald 1997). Eight threatened flowering plants occur on 'Eua and 16 other threatened plants found in other parts of the Pacific are also found in 'Eua (Bellingham and Fitzgerald 1997).

'Eua supports 13 land bird species of which none is unique to Tonga (Bellingham and Fitzgerald 1997). Bellingham and Fitzgerald (1997) also recorded nine species of lizards 'Eua and two species of bats, peka (*Pteropus tonganus*) and pekepeka (*Emballonura semicaudata).*

Because 'Eua supports a rich and unique forest, in the 1960's, the first recommendation by to preserve an area of rainforest as a National Park. A similar recommendation was made by the East-West center of Hawaii in 1989 and other agencies in New Zealand and again in 1996 by Bellingham and Fitzgerald. Bellingham and Fitzgerald (1997) noted that 'Eua contains some of the last substantial areas of rain forest to be found in Tonga. 'Eua National Park now constitutes an area of 449.4 ha of tropical rainforest occupying most of the coastal south-eastern part of the island (Bellingham and Fitzgerald 1997), preserves and conserves the remaining biotically significant forest of 'Eua.

1.4 THESIS ORGANISATION

In order to recommend ways of monitoring and conserving a declining population, it is vital to know the size and density of the population, and how other areas of the species' ecology influence population size. This thesis comprises four data chapters and a concluding synthesis chapter where the overall findings are drawn together.

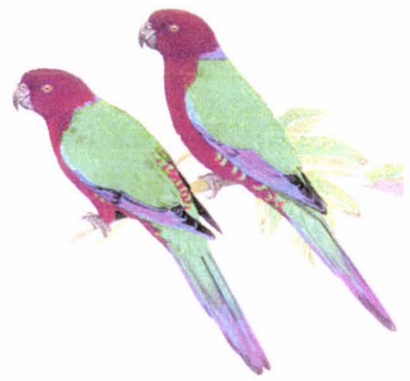
Chapter Two presents estimates of Koki density by Line Transect and Point Count methods for six transect lines in the 'Eua Plantation Forest. Koki flights and calling above the National Park, as observed from two lookouts, are also presented.

Chapter Three discusses the forest on 'Eua and its division into four forest types. Existing detailed maps and the Line Transect and Point Count data collected on the six transect lines were used to determine in which forest type each Koki was detected. Koki density was estimated for the four forest types, and Koki abundance was calculated, based on the density estimates. Other bird species present in the 'Eua Plantation Forest, and the tree species used by Koki are also presented in Chapter Three.

Chapter Four presents information on how Koki feed on pawpaw and other wild fruits, an assessment of the utilization of pinecones by Koki, and observations on the feeding behaviour of two captive parrots kept separately by locals as pets.

Chapter Five describes the locations of Koki nests found during the period June to October 2000. The activity of breeding Koki at these nests, and their outcomes, and the description of each nest site is also presented.

Chapter Six, summarizes the results from the previous chapters. Recommendations for future Koki management and monitoring are presented.



CHAPTER 2

POPULATION ESTIMATES AND DENSITY OF KOKI

2.1. INTRODUCTION

Many studies of biological populations require estimates of population density and abundance (Buckland *et al* 1993). This is essential if the population being studied is at a critical state where it is declining, or already at a small size, and the focus is on ways to maintain population viability (Caughley 1994, Young 2000)

There is concern about the conservation status of the Red Shining Parrot, or Koki (*Prosopeia tabuensis)* in Tonga. The Koki is not listed as a threatened species in the 'Red Data Book (1996) or in the 'Threatened birds of the world' (Birdlife International 2000) but it is rapidly declining in Tonga where it needs attention. However, two of the close relatives of the Koki found in Fiji are listed in the 'Threatened birds of the world' (Birdlife International 2000), which are Crimson Shining-Parrot (*Prosopeia splendens*) and Masked Shining-Parrot (*Prosopeia personata*). Introduced from Fiji in the eighteenth century (Watling 1982, Low 1994) the Koki population has declined dramatically due to habitat loss, deforestation and hunting by local people (Rinke 1987, Bellingham and Fitzgerald 1998). The local people have hunted, and are hunting, the Koki for its much-prized red feathers (Watling 1982). The Koki was once widespread on the main island, Tongatapu, but is now found only on 'Eua. The population on 'Eua mainly exists on the east coast in remaining native forest, part of which is preserved in 'Eua National Park (Bellingham and Fitzgerald 1998).

Dieter Rinke (1987) conducted the only detailed ecological study of 'Eua's remnant Koki population, and focused on reproductive biology. Juniper and Parr (1998) estimated the Koki population in 1988 at between 700 – 1,000. Apart from these studies, there is very little other information available on Koki. There is therefore a great need to obtain baseline knowledge of Koki abundance and density that will enable the population to be monitored and preserved.

This study uses and compares two census methods - Line Transects (Buckland *et al* 1993) and 5-minute Point Counts (Dawson and Bull 1975) to estimate Koki density and abundance on 'Eua.

The 5-minute point count method described by Dawson and Bull (1975) provides relative density counts of birds (Barraclough 2000). The method involves an observer standing at one place for 5 minutes, counting all the birds seen and heard (Bibby *et al*, 1992) and estimating the distance ('radial distance') from the point to the bird. The period spent at each point can vary depending on the species studied. Barraclough (2000) suggests for mobile species the briefer the time spent at each point the better and in tall forest two minutes is enough for detecting and recording species. Long counting periods can result in overestimating species density (Barraclough 2000).

The line transect method involves an observer walking along a randomly placed line (Buckland *et al* 1993) counting all birds seen and heard (Bibby *et al* 1992). The perpendicular distance from the line to each detected bird is recorded (Buckland *et al* 1993). The assumptions for the Point Count and the Line Transect methods are discussed by Bibby *et al* (1992) and Buckland *et al* (1993).

Point Count and the Line Transect methods are both suitable for study in extensive areas. Point counts, however, are more appropriate in areas where access is poor, or in fine-grained habitats (Bibby *et al* 1992). Line transects are recommended for sparsely distributed populations whereas point counts are recommended for dense populations (Barraclough 2000). Of the two methods, line transects are more widely applicable than point counts (Cassey & McArdle 1999). Observers carrying out these population estimate methods need to be well trained and motivated (Barraclough 2000) because the observer's skills can affect the accuracy of the data gathered.

Distance sampling estimates the absolute density of biological populations, using accurate distance measurements of all objects or species near a line or point (Buckland *et al* 1993, Barraclough 2000). Point count and line transect are both primary distance sampling methods (Buckland *et al* 1993, Cassey & Mcardle 1999, Barraclough 2000). Distance sampling is based on three key assumptions, which are firstly; objects on the line or point are detected with certainty. Secondly, objects are detected at their initial location and lastly, measurements are exact.

Distance sampling methods have been extensively developed to be widely applied for sampling animal populations (Burnham and Anderson 1984). Distance methods have been effective in sampling a wide range of species like tuatara (Cassey& Ussher 1999) benthic stream fishes, birds, whales, and also polar bears (Barraclough 2000).

Koki density on 'Eua was estimated with Point Count and the Line Transect methods. The data were analyzed using the distance sampling computer program 'DISTANCE' version 3.5 (Buckland *et al* 1993). The DISTANCE 3.5 program provides a range of models that are effective in the analysis of distance data, both point counts and line transects.

This chapter therefore presents and compares estimates of Koki abundance and density on 'Eua, Tonga, from Point Count and Line Transect methods. It also analyses the flight and calling of Koki flying as observed from the Lokupo and Lauua lookouts above the National Park.

2.2. METHODS

2.2.1. Establishment of transect line

A series of long transects were set up on the eastern slope of 'Eua, Tonga, within the 'Eua Forest Plantation. Six transects (Figure 2.1) between 1.4 to 2.1 km in length and totalling 9.8 km (Table 2.1) were established through a variety of forest types, following existing forestry tracks (Landcare Research 1997). All major forest types were represented by these transects. Along the transects, 54 points were installed at 200m intervals. The forest types in Table 2.1 are defined in Chapter 3.

Table 2.1 Transects lines for estimating Koki population from March 2000 to October 2000

Transect	Length (approx km)	Points	Principal forest type	Repetitions
1	2.2	11	Native forest	25
2	2.0	10	*Pinus caribaea*	15
3	1.4	7	*Pinus caribaea*	16
4	1.8	9	*Pinus caribaea*	15
5	1.4	7	Native forest	19
6	2.0	10	Mixed forest	32
TOTAL	9.8	54		122

The transects were walked by two observers each week (Transect 1 & 6) or fortnight (Transects 2,3,4,5) between March 2000 and November 2000.

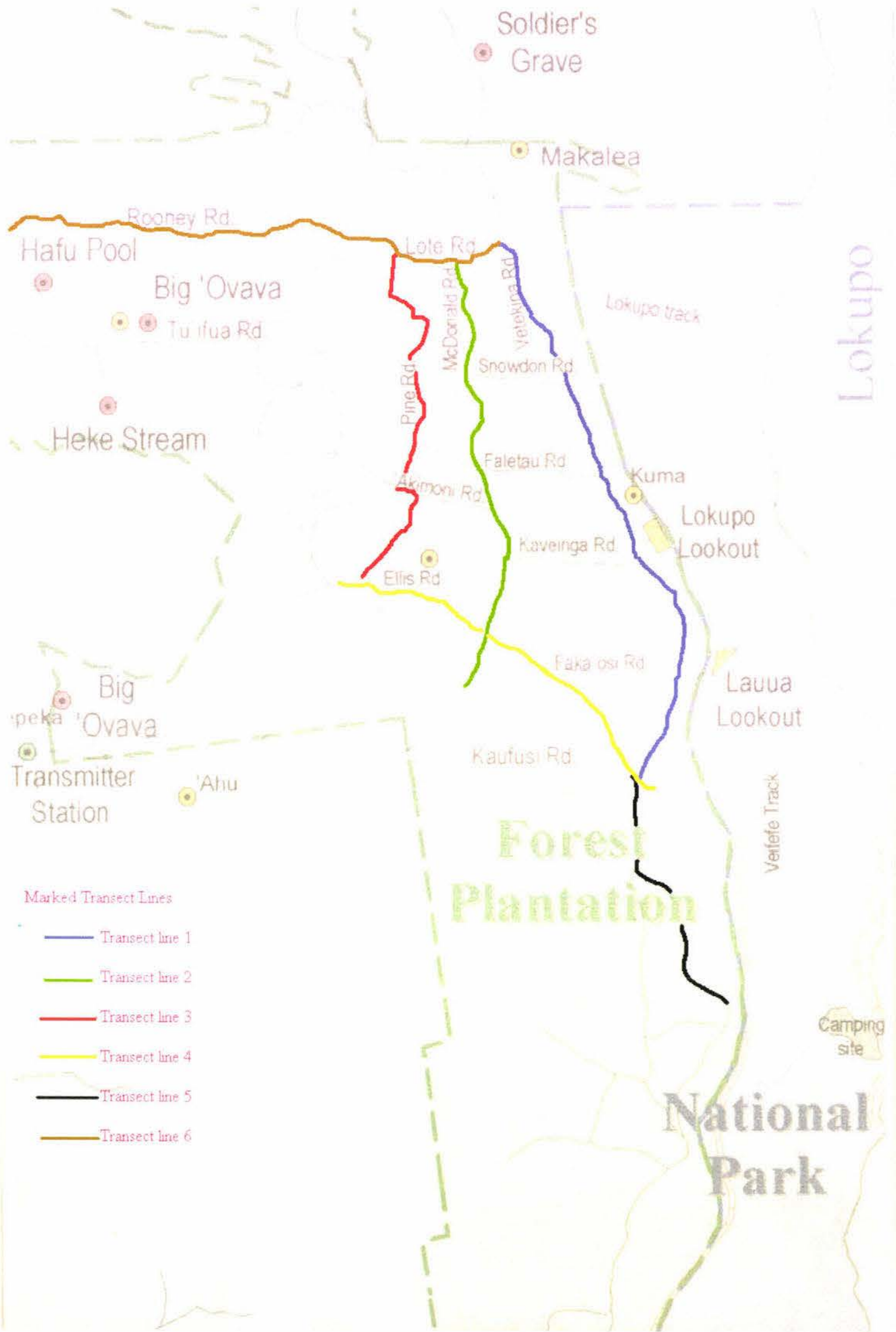


Figure 2.1. The six transect lines in the 'Eua Forest Plantation are shown. From Bellingham and Fitzgerald 1997.

The transects were divided into two groups that could each be carried out in one day between about 07:30 and 16:00 hours. Transects 1 and 6 were part of both groups which comprised (in order of walking), Group1: Transects 6,1,4,3; Group 2:Transects 6,1,5,2.

2.2.2. Distance Sampling (Line Transect and Point Counts).

On each transect, Koki numbers were assessed by means of Line Transect and Point Counts (Bibby *et al* 1992, Buckland *et al* 1993, Barraclough 2000).

The Line Transect method involves continuous sampling as the observer moves along the transect which is assumed, in the model, to approximate a straight line. When a Koki was seen or heard the compass direction (θ, degrees) of the bird (= object in Figure 2.2) was recorded and the distance (r) (in metres) from the observer was also estimated (Fig 2.2) the perpendicular distance (x) from the bird to the transect was later calculated (Fig 2.3).

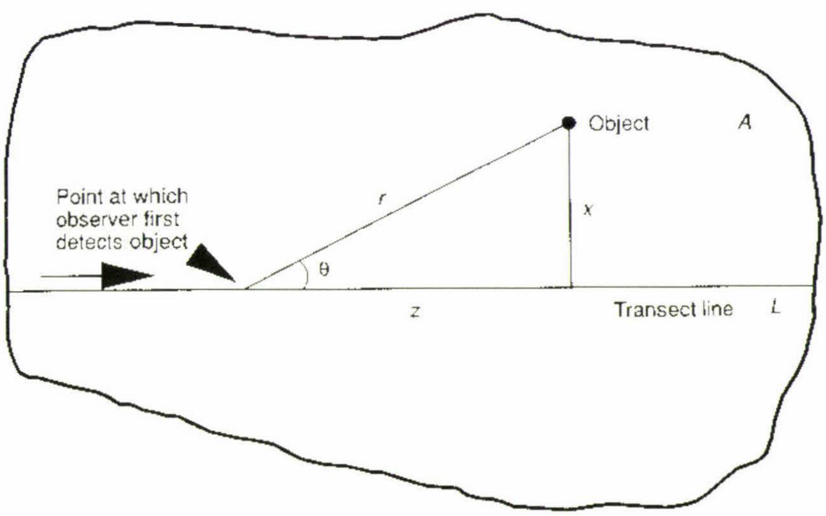


Figure 2.2 Basic distance measurements in line transect sampling. From (Buckland *et al* (1993). An area of size A is sampled by a single line of length L. The sighting distance is denoted by r and θ is the sighting angle, which allows analysis of the perpendicular distances x, calculated as $x = r \bullet \sin(\theta)$. The distance of the object (=bird) from the observer parallel to the transect at the moment of detection is $z = r \bullet \cos(\theta)$.

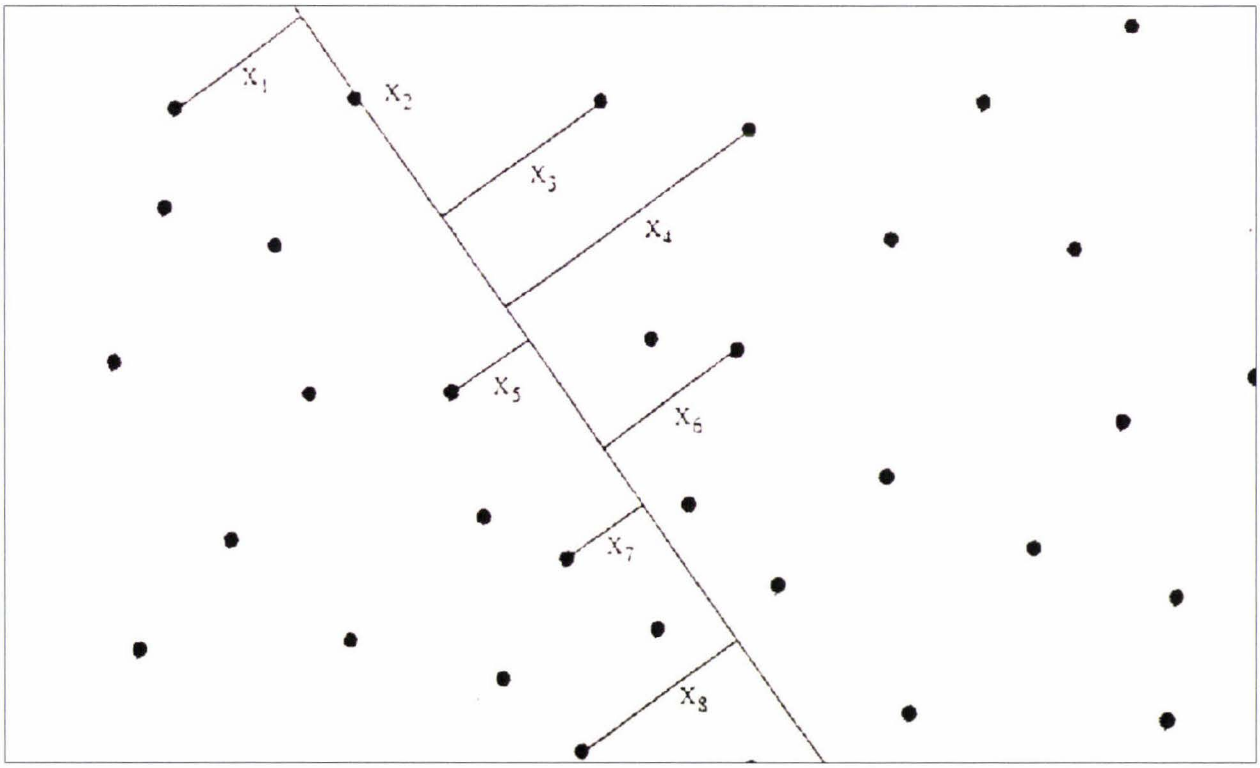


Figure 2. 3 Line transect sampling method showing a single, randomly placed line of length L. Eight birds ($n = 8$) were detected at perpendicular distances $x_1, x_2, \ldots x_8$. Many lines are used to estimate the population. From Cassey (1999).

Landcare Research (1997) prepared detailed maps of the 'Eua forest plantation comprising information on principal canopy species, years of establishment, estimated basal areas, land use, and area and average height of trees species. These detailed maps allowed every Koki that was recorded to be associated with the forest type at the bird's estimated point of location. The pooled data were analyzed by season and principal forest type using DISTANCE (Buckland *et al*, 1993).

Point Counts consisted of 5-minute observations for Koki at the 54 fixed points along the six transects. The method described by Dawson and Bull (1975), Bibby *et al* (1992) was followed, and care was taken to record each bird seen and heard once during any 5-minute count period (Fig 2.4). Point Counts were carried out in conjunction with distance sampling.

Line Transect counts were made only while walking the transects, while point counts were made only when standing still at each point count station.

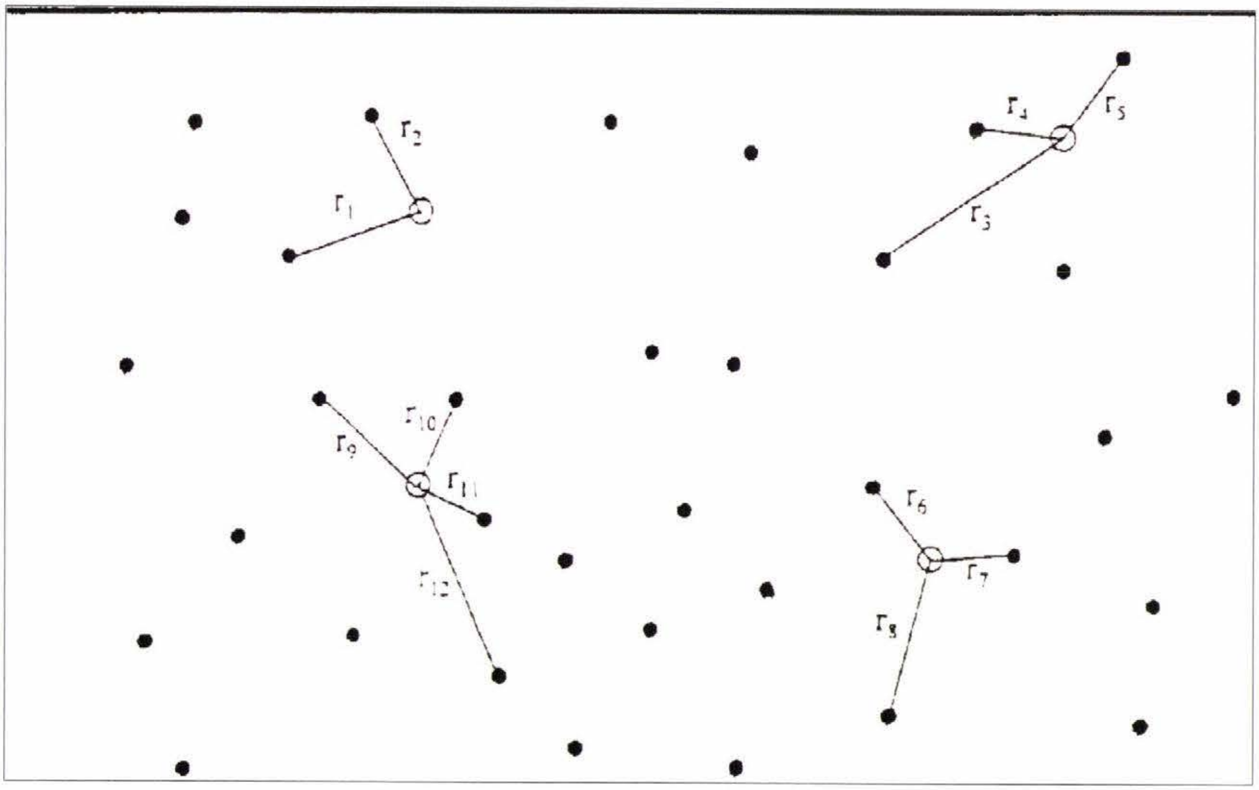


Figure 2.4 Point count sampling method (Cassey 1999) illustrating four randomly placed points (k=4), shown by open circles. Twelve birds were detected at sighting distances r_1, r_2,......r_{12}.

Koki encountered during Line Transect or Point Counts were as recorded as flying, feeding or perched (stationary), and as silent or calling. The direction taken by each flying Koki was noted. When the distance sampling methods were being carried out the second observer identified and recorded the presents of other bird species.

2.2.3. Direct observations of Koki flights at the Lookouts.

The eastern slopes of 'Eua rise to a crest at 312 ma.s.l (Fig 1.2) from which very steep cliffs fall to the eastern sea shore (Drake 1996). 'Eua National Park lies below, and east, of the crest and comprises a significant stand of native forest (Drake, 1996). From the crest, the forest (c 2-300m below) can be seen clearly and therefore Koki movement above the canopy is readily detected because the birds are large, bright, and sometimes noisy.

I used two vantage points above the National Park to look for Koki. These were Lokupo and Lauua lookouts (Figure 2.1), adjacent to Transect line 1. These lookouts were visited about weekly during the regular traverse of Transect 1. From March 2000 to May 2000, I spent 30 minutes at each lookout looking vertically down on the canopy of the National Park forest. From June 2000 to October 2000, as breeding progressed, this time was reduced to 15 minutes because the Koki were increasingly involved with breeding and few were seen.

On each occasion observations included: - durations of each flight, compass bearing of each flight, estimated length (m) of the flight, whether the parrot was vocal or silent during the flight,
tree species used at the start and end of the flight and weather conditions.

2.2.4. DISTANCE 3.5 Analysis

DISTANCE 3.5 (Buckland *et al* 1993) allows the estimation of density (D = number per unit area) of a biological population, and the data gathered using Point Counts and Line Transects are distances y_i from a randomly placed line or point to the species of interest (Buckland *et al* 1993). Buckland (*et al* 1993) clearly describes assumptions that underlie the theory behind the detection of species of interest. An important concept with estimating density of species using distance sampling is the detection function $g(y) = prob\ \{\text{detection} \mid \text{distance } y\}$, where detectability decreases with increasing distance from the random line or point (Buckland *et al* 1993, Cassey 1997, Barraclough 2000). Histograms of perpendicular distance measurements for the Line Transect method and radial distance measurements for the Point Count method provide models for the detection function (Cassey 2000).

DISTANCE 3.5 (Buckland *et al* 1993) provides several models for analyzing Point Count and Line Transect data. The modeling process can be broken down to two steps. The first step is selecting a 'key function', based on the shape of the histogram of the data gathered. There are four key functions to choose from which are: uniform; half-normal; hazard-rate; and negative exponential. The second step to modelling processing is 'series expansion', where the key function is adjusted to improve the fit of the model to the data gathered. The possible series expansions are: cosine; simple polynomial; and hermite polynomial. Therefore, there are twelve (4 x 3) possible models that could be applied to the data gathered, These include uniform + cosine; half-normal + cosine; hazard-rate + cosine; negative exponential + cosine; uniform + simple polynomial; half-normal + simple polynomial; hazard-rate + simple polynomial; negative exponential + simple polynomial; uniform + hermite polynomial; half-normal + hermite polynomial; hazard-rate + hermite polynomial; and negative exponential + hermite polynomial. These models were applied to the data gathered on Koki but only the most likely best-fitted models are presented.

Buckland (*et al* 1993) describes how best fitted models are selected, however what follows is a standard was of selecting models. Selected models are recommended (Buckland *et al* 1993) to have three properties, which are: model robustness; the shape criterion; and estimator efficiency. Model robustness requires the models to be flexible and be able to take a range of shapes that are likely for the true detection function. The shape criterion property requires the detection function plot provided by DISTANCE 3.5 to have a 'shoulder' near the line or point, and estimator efficiency requires estimates with small variances. The difference in Akaike's Information Criterion (ΔAIC) between all the models is a good indicator of which model to select. ΔAIC is computed for each model, the model with the lowest ΔAIC is selected. Truncating large observations also takes place to achieve the properties required. Detection probability plots are also presented. DISTANCE provided several plots, the plots with the high value of the probability of goodness of fit were selected (Buckland *et al* 1993).

2.2.5 SAS Analysis

The SAS statistical computer program was used to analyze data obtained from the two lookouts. ANOVA and chi-square tests were also used.

2.3. RESULTS

2.3.1. Koki count at the six transect lines - (Raw Data)

The two Distance Sampling methods – Line Transects and Point Counts - were carried out on the six transect lines from March - October 2000. The basic data are summarized in Tables 2.2 to Table 2.7. The figures for Tables 2.2, 2.4 and Table 2.6

were obtained by dividing the number of Koki detected (birds seen, birds heard and total seen or heard) along each transect by the number of times each of the transects was repeated (shown in Table 2.1 in Methods). The overall mean number of Koki detected (seen and heard) on each transect is presented in Table 2.2.

Table 2.2 Overall mean number of Koki detected (seen and heard) using the Line Transect and the Point Count methods on the six transect lines, March – October 2000.

Transect line	Mean ± SE number of Koki detected	
	5-minute Point Count	Line Transect
1	7.16 ± 0.02	4.40 ± 0.03
2	8.13 ± 0.02	3.60 ± 0.003
3	6.94 ± 0.02	5.40 ± 0.02
4	9.00 ± 0.03	5.80 ± 0.02
5	4.10 ± 0.01	3.20 ± 0.03
6	18.25 ± 0.02	13.56 ± 0.02

For every transect the mean number of Koki detected by 5-minute Point Counts was higher than the mean number detected by line transects. For the six transects the combined mean number of Koki detected using 5-minute point counts was 53.58 ± 0.80 while the number detected using line transects was 35.96 ± 0.64. This suggests that nearly one and a half times (+49%) as many Koki were encountered during 5-minute Point Counts as were found by walking the transect lines.

When the transect lines were ranked from the least Koki detected by sight and hearing to the most (Table 2.3), the two methods showed some similarities. For instance both methods showed that most Koki were detected on transect 6 and least on transect 5, and transects 1 and 4 had similarly ranked positions with both methods. The forest type on transect 6 is a mixture of native and introduced species while transect 5 is a mixture of native forest and *Pinus caribaea.* Transect 1 is mainly native forest while transects 2, 3 and 4 primarily run through *Pinus caribaea.*

Table 2.3 Transect lines ranked from least to most overall mean number of Koki detected by 5-minute Point Counts and Line Transects, March – October 2000.

	Transect lines ranked from least to most Koki detected					
	Least					**Most**
5-minute Point Count	5	3	1	2	4	6
Line Transect	5	2	1	3	4	6

The mean number of Koki detected visually on each transect varied according to the two population estimate methods (Table 2.4).

Table 2.4 The mean number of Koki seen on the six transect lines using the 5-minute Point Count and the Line Transect methods from March – October 2000.

Transect Lines	Mean ± SE number of Koki seen	
	5-minute Point Count	Line Transect
1	0.48 ± 0.00	0.64 ± 0.12
2	0.53 ± 0.13	1.20 ± 0.11
3	0.62 ± 0.09	0.68 ± 0.10
4	0.27 ± 0.26	1.13 ± 0.08
5	0.21 ± 0.00	0.37 ± 0.00
6	2.47 ± 0.12	2.75 ± 0.12

Table 2.4 shows that on average more Koki were seen while using the Line Transect method than the 5-minute Point Count method, but there were differences between transects. The overall mean number of Koki seen by the Line Transect method is 6.77 ± 0.14 while for the 5-minute Point Count method it is 4.58 ± 0.14. Thus detecting Koki by sight was not greatly affected by which population estimate method was used. When the six transects are ranked from least to most mean number of Koki detected visually (Table 2.5), the order of the lines differs from that generated by total Koki heard and seen (Table 2.3), except that again most Koki were seen on transect line 6 and the least on transect 5.

Table 2.5 Transect lines ranked from least to most Koki detected visually March – October 2000.

	Transect lines ranked from least to most Koki seen					
	Least					**Most**
5-minute Point Count	5	4	1	2	3	6
Line Transect	5	1	3	4	2	6

By the 5-minute Point Count method, Koki were seen most on transects 6, 3, and 2 in that sequences but by the Line Transect method Koki were seen most (sequentially) on transects 6, 2 and 4.

The mean number of Koki detected aurally using the Line Transect and the 5-minute Point Count methods also varied between transects (Table 2.6).

Table 2.6 The mean number of Koki heard on the six transect lines using the 5-minute Point Count and the Line Transect method from March – October 2000.

Transect lines	Mean number of Koki heard ± SE	
	5-minute Point Count	Line Transect
1	6.68 ± 0.02	3.76 ± 0.02
2	7.60 ± 0.01	2.40 ± 0.00
3	6.31 ± 0.02	4.75 ± 0.02
4	8.73 ± 0.03	4.60 ± 0.02
5	3.89 ± 0.01	2.80 ± 0.23
6	15.80 ± 0.01	10.80 ± 0.01

Table 2.6 strongly reflects the pattern in Table 2.2 where the 5-minute Point Counts consistently detected more birds than the Line Transect method. The overall mean for the number of Koki heard by the 5-minute Point Count method was 49.01 ± 0.68 and by the Line Transect method 29.11 ± 0.51. Thus approximately 70% more Koki were detected by their calling with 5-minute point counts than by walking the transect lines.

The six transects were ranked from least to most Koki detected aurally (Table 2.7) and once again showed that most birds were detected on transect 6. But the least number of Koki heard by 5-minute Point Counts were on transect 5 while by the Line Transect method the least number detected were on transect 2.

Table 2.7 Transect lines ranked from least to most Koki detected aurally March – October 2000.

	Transect lines ranked from least to most Koki heard					
	Least					**Most**
5-minute Point Count	5	3	1	2	4	6
Line transect	2	5	1	4	3	6

The ranked order of the six transects by the 5-minute Point Count method (Table 2.7) is in the same sequence as that for the total Koki detected (Table 2.3). For the Line Transect method the three transects where most Koki were heard are the same as those for total Koki seen or heard (Table 2.3), but the order is slightly different. Koki were mostly heard on transect 6, then transect 3, and third transect 4.

Overall, therefore, more Koki were seen and heard, or only heard, by the 5-minute point count method, but slightly more were seen by the line transect method. Many more birds were heard than seen, (approximately 3.9 – 6.3 times more by line transects and point counts respectively) and these data strongly influenced the overall results. Overall, most Koki were recorded along transect 6, and least on transect 5.

2.3.2 Koki density estimates by DISTANCE 3.5

The Line Transect and the Point Count methods were used to record the number of Koki visually and aurally detected from the six transect lines. The data gathered by the Line Transect method from each transect line were analyzed using DISTANCE 3.5 (Buckland *et al* 1993). DISTANCE 3.5 provided an estimate of the Koki density for both of the methods for each transect line. To obtain the best fit model for each transect line, the four key functions (uniform, half normal, hazard, and negative exponential) were applied and adjusted with the three series expansions (cosine, simple polynomial, and the hermite polynomials). The ΔAIC value is a very good indicator of which model to choose. The model with the lowest ΔAIC value is selected. The competing models are presented for each transect line, together with the number of parameters, ΔAIC, AIC weight, percentage of coefficient of variation and the 95% confidence interval. Models with ΔAIC values lying between 0 –2 are competing models. The best possible models, were chosen and analyzed further which involved truncation to obtain a robust model with a more likely true detection function. The lengths, number of points and the principal forest types on each lines are presented in Table 2.1.

Line Transect

The Line Transect method was used to record the number of Koki detected on six transect lines. Perpendicular distances from the observer to the Koki detected while traversing the six transect lines were calculated. The Line Transect data gathered from the six transect lines were analyzed using DISTANCE 3.5 (Buckland *et al* 1993). Models with ΔAIC values lying between 0-2 are presented as competing models. The best-fitted models are highlighted based on lowest ΔAIC value, highest percentage of AIC weights and fulfilling the properties required for robust models.

Transect line 1 – Line Transect

Transect line 1 is approximately 2.2km in length and the principal forest type is mainly Native Forest. Ninety-nine observations were collected from Transect line 1 using the Line Transect method, where 860m was the largest perpendicular distance observed. To produce more robust models, 8% of the largest observations were truncated, leaving 91 observations. Table 2 .8 shows summary of the only model that meet the properties for a robust model and the ΔAIC value lying between 0 –2, for Transect line 1.

Table 2.8 Summary of ΔAIC, AIC weights, density estimates of Koki per hectare, percentage of coefficient of variation, 95% confidence interval for competing model for Line Transect data gathered from Transect line 1.

Model (key + adjustments)	Total parameters	ΔAIC	AIC_w %	Density	C.V. %	95% C.I.
Hazard-rate + cosine	**2**	**1.23**	**100**	**0.193**	**19**	**0.133 – 0.279**

Table 2.8 shows the hazard-rate + cosine model was the best-fitted model for Transect line 1 using the Line Transect method. The hazard-rate + cosine model estimates Koki density on Transect line 1 as 0.193 (95% C.I.= 0.159 – 0.273) per hectare.

Figure 2.5 shows the histogram of detection function for Transect line 1 using the Line Transect method.

Figure 2.5 Histogram of detection function for Transect line 1 using the Line Transect method. The fit of the hazard-rate + cosine model (detection probability) is shown.

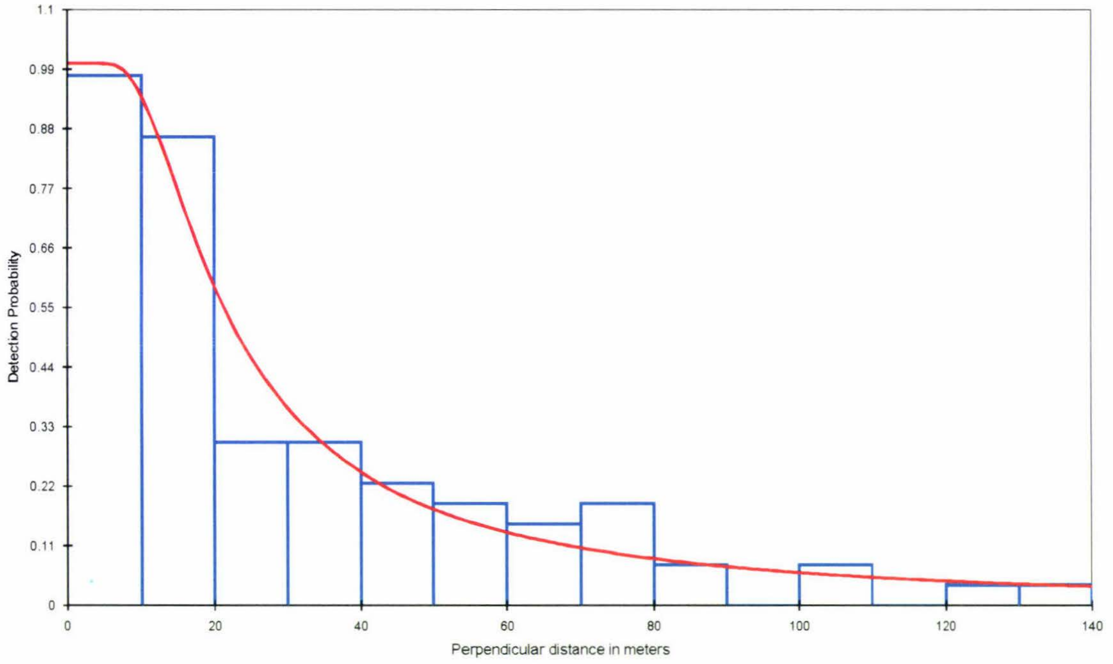


Figure 2.5 shows that Koki detection was greatest in the first distance interval (0 – 10m) and closely followed by the second distance interval (10 – 20m). Detection probability dropped rapidly at distance greater than 20m.

Transect line 2 – Line Transect

Transect line 2 was approximately 2.0km in length and *Pinus caribaea* was the principal forest type. The analysis was based on 49 observations and the largest distance recorded was 675m. To create more robust models, 10% of the largest observations were truncated, leaving 44 observations with 260m as the largest perpendicular distance observed.

The hazard-rate + cosine model was chosen to be the best-fitted model, because after truncating 10% of the largest observations, none of the ΔAIC value for other models lie between 0-2) to compete with the hazard-rate + cosine model. Table 2.9 presents the hazard-rate + cosine model for Transect line 2.

Table 2.9 Summary of delta AIC, AIC weights, density estimates of Koki per hectare, percentage of coefficient of variation, 95% confidence interval for best-fitted model for Line Transect data gathered from Transect line 2.

Model (key + adjustments)	Total parameters	Delta AIC	AIC_w %	Density	C.V. %	95% C.I.
Hazard-rate + cosine	**2**	**0.00**	**100**	**0.147**	**37.37**	**0.304 – 0.712**

The hazard-rate + cosine model in Table 2.9 estimates the Koki density on Transect line 2 using the Line Transect method, as 0.147 (95% C.I.= 0.304 – 0.712) per hectare.

Figure 2.6 shows the detection function histogram for Transect line 2 using the Line Transect method, with a probability of goodness of fit of 0.806.

Figure 2.6 Histogram of detection function for Transect line 2 using the Line Transect method. The fit of the hazard-rate + cosine model, detection probability is shown (red line).

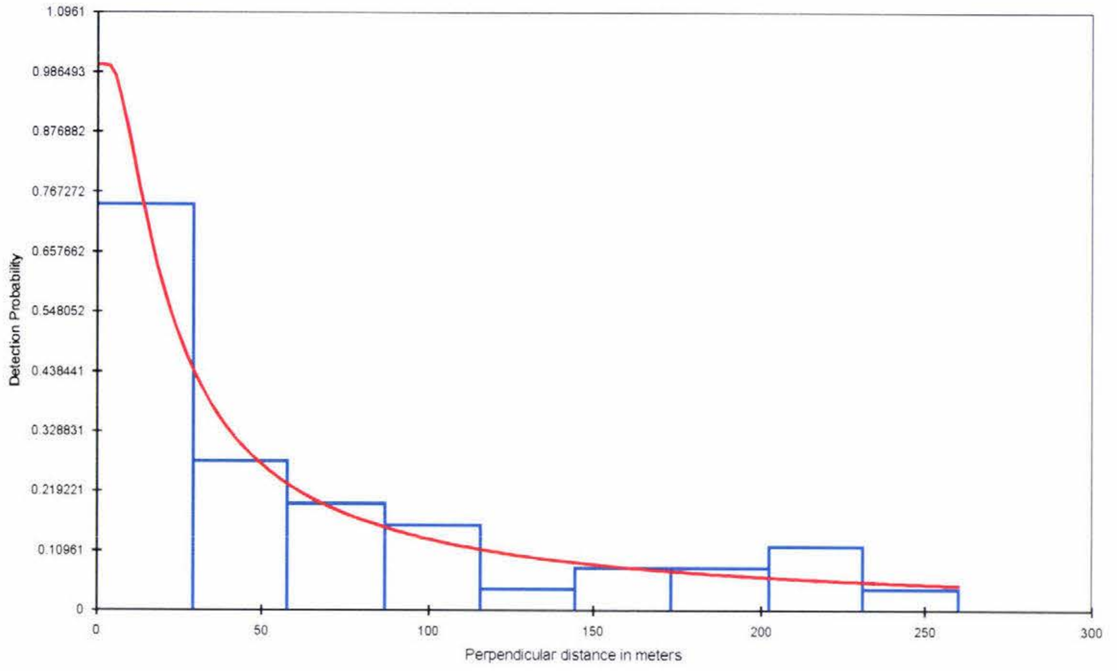


Figure 2.6 shows that detection is greater in the first distance interval (0-28.9m).

Transect line 3 – Line Transect

Transect line was approximately 1.4km in length. The principal forest type was *Pinus caribaea*. There were 79 observations recorded on Transect line 3 using the Line Transect method with 600m as the largest distance observation. Truncation of 10% of the largest observations took place to produce more robust models, leaving 78 observations and 168m as the largest observation.

Table 2.10 presents a summary of competing models for Transect line 3 using the Line Transect method.

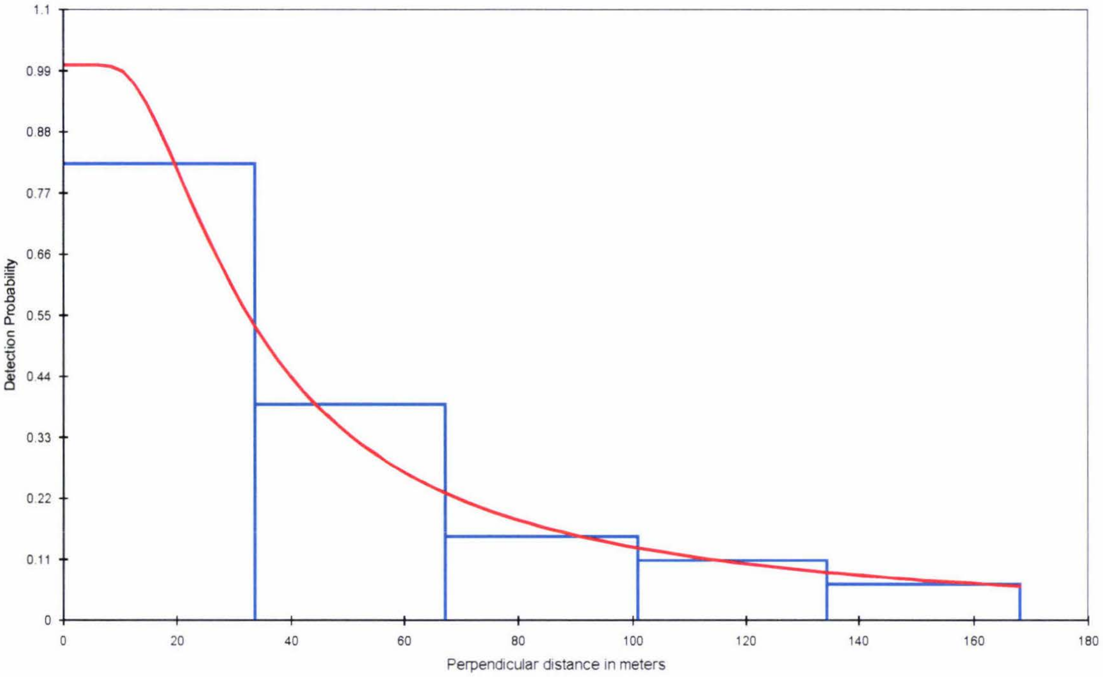
Table 2.10 Summary of ΔAIC, AIC weights, density estimates of Koki per hectare, coefficient variation, 95% confidence interval for competing model for Line Transect data gathered from Transect line 3.

Model (key + adjustments)	Total parameters	ΔAIC	AIC_w %	Density	C.V. %	95% C.I.
Uniform + cosine	3	1.570	22.00	0.121	13.80	0.09 – 0.16
Half-normal + cosine	2	0.740	33.3	0.123	13.85	0.09 – 0.16
Hazard-rate + cosine	**2**	**0.150**	**44.7**	**0.135**	**21.36**	**0.09 – 0.20**

The Hazard-rate + cosine model was chosen to be the best-fitted model for Transect line 3 using the Line Transect method, based on the lowest ΔAIC and the highest percentage of AIC weights (44.7%). The hazard-rate + cosine model estimates the Koki density on Transect line 3, using the Line Transect method as 0.135 (95% C.I.= 0.09 – 0.20) per hectare.

Figure 2.7 shows the histogram of the detection probability for Transect line 3 using the Line Transect method.

Figure 2.7 Histogram of detection probability for Transect line 3 using the Line Transect method. The fit of the hazard-rate + cosine model, detection probability is shown (red line).



In Figure 2.7 detection was greatest in the first distance interval [0 – 33.6 metres], then the detection probability dropped in the remaining distance intervals.

Transect line 4 – Line Transect

Transect line 4 was approximately 1.8km with the principal forest type was *Pinus caribaea*. There were 76 observations recorded from Transect line 4 with 790m as the largest distance observation. To achieve robust models, 10% of the largest observations were truncated, leaving 68 observations with 128m as the largest observation. Table 2.11 shows a summary of the competing models for Transect line 4.

Table 2.11 Summary of ΔAIC, AIC weights, density estimates of Koki per hectare, coefficient of variation, 95% confidence interval for competing model for Line Transect data gathered from Transect line 4.

Model (key + adjustments)	Total parameters	Delta AIC	AIC_w %	Density	C.V. %	95% C.I.
Half-normal + cosine	2	1.340	21.3	0.157	14.83	0.118 – 0.211
Hazard-rate + cosine	**3**	**0.000**	**41.7**	**0.175**	**20.22**	**0.117 – 0.260**
Hazard-rate + simple	2	0.230	37.1	0.174	22.63	0.174 – 0.112

Table 2.11 shows the hazard-rate + cosine was the chosen best-fitted model with the lowest ΔAIC value (0.00) and highest percentage of AIC weight (41.7). The hazard-rate + cosine model estimates the Koki density for Transect line 4 using the Line Transect method as 0.175 (95% C.I.= 0.118 – 0.255) per hectare.

Figure 2.8 shows the histogram of the detection probability for the hazard-rate + cosine model for Transect line 4 using the Line Transect method, with a probability goodness of fit of 0.893

Figure 2.8 Histogram of detection probability for Transect line 4 using the Line Transect method. The fit of the hazard-rate + cosine model, detection probability is shown (red line).

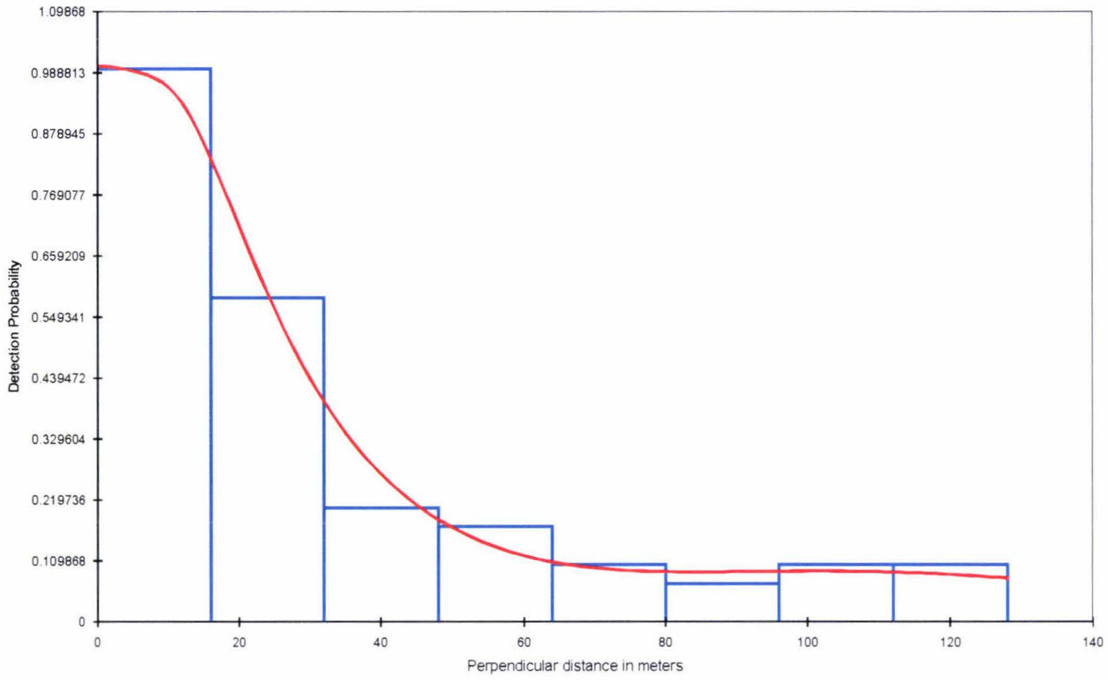


Figure 2.8 shows that detection is greater in the first distance interval (0-16m).

Transect line 5 – Line Transect

Transect line 5 was approximately 2.0km in length and Native forest was the principal forest type. Fifty-one observations were collected from Transect line 5 using the Line Transect method, with 424m as the largest perpendicular distance observed. Observations greater than 120 meters were truncated to achieve robust models. Table 2.12 presents a summary of the only model that best fits the Line Transect data gathered from Transect line 5.

Table 2.12 Summary of delta AIC, AIC weights, density estimates of Koki per hectare, coefficient of variation, 95% confidence interval for best-fitted model for Line Transect data gathered from Transect line 5.

Model (key + adjustments)	Total parameters	ΔAIC	AIC_w %	Density	C.V. %	95% C.I.
Hazard-rate + cosine	**2**	**0.560**	**100**	**0.105**	**30.2**	**0.06 – 0.19**

The hazard-rate + cosine model estimates the Koki density for transect line 5 using the Line Transect method as 0.105 (95% C.I. = 0.06 – 0.19) per hectare.

Figure 2.9 shows a probability detection histogram of the hazard-rate + cosine model for Transect line 5 using the Line transect method, with a probability of goodness of fit of 0.109.

Figure 2.9 Histogram of detection probability for Transect line 5 using the Line Transect method.

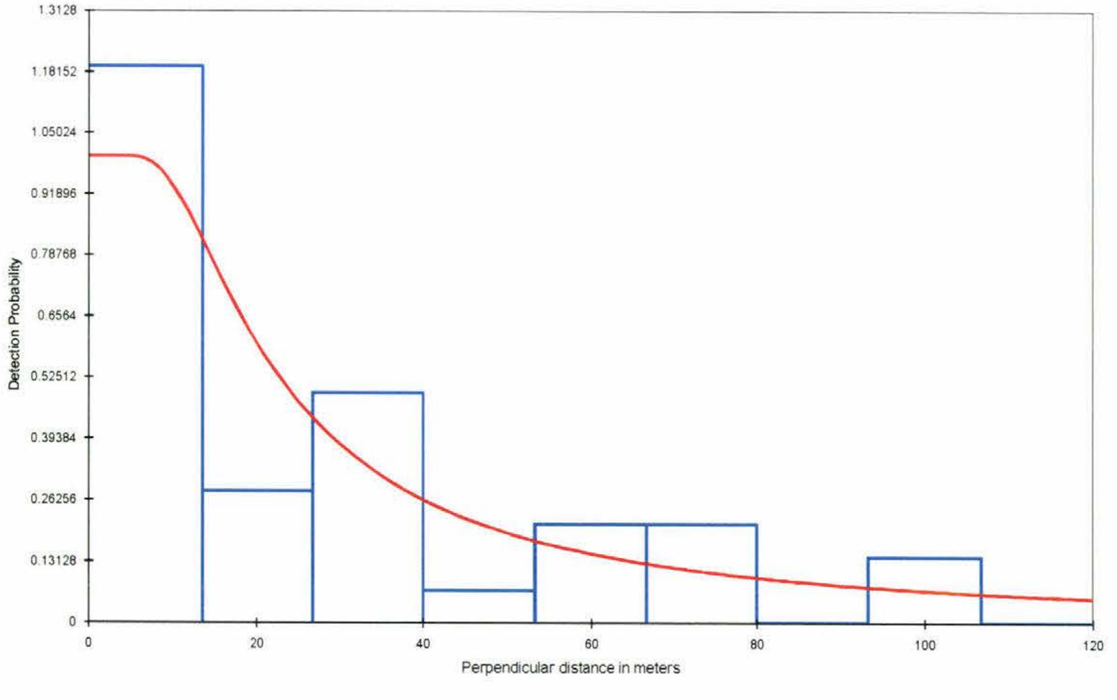


Figure 2.9 shows that detection is greater in the first distance interval of 0 – 13 meters.

Transect line 6 – Line Transect

Transect line 6 was approximately 2.0km with Mixed Forest as the principal forest type. The Line Transect method was used to collect 366 observations from Transect line 6, with 820m as the largest observation. Eight percent of the largest observations were truncated to create robust models, leaving 337 observations with 204m as the largest perpendicular distance observed. Table 2.13 presents competing models for Transect line 6.

Table 2.13 Summary of ΔAIC, AIC weights, density estimates of Koki per hectare, coefficient variation, 95% confidence interval for competing model for Line Transect data gathered from Transect line 6.

Model (key + adjustments)	Total parameters	ΔAIC	AIC_w %	Density	C.V. %	95% C.I.
Half-normal + cosine	2	1.700	43	0.163	7.87	0.14 – 0.19
Hazard-rate + cosine	**2**	**1.600**	**45**	**0.164**	**9.62**	**0.136 – 0.199**

Table 2.13 shows that the hazard-rate + cosine model is the best-fitted model based on the lowest ΔAIC value (1.600) and the high percentage of AIC weight (45%). The hazard-rate + cosine model estimates the Koki density on Transect line 5 as 0.164 (95% C.I. = 0.136 – 0.199) per hectare using the Line Transect method.

Figure 2.10 shows a histogram of detection probability for the hazard-rate + cosine for Transect line 6 using the Line Transect method.

Figure 2.10 Histogram of detection probability for the hazard-rate + cosine (8% truncation) model for Transect line 6 using the Transect Line method.

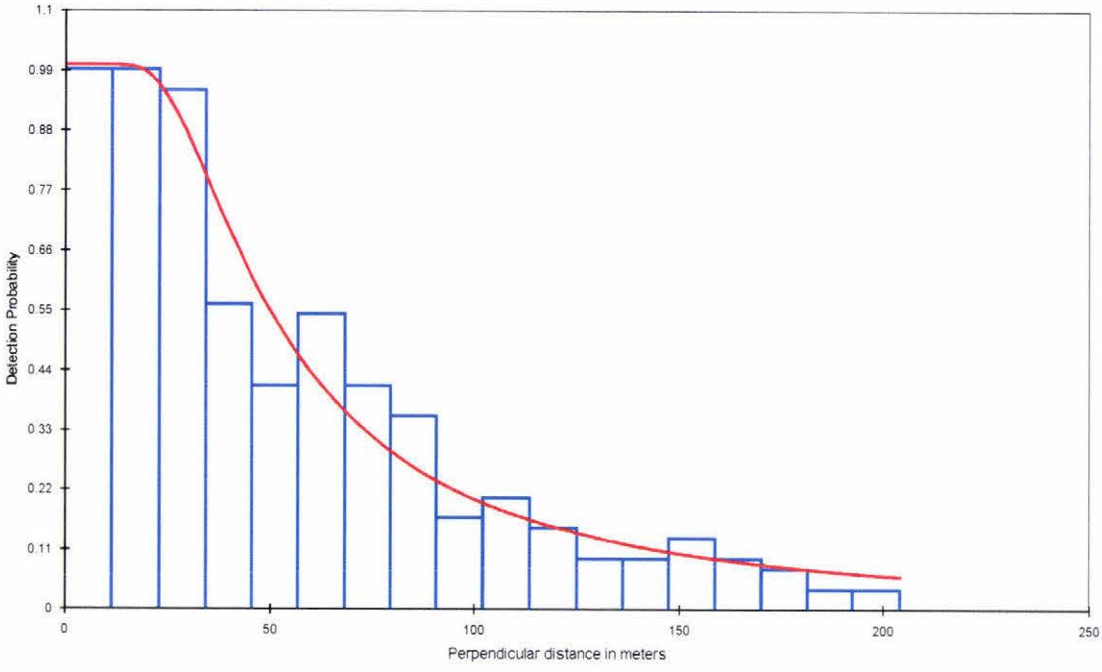


Figure 2.10 shows that detection was greater in the first and second distance interval (0-11.3m, 11.3 – 22.7m), then a slight decrease to the third distance interval (22.7 – 34m) then drops gradually.

Point Count

The Point Count method was used to record the number of Koki detected on six transect lines. Five minutes was spent at each point, radial distances were estimated from the point count station to the Koki detected. The point count data gathered from the six transect lines were analysed using DISTANCE 3.5 (Buckland *et al* 1993) to provide a density estimate for each line. The competing models are presented for each line. Models are said to be competing if the ΔAIC value lies between 0 – 2. The length, number of points and the principal forest types for the six transect line are presented in Table 2.1. The points were 200 metres apart.

Transect line 1 –Point Count

The best –fitted model to the data gathered from 11 points along transect line 1 using the Point Count method is presented in Table 2.14. Models were applied to 177 observations with 710m at the largest radial distance.

To create a more robust model, observations greater than 140 metres were truncated, leaving 120 observations to be analysed with 120m as the largest radial distance. Table 2.14 presents a summary of the ΔAIC, AIC_w, estimate of Koki density, percentage of coefficient of variation and 95% confidence interval for competing models.

Table 2.14 Summary of ΔAIC, AIC weights, density estimates of Koki per hectare, percentage of coefficient of variation, 95% confidence interval for competing model for Point Count data gathered from Transect line 1.

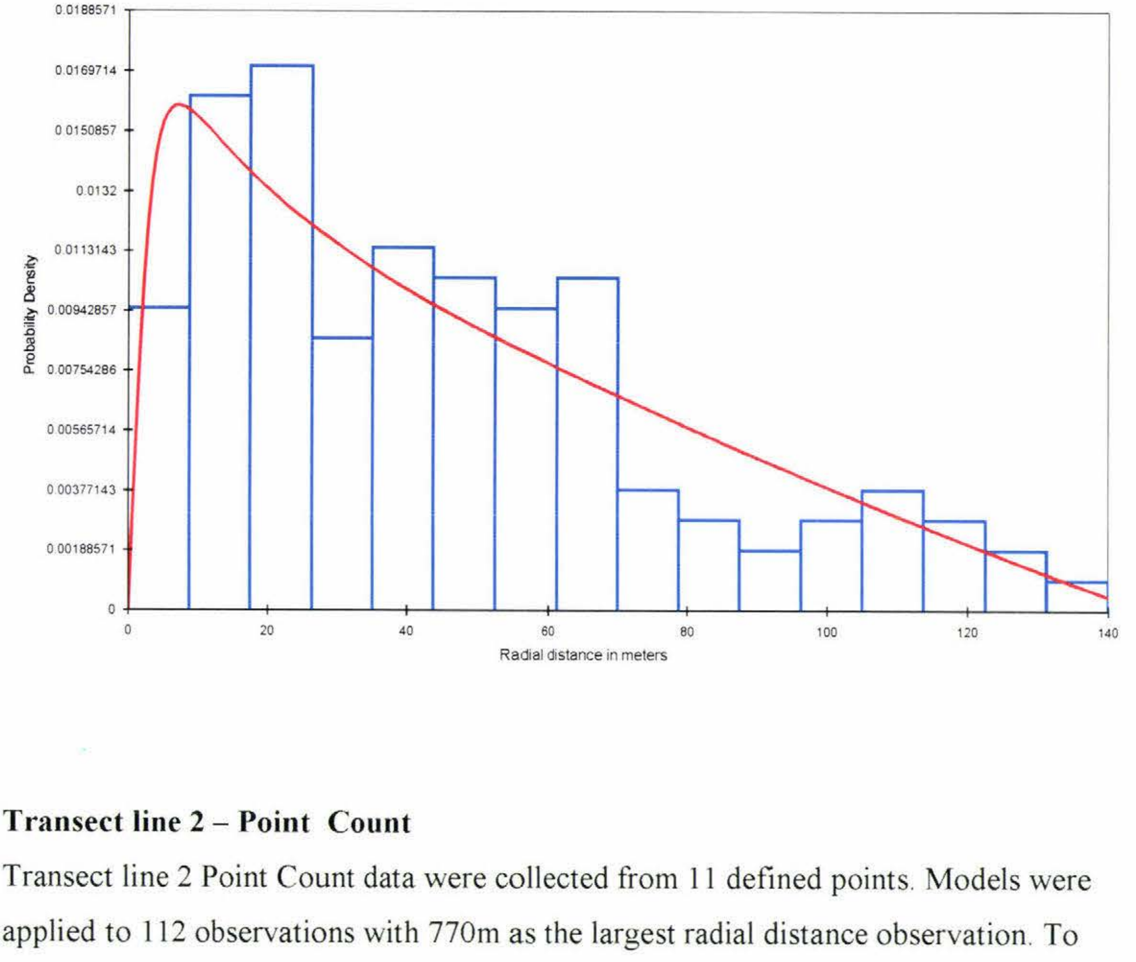
Model (key + adjustments)	Total parameters	ΔAIC	AIC_w %	Density	C.V.%	95% C.I.
Hazard-rate + polynomial	3	1.8	29.9	4.28	34.33	2.21 – 8.28
Hazard-rate + hermite	**3**	**0.10**	**70.1**	**8.86**	**56.39**	**3.13 – 25.08**

Table 2.14 shows the hazard-rate + hermite is the best-fitted model to represent the Transect line 1 data using the Point Count method. The hazard-rate + hermite model is chosen, because it provides the lowest ΔAIC value (0.10) and the highest percentage of AIC weight (70.1%) out of two competing models. The hazard-rate +

hermite model estimates the Koki density for Transect 1 as 8.86 (95% C.I. = 3.13 – 25.08) per hectare.

Figure 2.11 shows the probability detection function plot for transect line 1 with a goodness of fit probability levels of 0.734.

Figure 2.11 Probability detection function plot for Transect line 1.



Transect line 2 – Point Count

Transect line 2 Point Count data were collected from 11 defined points. Models were applied to 112 observations with 770m as the largest radial distance observation. To achieve more robust models, 10% of the largest observations were truncated, leaving 104 observations with 480m as the largest radial distance. Table 2.15 is a summary of the ΔAIC value, percentage of AIC weights, Koki density estimate per hectare, critical value and the 95% of confidence interval for the best-fitted model for Transect line 2 using the Point Count method.

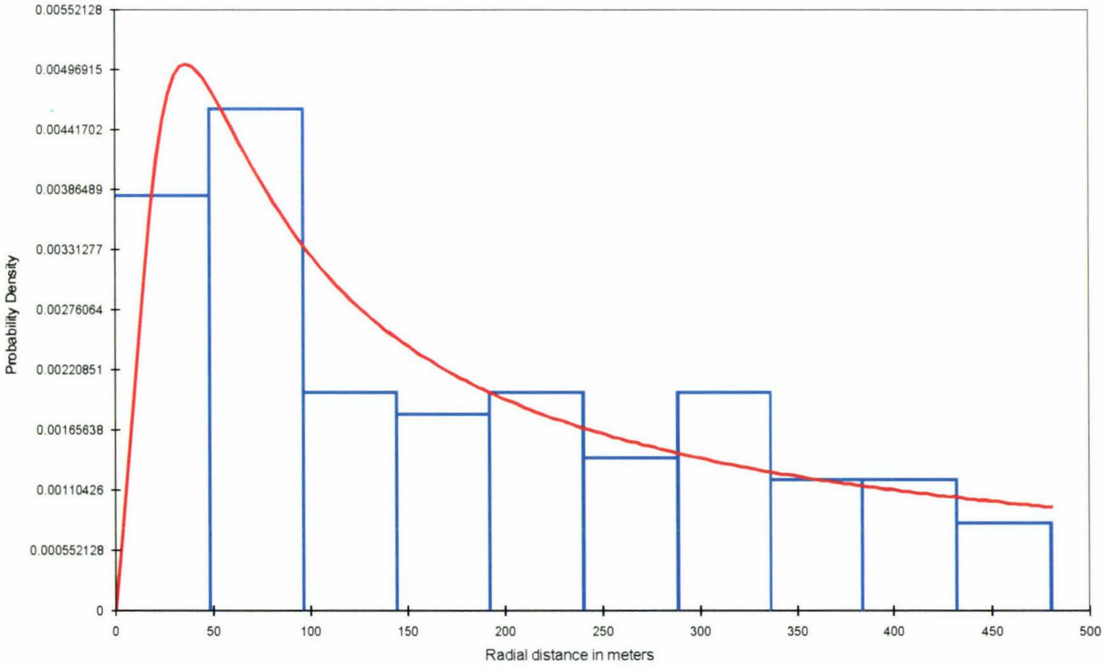
Table 2.15 Summary of ΔAIC, percentage of AIC weights, density estimates of Koki per hectare, percentage of coefficient of variation, 95% confidence interval for competing model for Point Count data gathered from Transect line 2.

Model (key + adjustments)	Total parameters	ΔAIC	AIC_w %	Density	C.V.%	95% C.I.
Hazard-rate + cosine	**2**	**0.600**	**100**	**0.46**	**38.04**	**0.22 – 0.95**

Table 2.15 shows that the hazard-rate + cosine model was the only best-fitted model for Transect line 2 based on the lowest ΔAIC value and the highest percentage of AIC weight. The hazard-rate + cosine model estimates Koki density as 0.66 (95% C.I. = 0.43 – 1.01) per hectare for Transect line 2 using the Point Count method.

Figure 2.12 presents the probability detection function plot for the hazard-rate + cosine model for Transect line 2, with a probability of goodness of fit of 0.763.

Figure 2.12 Probability detection function plot for the hazard-rate + cosine (10% truncation) model for Transect line 2.



Transect line 3 – Point Count

There were 7 defined points on Transect line 3 where 104 observations were collected with 780m as the largest radial distance observed. To create robust models, observations greater than 180m were truncated, leaving 72 observations. Table 2.16 is a summary of competing models for Transect line 3 using the Point Count method.

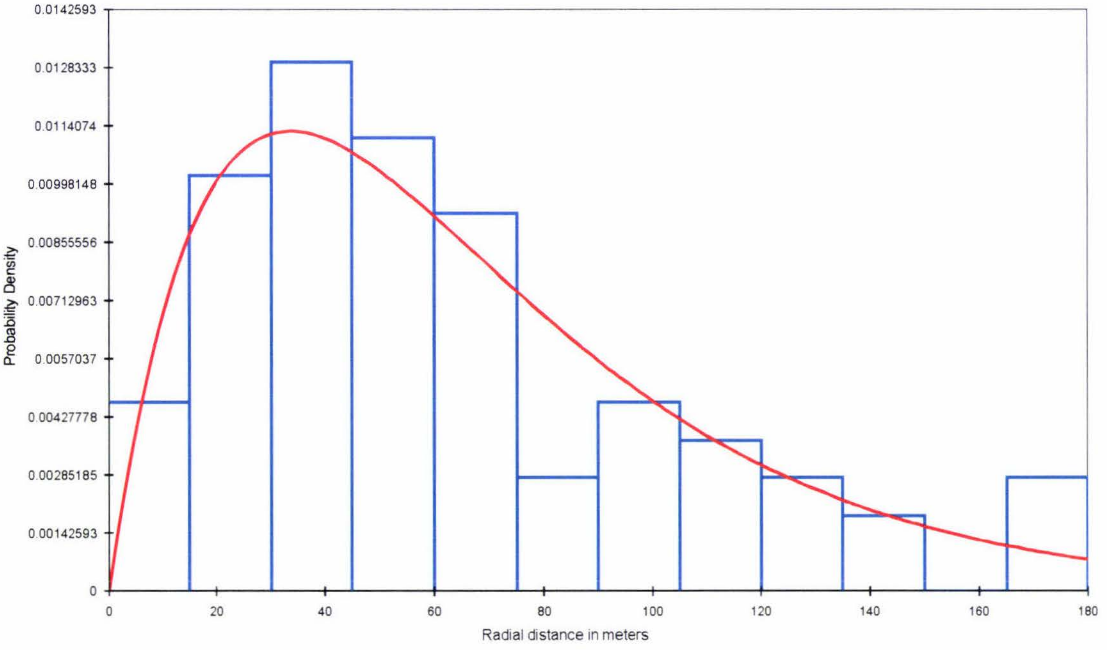
Table 2.16 Summary of ΔAIC, percentage of AIC weights, density estimates of Koki per hectare, percentage of coefficient of variation, 95% confidence interval for competing model for Point Count data gathered from Transect line 3.

Model (key + adjustments)	Total parameters	ΔAIC	AIC_w %	Density	C.V.%	95% C.I.
Half-normal + cosine	2	1.29	22.8	1.11	18.36	0.78 – 1.60
Hazard-rate + cosine	2	0.55	33.3	0.93	24.59	0.58 – 1.51
Negative exponential + cosine	**1**	**0.00**	**43.9**	**1.71**	**20.84**	**1.14 – 2.57**

Table 2.16 shows that the negative exponential + cosine model is the best-fitted model based on the lowest ΔAIC value (0.00) and the highest percentage of AIC weight. The negative exponential + cosine model estimates the Koki density as 1.71 (95% C.I. = 1.14 – 2.57) per hectare for Transect line 3 using the Point Count method.

Figure 2.13 presents the probability detection function plot for the negative exponential + polynomial model for Transect line 3, with a probability of goodness of fit of 0.779.

Figure 2.13 Probability detection function plot for the exponential + cosine model for Transect line 3 using the Point Count method.



Transect line 4 – Point Count

There were 9 defined points on Transect line 4, 127 observations were collected and 899m was the largest radial distance observed. Observations greater than 200m were truncated to create a more robust models. Competing models for Transect line 4 using the Point Count method are presented in Table 2.17.

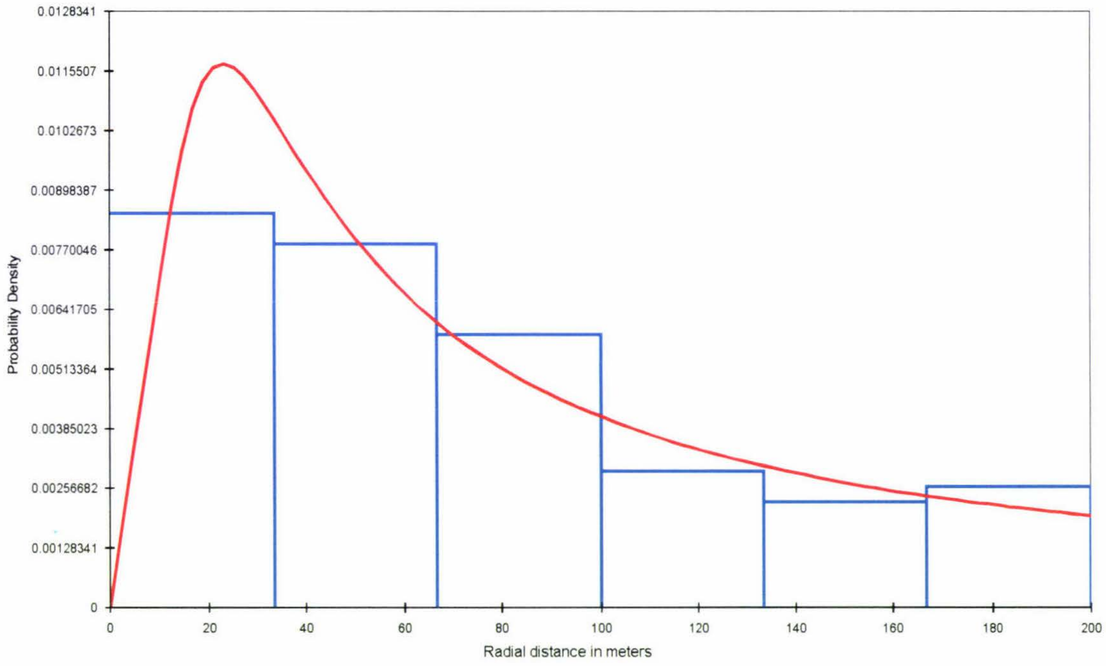
Table 2.17 Summary of ΔAIC, percentage of AIC weights, density estimates of Koki per hectare, percentage of coefficient of variation, 95% confidence interval for competing model for Point Count data gathered from Transect line 4.

Model (key + adjustments)	Total parameters	ΔAIC	AIC_w %	Density	C.V.%	95% C.I.
Uniform + cosine	4	1.13	26.2	1.07	16.14	0.78 – 1.47
Half-normal + cosine	2	1.01	27.8	0.99	15.65	0.73 – 1.34
Hazard-rate + cosine	**2**	**0.00**	**46**	**1.40**	**31.67**	**0.76 – 2.58**

The hazard-rate + cosine model is chosen to be the best-fitted model based on the lowest ΔAIC value and the highest percentage of AIC weight. The hazard-rate + cosine model estimates the Koki density as 1.40 (95% C.I. = 0.76 – 2.58) per hectare for Transect line 4 using the Point Count method.

Figure 2.14 presents a probability detection function plot for the hazard-rate + cosine model for Transect line 4 with a probability of goodness of fit of 0.740.

Figure 2.14 Probability detection function plot for the hazard-rate + cosine model for Transect line 4.



Transect line 5 –Point Count

There were 7 defined points on Transect line 5, where 72 observations were collected and 910m was the largest radial distance. Observations greater than 200m were truncated to achieve more robust models, leaving 49 observations. The hazard-rate + cosine model is chosen to be the best-fitted model. The ΔAIC value for other models were greater than 2, therefore no other models competed with the hazard-rate + cosine model. Table 2.18 presents the hazard-rate + cosine model for Transect line 5.

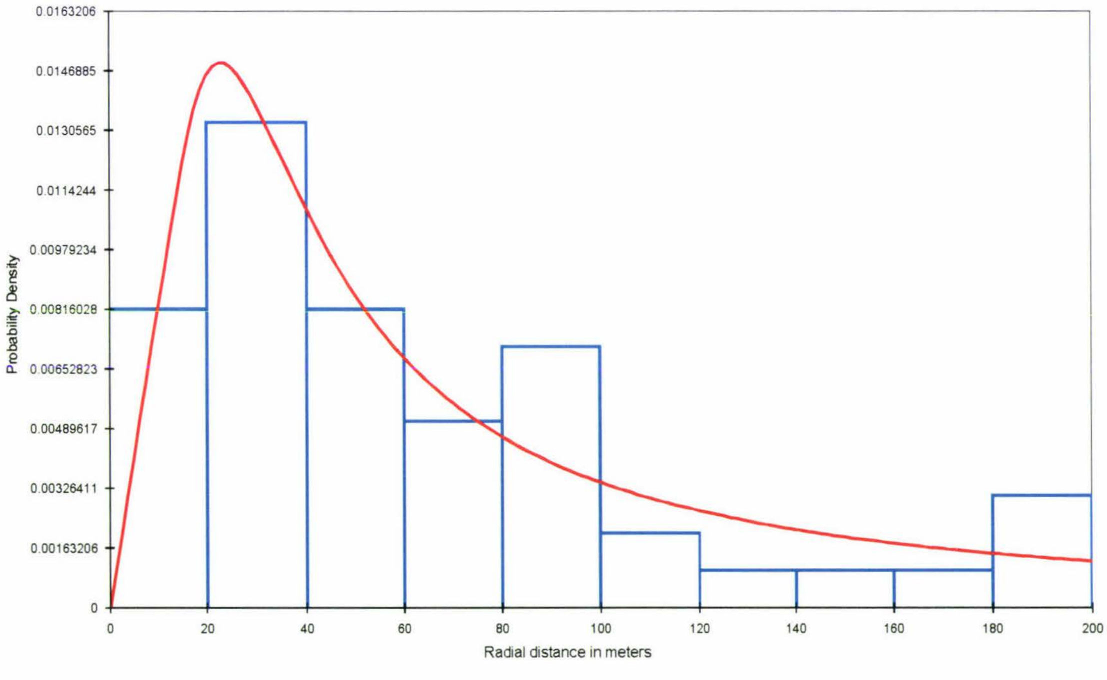
Table 2.18 Summary of ΔAIC, percentage of AIC weights, density estimates of Koki per hectare, percentage of coefficient of variation, 95% confidence interval for competing model for Point Count data gathered from Transect line 5.

Model (key + adjustments)	Total parameters	ΔAIC	AIC_w %	Density	C.V. %	95% C.I.
Hazard-rate + cosine	**2**	**0.00**	**100**	**1.33**	**36.8**	**0.650 – 2.709**

The hazard-rate + cosine model estimates the Koki density on Transect line 5 as 1.33 (95% C.I. = 0.583 – 3.373) per hectare.

Figure 2.15 shows a plot of probability detection function for Transect line 5 with a probability of goodness of fit of 0.5114.

Figure 2.15 Probability detection function plot of the hazard-rate + cosine model for Transect line 5.



Transect line 6 – Point Count

There were 11 defined points on Transect line 6 where 520 observations were collected and 941m was the largest radial distance. To create more robust models, observations greater than 280m were truncated, leaving 432 observations. There were no competing models therefore the model with the lowest ΔAIC was chosen to be the second best-fitted model. Table 2.19 presents a summary of the hazard-rate + cosine model for Transect line 6 using the Point Count method.

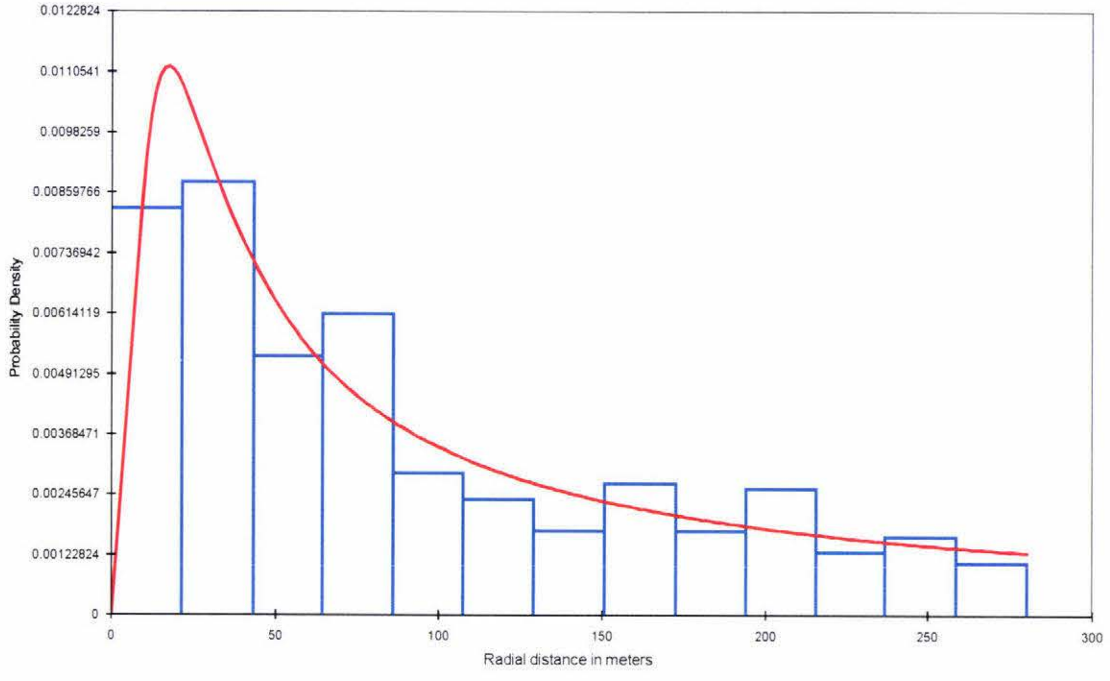
Table 2.19 Summary of ΔAIC, percentage of AIC weights, density estimates of Koki per hectare, percentage of coefficient of variation, 95% confidence interval for best-fitted model for Point Count data gathered from Transect line 5.

Model (key + adjustments)	Total parameters	ΔAIC	AIC_w %	Density	C.V. %	95% C.I.
Hazard-rate + cosine	**2**	**33.30**	**100**	**2.914**	**17.3**	**2.08 – 4.08**

The hazard-rate + cosine model estimates the Koki density on Transect line 6 as 2.914 (95% C.I. = 3.04 – 5.45) per hectare.

Figure 2.16 shows a probability detection function plot for the hazard-rate + cosine for Transect line 6 with a probability of goodness of fit of 0.75478.

Figure 2.16 Probability detection function plot for the exponential + cosine model for Transect line 6.



Summary of Line Transect and point Count estimates for the six transect line.

Table 2.20 presents the Koki density estimates per hectare for each transect line for the Point Count and the Line Transect methods.

Table 2.20 Summary of Koki densities in six transect lines using the Line Transect and the Point Count method.

Transect lines	Line Transect Density (95% C.I.)	Point Count Density (95% C.I.)
1	0.193 (0.133 –0.279)	8.86 (3.13 – 25.08)
2	0.147 (0.304 – 0.712)	0.46 (0.22 –0.95)
3	0.135 (0.09 –0.20)	1.71 (1.14 –2.57)
4	0.175 (0.117 – 0.260)	1.40 (0.76 –2.58)
5	0.105 (0.06 – 0.19)	1.33 (0.650 –2.709)
6	0.164 (0.136 –0.199)	2.914 (2.08 – 4.08)

Table 2.20 shows that the density estimates given by the Point Count method are higher than those given by the Line Transect method.

Table 2.21 shows the six transect lines being ranked according to the Koki densities provided by the Line transect and the Point Count method.

Table 2.21 Transect lines ranked from least to most Koki density estimates for the Line Transect and the Point Count methods.

	Transect lines ranked from least to most Koki seen					
	Least					**Most**
5-minute Point Count	2	5	4	3	6	1
Line Transect	5	3	2	6	4	1

Table 2.21 shows that both methods provided the greatest estimate for Koki density on transect line 1.

2.3.3 Direct observations of Koki flights at two lookouts above Eua National Park forest.

Koki detected at the two lookouts were combined for analysis. The parrots were grouped according to the activity they were carrying out when detected. These activities were; heard but not seen; seen and silent; and seen and calling. The activities were further grouped by seasons depending on the breeding activity of the Koki. These seasons were; egg laying (May, June and July), incubation (August, September and October) and post-breeding (November, December and January). Table 2.22 shows the number of Koki detected in three seasons.

Table 2.22 Number of Koki detected at the two lookouts from May – October 2000.

Frequency	Heard/Not seen	Seen/Silent	Seen/Calling	TOTAL
Egg laying	15	42	91	148
Incubation	5	0	0	5
Post-breeding	7	5	8	20
TOTAL	27	47	99	173

Table 2.22 shows that a lot of the Koki detected at 'Eua National Park were seen and calling and during the laying period. However, most (85.5%, n = 173) observations were made during the laying period.

A generalised linear model was carried out to investigate any significant differences between the three seasons and also between the three types of activities. Table 2.23 presents the Generalised linear model of season and activity

Table 2.23 Generalised linear model of season and activity

Source	Deviance	Num DF	Den DF	Chi-square	Prob > ChiSq
Intercept	261.0650				
Season	223.1995	2	54	13.14	0.0014
Activity	182.2057	2	54	14.22	0.0008
Season*Activity	155.6250	4	54	9.22	0.0558

Table 2.23 shows that frequency of sighting varies between season on its own (0.0014), and the same applies for type of activity (0.0008), however there is marginal significant difference with the season*activity interaction (0.0558). therefore , this indicates that the type of activities changes within seasons.

Duration of Koki flights over 'Eua National Park.

The duration of each Koki flight was analysed for significant differences between the seasons and types of activity. The duration and distance of each flight shows that the variances of residuals increased as the mean distance and flight duration increased. For this reason data were transformed to the log of distances and durations. Table 2.24 shows the ANOVA of log duration for Koki flight over the 'Eua National Park.

Table 2.24 ANOVA of log duration of flight plus error.

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Date (Month*Season)	10	6.772378	0.677238	0.89	0.5456
Calling	1	6.805935	6.805935	8.94	0.0034
Season*Calling	1	0.117454	0.117454	0.15	0.6953
Month (Season*Calling)	3	1.699084	0.566361	0.74	0.5282
Date (Month*Season*Call)	8	10.690084	1.336261	1.75	0.0931
Error: MS (Error)	117	89.116177	0.761677		

Table 2.24 clearly shows that calling is the only variable with significant differences shown by the Pr > F value of 0.0034.

The mean interval between calls for Koki calling while flying is 6.79 seconds with a 95% confidence interval of 5.78 to 7.99 seconds. In comparison the mean time for Koki flying silently is 4.40 seconds with a 95% of confidence interval of 3.37 to 5.74 seconds. Thus Koki flying over the 'Eua National Park tend to call when flying longer distances.

Distance of Koki flights over the 'Eua National Park.

The distances travelled by Koki flying over 'Eua National Park were analysed to investigate any significant differences between the three seasons and the three types of activities. Table 2.25 shows ANOVA's of log distances for Koki flight over 'Eua National Park.

Table 2.25 ANOVA of log distances of Koki flight over 'Eua National Park as seen from the two lookouts, May – October 2000.

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Date (Month*Season)	10	46.395533	4.639553	1.68	0.0933
Calling	1	36.902621	36.902621	13.37	0.0004
Season*Calling	1	0.015251	0.015251	0.01	0.9409
Month (Season*Calling)	3	2.508294	0.836098	0.30	0.8233
Date (Month*Season*Call)	8	35.705644	4.463205	1.62	0.1273
Error: MS (Error)	117	323.042549	2.761047		

Table 2.25 shows that calling is the only variable with significant differences within day versus bird-to-bird variation, with a Pr > F value of 0.0004.

The mean distance travelled by Koki flying and calling over the National Park, was 134.50m with a 95% confidence interval of 187.02m to 96.73m. In comparison, the mean distance travelled by Koki flying silently was 46.07m with a 95% confidence interval of 77.43m to 27.41m. From the data presented on the flight distances of Koki over the National Park observed from Lokupo and Lauua lookouts, it is clear that Koki fly longer distances when they are calling.

2.4. DISCUSSION

The development of the distance sampling methods for estimating population density and abundance allows for effective assessment and monitoring of declining populations (Barraclough 2000). Juniper and Parr (1998) estimate the 1988 Koki population for Tonga at 700 – 1000 individuals but they do not state the basis for that estimate. Therefore this study was carried out in order to obtain baseline knowledge of Koki density and abundance for future monitoring and conservation. The current absolute density of Koki on 'Eua is not known, so this study's density estimates from six transect lines have no basis for comparison.

The raw data results shows that the mean number of Koki detected by 5-minute Point Count were higher than the mean number of Koki detected using the Line Transect method for the six transect lines. This pattern was also reflected in the estimates for the six Transect lines using DISTANCE. When comparing the two methods used by DISTANCE to estimate the density of Koki on the six transect lines, Point Count estimates are far higher than the Line Transect estimates, except for Transect line 2 where the Line Transect estimate was greater than the Point Count estimate. In reality it appears that the Point Count estimates tend to overestimate the Koki densities on the six transect lines. Several possible explanations are offered.

The theoretical aim of Point Count is to capture a 'snapshot' of the species studied in time (Barraclough 2000). The first explanation for the overestimation of the Point Count method is the amount of time spent at each defined point. It is important that the amount of time spent at each defined point fulfils the distance sampling assumptions and simultaneously avoids overestimating the real density. A long counting time at each point tends to overestimate bird density because the birds may move through the sampled area and are therefore counted more than once (cited by Baillie 1991 in Barraclough 2000). Second, it is easier to detect and observe birds when the observer is stationary at a point instead of moving while traversing the Transect line as in the Line Transect method. Once the observer is at a point, he or she can concentrate solely on detecting, locating and identifying birds (Buckland *et al* 1993). Third, the training received by the observer before conducting this study was limited. Scott *et al* (1981) recommended that observers be trained in estimating distances for birds that can be seen, and work up to estimating distances for birds that are heard but not seen.

A similar study was carried out by Cassey (1997), where the effectiveness of Line Transect and Point Count techniques for estimating the abundance of the North Island saddleback (*Philesturnus carunculatus*) on Tiritiri Matangi Island were determined. This study showed the 5-minute Point Count tended to overestimate saddleback abundance.

It appears, therefore that the densities provided by the Line Transect method are more reliable that the densities provided by the Point Count method. The density estimates of the six transect lines provided by the Line transect method ranged from 0.105 Koki per hectare for Transect line 6 to 0.193 Koki per hectare for Transect line 1. An average of the density estimates for the six transect lines provided by Line Transect is 0.153 Koki per hectare, that is about 1 Koki per 6 hectares.

Line Transect and the Point Count methods both showed that Koki densities were greatest on transect line 1. The principal forest type on Transect line 1 is Native Forest. Transect line 1 is parallel to the east coast where 'Eua National Park is located and also the furthest from disturbances by local people. The Line Transect density estimate was least on transect line 5 and the Point Count method provided the least density estimate on transect line 2. Transect line 5 and transect line 2, were frequently travelled by local people and the Forestry workers to get to access work areas. It is possible, therefore, that disturbances by people could limit the distribution of Koki. On the other hand transect line 6 is a heavily travelled road for which both estimate methods provided high density measures. Thus disturbances by people may limit the distribution of Koki, but the type of habitat may also contribute to the distribution of Koki and this will be further discussed in Chapter 3.

Buckland (*et al* 1993) warns about using trails and roads as transect lines. This study used existing tracks as transect lines which may have affected the density estimates along the six transect lines. Buckland (1985 cited in Cassey 1997) predicted that long-term disturbances caused by walkers and vehicles along tracks could lead to a lower density near the tracks than elsewhere. Although laying transect lines along existing tracks is theoretically undesirable, under the field constraints of the extremely difficult terrain on 'Eua there was no alternative.

The probability detection function plot provided for the Point Count estimates of all the six transect lines shows, that detection were greatest closer to the point. This may suggest that Koki have assembled at the edges of the forest by the trails and roads. Thus, edge effect may have contributed to the overestimation of the Point Count density estimates. All Point Count probability detection plots were skewed to the left, which may suggests that the method of collecting Point Count data was inaccurate. The third Distance Sampling assumption of exact measurements may have been violated.

The results from the two lookouts show, that Koki are very mobile and tend to call when flying longer distances. This behaviour could constitute contact calling when a bird leaves familiar surroundings, such as a rest site, roost site, or nest to seek food.

This chapter provides baseline knowledge of the current Koki density on six transect lines. However, there is a need for continual monitoring of the Koki population on 'Eua if the population is to be sensibly conserved, the importance of training the observer is paramount to avoid biases. Biases can reduce the credibility of any bird population sampling effort (Faanes and Bystrak 1981). Faanes and Bystrak (1981) also stated that just as hearing loss can affect the results so can an unprepared observer. Distance sampling assumes detection of all birds actually on a transect line or at a point. Moreover, birds should be detected at their initial location and measurements must be exact (Buckland *et al* 1993). Thompson (2002) suggests that the first and the second assumptions are difficult to satisfy. However, all three assumptions can be satisfied if observers are well trained and familiar with the study area before conducting the study. Prepared and well-trained observers will lead to reliable and accurate estimates of density and abundance.

The Line Transect method is highly recommended as the first choice of a monitoring method for Koki because it provides realistic estimates based on the six transect lines used. Line transect method are recommended for sparsely distributed populations and in open areas (Bibby *et al* 1992, Buckland *et al* 1993, Barraclough 2000), both of which apply to 'Eua.

Due to the topography of 'Eua, some areas are virtually inaccessible (e.g. 'Eua National Park). Therefore, the Point Count method is also recommended, but requires improvement. The Point Count estimates may improve if the points are randomly distributed and not on existing tracks and trails. This way the National Park could also be monitored. The observations at the two lookouts, confirm that Koki are very mobile birds. The 5-minute period spent at each defined point may, therefore, need to be reduced to avoid counting Koki twice.

The use of both the Line Transect and the Point Count methods will provide vital information if the remaining Koki population is to be continually monitored.

CHAPTER 3

KOKI SPACING AND HABITAT CHOICE

3.1 INTRODUCTION

The way birds use habitat is important in determining their distribution (Watling 1982) and for most species there are two major habitat components; breeding and foraging. The Koki is known to occur naturally in mature forests (Juniper and Parr 1998) and in secondary scrub association forests (Watling 1982). Mature native forest trees provide cavities required by Koki for nesting (Watling 1982, Rinke 1987, Juniper and Parr 1998), while the fruits and seeds they seek in foraging are associated with native forest trees and introduced forest plantations.

Parrots may be confined to specific forest types due to narrow habitat requirements. A good example comes from Greene's (1998) study of Red-crowned Parakeets (*Cyanoramphus novaezelandiae novaezelandiae*) and Yellow crowned Parakeets (*C.#auriceps auriceps*) on Little Barrier Island of New Zealand. Greene found that the Red-crowned Parakeets utilized diverse vegetation types and were commonly well represented in open vegetation, where they fed on a variety of plants. Yellow-crowned Parakeets, on the other hand, were mostly found in heavy forest and fed more on invertebrates than the Red-crowned Parakeet.

Island birds have been shown to have wide tolerance to habitat change (Watling 1982). On 'Eua it appears that Koki have adapted to the changes resulting from the clearance of native forest for the planting of traditional crops, and to the establishment of introduced species like Caribaea pine *Pinus caribaea*. On 'Eua, Koki were found in native forest, introduced forest and also in crop plantations.

Nest site and food resources are likely to be significant influences on Koki spacing and movements. The occurrence of other bird species could also affect Koki distribution. Therefore this chapter presents and compares estimates of Koki abundance and density in the four forest types in 'Eua Plantation Forest, based on point count and line transect methods. The trees species used by Koki and counts of the four commonest other bird species in the forests are presented.

3.2. METHODS

3.2.1. Distance Sampling (Line transect and Point Count)

The methods employed are those described in Chapter 2.

The two census methods, Point Count and Line Transect (described in Chapter 2) were used and compared to determining the forest types in which Koki were mostly detected. The Distance Sampling methods were carried out on six transect lines that ran through a variety of forest types in the 'Eua Plantation Forest on the eastern slopes of 'Eua.

3.2.2. Habitat Choice (Forest types)

The forest at the 'Eua Forest Plantation were categorized into four forest types, Native forest; Exotic species minus *Pinus caribaea*; *Pinus caribaea* forest; and Mixed species forest. The forest was grouped into four major types (Table 3.1).

Forest type A is Native forest. This is the original forest cover of 'Eua that has not been disturbed by the local people. These areas are protected for conservation by the 'Eua Forestry Division. Forest type B comprises the Exotic Forest planted by the 'Eua Forestry Division, for timber, including *Agathis robusta, Cordia alliodora, Cupressus lusitanica, Cedrella odorata, Eucalyptus* species, *Swietenia macrophylla, Santalum yasi, Toona ciliata and Tectona grandis. Pinus caribaea*, which occurs as a monoculture in large blocks, is excluded and treated as a separate forest type.

Forest type C is Mixed Forest, which is a mixture of native and introduced species all growing together, especially in watershed areas.

Forest type D is *Pinus caribaea* Forest. *Pinus caribaea* is widely planted in the 'Eua Plantation Forest by the 'Eua Forestry Division to provide timber.

Table 3.1. Forest types in 'Eua Plantation Forest. *Pinus caribaea* is not included in the Introduced species forest types, see text for details.

Forest type	Description
A	Native Forest
B	Exotic Forest
C	Mixed Forest
D	*Pinus caribaea* Forest

Density estimates for the four forest types.

The data gathered by Distance Sampling were analysed using the computer program DISTANCE version 3.5 (Buckland *et al*, 1993) to determine the Koki density for each forest type.

Abundance estimates for the four forest types.

Using the forest component maps (Landcare Research 1997), the approximate total areas in hectares for each forest type were calculated using a planimeter.

3.2.3. Use of tree species by Koki.

The tree species used by Koki were also recorded during the two census methods, casual observations and observations of the National Park from vantage points at Lokupo and Lauua lookouts (Fig 2.1). At the two lookouts flights of Koki were easily seen. Observations from these lookouts also provided data on the frequency of calling during flights.

While walking Line transects, taking point counts, and making observations at Lokupo and Lauua lookouts, records were kept of parrots seen resting or foraging in trees. The trees recorded as resting or feeding sites for Koki included tavahi (*Rhus taitensis*), mo'ota (*Dysoxylum forsteri*), 'ovava (*Ficus obliqua*), kotone (*Myristica *hypargyraea)*, toi *(Alphitonia zizphoides)*, ahi *(Santalum yasi)*, ngatata *(Elattostachys falcata)*, salato (*Dendrocnide harveyi)*, sita hina (*Cedrella odorata*), sita kula (*Toona ciliata*) and paini (*Pinus caribaea*).

3.2.4. Transect counts of other bird species

Other bird species present on the six transect lines were recorded, using the point count method (Dawson and Bull, 1975), from April 2000 to October 2000. Transects 1 and 6 were carried out each week and transects 2,3,4 and 5 were carried out fortnightly. For the Point Counts, 5 minutes were spend at each point, which were 200m apart. Koki heard and seen at each point were recorded, together with an estimated distance from the point to the bird. The estimated distance helped determine in which forest type the bird was initially detected.

The birds recorded on the transects included Red Jungle Fowl *(Gallus gallus*), Banded Rail (*Gallirallus philippensis*), Fairy Tern (*Gygis alba candida*), Pacific Pigeon (*Ducula pacifica*), Purple Crowned Fruit Dove (*Ptilinopus porphyraceus*), Barn Owl (*Tyto alba)*, Pacific Swallows (*Hirundo tahitica*), White-rumped Swiftlet (*Aerodramus spodiopygius*), White-collared Kingfisher (*Halcyon chloris*), Honeyeaters (*Foulehaio carunculata*), Polynesian Trillers (*Lalage maculosa*), and Polynesian Starling (*Aplonis tapuensis*),

Here the counts for the four most common bird species will be presented and the remaining species will be categorized according to how frequently they were seen.

3.3 RESULTS

3.3.1. Koki count on the four forest types by Point Count (Raw data)

The following raw data results, are presented without taking into account the area of each habitat, which will be discussed in the DISTANCE analysis of these forest types. The Point Count method was used to determine in which forest type, Koki were located (Tables 3.2 – 3.4). The figures in Table 3.2 to Table 3.4 were obtained by dividing the total number of Koki detected in a forest type by the number of points on each transect line together with the number of times each transect line was monitored (see Table 2.1 under Repetition). The total number of Koki detected in the four forest types by sound and sight appear in Table 3.2

Table 3.2 Mean number of Koki detected in the four forest types by Point Counts.

Transect line	Native Forest	Exotic Forest	Mixed Forest	*Pinus caribaea*
1	0.30	-	-	-
2	0.007	0.25	-	0.55
3	0.009	0.10	-	0.81
4	0.24	0.26	0.015	0.50
5	0.30	0.11	-	0.15
6	0.019	0.32	0.92	0.56
TOTAL	0.875	1.04	0.935	2.57

Table 3.2 shows that Koki were mostly detected in *Pinus caribaea* Forest about two and a half times more frequently than in Exotic Forest, and nearly three times more frequently than Native Forest. Mixed Forest took an intermediate position, but detection rates in the forest types apart from *Pinus caribaea* Forest were in the same order with mean values between 0.875 and 1.04.

The mean number of Koki detected aurally in the four forest types are presented in Table 3.3

Table 3.3 Mean number of Koki heard in the four forest types by Point Counts.

Transect line	Native forest	Exotic Forest	Mixed forest	*Pinus caribaea*
1	0.28	-	-	-
2	0.007	0.24	-	0.51
3	-	0.19	-	0.71
4	0.22	0.22	0.015	0.47
5	0.29	0.10	-	0.13
6	0.19	0.27	0.78	0.50
TOTAL	0.82	1.02	0.795	2.32

Koki were heard in *Pinus caribaea* Forest more than twice as frequently as in Introduced species forest, and, nearly three times more often than in Native or Mixed forest.

Table 3.4 The mean number of Koki seen in the four forest types by Point Counts.

Transect line	Native forest	Exotic Forest	Mixed forest	*Pinus caribaea*
1	0.02	-	-	-
2	-	0.01	-	0.04
3	0.009	-	-	0.10
4	0.02	0.04	-	0.03
5	0.01	0.01	-	0.02
6	-	0.05	0.14	0.06
TOTAL	0.059	0.11	0.14	0.25

Koki were seen in *Pinus caribaea* forest four times more frequently than in Native forest, and about twice as frequently as in Exotic or Mixed forest.

3.3.2 Koki count on the four forest types by Line Transect (Raw data).

Line Transects were also used to determine in which forest type Koki were located (Tables 3.5 – 3.7). The figures in Table 3.5 to Table 3.6 were obtained by dividing the number of Koki detected in a forest type by the number of times each transect line was monitored.

The mean number of Koki detected in each of the forest types using the Line Transect method is presented in Table 3.5.

Table 3.5 Mean number of total Koki detected in the four forest types by the Line Transect method.

Transect line	Native	Exotic Forest	Mixed forest	*P. caribaea*
1	0.78	0.62	-	0.64
2	-	0.23	-	1.5
3	1.20	1.20	0.05	2.5
4	0.60	0.74	-	1.89
5	1.28	0.30	-	0.41
6	-	1.55	3.19	2.05
TOTAL	3.86	3.44	3.20	8.99

Table 3.5 shows that detection of Koki was higher in *Pinus caribaea* than any other forest type, ranging from 2.3 times higher than Native Forest to 2.8 times higher in Mixed forest.

When the data presented in Table 3.5 are further divided into Koki detected aurally and visually, the mean number detected aurally in *Pinus caribaea* (Table 3.6) ranged between about 1.9 times and 3.1 times higher respectively than in Introduced species forest and Native forest.

Table 3.6 The mean number of Koki heard in the four forest types by Line Transects.

Transect line	Native Forest	Exotic Forest	Mixed Forest	*Pinus caribaea*
1	0.64	0.56	-	0.53
2	-	0.20	-	1
3	-	1.16	0.04	2.05
4	0.52	0.59	-	1.48
5	1.09	0.26	-	0.41
6	-	1.03	2.69	1.62
TOTAL	2.25	3.8	2.73	7.09

The mean number of Koki detected visually in the four forest types by Line Transects are presented in Table 3.7.

Table 3.7 The mean number of Koki seen in the four forest types by Line Transects.

Transect line	Native Forest	Exotic Forest	Mixed Forest	*Pinus caribaea*
1	0.14	0.06	-	0.11
2	-	0.03	-	0.5
3	-	0.04	-	0.45
4	0.08	0.15	-	0.41
5	0.19	0.04	-	-
6	-	0.52	0.50	0.43
TOTAL	0.41	0.84	0.50	1.9

Table 3.7 shows that more Koki were seen in *Pinus caribaea* forest than in any other forest type. Fewest Koki were seen in Native Forest.

As with point counts (Tables 3.3 & 3.4) far fewer Koki were detected visually (Table 3.7), compared with aurally by Line Transect in any forest type. Again, Koki were seen relatively most often in *Pinus caribaea* where the numbers detected were between about 2.3 times higher than in Introduced forest, and 4.6 times higher than in Native forest.

3.3.3. Koki density estimates in the four forest types using DISTANCE 3.5.

The data gathered from the six transect lines using the Line Transect and the Point Count method was used to determine which forest type the Koki were detected in. The four forest types are described in Table 3.1. The Koki detected in the four forest types using the Line Transect and the Point Count methods were analyzed using DISTANCE 3.5 (Buckland *et al* 1993). The competing models for each forest type for Line Transect and Point Count are presented. The best-fitted models are highlighted. Refer to Chapter 2 for ways of selecting the best-fitted models.

Line Transect

Native Forest – Line Transect

Eighty-three Koki were detected in the Native Forest type with 830m as the largest distance being observed. To obtain a more robust model observations greater than 180 meters were truncated, leaving 71 observations. Competing models were selected based on the ΔAIC value, lying between 0 – 2. The hazard-rate + cosine model was chosen to be the best-fitted model and there were no competing models. Table 3.8 presents a summary of the hazard-rate + cosine model.

Table 3.8 Summary of ΔAIC, AIC weights, density estimates of Koki per hectare, percentage of coefficient of variation, 95% confidence interval for the best –fitted model for the Native Forest type.

Model (key + adjustments)	Total parameters	ΔAIC	AIC_w %	Density	C.V. %	95% C.I.
Hazard-rate + cosine	**2**	**0.00**	**100**	**0.575**	**31.9**	**0.309 – 1.069**

The hazard-rate + cosine model estimates the Koki density in the Native Forest type as 0.575 (95% C.I. = 0.309 – 1.069) per hectare.

Figure 3.1 presents a histogram of detection function for Koki detected in the Native Forest type, with a probability of goodness of fit of 0.843.

Figure 3.1 Histogram of detection function for Koki detected in Native Forest type.

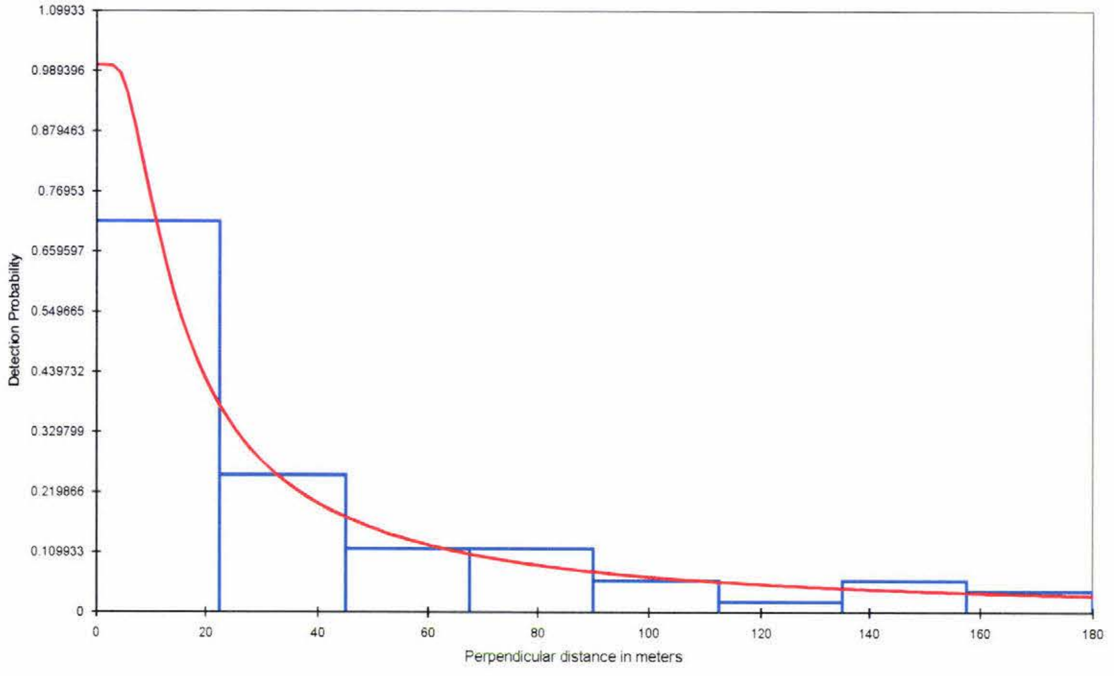


Figure 3.1 shows that detection is greater in the first distance interval (0 – 20m).

Exotic Forest – Line Transect

One hundred and two observations were recorded in the Exotic Forest type using the Line Transect method with 675m as the largest distance. To achieve robust models 10% of the largest observations were truncated, leaving 146 observations with 145m as the largest distance. Table 3.9 presents a summary of competing models for the Exotic Forest type.

Table 3.9 Summary of ΔAIC, AIC weights, density estimates of Koki per hectare, percentage of coefficient of variation, 95% confidence interval for the best–fitted model for the Exotic Forest type.

Model (key + adjustments)	Total parameters	ΔAIC	AIC_w %	Density	C.V. %	95% C.I.
Hazard-rate + cosine	**2**	**0.00**	**64.5**	**0.561**	**33.8**	**0.289 – 1.089**
Negative exponential + cosine	1	1.200	35.5	0.602	32.1	0.319 –1.135

Table 3.9 shows that hazard-rate + cosine model is the best-fitted model based on the lowest ΔAIC value and the highest percentage of AIC weights. The hazard-rate + cosine model estimates the Koki density in Exotic Forest type as 0.561 (95% C.I. = 0.289 – 1.089) per hectare.

Figure 3.2 presents a histogram of detection function for Exotic Forest type using the Line Transect method, with a probability of goodness of fit of 0.944.

Figure 3.2 Histogram of detection function for Koki density in Exotic Forest type.

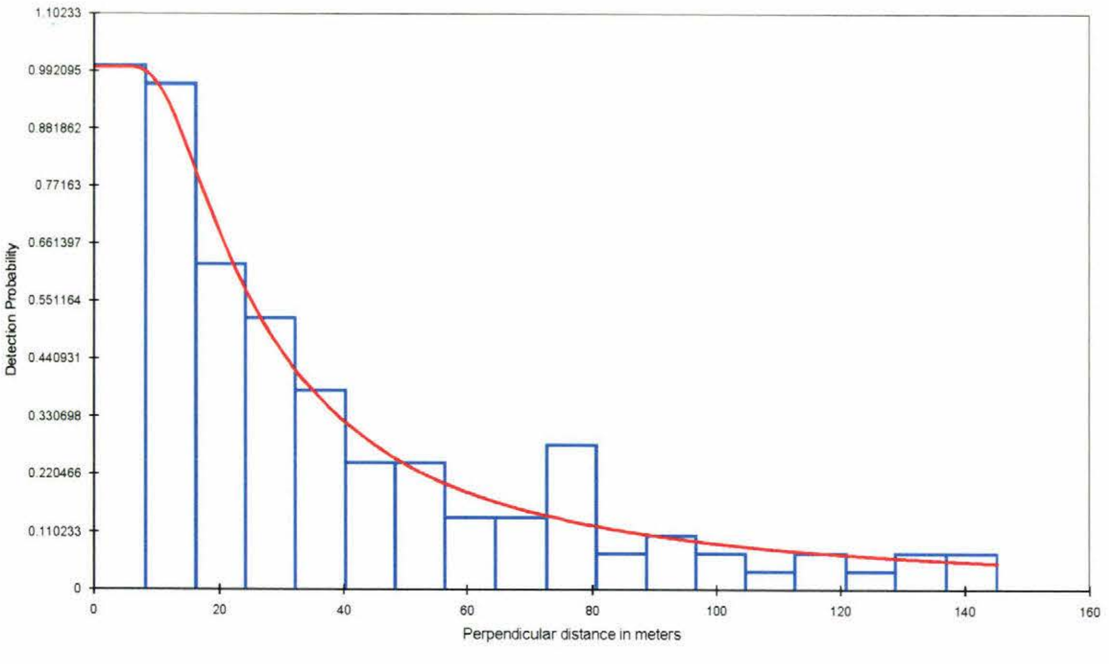


Figure 3.2 shows that detection was greatest in the first distance interval (0 – 8.06m) and closely followed by the second distance interval (8.06 – 1.61m).

Mixed Forest – Line Transect

One hundred and eighty observations were recorded in Mixed Forest types with 820m as the largest distance. To obtain robust models 10% of the largest observations were truncated, leaving 163 observations with 206m as the largest observation. Table 3.10 presents competing models for Mixed Forest type using the Line Transect method.

Table 3.10 Summary of ΔAIC, AIC weights, density estimates of Koki per hectare, percentage of coefficient of variation, 95% confidence interval for the best –fitted model for the Mixed Forest type.

Model (key + adjustments)	Total parameters	ΔAIC	AIC_w %	Density	C.V. %	95% C.I.
Half-normal + cosine	2	1.600	19.8	0.827	38.8	0.368 – 1.859
Hazard-rate + cosine	**2**	**0.00**	**44.1**	**0.861**	**40.2**	**0.377 – 1.966**
Negative exponential + cosine	1	0.400	36.1	1.016	39.1	0.449 – 2.295

Table 3.10 shows that hazard-rate + cosine is the best-fitted model because it provides the lowest ΔAIC (0.00) and the highest AIC weight (44.1%). The hazard-rate + cosine model estimates the Koki density in Mixed Forest type as 0.861 (95% C.I. = 0.377 – 1.966) per hectare.

Figure 3.3 shows a histogram of detection function for Mixed Forest using the Line Transect method, with a probability of goodness of fit of 0.847.

Figure 3.3 Histogram of detection function for Koki density in Mixed Forest type.

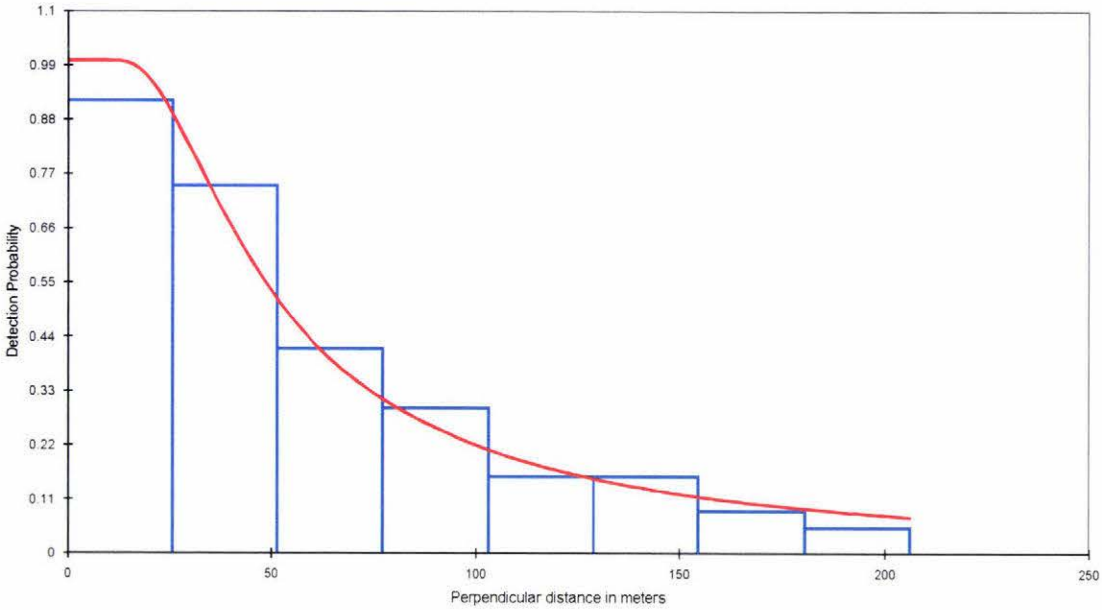


Figure 3.3 shows that detection is greatest in the first distance interval of 0 – 25.8 meters.

Pinus caribaea Forest – Line transect

Two hundred and ninety-eight observations were collected from *Pinus caribaea* Forest type with 570m as the largest distance. Observations greater than 260m were truncated, leaving 292 observations. Table 3.11 presents competing models for *Pinus caribaea* Forest type using the Line Transect method.

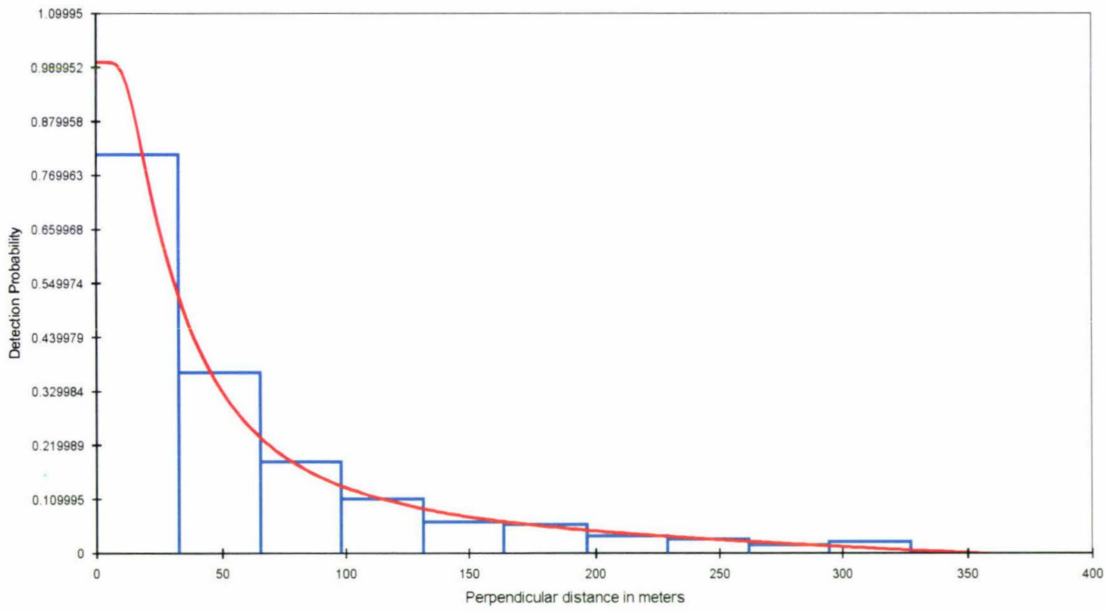
Table 3.11 Summary of ΔAIC, AIC weights, density estimates of Koki per hectare, percentage of coefficient of variation, 95% confidence interval for the best -fitted model for the *Pinus caribaea* Forest type using the Line Transect method.

Model (key + adjustments)	Total parameters	ΔAIC	AIC_w %	Density	C.V. %	95% C.I.
Hazard-rate + polynomial	**3**	**0.000**	**61**	**0.581**	**21.8**	**0.378 – 0.893**
Hazard-rate + hermite	3	0.900	39	0.585	22.2	0.378 – 0.905

Table 3.11 shows that hazard-rate + polynomial is the best-fitted model based on the lowest ΔAIC value (0.00) and the highest percentage of AIC weight (61%). The hazard-rate + polynomial estimates the Koki density in *Pinus caribaea* Forest type as 0.581 (95% C.I. = 0.378 – 0.893) per hectare.

Figure 3.4 shows a histogram of detection function for Koki density in *Pinus caribaea* Forest type using the Line Transect method, with a probability of goodness of fit of 0.818.

Figure 3.4 Histogram of detection function for Koki density in *Pinus caribaea* Forest type.



Point Count

Native Forest – Point Count

One hundred and fifty-three observations were collected from Native Forest type using the Point Count method, with 941m as the largest distance. To achieve robust models, observations greater than 150 meters were truncated, leaving 98 observations. Table 3.12 presents the best-fitted model for Native Forest using the Point Count method.

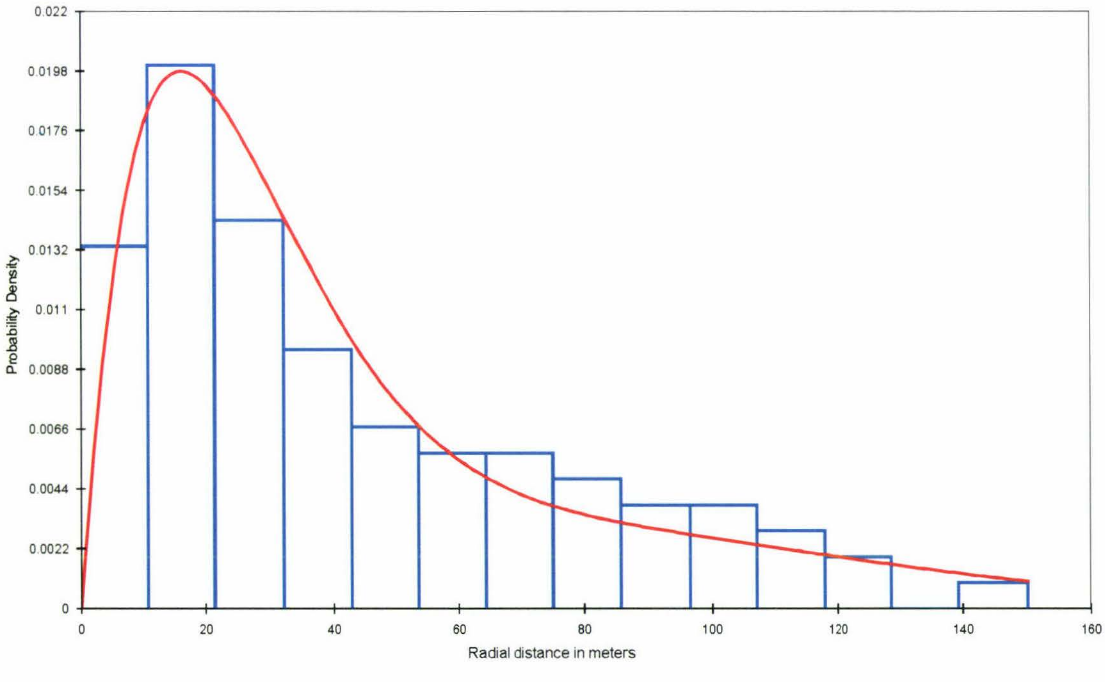
Table 3.12 Summary of ΔAIC, AIC weights, density estimates of Koki per hectare, percentage of coefficient of variation, 95% confidence interval for the best –fitted model for the Native Forest type using the Point Count method.

Model (key + adjustments)	Total parameters	ΔAIC	AIC_w %	Density	C.V. %	95% C.I.
Negative exponential + hermite	**4**	**0.000**	**100**	**18.68**	**32**	**10.03 – 34.77**

The exponential + hermite model estimates the Koki density in Native Forest type to be 18.68 (95% C.I. = 10.03 –34.77) per hectare.

Figure 3.5 presents the probability detection function plot for the exponential + hermite model for the Native Forest type using Point Count, with a probability of goodness of fit of 0.799.

Figure 3.5 Probability detection function plot for the Native Forest type using the Point Count method.



Exotic Forest – Point Count

Two hundred and thirteen observations were collected from Exotic Forest using the Point Count method. To achieve a close to robust model, observations greater than 150 were truncated leaving 135 observations. Models were not competing but the more robust model was chosen for Koki detected in Exotic Forest.

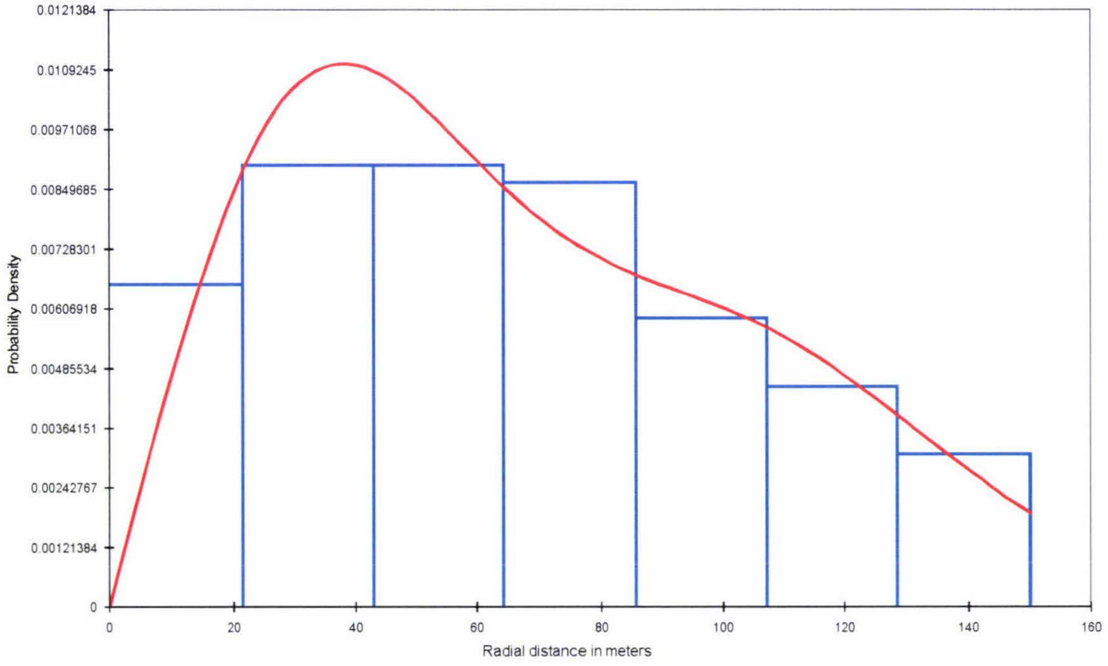
Table 3.13 Summary of ΔAIC, AIC weights, density estimates of Koki per hectare, percentage of coefficient of variation, 95% confidence interval for the model that closely represents the Exotic Forest type using the Point Count method.

Model (key + adjustments)	Total parameters	ΔAIC	AIC_w %	Density	C.V. %	95% C.I.
Half-normal + cosine	**2**	**20.20**	**100**	**2.58**	**32.8**	**1.36 – 4.88**

The half-normal + cosine model estimated the Koki detected in Exotic Forest as 2.58 (95% C.I. = 1.36 – 4.88) per hectare.

Figure 3.6 shows a plot of probability detection function for the Exotic Forest using the Point Count method with a probability of goodness of fit of 0.510.

Figure 3.6 Probability detection function plot for Exotic Forest using the Point Count method.



Mixed Forest – Point Count

Two hundred and sixty-six observations were gathered from Mixed Forest using the Point Count method. Observations greater than 100m, were truncated to produce robust models. However none of the models were robust, therefore the model with a reasonable probability of goodness of fit was chosen. Table 3.14 presents the negative exponential + simple model for Exotic Forest using the Point Count method.

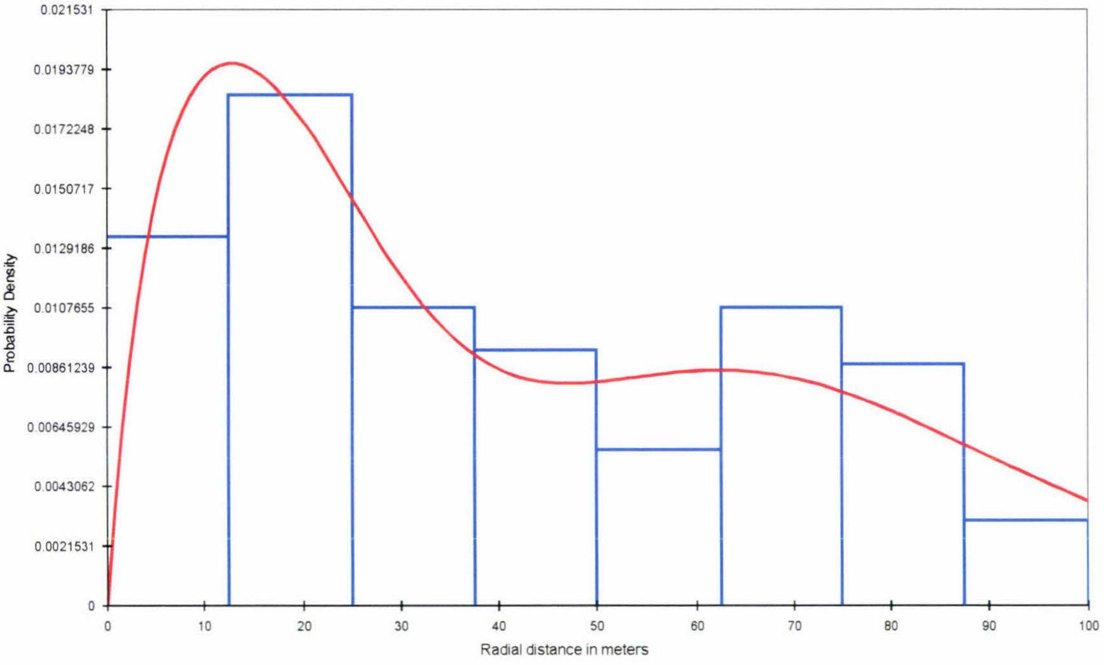
Table 3.14 Summary of ΔAIC, AIC weights, density estimates of Koki per hectare, percentage of coefficient of variation, 95% confidence interval for the model that closely represents the Mixed Forest type using the Point Count method.

Model (key + adjustments)	Total parameters	ΔAIC	AIC_w %	Density	C.V. %	95% C.I.
Negative exponential + simple	**4**	**71.30**	**100**	**101.20**	**43.3**	**42.46 – 241.20**

The negative exponential + simple model estimated the Koki density in Mixed Forest as 101.20 (95% C.I. = 42.46 – 241.20) per hectare.

Figure 3.7 presents the probability detection function plot for Mixed Forest using the Point Count method with a probability of goodness of fit of 0.117.

Figure 3.7 Probability detection function plot for Mixed Forest using the Point Count method.



Pinus caribaea Forest – Point Count

Four hundred and ninety-six observations were gathered from *Pinus caribaea* Forest with 899 meters as the largest observation. To create a more robust model observations greater than 150m were truncated, leaving 311 observations. Competing models are presented in Table 3.15.

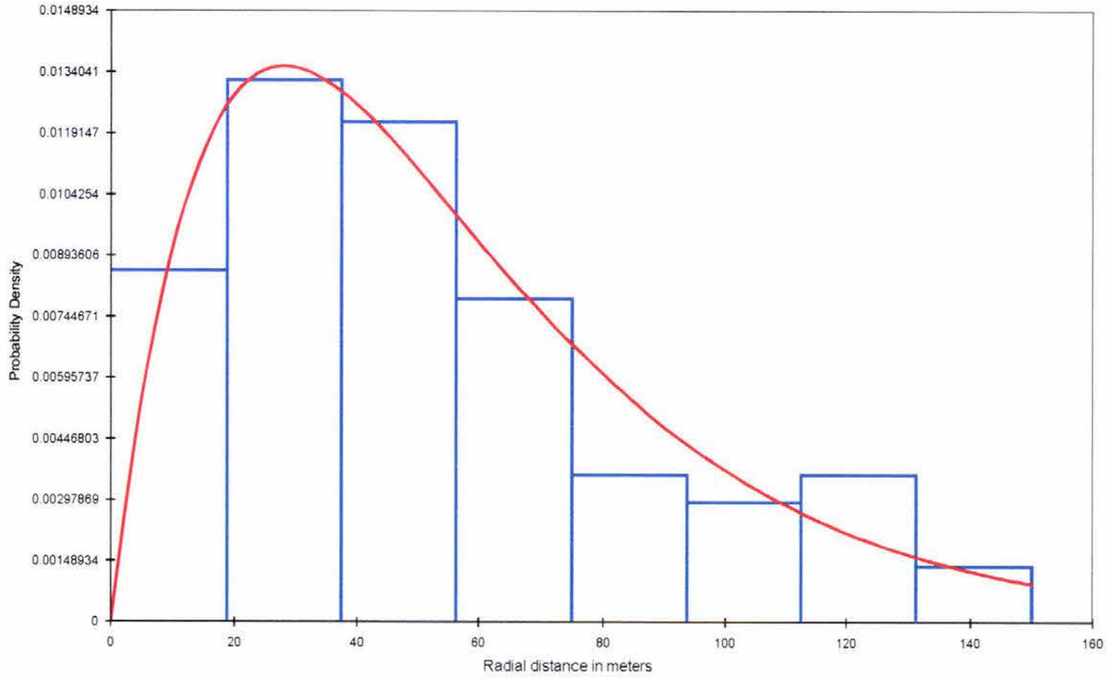
Table 3.15 Summary of ΔAIC, AIC weights, density estimates of Koki per hectare, percentage of coefficient of variation, 95% confidence interval for the competing models for the *Pinus caribaea* Forest type using the Point Count method.

Model (key + adjustments)	Total parameters	ΔAIC	AIC_w %	Density	C.V. %	95% C.I.
Uniform + cosine	3	0.200	29.6	7.53	18.17	5.25 – 10.80
Half-normal + cosine	2	0.00	32.9	8.42	18.66	5.82 – 12.18
Exponential + cosine	**1**	**0.90**	**21**	**13.01**	**19.44**	**8.87 – 19.09**
Half-normal + simple	3	1.40	16.5	7.33	18.67	5.07 – 10.61

The competing models presented in Table 3.15 shows that the Half-normal + cosine model provides the lowest ΔAIC value (0.00) and the highest percentage of AIC weight. However the exponential + cosine model is chosen to be the best-fitted model because it provides a plot of probability detection function with the best shape criterion. The exponential + cosine model estimates the Koki density in *Pinus caribaea* Forest as 13.01 (95% C.I. = 8.87 – 19.09) per hectare.

Figure 3.7 presents the probability detection function plot for Koki detected in *Pinus caribaea* Forest with a probability of goodness of fit of 0.077.

Figure 3.7 Probability detection function plot for the *Pinus caribaea* Forest type using the Point Count method.



Summary of Koki density estimates for the four forest types.

Table 3.16 presents a summary of Koki density estimates for the four forest types using the Line Transect and the Point Count method.

Table 3.16 Summary of Koki density estimates per hectare for four forest types using the Line Transect and the Point Count methods.

Forest types	Line Transect (95% C.I.)	Point Count 95% C.I.)
Native Forest	0.58 (0.309 –1.069)	18.68 (10.03 – 34.77)
Exotic Forest	0.56 (0.289 – 1.089)	2.58 (1.36 – 4.88)
Mixed Forest	0.86 (0.377 – 1.966)	101.20 (42.46 – 241.20)
Pinus caribaea Forest	0.58 (0.378 – 0.893)	19.44 (8.87 – 19.09)

Table 3.16 shows that the Koki density estimates given by the Point Count method is far greater than the density estimates given by the Line Transect method.

The four forest types are ranked according to the Koki density estimates provided by the Line Transect and the Point Count methods.

Table 3.17 The four forest types ranked from least to most Koki density estimates using the Line Transect and the Point Count methods.

	Transect lines ranked from least to most Koki seen			
	Least			**Most**
5-minute Point Count	Exotic	Native	*Pinus caribaea*	Mixed
Line Transect	Exotic	*Pinus caribaea*	Native	Mixed

Table 3.17 shows that the Koki density estimate was greatest in the Mixed Forest type and least detected in Exotic Forest type for both the Point Count and the Line Transect methods.

3.3.4 Abundance of Koki in the four forest types.

The total area of the four forest types in the 'Eua Plantation Forest were calculated based on the maps provided by Landcare Research (1997) were calculated using a planimeter. Table 3.16 presents approximate total area for the four forest types.

Table 3.18 Approximate total area for the four forest types in the 'Eua Plantation forest.

Forest type	Total area (hectare)
Native Forest	364.29
Exotic Forest	159.92
Mixed Forest	147.99
Pinus caribaea Forest	332.08
TOTAL AREA	1004.28

The Line Transect density estimates provided by DISTANCE is considered to be more realistic than the density estimates provided by the Point Count method. Therefore the Line Transect density estimates are used to calculated the Koki abundance in each of the four forest types in the 'Eua Plantation Forest. Table 3.19 presents approximate Koki abundance in the four forest types using the Line Transect density estimates. The Koki abundance in the four forest types, are obtained by multiplying the density estimates provided by the line Transect method and the approximate total area for each forest type presented in Table 3.18.

Table 3.19 Koki abundance in the four forest types of the 'Eua Plantation Forest.

Forest type	Approximate Number of Koki (95% confidence interval)
Native Forest	211 (112 – 389)
Exotic Forest	90 (46 – 174)
Mixed Forest	127 (56 – 291)
Pinus caribaea Forest	193 (125 – 296)
TOTAL KOKI	621 (339 – 1150)

Table 3.19 shows that there is approximately 621 Koki in the 'Eua Plantation Forest.

3.3.5 Tree species used by Koki.

Tree species used by Koki were recorded when the two census methods were conducted and observations of Koki in the National Park were made from the two lookouts. Koki were noted as either foraging or resting on specific trees, which were classified as food trees or roosting trees. Trees known to be nesting trees were also noted. Table 3.11 shows the tree species used by Koki.

Table 3.20 The tree species used by Koki from March – October 2000.

Tongan Name	Scientific Name	Number of Koki observed	Presumed Resource
Paini	*Pinus caribaea*	56	Food
Ngatata	*Elattostachys falcata*	2	Roost / Nest
Sita	*Toona ciliata*	39	Roost
Toi	*Alphitonia zizyphoides*	5	Roost
Telie	*Terminalia catappa*	7	Food / Roost
'Ovava	*Ficus* spp	7	Food / Roost
Tavahi	*Rhus taitensis*	4	Roost / Nest
'Oke	*Grevillea robusta*	18	Roost
Salato	*Dendrocnide harveyi*	10	Roost / Nest
Ponga	*Cyathea lunulata*	6	Roost
Kotone	*Myristica hypargyraea*	4	Food /Roost
Ahi	*Santalum yasi*	2	Roost
Mo'ota	*Dysoxylum forsteri*	2	Roost / Nest

Fruit-bearing species such as pawpaw, guava, lemon and firewood fruit were scattered sub-canopy plants and are not listed in the Table 3.20 but were used by Koki as occasional food resources.

Of the total 162 occasions in which a Koki was observed in a tree, 34.6% occurred in paini, 24.1% in sita, 11.1% in 'oke and 6.2% in salato. The remaining 9 species were recorded on fewer than 5% of the occasions. The most frequently used tree species (paini) was undoubtedly a food source but sita, 'oke and salato appeared to serve as temporary or long-term roost sites.

Some tree species offered more than one presumed resource, as shown in Table 3.20, however 12 of the tree species were presumed to be used mainly for roosting, four for food and four for nesting.

3.3.6 Transect counts of other bird species.

Thirteen other bird species were recorded along the six transect lines. These birds were recorded using the Point Count and included Red Jungle Fowl *(Gallus gallus)*, Banded Rail (*Gallirallus philippensis*), Fairy Tern (*Gygis alba candida*), Pacific Pigeon (*Ducula pacifica*), Purple Crowned Fruit Dove (*Ptilinopus porphyraceus*), Barn Owl (*Tyto alba),* Pacific Swallows (*Hirundo tahitica*), White-rumped Swiftlet (*Aerodramus spodiopygius*), White-collared Kingfisher (*Halcyon chloris*), Honeyeaters (*Foulehaio carunculata*), Polynesian Trillers (*Lalage maculosa*), and Polynesian Starling (*Aplonis tapuensis*).

These birds were categorised into two groups according to how frequently they were detected, i.e. the four most common birds, and the remaining species grouped into low, medium and high rate of detection.

Four most common birds.

Swiftlets, Honeyeaters, Polynesian Trillers and Polynesian Starlings were the four most common birds present on the six transect lines. Bird counts of the four common birds aurally detected are presented in Table 3.21.

Table 3.21 The four most common birds, heard on the six transect lines from March - October 2000.

Transect	Swiftlets	Honeyeaters	P/trillers	P/starlings
1	0	202	160	78
2	0	91	72	36
3	0	113	55	32
4	5	84	70	38
5	0	67	45	21
6	4	270	184	111
TOTAL	9	827	586	316

When the aurally detected birds in Table 3.21 were ordered Honeyeaters were heard most often. Polynesian Trillers and Polynesian Starlings ranked second and third respectively in abundance and Swiftlets were rarely heard.

Bird counts of the four most common birds detected visually are presented in Table 3.22.

Table 3.22 The four most common birds visually detected at the six transect lines from March – October 2000.

Transect	Swiftlet	Honeyeaters	P/trillers	P/starlings
1	139	57	52	13
2	139	21	23	9
3	88	7	22	10
4	103	28	22	8
5	79	7	7	14
6	252	84	64	20
TOTAL	800	204	190	74

When ranked in terms of visibility, Table 3.22 clearly shows that Swiftlets were seen much more often than the other three species. Honeyeaters and Polynesian Trillers were seen about equally often and Polynesian Starlings seen the least often of the four species.

Birds less frequently detected.

Nine birds were less frequently detected between March and October 2000. The mean number of birds seen per month or heard were calculated for each of the nine species and presented in Table 3.23.

Table 3.23 Mean number of birds visually and aurally detected per month from March –October 2000. * Fruit Bats included for completeness.

Birds	Seen	Heard
Red Jungle Fowl	2.4	4
Banded Rail	0.6	25.4
White Tern	18.6	12.6
Pacific Pigeon	2.6	8.6
Purple Crowned Fruit Dove	6	9.4
Barn Owl	1.4	8
Pacific Swallow	9.4	0
White-collared Kingfisher	9.6	31.6
Fruit Bat	2.2	0.4

From Table 3.23 the less frequently detected birds can be further divided by low, medium and high rates of detection. The means presented in Table 3.22 are classed; Low rate range from 1 – 5, Medium rate range from 6 – 10 and High rate range from 11 – 40. The birds visually detected are grouped in Table 3.24.

Table 3.24 Visually detection rate for the less frequently detected birds per month from March – October 2000.

Low (1 –5)	Medium (6 – 10)	High (11-40)
Red Jungle Fowl	Fruit Dove	Fairy tern
Banded Rail	White-collared Kingfisher	
Barn Owl	Pacific Swallow	
Pacific Pigeon		
Fruit Bat		

For the visually detected birds in Table 3.24 most (five species) were detected at a low rate, three were in medium group and one in the high rate group.

Birds aurally detected are grouped according to their frequency of detection and presented in Table 3.25. The same classes applied to the visually detected birds are used for the aurally detected birds.

Table 3.25 Aural detection rate for less frequently detected birds per month from March – October 2000.

Low (1-5)	Medium (6 – 10)	High (11 – 40)
Red Jungle Fowl	Barn Owl	Banded Rail
Fruit Bat	Pacific Pigeon	White-collared Kingfisher
Pacific Swallow	Fruit Dove	Fairy tern

The nine species were evenly distributed over the three detection rate groups. Tables 3.22 to 3.25 clearly show that more birds were aurally detected than visually detected, however some species (Polynesian Swallow, Fairy Tern and Fruit Bat) were detected visually more than aurally detected. In contrast, Red Jungle Fowl, Barn Owl, Pacific Pigeon, and Fruit Dove, Banded Rail and White Kingfisher were detected by sound more than sight. These species shared the characteristic of having loud or distinctive calls.

3.4 DISCUSSION

In order to understand why density and abundance vary in the ways they do, we must know how populations relate to habitats (Weins and Rotenberry 1981). Juniper and Parr (1998) found that Koki benefit from agriculture, but depend heavily on mature forest for nesting. This chapter compared Koki density in four forest types in 'Eua Plantation Forest determining which habitat most supports Koki will be vital in future monitoring of the parrots and their conservation.

The Line Transect and the Point Count raw data both agree that Koki were mostly detected in *Pinus caribaea* Forest. There are at least reasons why Koki were mostly detected in *P.caribaea* Forest. First, as shown in Chapter 4, *P.caribaea* pinecones are readily available all year round and are a major item in Koki diet, therefore Koki were most probably foraging when detected in *P.caribaea* Forest. Second, *P.caribaea* trees were planted in orderly rows and distances from each other, and this open structure may have helped detection of Koki. In contrast, the other three forest types (especially Native Forest and Mixed Forest) were more closed and dense, with vines and epiphytes, making it harder to detect Koki visually. Third, *P.caribaea* trees are big, and generally higher than trees in the other three forest types. Marsden *et al* (2000) found several *Amazon* parrot species in Brazil to be strongly associated with big tree forests.

The density estimates provided by DISTANCE 3.5 (Buckland *et al* 1993) shows that the Point Count estimates were far higher that the estimates provided by the Line Transect method. As shown in Chapter 2, the Point Count method tends to overestimate Koki densities (refer to Chapter 2 for explanations on overestimation of the Point Count method). Therefore the Line Transect density estimates probably better reflect Koki density in the four forest types.

Probability detection function plots for the four forest types using the Point Count method were not robust, which were unsatisfactory. Exotic and Mixed Forest were of most concern, this problem could be due to the violation of the third Distance Sampling assumptions of measurements from the observer to the bird being exact.

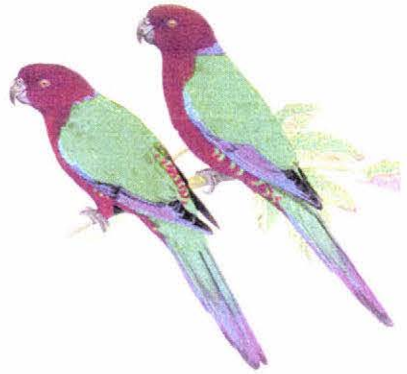
Low percentage of variability is preferable, however models presented produced high percentage of variability. Forest type data gathered using Line Transect and the Point Count methods, were pooled to reduce the high variability percentage but was not attainable.

It is estimated that at the time of the study there were about 620 Koki in the 'Eua Plantation Forest. Koki abundance was relatively higher in the Native Forest (c 211) closely followed by *Pinus caribaea* Forest (c 193). Higher Koki numbers in Native Forest and *P.caribaea* Forest may simply reflect the larger total areas of these habitats than the other forest types. High Koki abundance in these two forest types could be because Native Forest contains mature trees use by Koki for nesting, and *P.caribaea* Forest provides pinecones, a significant component of Koki diet.

The Koki abundance estimate derived in this chapter applies only to the 'Eua Plantation Forest. Because the total area for the four forest types in the whole of 'Eua is unknown, an abundance estimate for the whole island can not be given.

Thirteen other bird species were detected at the 'Eua Plantation Forest. The four most common species (honeyeaters, swiftlets, Polynesian trillers and Polynesian starlings) are widely distributed in Tonga, Samoa and Fiji (Watling 1982). The Honeyeater, the most common of all the species, is found from montane forest to the seaward edge of mangroves (Watling 1982). None of the other bird species found in 'Eua Plantation Forest shares the diet or nesting requirements of Koki. The 'Eua Plantation Forest appears to support the thirteen species and Koki with no evidence of resource competition. MacArthur (*et al* 1962) found that the variety of patches within a habitat determines the variety of bird species breeding there. This implies that providing key resources required by Koki (e.g. suitable nesting trees and sufficient food) remain Koki numbers on 'Eua will hold. As detailed elsewhere (Chapter 5) however, there are significant pressures on nesting sites.

From the results presented in this chapter it is clear that Koki were more abundant in Native and *Pinus caribaea* Forests. These two forest types are essential for the nesting and foraging needs of Koki. Therefore, for the future maintenance of Koki there is a need to preserve these two forest types so that the remaining Koki population is sustained. The Native Forest on 'Eua is being rapidly cleared for agricultural purposes, and for planting *P.caribaea* and exotic species. But Native Forest tree species provide the nesting sites for Koki. Marsden (*et al* 2000) suggests preserving rare species in large reserves. Engstorm (1981) notes that species abundance is reflected by the size of the area. The result of this study suggest that continually, reducing the area of Native Forest on 'Eua, coupled with the destruction of nest sites by locals, will lead inevitably to the disappearance of wild Koki on 'Eua.



CHAPTER 4

FOOD AND FEEDING

4.1. INTRODUCTION

The majority of parrots feed on seeds and fruits (Forshaw and Cooper 1973). Canopy bird species make up 40-50% of tropical forest bird communities, and parrots tend to dominate canopy bird communities (Terborgh *et al* 1990, cited in Renton 2001). But Renton (2001) notes that very little is known about the relationship between parrots and their food resources, however parrots tend to rely on food types which may show high temporal and spatial variability in abundance.

Koki (*Prosopeia tabuensis)* feed on the fruits and seeds of a wide range of forest trees (Watling 1982, Juniper and Parr 1998). Koki chicks taken from nests by local people of 'Eua and kept as pets are fed mainly root crops like taro and sweet potatoes, and Rinke (1995) considered that the life expectancy of these Koki was poor. Rinke (1995) maintained captive Koki on items such as soaked wheat, soaked mung beans, sunflower seeds, unripened coconut flesh, pawpaw, mango guava (in season) and mineral and vitamin supplements. Records from Fiji show that wild Koki also feed on pinecones, and in maize fields and banana plantations (Rinke 1995), so a range of food types are accepted by the birds, but root crops would not normally be available to free-living Koki.

Some aspects of the feeding activities of Koki on 'Eua were observed from July to December 1999 and from March to November 2000. This chapter presents information on how Koki feed on pawpaw and other wild fruits; an assessment of the utilisation of pinecones by Koki; and observations on the feeding behaviour of two captive parrots kept separately by locals as pets.

4.2. METHODS

4.2.1. Pawpaw Monitoring

Pawpaw *(Carica papaya)* trees accessible to wild Koki and growing along, or adjacent to, the transect lines were monitored between May and October 2000. Fruits of all sizes on these trees were recorded and the position and extent of koki feeding was noted. Of 22 pawpaw trees located in May 2000, three were cut down by local people and one died, but six new trees were found, so there were partial or continuous records for 29 trees. By the end of October 2000 there were 23 pawpaw trees: 13 on transect 6, four on transect 4, and one each on transects 1 and 3. The trees on transect line 1 and 6 were monitored about weekly and those on transect line 2,3 and 4 were monitored fortnightly.

4.2.2. Feeding on wild fruit other than pawpaw

Feeding by wild Koki on any wild fruits such as guava (*Psidium guajava*), lemon (*Citrus lemon*), firewood fruit (orange – *Citrus grandis*) and wild nutmeg (*Myristica hypargyraea*) was recorded.

4.2.3. Assessment of the utilisation of pinecones by Koki.

The introduced conifer *Pinus caribaea* occurs in extensive plantations on the upper eastern slopes of 'Eua and the ripe cones attract Koki. Fallen cones were examined to assess the extent and nature of feeding by the parrots. Feeding sign was ascribed to four categories: none; slight (some pecking); moderate; and extensive. Feeding by Koki on the cones is restricted to the canopy, so only fallen cones on the ground could be measured. This was achieved by means of large samples from transect 2 on 10 May 2000, and transect 4 on 8 June 2000. All pinecones encountered on the transect were assessed, unless they were broken by vehicles or very muddy.

4.2.4. Feeding by captive Koki.

Two Koki, held separately as captives by local people at 'Ohonua, 'Eua, were presented with known or potential foods, including pinecones, pine shoots, green plantain, cassava, raw yam, taro, fehi seeds, green pawpaw (whole and sliced) and guava fruits. Each item was presented for a five-minute period, during which the method of handling employed by the bird was recorded, along with the weight of the item before and after feeding.

4.3. RESULTS

4.3.1. Pawpaw monitoring

Pawpaw (*Carica papaya)* trees found on the edges of the forest by the transect lines were monitored from May to October 2000 for evidence of Koki feeding on the fruits. Throughout the monitored period, Koki fed on green, not ripe, pawpaw fruit preferring the flesh but seeds were also eaten. Some feeding signs were very limited, sometimes consisting of one peck to the fruit. Once a fruit was damaged the Koki did not return to it for a second feeding. Figure 4.1. shows two pawpaw fruits with signs of feeding by wild Koki. Table 4.1 summarises the pawpaw trees monitored for evidence of feeding by wild Koki.

Figure 4.1 Signs of feeding by wild Koki on green pawpaw fruits. Note the clear concave scooped marks left by the Koki beak. The pen is 14cm long.

Photo: RA Fordham

Table 4.1. Pawpaw trees monitored for evidence of feeding by wild Koki, May – October 2000. * Denotes tree cut down by local people.

Date found	Transect	Total fruit grown by tree	Feeding sign	Last record
19 May	6	38	No	10 Aug *
19 May	6	11	Yes	27 Oct
19 May	6	13	No	27 Oct
19 May	6	14	Yes	27 Oct
19 May	6	13	No	22 Jun *
19 May	6	14	Yes	27 Oct
23 May	2	4	No	27 Oct
23 May	2	6	No	27 Oct
23 May	2	1	No	27 Oct
23 May	2	11	No	26 May *
23 May	2	0	No	27 Oct
23 May	4	6	Yes	27 Oct
23 May	4	0	No	27 Oct
23 May	4	24	Yes	27 Oct
23 May	4	7	Yes	27 Oct
23 May	6	11	Yes	27 Oct
23 May	6	13	Yes	20 Oct *
23 May	6	18	No	27 Oct
25 May	1	10	No	27 Oct
25 May	1	14	No	10 Aug *
26 May	6	14	Yes	27 Oct
26 May	6	13	Yes	27 Oct
1 June	6	39	No	27 Oct
1 June	6	22	Yes	7 Jul *
25 July	6	14	No	27 Oct
2 Aug	6	10	Yes	27 Oct
12 Sep	6	9	No	27 Oct
12 Sep	6	11	No	27 Oct
29 Sep	3	4	No	27 Oct

Two trees (found 23 May) had no fruit throughout the six month monitoring period. Both were male trees, which do not bear fruits. The maximum number of pawpaw fruit grown by one tree (found 1 June) was 39. The mean maximum number of pawpaw fruits grown by the 27 trees was 12.55 (st dev 9.17). Table 4.2 shows the pawpaw fruits that had evidence of feeding by Koki.

Table 4.2: Pawpaw trees with fruits fed on by Koki from May to October 2000. The table shows the date when feeding was first noted; the number of fruits on each tree when the feeding occurred; the number of fruits fed on by the Koki; approximate percentage of each fruit eaten by the Koki, using the following scale, 1-5%, 6-10%, 11-25%, 26-50% and 51-100%; and the position of the fruit on the tree (T-top third, M-middle third, B-bottom third)

Date	Total Fruits on tree	Fruits eaten (%)	% of Fruit eaten	POSITION (T, M, B)
30 May	6	4 (66.6)	26-50	T
01 Jun	11	1 (9.0)	1-5	T
08 Jun	22	1 (4.5)	1-5	T
22 Jun	14	2 (14.3)	1-5	M
07 Jul	9	1 (11.1)	1-5	M
13 Jul	1	1 (100)	1-5	T
13 Jul	7	1 (14.3)	1-5	M
13 Jul	18	1 (5.5)	1-5	M
02 Aug	3	1 (33.3)	1-5	T
02 Aug	6	1 (16.7)	16-10	T
10 Aug	19	1 (5.3)	1-5	B
12 Sep	2	1 (50)	1-5	B
29 Sep	8	1 (12.5)	1-5	B
20 Oct	7	1 (14.3)	1-5	T
27 Oct	16	2 (12.5)	1-5	B

Wild Koki pecked at only 1 - 4 of the fruits available on each tree, but the amount consumed was generally small (less than 5%), and more than that on only two trees. On 7 (47%) of the 15 trees the fruits attacked were in the top third of the tree and the remainder were evenly spread (four trees each) between the middle and lower parts of the tree.

4.3.2. Feeding on wild fruit other than pawpaw.

Feeding by Koki on wild fruits other than pawpaw were recorded throughout the year while the main fieldwork was being carried out. The fruits taken by the birds and the number of birds seen appear in Table 4.3.

Table 4.3: The wild fruits apart from pawpaw fed on by Koki.

Tongan Name	Common Name	Scientific Name	Number of Koki observed (%) (n=76)
Paini	Pine	*Pinus caribaea*	56 (73.7)
Telie	Beach Almond	*Terminalia catappa*	7 (9.2)
‘Ovava	Weeping Fig	*Ficus benjamina*	7 (9.2)
Kotone	Wild Nutmeg	*Myristica hypargraea*	*
Lemani	Lemon	*Citrus lemon*	1 (1.3)
Moli Tonga	Firewood Fruit	*Citrus grandis*	1 (1.3)
Kuava	Guava	*Psidium guajava*	4 (5.3)

Kotone is not included in Table 4.3 because the trees were quite restricted in distribution and not encountered during regular fieldwork as frequently as the other species.

Nearly (73.7%) of the observed Koki were feeding on pinecones; beach almond and weeping fig both shared 9.2% and 5.3% fed on guava.

4.3.3 Assessment of feeding damage to Pinecones.

Pinus caribaea cones fed on by Koki were collected from the ground beneath the trees, measured, and grouped according to the intensity of feeding: None, Slight, Moderate and Extensive (Table 4.4). Direct observation repeatedly showed that the birds sit high in the trees, where they hold each ripe cone in one foot while removing seeds and bracts with their beak, leaving distinctive scars on the cone. When a bird finished with a cone it was dropped on the forest floor. Figure 4.2. shows pinecones eaten by wild Koki.

Figure 4.2 Koki feeding signs on fallen pine (*Pinus caribaea*) cones collected from the forest floor, May – June 2000. Note: the pen is 14cm long.

Photo: R.A. Fordham

Table 4.4. Koki feeding signs on fallen pinecones, May – June 2000. All sizes of cones grouped.

Feeding sign	Transect 2 (10 May) (%)	Transect 4 (8 & 10 June) (%)	TOTAL
None	44 (22.6)	16 (27.1)	60 (23.6)
Slight	77 (39.5)	34 (57.6)	111 (43.7)
Moderate	44 (22.6)	5 (8.5)	49 (19.3)
Extensive	30 (15.3)	4 (6.8)	34 (13.4)
TOTAL	195 (100)	59 (100)	254 (100)

Cones on Transect 2 showed significantly more intense feeding sign than those on Transect 4 (x^2=10.975, df=3, p<0.05), and on both transects the cones were distributed evenly with no evidence of clumping (Transect 2 x^2 = 14.226, df=9, p<0.2: Transect 4 x^2 = 3.74, df=6, p<0.8)

A two-way ANOVA was carried out to compare the lengths of the pinecones in relation to the intensity of Koki feeding (None, Slight, Moderate and Extensive) along the two transect lines. The result is shown in Table 4.5.

Table 4.5. Intensity of Koki feeding sign on pinecones of different lengths May – June 2000.

Source	DF	F value	Probability
Model	7	2.24	0.0318
Transect	1	0.77	0.3804
Condition	3	3.24	0.0229
Transect*Condition	3	1.73	0.1611

The overall F value (2.24) and the probability p=0.0318 indicates that the model well describes the variation about the overall mean length. Therefore there is a significant difference in the lengths of the pinecones on the two transect lines. In the detailed source of variation, the TRANSECT variable is not significant at 0.3804 and neither is the TRANSECT*CONDITION interaction at 0.1611 but the CONDITION variable on its own is significant at 0.0229.

The mean length of pinecones showing the four levels of feeding intensity is analysed in Table 4.5 and Table 4.6 which shows that there is no major variation in the mean lengths for the four damaged conditions in the two transects. The mean length (cm) of the damaged pinecones ranges from 10.4cm (std dev 1.385) for cones showing extensive damage to 11.2cm (std dev 2.056) for the undamaged pinecones.

Table 4.6 The mean length and standard deviation of the damaged pinecones in the four conditions in the two transects combined.

Damage	Frequency	Mean	Standard deviation
None	60	11.2	2.056
Slight	111	11.2	1.909
Moderate	49	10.6	1.613
Extensive	34	10.4	1.385

4.3.4. Captive Koki.

Food items presented to Captive Koki.

Two Koki taken from their nest as chicks were held separately by two families in 'Ohonua as pets. Koki 1 was kept by the Siakumi family for four years, and Koki 2 was kept by the Takai family for one and a half years. The following known and potential food items presented to Koki 1 and Koki 2 are shown in Table 4.7.

Table 4.7 Food items presented to Captive Koki 1 and Captive Koki 2.

Koki 1 and Koki 2		Koki 1 only	
Food Items	Name	Food Items	Name
Pinecones	*Pinus caribaea*	Taro	*Colocasia esulenta*
Pine shoots	*Pinus caribaea*	Plantain	*Musa paradisiaca*
Pawpaw (green)	*Carica papaya*	Tapioca (raw)	*Manihot esculenta*
Guava (green)	*Psidium guajava*	Yam (cooked)	*Dioscorea alata*
Fehi seeds	*Instia bijuga*		

Pinecones were offered to Koki 1 on three occasions. Once, Koki 1 took three pecks at the pinecones presented then ignored them as it did on the other two occasions. Koki 1 also took no interest in pine shoots.

Koki 1 pecked and nibbled at taro and cassava, stopping at intervals, then returning to them. It also pecked and nibbled at the plantain and the fehi seeds. Koki 1 rolled fehi seeds in its mouth using its tongue then dropped the outer casings and swallowed the rest. However Koki 1 did not sample the guava or sliced green pawpaw. When a whole small pawpaw was presented it pecked twice, making no opening, repeated this after an interval, and then ignored the fruit. Most of time, Koki 1 did not use its feet to assist with feeding.

In comparison with Koki 1, Koki 2 (the shorter term captive) investigated most of the food items offered to it including pinecones, pine shoots, slices of pawpaw, guava and fehi seeds with pinecones. Koki 2 peck the pinecone then held the cone down with one foot before biting a piece out and nibbling it. With the pine shoots Koki 2 pecked at both ends of the shoot, later raising the shoot with one foot to its beak where it bit, nibbled then swallowed. With the slice of green pawpaw, Koki 2 pecked the seeds, rolled them with its tongue, nibbled then swallowed. Part of the seeds were spat out. With the guava, Koki 2 held the fruit down with one foot then pecked the skin and flesh off. It took some bites and nibbles, dropping some then disregarded the remains. The fehi seeds were presented to Koki 2 still in a pod and the bird fed on two of the seeds by opening the outer casing, rolling the seed with its beak and tongue, dropping the outer casing, and consuming the rest.

Amount of food consumed by Captive Koki.

The food items were weighed before and after they were presented to the captive birds. The captives did not attempt to eat all the items presented, nor did they eat much of the ones they did peck at (Table 4.8). The food items the captive birds did not feed on are not shown in Table 4.8. Koki 2 pecked at most of the food items presented to it, but consumed little.

Table 4.8 Amount of food items consumed by Koki 1 and Koki 2. Plaintain (1) and Plantain (2) means that plantain was fed to Koki 1 on two different occasions.

Food items	Amount consumed by Koki 1 (g)	Amount consumed by Koki 2 (g)
Pinecones	4	0.5
Fehi seeds	Negligible	Negligible
Cassava	1	-
Taro	0.5	-
Plaintain (1)	2	-
Plantain (2)	3	-
Guava	-	2
Pawpaw	-	2
Pine shoots	-	Negligible

The captive Koki were also fed the following food items by their owners: raw green and ripe banana, coconut, pawpaw, fehi seeds, cooked taro, plantain, yams, cassava and bread and crackers.

4.4. Discussion

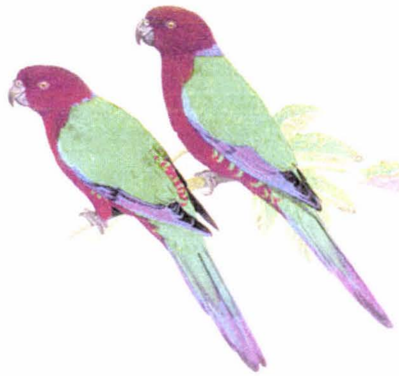
Most parrot species are primarily canopy seed eaters (Smith and Moore 1991) with some being frugivorous (Wermunndsen 1997). The seeds and fruits are eaten either in the treetops, or on the ground (Forshaw and Cooper 1974). Most studies on the relationship between bird communities and resource variability have been done on frugivores (Renton 2001). Koki do eat the pawpaw seeds, and Juniper and Parr (1998) suggest that for some birds it is the seed embedded in the fruit, rather than the flesh of the fruit, that the birds need. In most cases the pawpaw fed on by wild Koki was not fully opened to expose the seeds. It is unclear whether this indicates that the flesh was sufficient for the birds, or that they were distracted during feeding by humans. It is likely that sometimes people did disturb Koki feeding on the pawpaw trees because they were adjacent to tracks used by local people travelling to and from the bush. The active foraging time for the Koki in the early morning, and before sunset, would coincide with the movements of local people.

Rinke (1995) reported, without presenting details, that Koki diet consisted mainly of fruits and pinecones but also banana and maize. In Fiji Koki take mango fruits (Low 1994). On 'Eua the consumption by Koki of a range of wild fruits shows that both seeds and fruits are eaten, but wild Koki appear to focus more on pinecones than all the other wild fruits available. This is probably because pinecones are available all year round while all the other fruits mentioned are seasonal. Pinecones are clearly one of the main sources of food for wild Koki on 'Eua. The parrots took dry (i.e. ripe), not green cones, of any size apparently for the seeds they held. Even if natural seeding of pines was an aim in management of the planted pine forests on 'Eua, there are so many cones, and so many seeds remain after Koki have fed, that this level of herbivory would not be a concern.

The two captive Koki responded differently to the food items offered them. The older bird (Koki 1) did not attempt to taste all the foods provided, and displayed stereotypic behaviours often seen in captive animals – running around the cage for a period, before resting, then resuming the same behaviour over and over. The younger bird (Koki 2) was however, interested in most of the foods. The captives can eat a range of foods, including root vegetables that they would never encounter in the wild, which may cause other problems. Captive birds receiving diets high in protein concentrations can experience urate deposits (gout), according to Angel and Ballam (1995) cited in Frankel and Avram (2001).

Some parrots are known to be specialist feeders (e.g. *Anodorhynchus* macaws specialise on various palm nuts) while others are generalists (e.g. Ring-necked parakeet) (Juniper and Parr 1998). Koki on 'Eua manipulate their food with beak, tongue, and foot and live in a mosaic of forest (habitat) types. Mettke-Hoffmann *et al* (2002) tested exploration and neophobia related to feeding in 76 species of captive parrots. They concluded that species that have to manipulate their food (e.g. nuts, fruit) and species on islands, spent longer exploring their food than species with diets consisting of easily detected foods such as leaves and grass seeds. Moreover, species in complex habitats, such as forest edges, spent little time between food discovery and food consumption. On the whole Koki display generalist feeding behaviour by feeding on a wide range of plant products. On 'Eua no other bird species appear to feed on pinecones, pawpaw or some of the other wild fruits. Thus Koki may not face significant competition for these foods and may be seen as an opportunistic feeder by utilising what ever is available to them. This is exemplified by the way Koki feed on pawpaw i.e. they do not return to a fruit they have scarcely damaged for a second feeding, or always try to open the fruit on the first occasion. Their feeding behaviour on pinecones further indicates an opportunistic approach to foraging. The birds do attack dry cones, not green, but do not discriminate between small, medium, or large cones. Instead they tackle the cones at random and do not preferentially feed on larger ones.

The people of 'Eua often refer to Koki as "manu maumau" meaning wasteful animal. This term appears to have been applied because of the style of foraging by Koki, whereby interest in any one food type is short-lived, but may be rekindled repeatedly over time, and may result in the abandonment of apparently edible food on each occasion.



CHAPTER 5

NESTING

5.1. INTRODUCTION

Many bird species depend on tree cavities for nesting (Newton, 1994). For instance in Europe and North America 5% and 4% respectively of the avifauna are hole nesters, while in southern Africa and Australia equivalent figures are 6% and 11% respectively (Newton 1994). Parrots (Order *Psittaciformes)* are prominent among the cavity nesting birds.

On 'Eua, Koki (*Prosopeia tabuensis)* nest in cavities of live or dead forest trees including, occasionally, trees growing in plantations (Rinke 1987). Rinke (1987) found Koki nest cavities vary from < 0.5m to more than 5m deep. Nests in very deep cavities have the entrance high in the tree and the nesting or breeding chamber close to ground level. Rinke (1987) noted that Koki built their nests in *Rhus taitensis* (tavahi), *Elattostachys falcata* (ngatata) and *Laportea harveyi* (salato). Two of these species appear well suited to hole nesting; salato wood is very soft so Koki can easily enlarge natural cavities, while tavahi naturally shows rapid growth and subsequent decay (Rinke 1987). It appears that the Koki is a secondary cavity nester (Newton (1994), i.e. a species that does not or cannot excavate its own hole (non-excavator) but relies on existing holes produced by branch loss, insect damage or fungal decay. The Koki is therefore a non-excavator but can enlarge or modify cavities to suit its needs, as it does with the soft wood of the salato.

Secondary cavity nesters like the Koki are of concern because the breeding densities of many birds which nest in cavities are, in some areas, limited by shortage of nesting sites (Newton 1994). Lack of nest cavities has been shown to limit the breeding density of parrots (Beissinger and Bucher 1992). Beissinger and Bucher (1992) found that the milling of large trees from tropical forests such as Atlantic Forest of southeast Brazil and some islands of the Caribbean, together with the felling of nest trees to obtain parrot chicks for sale, has reduced available nest sites. This latter practice affected Koki on 'Eua with local people removing young from nests and in doing so damaging the nests. This problem was evident in Rinke's (1987) study, but appeared to have become more significant during the present study. Because Koki are known to reuse nests year after year (Rinke 1987), damage to the nest while removing young has both short, and long term, negative demographic effects.

Koki were introduced to the island of Tongatapu in the Tongan group before European contact, but became extinct due to loss of suitable habitat (Juniper and Parr 1998). Now the remaining Koki population is found only on 'Eua where they were introduced in the eighteenth century. The spread of agriculture on 'Eua has reduced the area of natural forest dramatically over the last four decades to the east coast of the island (Bellingham and Fitzgerald 1997). This remaining natural forest is now a stronghold of the Koki on 'Eua.

As quoted in Rinke (1987), Carlson (1974) stated that the breeding season of the Koki on 'Eua begins in July and ends in December but, according to Rinke (1987), the breeding season occurs from May to October. During the present study in 2000 it appeared that the breeding season extended from June to November. The period of breeding found by Carlson (1974), Rinke (1987) and the present study all fall in the cool dry season, and Rinke (1987) argues that the climate is the main factor timing the breeding of the Koki on 'Eua.

Because breeding is potentially such an important contributor to the population of any species at risk, the nesting of Koki was investigated in an effort to assess the level of production since the study by Rinke (1987). This work was, necessarily, a secondary aim of the overall research plan but was aimed at better understanding the current demographic status of Koki. In this chapter the locations of nests found during the period June to October 2000 will be described. The activity of breeding Koki at these nests and their outcomes will be presented, and finally a physical description of each nest site will be given.

5.2 METHODS

5.2.1. Location of Nests

Koki nests were searched for on the island of 'Eua between September - November 1999 and June – October 2000. Because the area of forest where potentially Koki could occupy suitable trees was very large, local people were approached for information. Mostly these were older men living or working on their bush allotments, planting traditional crops such as taro, yams and kava. The men sometimes provided information that narrowed the search to places where Koki were frequently seen or heard. These sites were then observed intensively to locate the nest tree, and to note whether one or both birds of the pair entered the nest cavity, or merely rested on nearby branches.

When a possible nest cavity was identified it was tested to see if Koki chicks were inside by carefully inserting a long thin branch with terminal leaves. This method is used by locals to identify nest cavities with chicks in them. The branch was left for about five minutes, and then removed, and any leaves showing peck marks indicated that Koki chicks were inside. This method confirmed three nests (1,6 and 7). Rinke (1987) did not mention using this method in his study. For some nests where the tree trunk was straight a torch was used to observe the nest directly. Nests known to be holding Koki chicks were watched by two observers for varying periods from a concealed hide 10 –15m from the nest tree. Observations included: the date, time period, weather, whether the bird was flying or resting near the nest tree, the distance and direction of the bird from the nest, and whether the bird was vocal or silent. Nests with no chicks were continually checked for entry by Koki. Signs of entry were confirmed by recording broken spider webs over the entrance hole, and later by tests with long fine, flexible, branches.

5.2.2. Nest tree habitat

All eight nest sites in 2000 were visited in late November and described. This included the species of nest tree, distance and direction to next nearest tree, and the height of the nest entrance. For nest trees that had been vandalised by local people, note was taken of the nature and extent of the damage, how it was inflicted, and the height of the damage.

5.3. RESULTS

5.3.1. Location of nests

The search for Koki nests extended from September – November 1999 and June – October 2000. No nests were found in 1999 and all evidence suggested that little or no breeding took place on 'Eua in that year. In 2000, eight nests were discovered in the south and east central area of 'Eua known as Mo'unga Te'emoa. (Figure 5.1)

Description of the eight nests

Of the eight nests found, Koki chicks were confirmed in three of them (1,6 and 7) and an adult Koki was seen entering and leaving nest 7. Unfortunately the chicks in these three nests were later taken by locals for sale and the nest trees vandalised. Damage to the nest tree usually consisted of an opening cut with an axe or machete in the trunk, about 85 –170cm above ground. Of the five nests where no eggs or chicks were present, two were already damaged by locals when found. The remaining three nests were continually checked for any sign of Koki activity but up to the end of the present study showed no signs of breeding. Table 5.1. describes the eight nests.

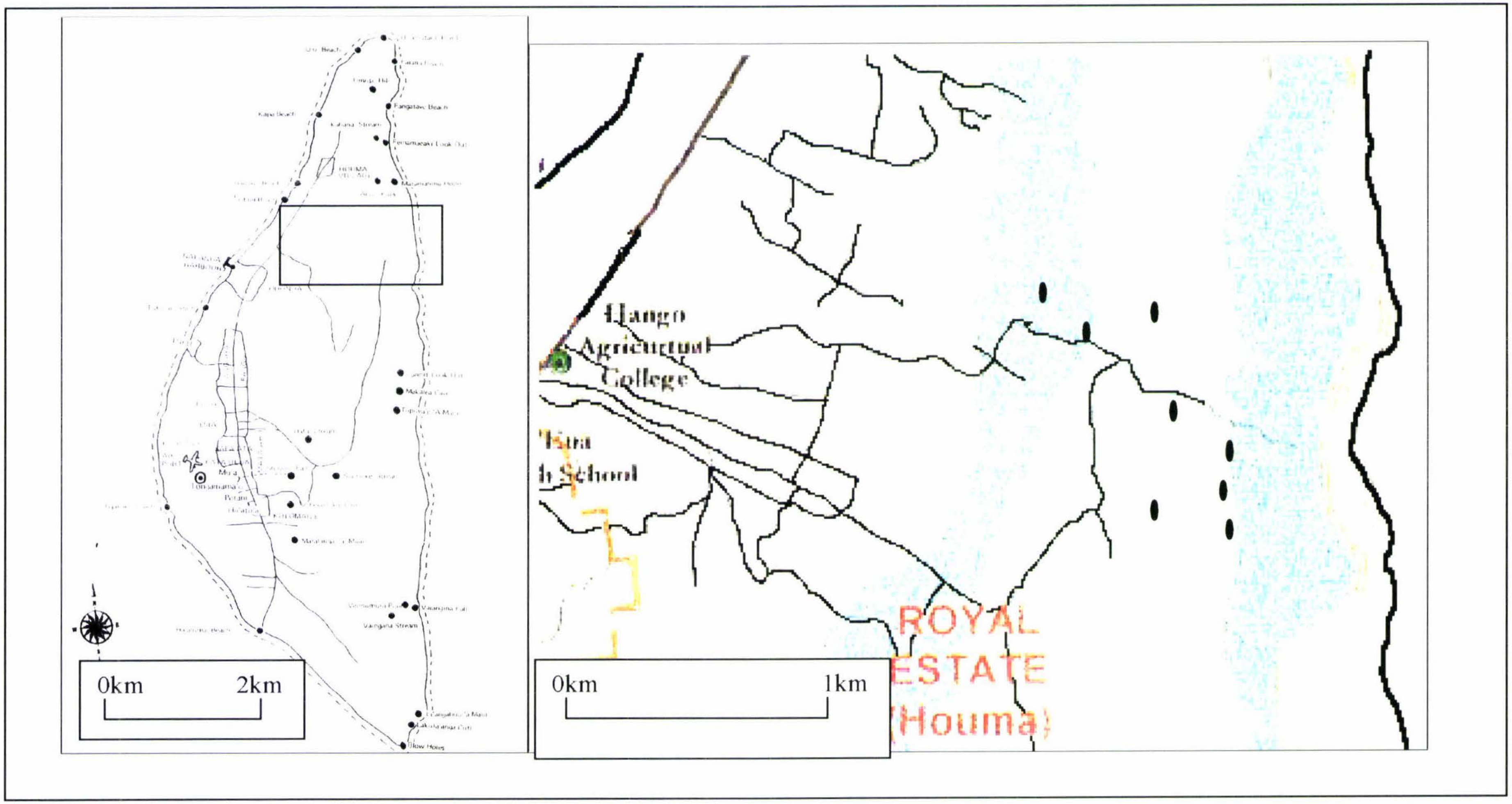


Figure 5.1 Location of eight nests found during the 2000 breeding season. Enclosed rectangle in the left hand map is enlarged in the right hand map.
● = nest trees

rectangle in the left

Table 5.1. Koki nests on 'Eua, June – October 2000. In the Damaged column, "Initially" means that the nest was already damaged when found, "Later" means that the Koki chick was removed when the nest was damaged; and "None" means that there was no damage inflicted on the nest tree. * Adult Koki seen attending the nest

Nest	Koki present	Tree	Damaged
1	Yes	Ngatata (*Elattostachys falcata*)	Later
2	No	Mamea (*Litsea mellifera*)	Initially
3	No	Pua-tonga (*Fagraea berteroana*)	None
4	No	Pua-tonga	None
5	No	Mamea	Initially
6	Yes	Ngatata	Later
7 *	Yes	Mamea	Later
8	No	Pua-tonga	None

Three nests with Koki chicks

Nest 1, 6 and 7 held Koki chicks when first found. Nest 1 was visited five times, and a total of 27 hours were spent observing the nest. No Koki was ever seen entering or leaving the nest, but birds were seen and heard as close as 6m from the nest. On the fifth visit the nest tree was found to be damaged and the chick removed

Nest 6 was in a rotting ngatata with no branches but an open tree trunk well covered by neighbouring trees and by vines growing on the trunk. Nest 6 was visited twice. On the first visit 6 hours were spent observing the nest, but no Koki was seen to enter or leave it. On the second visit the vegetation around the nest was found to have been cleared leaving the nest quite exposed, the tree trunk had been opened and the Koki chick removed.

Nest 7 was visited six times and observed for 31 hours. On the second and third visits (on 12 and 17 October) an adult parrot was seen on three occasions to enter the nest for 16, 4, and 57 minutes respectively. On two of these occasions another Koki rested 15m from the nest, making soft chirping noises. At each visit to the nest the approaching Koki would fly into the nest area calling, then rest silently for a few minutes before flying silently into the nest. When departing it flew out of the nest silently, rested c.20 m away from the nest calling, then flew off. On the sixth visit the tree had been damaged by locals who removed the young.

5.3.2. Nest trees.

In 2000 the eight nests were found in three species of tree (Table 5.3). Two were in ngatata (*Elattostachys falcata)*, three in pua-tonga *(Fagraea berteroana)* and three in mamea (*Litsea mellifera)*. All eight nests were situated in patches or strips of native forests surrounded by crop plantations and cliffs. Nest 7 was an exception, being at the bottom of a c.30m deep gully with a stream 3m away from it.

Nest entrances.

The average height of the nest entrance from the ground was 4.77±1.25m, and ranged from 0.82m to 10.15m. The lowest entrance (Nest 5) was in a pua-tonga tree on the edge of a gully, that extended down c.70m, and was well covered by native forest. The highest entrance (Nest 2) was in a mamea tree in a strip of native forest, 20m from a crop plantation and 30m from the edge of a cliff.

The width and height of nest entrances averaged 0.36±0.05m and 0.20±0.42m respectively, with no marked differences between tree types. (Table 5.2)

Table 5.2 The height above ground, length and width of the entrance into each nest.

Nest	Tree species	Height above ground (m)	Height (m)	Width (m)
1	Ngatata	3.40	0.22	0.13
2	Mamea	10.15	0.32	0.17
3	Pua-tonga	1.07	0.38	0.16
4	Pua-tonga	0.82	0.54	0.19
5	Mamea	4.17	0.27	0.21
6	Ngatata	4.37	0.57	0.47
7	Mamea	9.91	0.29	0.14
8	Pua-tonga	4.30	0.26	0.14
MEAN (± SE)		4.77±1.25	0.36±0.05	0.20±0.42

On average the entrances into the nests in mamea were considerably higher above ground (8.07m) than the entrances in ngatata (3.88m) and pua-tonga (2.06m) trees. The sizes of the entrance holes were, however, less variable between the three species of tree. The mean height of the entrance was 0.29m in mamea, 0.39m in pua-tonga, and 0.39m in ngatata. The mean width of the entrance was 0.17m in mamea, 0.16m in pua-tonga, and 0.30m for ngatata. Overall, therefore, the entrance holes to nests were relatively lower in mamea, and wider in ngatata than in the other two nest tree species.

Neighbouring trees.

All the nests occurred in forest with a closed canopy, and were situated in trees that were generally larger than any of their neighbours. The three trees closest to each of the nests were identified and their distances (m) from the nest tree measured. Eleven different species were recorded (Table 5.3), the most frequent of the 24 trees being feto'omaka (6), ngatata (5) and pua-tonga (3). The remaining eight species occurred once or twice each. For the most frequent recorded species the mean distances from the nest tree were: feto'omaka 3.11±0.83m, ngatata 3.23±0.90m and pua-tonga 1.54±0.60m. The closest tree was a pua-tonga, 0.36m away from Nest 4, which was also in a pua-tonga. The furthest tree of the three nearest tree species was a tavahi, 7.46 m away from Nest 2.

Table 5.3 Three nearest neighbour trees to the eight nest trees in 2000.

Nest	Name	Genus and species	Distance (m)	Mean for each nest
1	'Ai	*Caranium harveyi*	1.51	
	Pekepeka	*Maniltoa grandiflora*	1.62	
	'Ai	*Caranium harveyi*	3.60	2.24±0.70
2	Feto'omaka	*Garcinia myrtifolia*	3.38	
	Ngatata	*Elasttostachys falcata*	6.5	
	Tavahi	*Rhus taitensis*	7.46	5.78±1.23
3	Pua-tonga	*Fagraea berteroana*	1.10	
	Toi	*Alphitonia zizyphoides*	2.51	
	Feto'omaka	*Garcinia myrtifolia*	3.36	2.32±0.66
4	Pua-tonga	*Fagraea berteroana*	0.36	
	Pua-tonga	*Fagraea berteroana*	3.15	
	Ngatata	*Elasttostachys falcata*	3.48	2.33±0.99
5	Kotone	*Myristica hypargyraea*	2.53	
	Pekepeka	*Maniltoa grandiflora*	3.05	
	Feto'omaka	*Garcinia myrtifolia*	4.51	3.36±0.60
6	Ngatata	*Elasttostachys falcata*	1.25	
	Feto'omaka	*Garcinia myrtifolia*	1.72	
	Feto'omaka	*Garcinia myrtifolia*	4.63	2.53±1.06
7	Tamanu	*Calophyllum neo-ebudicum*	3.08	
	Koka	*Bischofia javanica*	3.15	
	Salato	*Dendrocnide harveyi*	4.18	3.47±0.35
8	Feto'omaka	*Garcinia myrtifolia*	1.07	
	Ngatata	*Elasttostachys falcata*	2.05	
	Ngatata	*Elasttostachys falcata*	2.89	2.00±0.53
	Overall Mean ± SE distance of nearest tree to a nest			3.00±0.34

The overall mean distance for the neighbouring trees was 3m. The distance of the closest tree to each nest ranged from 0.36m to 3.38m, and the overall was 1.78±0.40m. The furthest away of the neighbouring trees to the nests ranged from 2.89m to 7.46m, and the overall mean was 4.26±0.50m. The mean distance of the three neighbouring trees closest to each nest are shown in Table 5.4.

For the eight nest trees the mean distance of the three nearest ranged from 2m (Nest 8) to 5.78m (Nest 2) and the overall mean was 3.00 ± 0.34m.

Damaged nests.

Of the eight nests, five (1,2,5,6,7) were destroyed by local people, and chicks were removed for sale from nests 1,6 and 7. The nest trees were damaged by opening the trunk with an axe or machete where the breeding chamber was estimated to be, except for nest 6 in a tree with a rotting trunk, which was opened at the top. Nests 2 and 5 were found already opened at the trunk, indicating that locals had already removed the chicks. The damage is summarised in Table 5.4.

Table 5.4 Damage done to four of the nest trees by local people, 2000, 'Eua. Nest 6 was also damaged, but from the top, so is not included.

Nests	Height of damage above ground (m)	Height of cut hole (m)	Width of cut hole (m)
1	1.11	0.17	0.09
2	0.89	0.33	0.26
5	1.67	0.27	0.21
7	1.47	0.17	0.25
Mean±SE	1.28±0.17	0.23±0.04	0.20±0.04

The mean height of damage above ground was 1.28m, while the height and the width of the cut hole averaged 0.23m and 0.20m respectively.

5.4. Discussion

Like most parrots Koki are cavity nesters in hollow dead or live mature trees (Rinke 1987, Juniper and Parr 1998). Hollows form in the trees as a result of storm damage or other species such as fungi, insects or woodpeckers (Newton 1994, Juniper and Parr 1998). Koki are secondary excavators (Newton 1994), and since there are no woodpeckers in Tonga it appears Koki rely for their nesting on hollows forming as a result of storms breaking off branches, and decay by insects and fungi. The opportunities for such damage to occur are frequent. 'Eua and the rest of Tonga are periodically affected by cyclonic storms with wind speeds of over 200km/hr and high rainfall (Bellingham and Fitzgerald 1997). Koki can further excavate the storm-induced hollows with their very hard, strong beaks to suit their nesting preference.

In 1999 and 2000, breeding by Koki was far from successful. In 1999 no nests were found and there were no field signs of breeding taking place on 'Eua. Similarly, little or no nesting by captive Koki occurred in the Tonga Wildlife Centre on Tongatapu (c. Claudia Matavalea, Tonga Wildlife Centre, pers comm.). In 2000, however, eight nests were found but overall little breeding activity appeared to take place. Reasons for the very low breeding success of the Koki are unclear, but several factors could affect Koki population productivity. Beissinger and Bucher (1992) found that limited access to nests, and limited food sources, could restrain adults from breeding. Puerto Rican Parrots (*Amazon vittata*) were observed from 1973 to 1979 and each year during that period 57% did not breed, although some pairs were defending territories (Wiley *et al* 1992). In the case of the Koki in 'Eua, it appears that food is not in short supply but suitable nest sites may be are limited. Out of the eight nests discovered in 2000, three showed breeding activity, two were found damaged and three were available nests with no breeding activity in them. The three available nests were located in areas very close to roads and tracks. Location of the nests can, therefore, affect the suitability of the nests because those close to roads and tracks are much more likely to be detected by local people, and this would lead to the nests being cut open and chicks taken for sale.

Current parrot harvesting practices lead to loss of nest sites, where tree nests are cut down and the chicks are removed from the cavity (Beissinger and Bucher 1992). Rinke (1987) found that the local people of 'Eua damaged the Koki nests to collect chicks. However the present study indicates that the damage caused by local people was serious and significant. In most cases, the local people were opening the nest trees at the breeding chambers and removing the chicks. A survey carried out by Bellingham and Fitzgerald (1997) shows that most of the local women of 'Eua use Koki feathers to make ta'ovala (waist mats) at an average rate of about 1-2 Koki per woman per year. The same survey showed that Koki were hunted by 18% of households in 'Eua during that year (Bellingham and Fitzgerald, 1997) sometimes to sell them as pets. The current harvesting practice therefore has a dual effect; there is a loss of production by the nesting pair in a particular year by removal of any chicks, and the permanent loss of a nest site when the nest tree is vandalised.

Watling (1982) noted that the major threat to the avifauna of Fiji, Samoa and Tonga is habitat destruction through deforestation. Deforestation is occurring rapidly on 'Eua and is beginning to threaten the remaining stands of indigenous forest (Allen 1990 cited in Drake 1996). Deforestation clears mature trees that potentially can hold nesting sites for cavity nesters such as Koki. Local people are clearing forest for agricultural purposes, tracks, and roads, and this destroys existing and potential Koki nests.

Rinke (1987) found that the Koki nested in ngatata, tavahi and salato and the minimum distance between adjacent nests was 120m. In the present study the Koki nested in three tree species; mamea, pua-tonga, and ngatata and the minimum distance between adjacent nests were 85m. Ngatata is one of the dominant species in the secondary forest in Tonga together with tavahi and toi (Whistler 1992). Straatmans (1964) found the same combination of trees dominate secondary forest on 'Eua but ngatata is a 'minor component'. However a later unpublished study (1990) on a patch of forest near the airport on Tongatapu showed that in terms of relative dominance, ngatata comprised 45% of the canopy (Whistler 1992).

The dominant species in secondary forests grow taller than secondary shrubs and provide shade, which eventually eliminates smaller trees (Whistler 1992). Koki may select Ngatata for nesting because it towers over the other trees. There is, however, a problem with dominant secondary forest species such as ngatata. Whistler (1992) found few small ngatata individuals, indicating that when the current cohort of large individuals die, ngatata will be poorly represented in the forest, until long after the next major disturbance event.

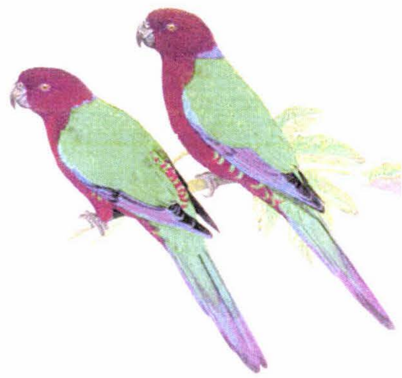
Mamea can grow to 35m (Yunker 1959). On 'Eua mamea is common in mixed upland rain forest on volcanic soils where no one species represents on average more than 12% of the relative basal area (Drake 1996). Drake found that the most abundant large tree in this type of rainforest is the tamanu, *Calophyllum neo-edudicum* as a co-dominant with mo'ota, *Dysoxylum tongense*. In the present study neither tamanu nor mo'ota was found as a nest tree, but tamanu featured as one of the three trees closest to a nest tree.

Pua-tonga is a medium to large tree (Yunker 1959), which normally occurs in montane forest community above 550m (Whistler 1992). Tonga is generally too low for montane forest (Whistler 1992) but pua-tonga is frequent in open forests throughout Tonga (Yunker 1959).

Most parrots prefer high nest site entrances (Juniper and Parr 1998). This also appears to be true in general for Koki because of the eight nests found in this study three were in mamea, on average 8.07m above ground, although the remaining nests in ngatata and pua-tonga were lower. Measurements of the sizes of the nest entrances show these were largest in area in ngatata, and smallest in mamea trees. Overall, therefore, Koki nesting in mamea trees with relatively small entrance holes may stand the greatest chance of avoiding detection and destruction by local people searching for Koki.

The nest sites of the Lilac-crowned parrot (*Amazona finschi*) of Mexico were similar in tree species, tree size, cavity height and entrance width (Renton and Salinas-Melgoza 1999). However the White-tailed black cockatoos *(Calyptorhynchus baudinii latirostris*) of Western Australia nests in any species of eucalypt with hollows of a suitable size (Saunders 1978). On 'Eua Koki use several species of trees for nesting, but it is not clear how Koki select nest trees or nest sites. Possibly they initially select hollows in whatever tree is available. For some parrots predation is an important influence on nesting. For instance predation is one of the major factors affecting the choice of nest hollows by the *Eclectus* parrots in the Iron Range National Park of Australia (Legge and Heinsohn 2000). On 'Eua predation of Koki is limited. Barn owls are known to attack Koki nest sites (Rinke 1987), and local people also report that rats attack Koki nest sites by feeding on the eggs. But the major factor that negatively affects nesting in the Koki, and which apparently affects the long term viability of the species on 'Eua, is human impact.

Currently the National Park along part of the east coast of 'Eua is a refuge for Koki and other wildlife as long as the local people of Tonga continue to preserve the area and avoid further disturbances such as deforestation.



CHAPTER 6

SYNTHESIS AND RECOMMENDATIONS

6.1 SYNTHESIS

Effective monitoring of the remaining Koki population on 'Eua relies heavily on population density and abundance estimates. This study provides the first objectively based, detailed population estimate of Koki on 'Eua. The Koki density and abundance estimates derived in this study are a first step towards conserving Koki on 'Eua.

The Distance Sampling primary methods - Line Transect and Point Count were chosen to compare how effective and accurate they would be in estimating the Koki population in the 'Eua Plantation Forest. Distance Sampling estimates absolute density of a population based on accurate measures of observer to animal distance (Buckland *et al* 1993). The Line Transect and the Point Count methods were chosen as cost-effective methods (Cassey 1997). Line Transect is suitable in extensive, open, and species-poor habitats, and is the most efficient of all Distance Sampling methods in terms of data gathered per unit effort (Bibby *et al* 1992). Bibby (*et al* 1992) also noted that the Point Count method is suitable for conspicuous birds in scrubby habitats and is more appropriate than the Line Transect method in areas where access is poor.

The density estimates provided by DISTANCE (Buckland *et al* 1993) for the Line Transect and the Point Count methods (Chapter 2 and 3) showed that Point Counts

tended to overestimate Koki density in the 'Eua Plantation Forest. The Line Transect density estimates appeared to better represent Koki density.
Density estimates of six transect lines at the 'Eua Plantation Forest, through different forest types, showed that Koki density was highest at Transect line 1 (0.193/ha) where the principal forest type was Native Forest. Transect line 1 also appeared to be the transect line least disturbed by local people. The average density for the six transect lines was 0.153 per hectare, suggesting about 1 Koki per 6 hectares in 'Eua Plantation Forest.

The forest habitats at 'Eua Plantation Forest were categorized into four forest types to identify the distribution and habitat use of Koki. Habitat use was ascribed to two major components: breeding and foraging. Koki density estimates (Chapter 3) were highest in Native Forest, closely followed by *Pinus caribaea* Forest. Native Forest provides large mature trees required by Koki for nesting. *Pinus caribaea* Forest provides pinecones which appear to be a major food component for Koki on 'Eua. The Native Forest and the *Pinus caribaea* Forest are the major habitats required by Koki. Existing detailed maps (Landcare Research 1997) of 'Eua Plantation Forest, together with Koki density estimates for the four forest types using the Line Transect method allowed an estimate of about 620 Koki in the 'Eua Plantation Forest during the study.

The diet of wild Koki on 'Eua consisted of wild fruits (Chapter 4) and the birds showed generalist feeding behaviour. It appears that Koki have adapted to feeding on what is available in the different forest types and that pinecones are a significant food item for Koki in the 'Eua Plantation Forest. Wild fruits were presented to two captive parrots which showed different feeding behaviours. The older Koki (c. 4 years) was reluctant to try most of the wild food items presented, whereas the young Koki (1½ years) tried almost all of the wild fruits presented. This suggests that the older Koki has adapted to the food items presented to it by it's owners instead of wild fruits fed on by wild Koki.

Eight Koki nests were found during the period June to October 2000. Activity of breeding Koki, descriptions of the eight nests and the outcomes of these nests are described in Chapter 5. Koki depend heavily on hollow cavities of large mature trees for nesting sites. However there is a significant problem for breeding Koki caused by the local people who cut open the nest trees and remove the chicks from the nest cavity. Koki do not return to damaged nests for breeding, therefore suitable nest sites are permanently reduced, and young Koki do not join the wild population.

In summary, Chapter Two and Three provided the Koki density and abundance estimates in the 'Eua Plantation Forest and the habitats mostly used by Koki. Chapter Four and Five show how and why the Koki use the habitats described. This study suggests that in order to retain the remaining Koki population on 'Eua, the nesting and the feeding requirements of the Koki need to be conserved.

6.2 RECOMMENDATIONS

'Eua supports the most unique forest in Tonga (Sykes 1978). However the rapid rate of forest clearing on 'Eua threatens its remaining forests (Drake 1996) and the species that inhabit the forests. The remaining Koki population in 'Eua is seriously affected by two major factors: clearing native forest for agricultural purposes, and damaging of nest trees by local people. Clearing native forest and damaging Koki nests both directly affect Koki breeding, where suitable nest trees are reduced. From this study it appears that Koki food is not in short supply but suitable Koki nest trees are limited.

The Line Transect and Point Count methods have been shown to have considerable potential in estimating population density and abundance in New Zealand (Cassey 1997). It is recommended that both Line Transect and Point Count methods be used to monitor Koki population on 'Eua. This study shows that the Line Transect method better represents the Koki population in the 'Eua Plantation Forest. It is recommended that the Line Transect method be used to monitor the Koki population on 'Eua, at five year intervals, but in areas with poor access the Point Count method is recommended. In undertaking the Line Transect and Point Count methods it is very important to train observers in gathering gather data that will produce reliable and accurate population estimates.

This study shows that Koki are mostly associated with Native and *Pinus caribaea* Forests. Native Forest provides the large trees essential for nesting, and *Pinus caribaea* Forest provides significant food for Koki in the 'Eua Plantation Forest. Therefore, to sustain the Koki population on 'Eua, it is recommended that a balance between the

Native Forest and *Pinus caribaea* Forest is maintained. Further clearing of Native Forest and damaging Koki nest trees permanently reduces the number of suitable nest sites. This, together with the removal of chicks, means that inevitably Koki numbers will fall, possibly quickly. It is therefore recommended that the remaining Native Forest on 'Eua, including Koki nest trees, be appropriately protected to ensure that the Koki population is sustained. *Pinus caribaea* forest will remain an important foraging site for Koki provided sufficient areas are maintained by replanting after logging takes place.

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