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NESTING SUCCESS AND POPULATION STATUS OF THE `ELEPAIO *(Chasiempis sandwichensis)* IN THE MAUNA LOA STRIP SECTION OF HAWAI`I VOLCANOES NATIONAL PARK

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ABSTRACT

We investigated the nesting success of `Elepaio (*Chasiempis sandwichensis*), in a 17 ha study grid located in the Mauna Loa Strip section of Hawai`i Volcanoes National Park during 1993 and 1994 breeding seasons. `Elepaio nests were most typically found in `a`ali`i (*Dodonaea viscosa*) trees in our study area even though this species was less abundant then the other co-dominant tree species koa (*Acacia koa*). Nest success was 26 of 44 (59%, n=27 pairs) in 1993 and 20 of 72 (28%, n=31 pairs) in 1994. Predation by black/roof rats and feral cats was the most prevalent reason for nest failure, accounting for 34% of failures in 1993, and 57% of failures in 1994. We found `Elepaio renested after either a nesting failure or successful attempt. In 1993, `Elepaio renesting attempts peaked at four. However, in 1994 we found 4 pairs that renested six, six, seven and eight times respectively without being successful. Because of their ability to renest after a nest failure, 74% of the `Elepaio pairs in 1993 were successful in fledging at least one chick from one successful nest during the season. Pair success was 65% during the 1994 nesting season. The ability of `Elepaio to renest repeatedly suggests double clutching and subsequent reintroduction of captive reared chicks may be a very useful technique to augment declining populations of this species in other areas in Hawai`i. The `Elepaio population in the Mauna Loa Strip Road study area provides an excellent opportunity to evaluate the effects of different levels of predator control relative to the bird's nesting success.

ACKNOWLEDGEMENTS

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INTRODUCTION

The `Elepaio (*Chasiempis sandwichensis*) is a species of Old World flycatcher (*Muscicapidae*) endemic to the Hawaiian Islands. Three sub-species (*Chasiempis sandwichensis sandwichensis*, *C.s. ridgwayi* and *C.s. bryani)*, are found on the island of Hawai`i (Pratt 1980). Different subspecies occur on O`ahu (*C.s. gayi)* and on Kaua`i (*C.s. sclateri)*, but `Elepaio have never been reported from the islands of Maui, Moloka`i, or L_na`i (Pratt 1980, Berger 1981, Olson and James 1982). Previous studies by Berger (1969, 1981), Conant (1977), and van Riper (1995) have noted many ecological similarities among the subspecies.

In recent years, populations of the `Elepaio have been declining on all of the islands from which they are known, particularly in low elevation areas (Scott *et al.* 1986). The population on O`ahu has been reduced to the point that it has recently been proposed as a candidate for listing as endangered by the U.S. Fish and Wildlife Service (L. Mehrhoff, USFWS, pers comm.). Although many of the `Elepaio populations on the island of Hawai`i appear to be stable over the past 20 years, some areas, including portions of Hawai`i Volcanoes National Park (HAVO), have seen this species decline, particularly in habitats below 1240m elevation.

`Elepaio are distributed throughout most of the native forest habitats on the island of Hawai`i (Scott *et al.* 1986) including mesic koa-`ohi`a (*Acacia koa-Metrosideros polymorpha*) forest, `_hi`a-h_pu`u (*Cibotium spp.*) rain forest and mesic upland koa parkland. In Hawai`i Volcanoes National Park this species is more abundant in the Mauna Loa Strip area than in four other areas studied in the Park (`_la`a, Thurston Lava Tube, East Rift Zone and K_puka Puaulu and K_) (Sarr et. al, unpublished data). These differences in the current abundance of `Elepaio reflect a decline of the populations over the past 20 years in the lower elevations of the Park.

In 1993, we initiated a study to evaluate breeding biology and nesting success of the `Elepaio population in the Mauna Loa Strip section of Hawai`i Volcanoes National Park. Because `Elepaio depend on insects for food, their abundance in HAVO koa forests may indicate the availability of invertebrates in forests recovering from feral ungulate damage. The status of populations of `Elepaio in a forest might also be a useful index in locating appropriate sites for reintroduction of three other endangered insectivorous bird species: `_kepa (*Loxops coccineus*), `Akiapola`au (*Hemignathus munroi*) and Hawai`i Creeper (*Oreomystis mana*), which previously were found in the Mauna Loa Strip section of Hawai`i Volcanoes National Park in the early 1940's (Baldwin, 1944).

STUDY AREA AND METHODS

Our study was conducted during two `Elepaio breeding seasons, January-June 1993, and January-August 1994. The study area was located at 1798 m elevation on the Mauna Loa Strip Road of HAVO on the island of Hawai`i (Figure 1). The vegetation of this study area is mountain parkland habitat dominated by koa (*Acacia koa*) and `a`ali`i (*Dodonaea viscosa*), with some `_hi`a (*Metrosideros polyporpha*) and a pukaiwe (*Styphelia tameiameiae*)-dominated shrub understory. The study site was chosen to overlap with a concurrent banding study in the area (Stone *et al.* unpublished data). A 17 ha grid (400 x 425 m) with 17 transects oriented in a north-south direction was established at 1798m elevation (Fig. 2, 3) for conducting bird and nest surveys. Sampling stations were located at 25 m intervals along the transects.

The locations of nests and nesting territory boundaries were determined by first plotting them on grid image maps of the study. These points and selected points of the sampling grid were subsequently confirmed using a Trimble global positioning system (GPS) unit. These data points were converted to ArcInfo geographic information system (GIS) coverages to facilitate analysis.

During 1993, nesting pairs of `Elepaio were found by systematically walking each transect and locating birds. Many of these birds had been previously banded during another project in 1992. Additional nesting pairs were captured and banded in their territories to aid with identification of individuals at nests. In 1994, nesting `Elepaio were located by visiting the 1993 territories and by systematic searches along the transects.

`Elepaio were banded with USFWS aluminum bands and a unique sequence of plastic color bands during our concurrent banding project (Stone, *et al.* unpub. data). Nets were also set up to band nesting pairs. Standard bird-banding measurements (weight of bird, bill length, wing length, sex and age if known, presence/absence of molt, cloacal swelling, brood patch, and disease lesions) were taken, as well as information on plumage characteristics such as percent of black or white on chin and throat of bird (T. K. Pratt, unpublished). We also described chin and throat color markings and other plumage characteristics of unbanded nesting pairs. Nesting territories were mapped by following marked and unmarked birds and noting their locations throughout the grid.

Active nests were checked every 4-5 days in 1993, and every 3 days in 1994 to follow nesting progress. Daily visits were made when an event change (i.e., incubation, hatching, fledging) was expected. Visits ranged from 1 minute to a longer observation (several hours), depending upon the information needed. A greater emphasis was placed upon locating nests and determining territory boundaries during the 1994 breeding season.

Upon nest discovery, we recorded tree species, nest height, nest placement, nest status and pair description. Nest trees were flagged and given an identification number. After nests became inactive, we measured tree height, tree diameter at breast height (DBH) and nest height for each nest tree. If the final outcome of a nest attempt was in question, the nest tree was climbed for closer examination of the nest. We distinguished several different types of nest placement in trees by `Elepaio. We defined a "nest in a fork" as one located off a tree branch away from the main trunk. "Nests in crotches" were defined as a nest found in a fork in the main trunk of the tree. "Molded nests" were nests found on a large branch with few or no supporting branches. Twenty-four nests were collected for further examination and measurement, including inside diameter of nest cup, outside diameter, nest wall thickness, nest width, bottom thickness, cup depth, branch diameter and number of supporting branches. Two measurements were taken of the collected nest's wall height, one at the tallest height and one at the lowest height.

For many of the nests that failed due to depredation there was physical evidence left by the predator. We classified each nest depredated into categories based on the type of predator sign left at the nest. For nests that failed at the egg stage we recorded: egg shells at base of nest tree, egg shell fragments in nest, nest empty and torn at bottom, or no visible sign of predation. For nests that failed during the nestling stage, we considered two categories: nestlings missing and pin feathers left in nest.

We obtained species composition, mean density, diameter, height and frequency of trees at the Keamoku study grid using the point-centered quarter method (Mueller-Dombois and Ellenberg, 1974). The center of each group of quadrants sampled was located 25 m from adjacent centers along every other transect, yielding a total of 288 trees sampled at 72 points.

Test for differences in nest dimensions between nest tree species, and nest tree measurements between species and between years were conducted using a two-tailed t-test. The relationship between nest tree height and nest height, and nest height versus diameter at breast height (DBH) for two principal tree species were examined using simple linear regression.

RESULTS

`Elepaio Breeding Biology and Nesting Characteristics

Nests were found mainly by observing `Elepaio behavior in territories during the nesting season (Table 1). The cue most often used to find nests was seeing a bird with nesting material (n=143, 42.7%). The female was more than twice as likely as the male to be the one observed with nesting material. Birds that made a straight flight through their territory (flight with a purpose) also led us to 22 nests. Chipping calls at nests and localized vocalizations were the next most prevalent cue. We found `Elepaio to be quite vocal during nest construction.

The nesting season for `Elepaio in the Mauna Loa Strip area began in early February and extended until August. We found the earliest nest under construction in the Keamoku study grid Feb. 18, 1994 and the latest nest found was July 9, 1994. Nests found under construction peaked in March for 1993 and 1994 (Fig. 4). Nests were found during all stages but 80% of all nests found in 1993 and 1994 were found during construction (Table 2).

Male and female `Elepaio both participated in nest building, incubation, brooding and feeding of hatchlings and fledglings. Based on the 1994 nesting season it took an average of 9.8 days for `Elepaio to build a nest (max.=21, min.=5, n=79); average incubation was 18.4 days (max.=21, min.=14, n=27); and the hatchling period lasted an average of 16.0 days (max.=20, min.=13, n= 20). Average clutch size was 1.8 eggs (std.dev.=0.49, n=56 nests). We found 11 clutches with 1 egg, 42 clutches with 2 eggs and 3 clutches with 3 eggs.

`Elepaio nests were typically found in `a`ali`i trees within our study area even though this species was less abundant than koa. In 1993, 35 (70%) of the 50 nests found were in `a`ali`i, 14 (28%) were in koa, and 1 (2%) was in mamane (*Sophora chrysophylla*). In 1994, 68 (73%) of 93 nests found were in `a`ali`i and 25 (27%) were in koa. Mean distance between trees was 2.46m, (n=287) yielding an absolute density of 16.5 trees per 100m^2. Relative density of koa was 53% and `a`ali`i density was 47%.

Average `Elepaio nest tree height, nest height and nest tree DBH were not significantly different between the 1993 and 1994 nesting seasons for both `a`ali`i and koa (Table 3, A and B). Therefore, we pooled data these two years in our comparisons of `a`ali`i and koa nesting sites (Table 3, C). Comparisons of 1993 and 1994 `a`ali`i nest height to 1993 and 1994 koa tree height, nest height and DBH were significantly different (tree ht.; P< 0.0001, nest ht.;. P=0.0004, DBH; P<0.0001). Regression analysis indicated nest height increased in both `a`ali`i and koa as tree height increased ($r^2$=0.650,`a`ali`i, r^2=0.151, koa, Figure 5).

Regression of DBH versus nest height showed no significant relationship for either \`a\`ali\`i or koa ($r^2$=0.013, \`a\`ali\`i, r^2=0.083, koa, Figure 6).

A comparison of \`Elepaio nest tree heights and DBH with Keamoku non-nest trees, revealed that average tree height and DBH for both koa and \`a\`ali\`i nest trees were significantly greater for both nest tree height and DBH (tree ht. \`a\`ali\`i, P< 0.0001, tree DBH \`a\`ali\`i, P< 0.0001, tree ht. koa, P< 0.0001, tree DBH koa, P< 0.0001) (Table 4 and Figure 7). These results suggest the birds are selecting large trees in the population for nesting.

We found 66% of \`Elepaio nests were placed in a fork of the tree. Nests in koa trees were almost always built molded to the tree trunk or a large branch while nests in \`a\`ali\`i trees were built in tree forks. In three instances we found nests built onto a small koa branch after it had fallen into an \`a\`ali\`i tree. It was hard to believe these nests stayed in the tree since it appeared as if a light wind would knock the tree branch and nest down. Nests in forks had a average of 3.0 (n=18, range 2-5) supporting branches, and molded nests had 1.83 (n=6, range 1-3) supporting branches.

Average nest bottom thickness was significantly greater in \`a\`ali\`i trees than in koa (P=0.0024). Branch diameters supporting nests were significantly larger for koa than \`a\`ali\`i (P=0.0001). Highest nest height in \`a\`ali\`i was significantly greater than in koa (P=0.0073). The remaining measurements were not significantly different between nests in the two tree species (Table 5).

<u>Nesting Behavior</u>

In 1993, we found 49 nests of 27 nesting pairs of \`Elepaio within the 400m x 425 m (17 ha) Keamoku study grid (Figure 8). At least one member each of 14 pairs was banded. In 1994, we found 89 nests of 31 pairs with territories in or immediately adjacent to the grid (Figure 9). Three additional pairs had territories in the grid but we were unable to locate the nests in 1994. An additional 11 nests of 7 other pairs were found outside the grid. In 1994, at least one member each of 23 pairs was banded. Many pairs of birds remained the same from 1993 to 1994 (Appendix 1). Three months after the end of the 1994 breeding season, a follow-up of 34 territories in the Keamoku grid showed that 71% (24/34) of pairs were the same as during the previous breeding season (Table 6).

\`Elepaio demonstrated a very strong renesting response throughout the nesting season, particularly after a nest failure (Figure 10). Of the 27 pairs we followed during the 1993 breeding season, 3 pairs nested 3 times and 1 pair nested four times. During the 1994 season only 8 of the 31 pairs nested just once, 4 pairs nested 4 times, 1 pair nested 7 times and 1 pair attempted 8 nests between

February and July (Table 7). In 1994, pairs that nested more than 4 times failed due to nest predation on almost every attempt.

`Elepaio were occasionally found to reuse material from their own old nests or from nests of Japanese white-eyes (*Zosterops japonica*). Three pairs of `Elepaio reused their own nest that had failed due to suspected depredation. One of these pairs was successful in fledging a chick while the other two failed. Two pairs that had two successful nests in 1993, failed numerous times in 1994. Three pairs in 1994 renested after raising a first clutch. One pair was successful, while the other two failed in this second attempt to raise a second brood. When a successful pair renested, the juveniles from the first nest remained in the territory and were fed occasionally by the parents.

In 1994, a male attended a nest with an adult female while concurrently nesting with a subadult female. The subadult female built her nest with assistance from the male about 5m from the adult female's active nest. The subadult rebuilt the remaining bottom cup of the male's nest from the previous year with the male's assistance. The subadult female and male incubated two eggs in their nest. The male alternatively incubated both nests. The adult female chased the subadult female on several occasions, and when the adult birds' eggs hatched the male appeared to have stopped incubating the subadult female's nest. As a result the eggs in this second nest were left uncovered during her breaks and she eventually abandoned her nest after 11 days. Since both the male and female `Elepaio incubate the eggs, `Elepaio nests were not often observed uncovered for very long during the incubation stage. Once the adult birds' hatchlings fledged, we could not locate either the adult female or subadult female in the territory. The fledglings were observed with the male throughout the rest of the season.

Nesting territory boundaries were located using successive resights and by following birds in their presumed territories. Bird sightings were recorded from our observations on grid maps. In 1994 we used GPS and GIS to locate and map territories and territory size (Figure 9). We found `Elepaio territories to range in size from 3,114 to 11,226 $m^2$ (.31 ha to 1.1 ha), with an average territory size of 5,691 $m^2$ (0.57 ha) (Figure 11). During the nesting season, trespassing `Elepaio were quickly chased out of territories by resident birds. Often, the birds that were chased occupied territories nearby. During the nesting season, if a stranger `Elepaio was in another's territory, that bird would not vocalize, presumably to avoid being detected. `Elepaio were noticeably quieter towards the end of the nesting season than at the start. Occasionally unpaired banded juveniles and adults were seen in the grid during the nesting season. Usually they would be quickly chased out of the territory by the resident pair. These unidentified birds might be looking for opportunities to find new mates. When two males lost females as a result of nest predation in 1994, new females were observed with the males within a day of the prior mates' disappearance.

Nesting Success or Failure

Overall nest success (eggs laid and at least one chick fledged) was 26 of 44 (59%, N=27 pairs) in 1993 and 20 of 72 (28%, N=31 pairs) in 1994. However, success rate for pairs (i.e., successfully fledging at least one chick during the entire nesting season) was 20 of 27 (74%) in 1993 and 20 of 31 (65%) in 1994. The apparent discrepancy in these two measures of success is due to multiple nesting attempts by most of the `Elepaio pairs in the study grid, in many cases following a nest failure. Three of the 26 pairs in 1993 were successful in fledging young on their first nest attempts but subsequently renested due to loss of fledglings. Three nests were abandoned before eggs were laid and two nests were found inactive of the 49 nests found. Thus 44 nests were used to calculate nest success. In 1994, 16 of the 88 nests were abandoned before eggs laid due to weather or unknown causes. The total number of nests for 1993 might be underestimated since we stopped our observations in mid-June; in 1994 we stopped in mid-August.

Reasons for nest failures were noted when possible (Table 8). Predation, most likely by roof rats (*Rattus rattus*) and feral cats (*Felis catus*), was the most prevalent reason for nest failure, accounting for 34% of failures in 1993, and 57% of failures in 1994. In 1994, three females disappeared after nest predation. In one of the three incidences, feather remains were found in the nest and at the base of the nest tree. For more than half of nests that were considered to have failed due to predation, we did not observe any physical evidence left by the predator (Table 9). Egg unhatchability and chick death from unknown causes accounted for 25% of failure for 1993 and 1994 combined. Weather-related factors, such as high winds and heavy rain, accounted for 12% of failures in 1993 and 1994.

DISCUSSION

The Keamoku grid supported a relatively high number of resident nesting `Elepaio during the two years we studied it. Our densities of birds are much higher and territory sizes are much smaller than those reported from similar studies of `Elepaio on O`ahu (Conant, 1977) and on Mauna Kea, Hawai`i (van Riper, 1995). Conant (ibid.) reported an average territory size of 20,000 m^2. Van Riper (ibid.) reported a range of 6,500 to 14,600 m^2 and an average territory size of 10,841 m^2 as compared to the average 5,691 m^2 we observed. We recorded several pairs with successful multiple nesting attempts as did van Riper (1995). The clutch size of the Mauna Loa Strip `Elepaio varied from 1-3 eggs. Neither van Riper (1995) nor Conant (1977) reported clutches of one egg. Renesting after a nest failure occurred in all studies. Both Conant (1977) and van Riper (1995) observed three renests by an individual pair. We observed up to eight renesting attempts by individual pairs in the Mauna Loa study area.

Predators were a major factor affecting nesting success for the Keamoku grid `Elepaio, with 34% of nest failures in 1993 and 57% in 1994 attributed to cats or rats. Sakai and Ralph (unpublished) reported in a study of *C.s. ridgwayi* a 60% (n=9/15) failure rate due to predation. In contrast, van Riper (1995) reported very little predation, and Conant (1977) reported predation as just one of several factors in the high nesting mortality of the `Elepaio on O`ahu.

In 47% (n=17, Table 9) of the nests predated in the Mauna Loa Strip study site we found egg shell fragments in the nest or at the base of the tree. On other occasions we found nests with eggs missing but without any other obvious predation sign. Major (1991) found during a predation study on dummy nests that rats do not always leave eggshell remains. Forty-one percent of dummy nests where the predator was positively identified as a rat did not have any eggshell remains or physical sign.

Pletschet and Kelly (1990) reported very little predation during the incubation stage (3.7%), in their Palila breeding biology study, while during the nestling stage predation was much higher (21.2%); this suggests a greater impact by feral cats than black rats. In our study, we observed very little predation during the nestling stage (5%), while predation during the incubation stage was quite high (46% for 1993 and 1994 combined). This may indicate the significant predators in our study are primarily rats, instead of cats. Eggs would probably satiate a small mammal like a rat, where as a nestling would more likely be taken by a larger mammal such as a cat. Moors (1983) found that rats tended to destroy proportionately more nests with eggs, while mustelid predators more often depredated nests with chicks. Although mongooses (*Herpestes auropunctatus*) are also known to be in the study area, they are suspected to occur in relatively low numbers and to be primarily on the ground. Mongooses probably do not directly impact `Elepaio nesting in this area.

It has been suggested that Hawaiian species may have higher infertility due to inbreeding. Van Riper (1987) found an 11.3% infertility rate for `Amakihi (*Hemignathus virens*). Pletschet and Kelly (1990) reported Palila egg infertility to be 18%. In our study we found the percentage of eggs that did not hatch to be about 35% in 1993 and 14% in 1994. Van Riper (1995) reported 25% (11/44) of eggs incubated to term did not hatch in the Mauna Kea `Elepaio. Our infertility percentage was also high, but we did not collect eggs to determine the exact cause of abandonment. In each case for this category, pairs were observed sitting on eggs beyond the expected hatching date and abandonment followed shortly after.

Weather was also a cause of nesting failure of the Keamoku birds for 1994 but not 1993. We observed that high wind and rain caused excessive swaying of the `a`ali`i nests. During 1994, a period of bad weather was probably responsible for 10 nests that failed of the 90 nests found. In some of these cases, the construction of the nest and eggs laid were subsequently abandoned without apparent damage to the nest and the adult birds were located renesting in the same area. In other cases, nests were dumped out from trees that were knocked down. Conant (1977) reported that non-native tall slender trees that `Elepaio nested in on `Oah`u contributed to nest failure when the weather was bad.

CONCLUSIONS

Predation appears to be the most important cause of nesting failure of `Elepaio. However, despite numerous failures `Elepaio are very resilient and are successful at maintaining their population in the Keamoku study area with frequent renesting. Repeated renesting suggests food resources (invertebrates) are not limiting and can carry the high density of birds in the area. Nesting failures are periodically caused by bad weather conditions. During our study there was no indication that avian diseases were responsible for nesting failures. However, one bird of a nest pair in 1993 was observed with pox-like lesions and appeared very weak. In 1994, this bird and mate were not relocated in their territory. Observations from a second study grid located at 1581m elevation on the Mauna Loa Strip Road indicated more `Elepaio with pox-like lesions. Based on this observation, `Elepaio in the Keamoku study grid may have trouble in the future if diseases or their vectors expand into higher elevation sites like Keamoku.

The unusual renesting ability shown by the `Elepaio in the Keamoku Study grid suggests that double-clutching and subsequent reintroduction may be a very useful technique to augment declining populations of this species on `Oah`u or in lowland sites on Kaua`i and Hawai`i when coupled with predator control. Additionally, the `Elepaio population in the Mauna Loa Strip Road study area provides an excellent opportunity to evaluate the effects of predator control on individually marked nesting pairs of birds. The intensity and timing of predator control could be compared with nesting success of the pairs throughout the grid.

We recommend a continuation of monitoring `Elepaio populations and nesting failures in the Mauna Loa Strip area in collaboration with a predator control program. A successful predator control program may enable researchers to eventually translocate some of the Park's missing endangered birds (`Akepa, `Akiapola`au and Hawai`i Creeper) back into the Mauna Loa Strip area where they previously were found.

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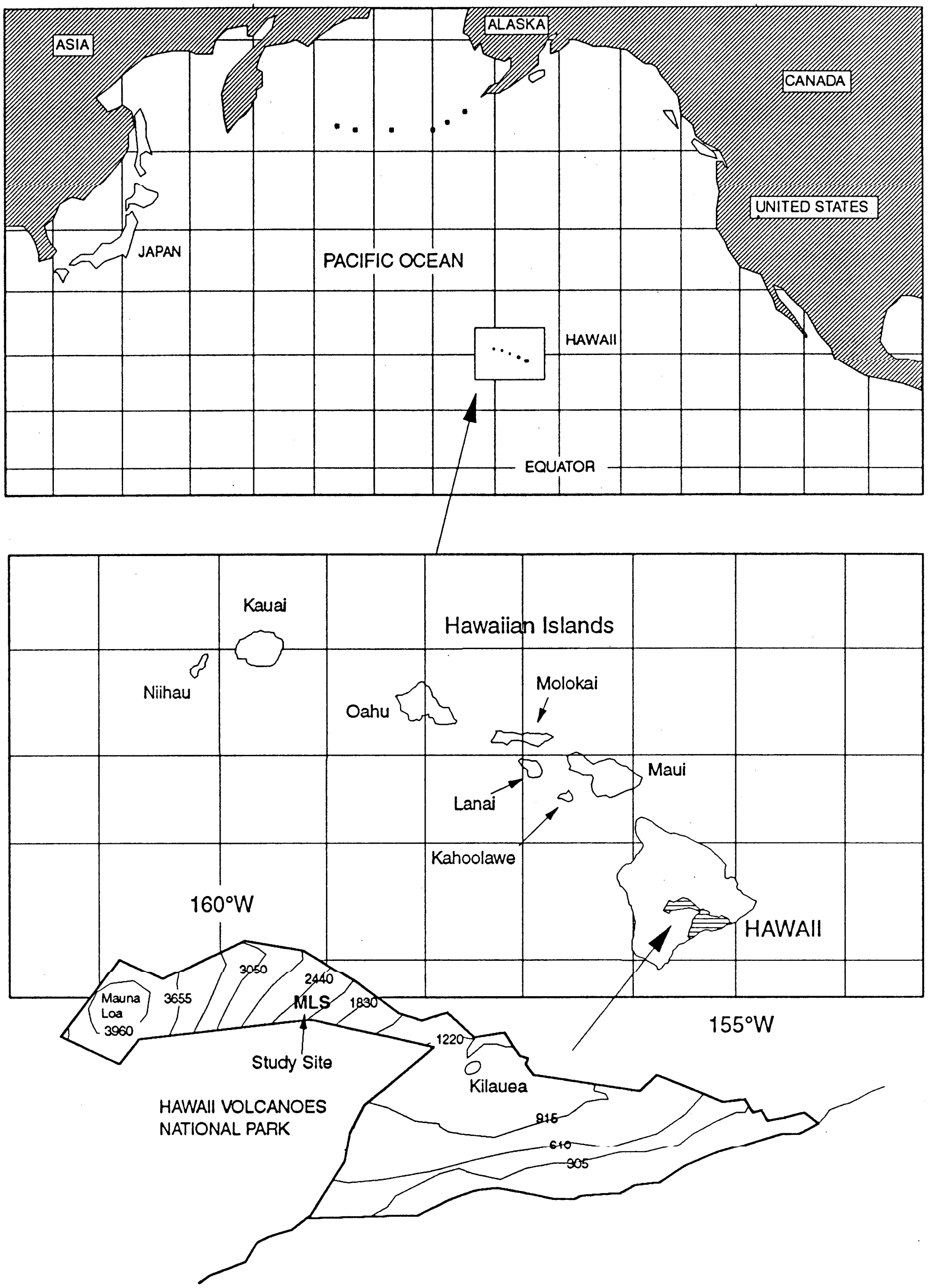


Figure 1. Location of the Hawaiian Islands, Hawai'i Volcanoes National Park, and Keamoku study site.

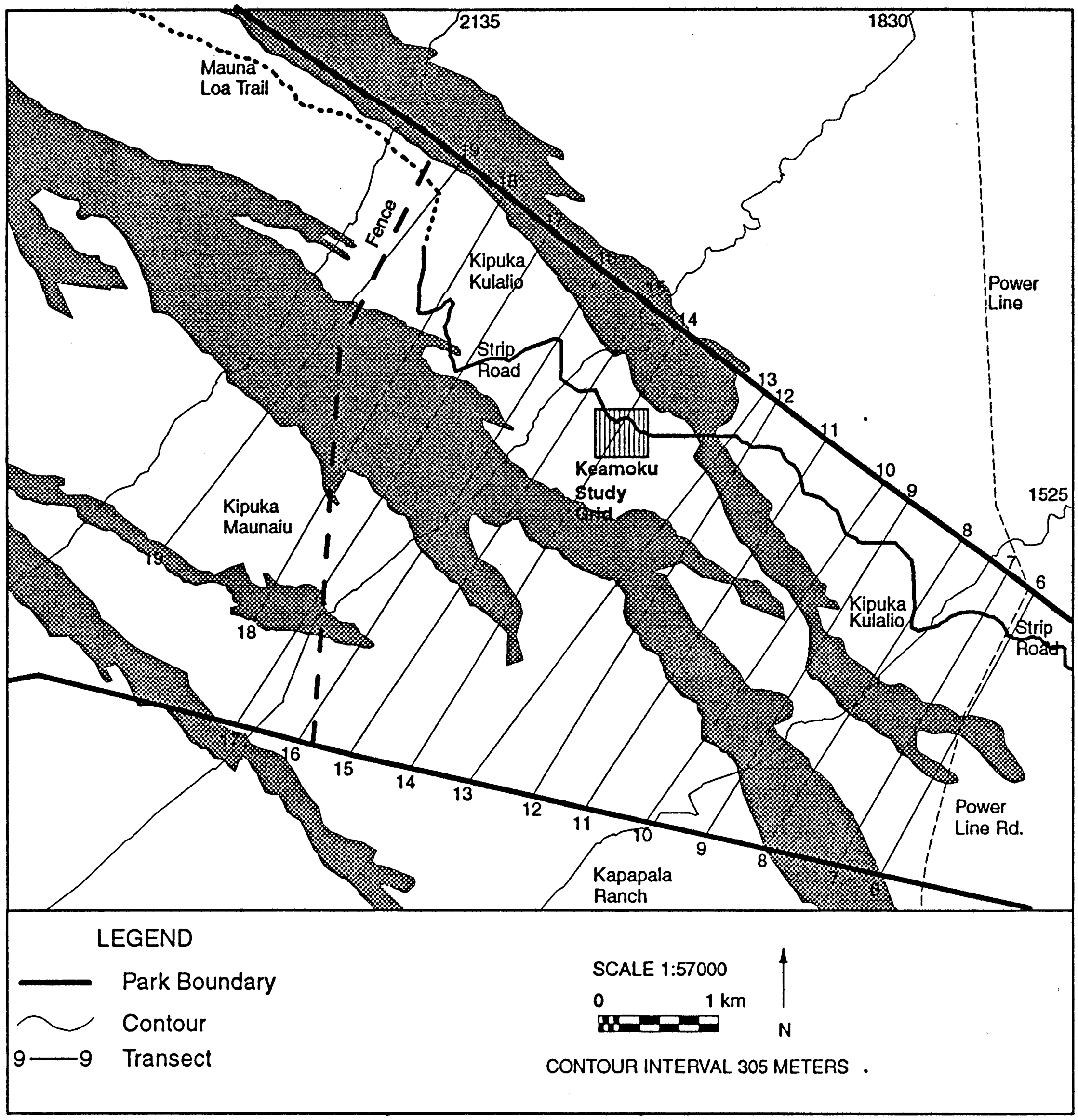


Figure 2. Location of the Keamoku Study Grid in the Mauna Loa Strip section of Hawai'i Volcanoes National Park.

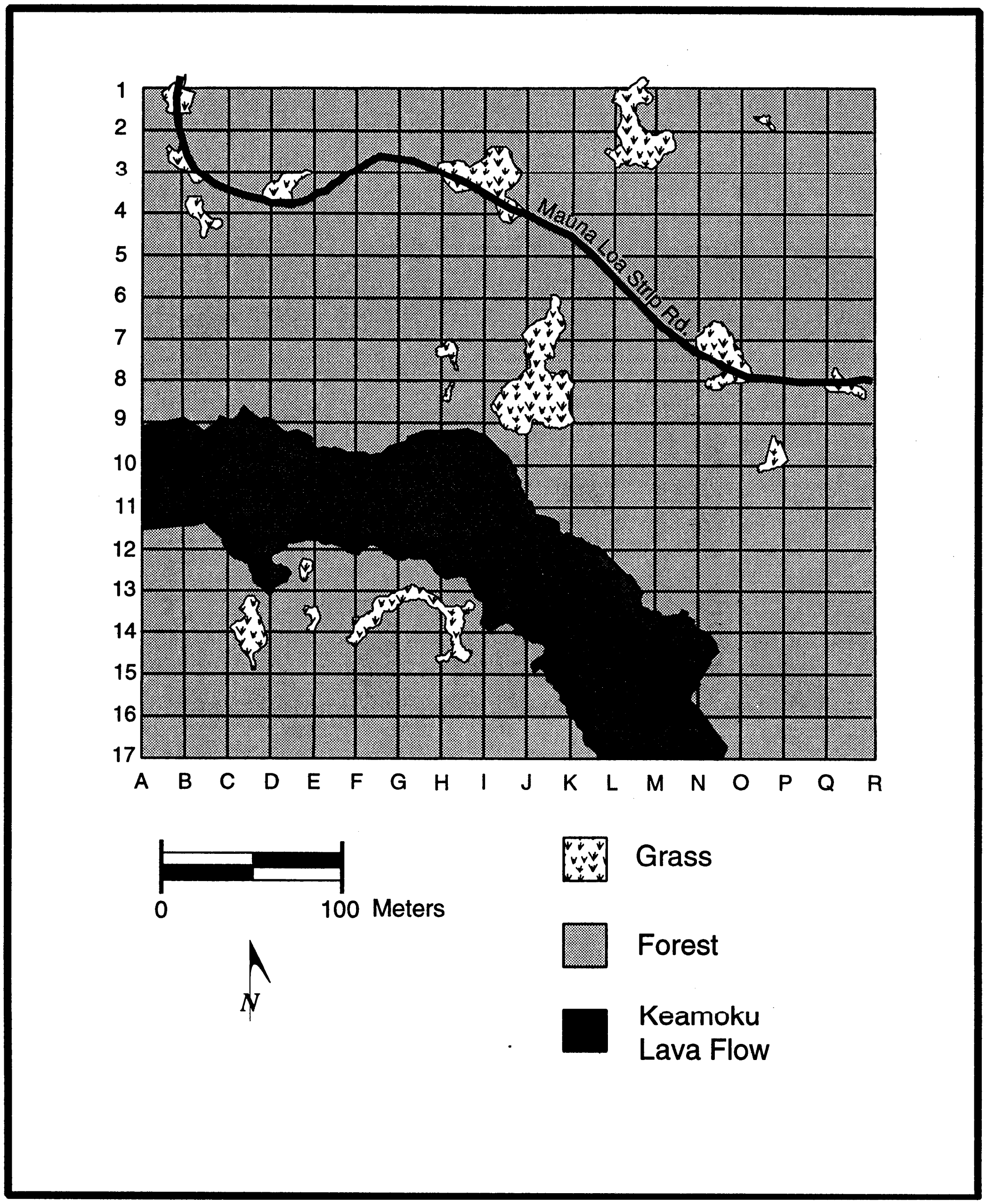


Figure 3. General vegetation characteristics and grid layout for Keamoku study area.

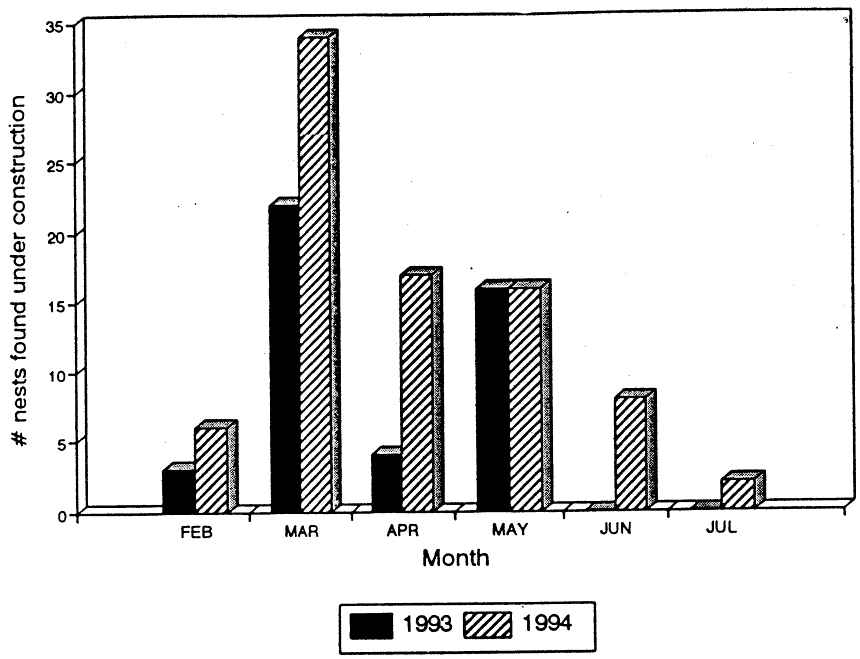
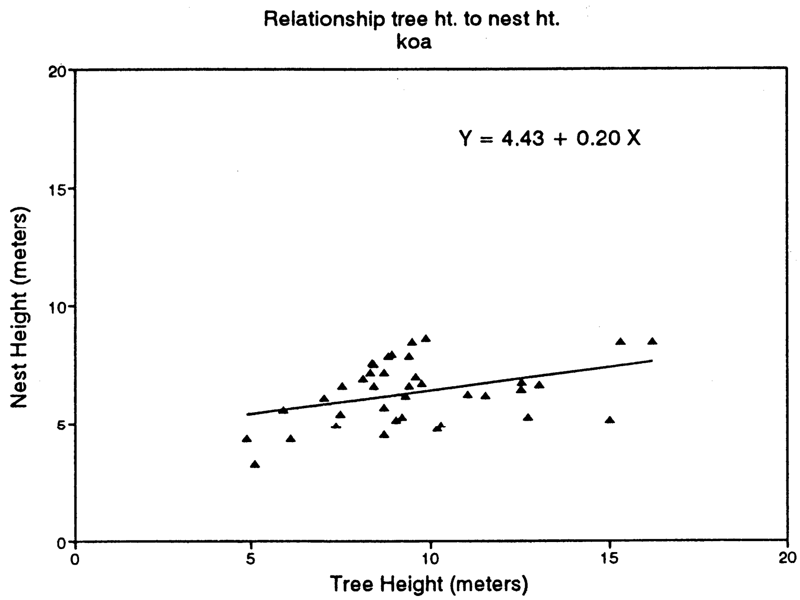


Figure 4. Number of ‘Elepaio nests found under construction during the 1993 and 1994 nesting seasons at Keamoku grid.

Graph A



Graph B

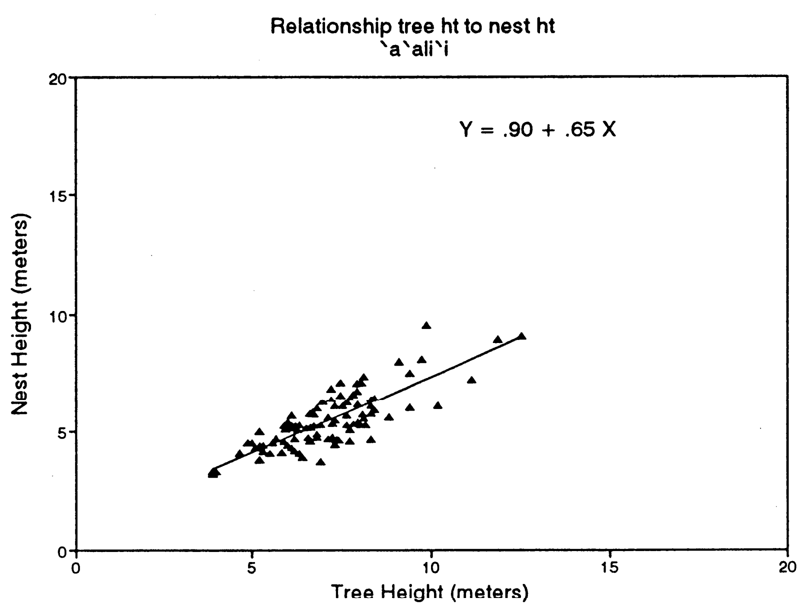
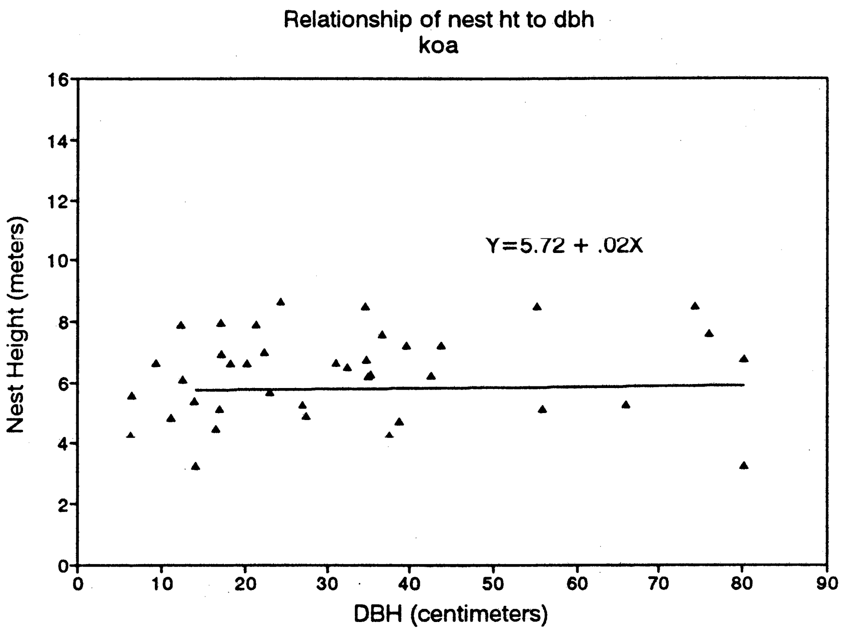


Figure 5. Relationship of tree height to nest height in koa (Graph A) and for ‘a‘ali‘i (Graph B) in the Keamoku study grid.

Graph A.



Graph B.

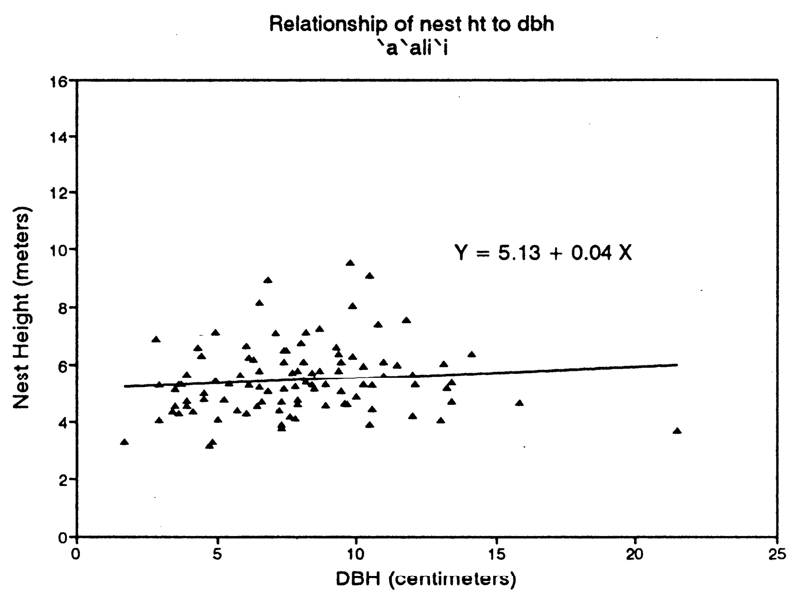
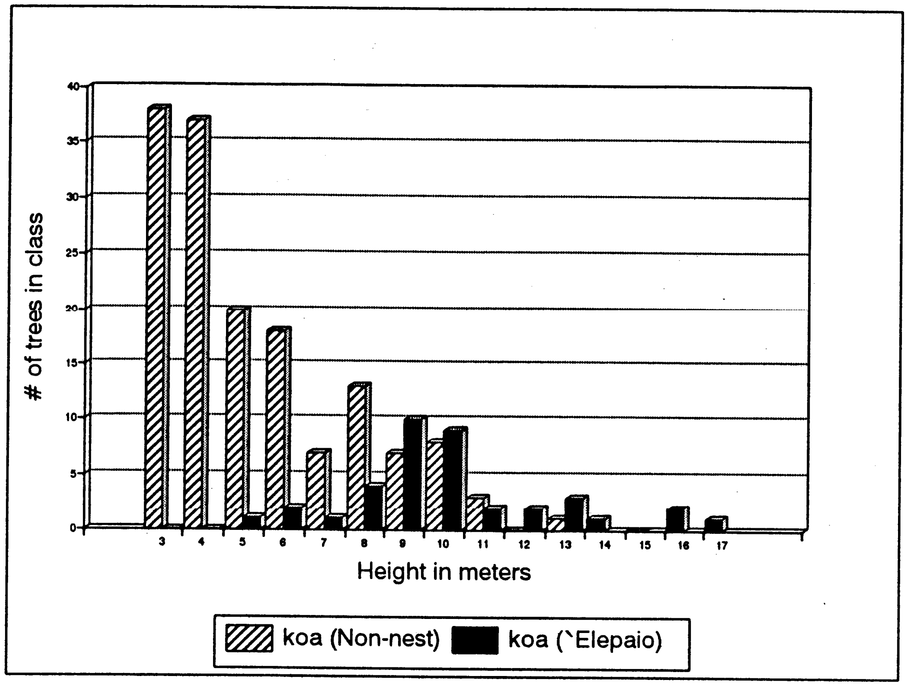
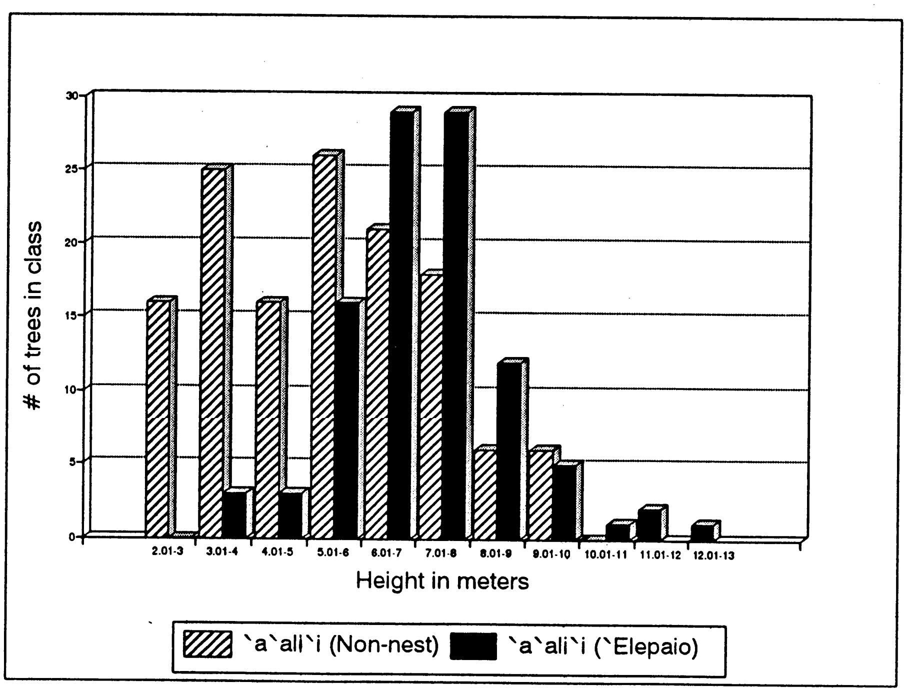


Figure 6. Relationship of DBH to nest height in koa (Graph A) and for ‘a‘ali‘i (Graph B) in the Keamoku study grid.



Graph A



Graph B

Figure 7. Size classes of ‘Elepaio nest trees vs. non-nest grid trees for koa (Graph A) and ‘a‘ali‘i (Graph B) in the Keamoku study grid.

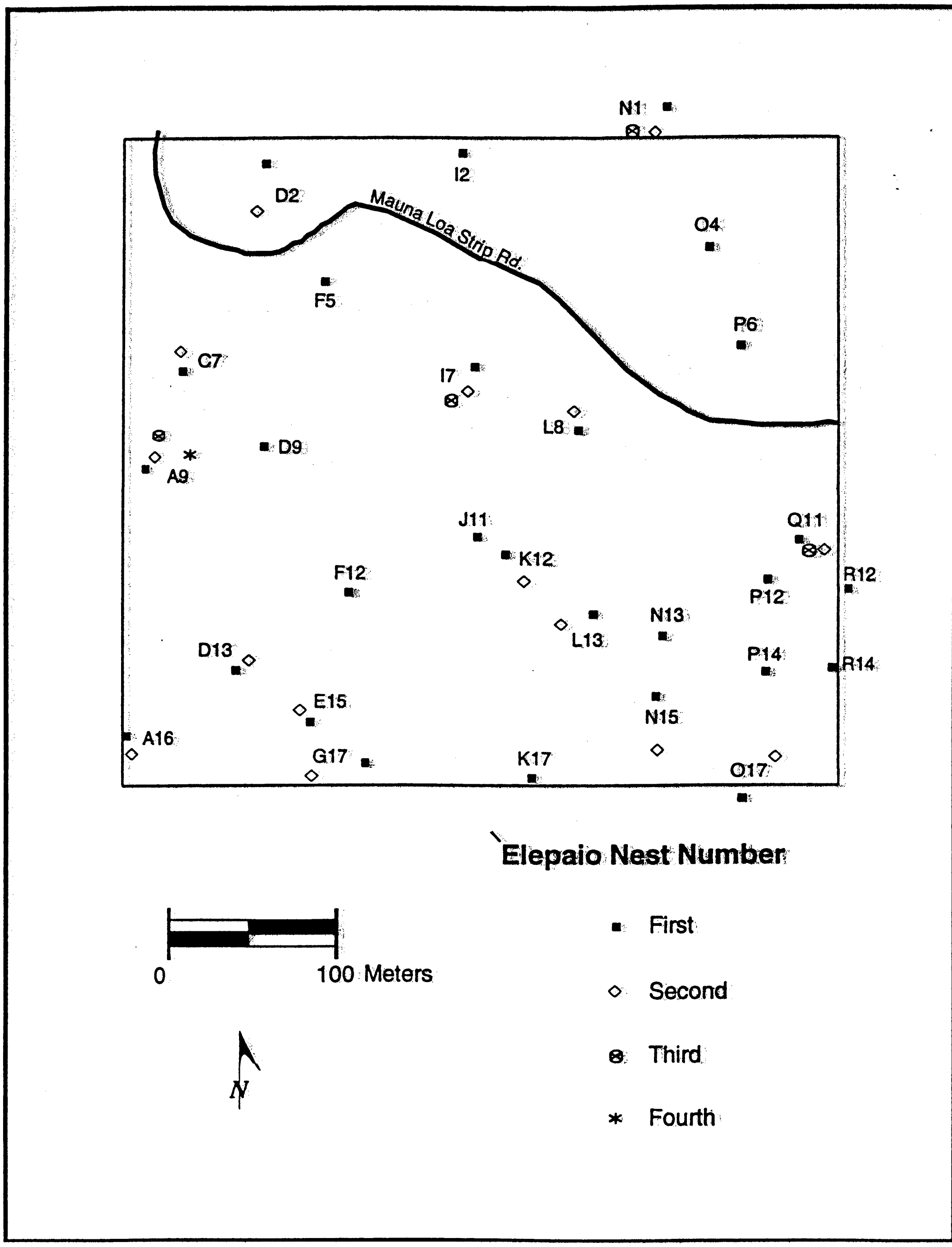


Figure 8. 'Elepaio nest locations for 1993 within the Keamoku study grid.

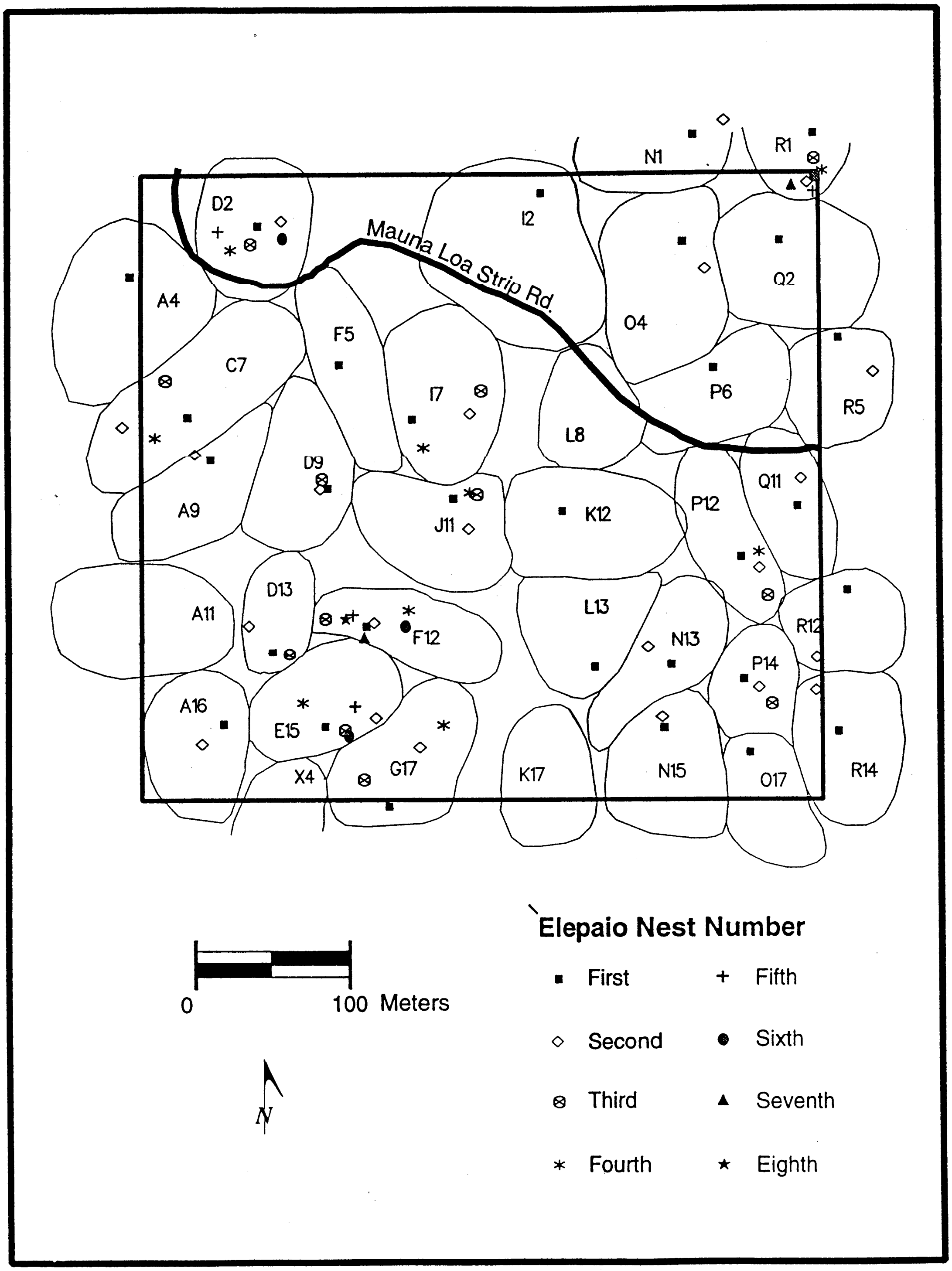


Figure 9. 'Elepaio nest locations and territories for 1994 within the Keamoku study grid.

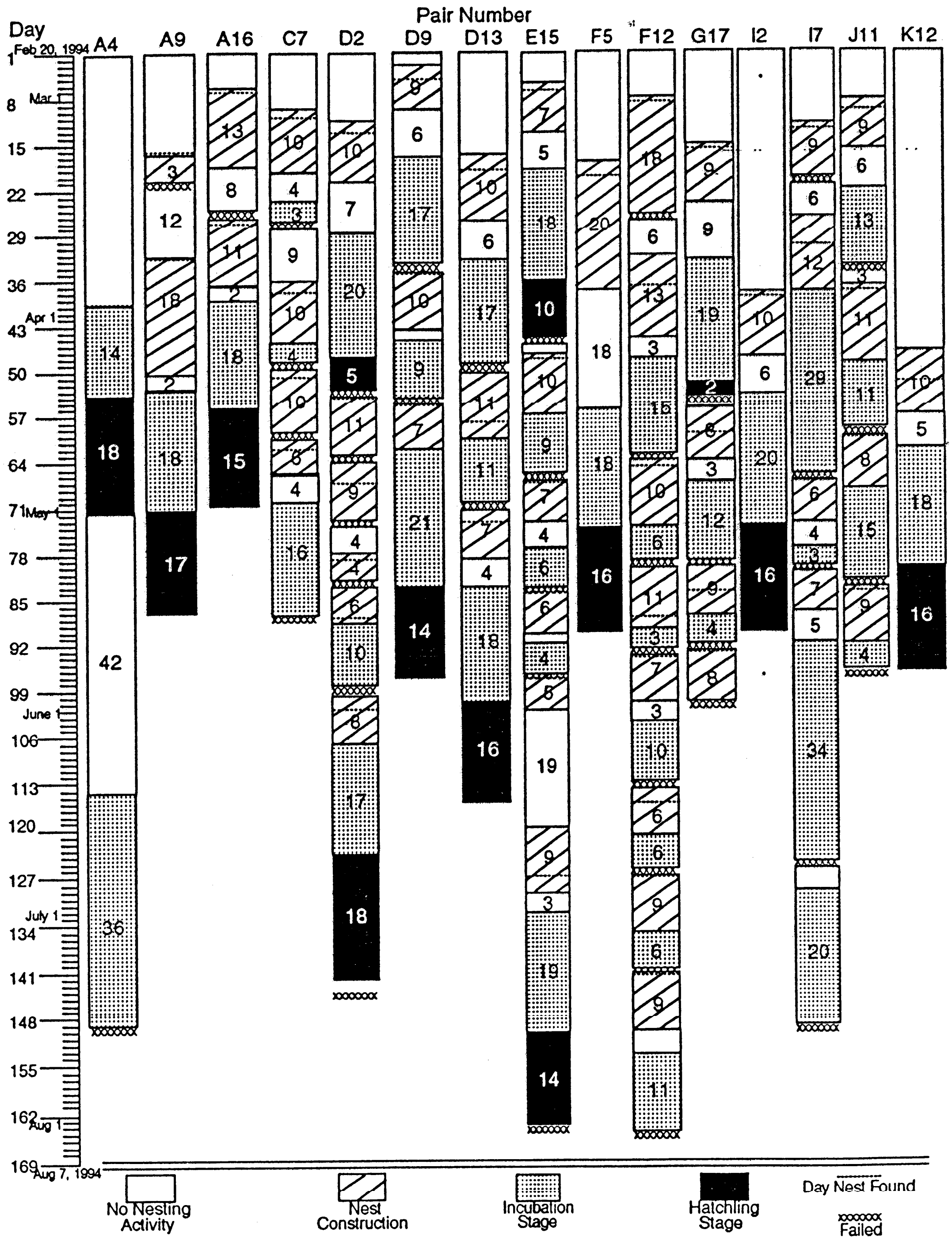


Figure 10. Nesting history for 'Elepaio pairs in the Keamoku study grid during 1994.

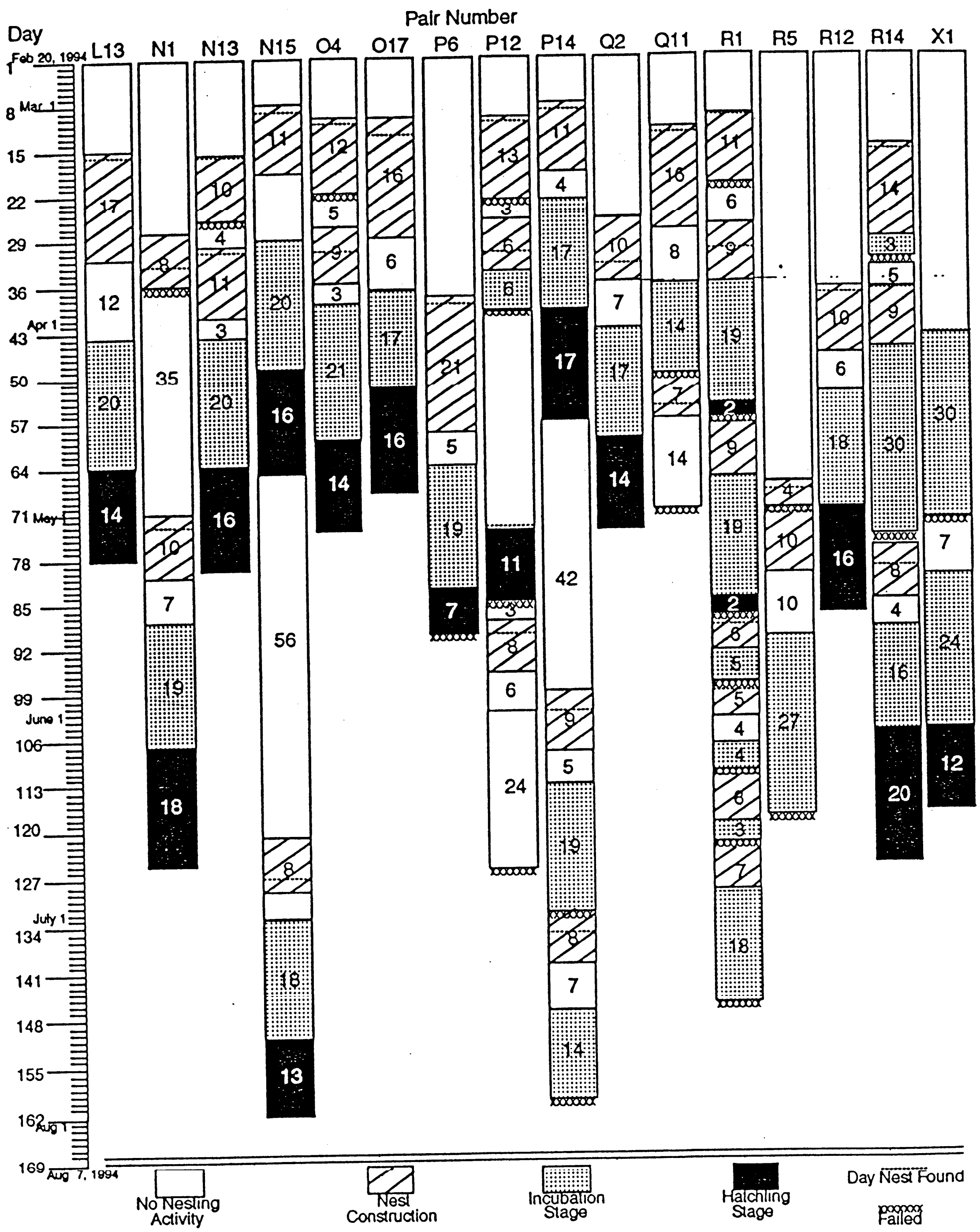


Figure 10. (Continued) Nesting history for ‘Elepaio pairs in the Keamoku study grid during 1994.

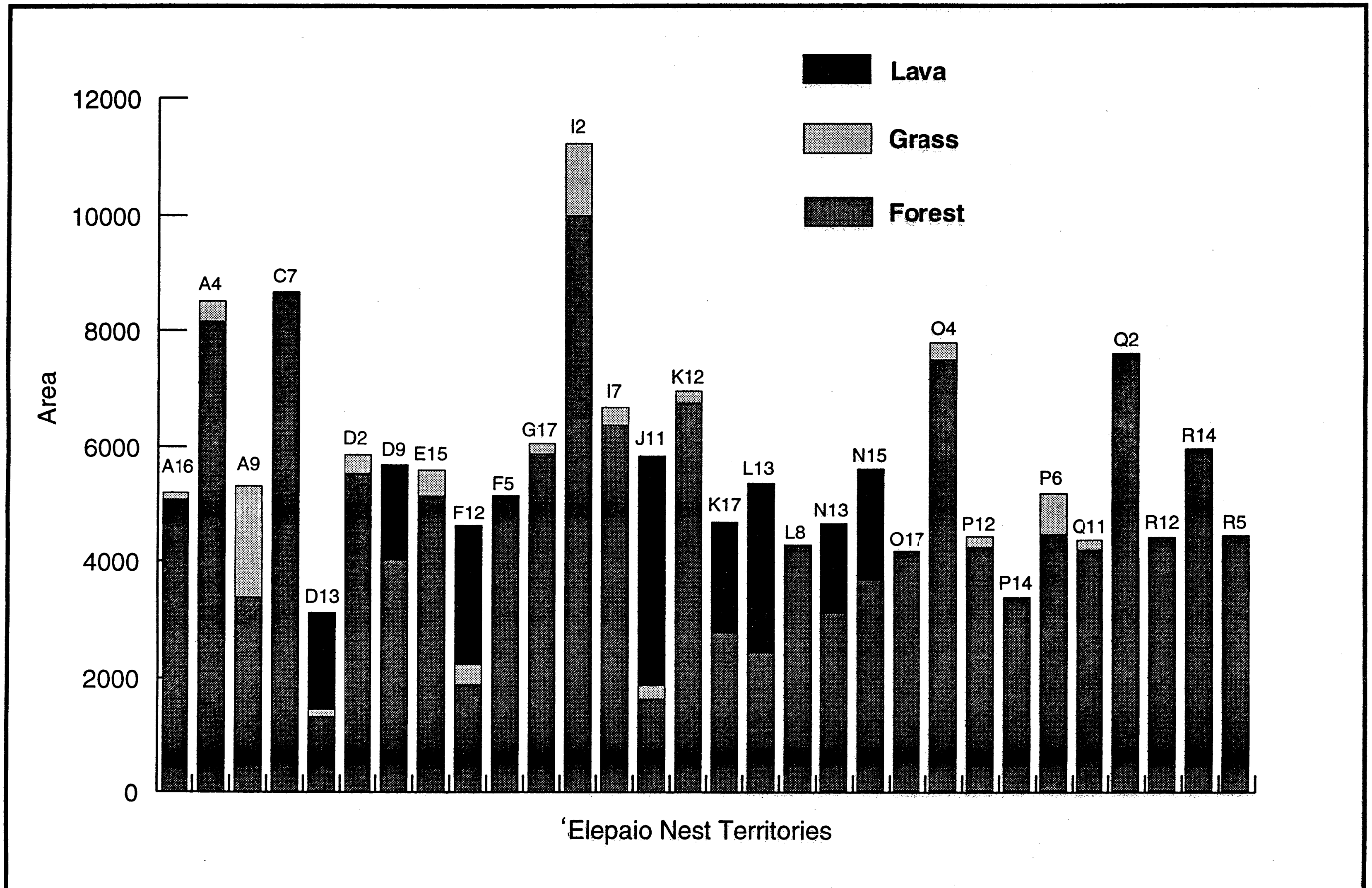


Figure 11. Area of 'Elepaio territories covered by forest, grass and lava within the Keamoku study grid.

Table 1. Cues used to locate `Elepaio nests in the Keamoku study grid for 1993 and 1994.

Nest Located By	Total%	# of Nests	M	F	Both	Unk
Bird seen with nesting material	42.7	61	16	34	6	5
Flight with a purpose	15.4	22	3	6	4	9
Chipping at nest	11.2	16	3	8	2	3
Localized vocalizations	10.5	15	2	4	3	6
Following bird	8.4	12	3	6	1	2
Visual(just saw nest)	7.0	10	n/a	n/a	n/a	10
Suspicious foraging activity	2.1	3	1	1	0	1
Bird at old nest, getting nesting material	1.4	2	0	1	1	0
Aggressive behavior towards same species	0.7	1	1	0	0	0
Aggressive behavior towards another species	0.7	1	1	0	0	0
Totals	100	143	30	60	17	36

Table 2. Initial status of nests found in the Keamoku study grid for 1993 and 1994 nesting seasons.

Nest Type	1993	%	1994	%	Total %
Inactive	3	6	0	0	3
Under construction	27	54	89	95	80
Incubation	18	36	4	4.3	15
Nestling stage	1	2	1	1.1	1
After construction, before incubation	1	2	0	0	1
Totals	50	100	94	100	100

Table 3. `Elepaio tree height, nest height and nest tree DBH for 1993 and 1994 nesting seasons within the Keamoku study grid. Comparisons were made using a two-tailed t-test.

A. `Elepaio nest tree measurements for `a`ali`i..

Measurements	Tree Height(m)		Nest Height(m)		Nest Tree DBH(cm)	
`a`ali`i	1993	1994	1993	1994	1993	1994
N	35	68	33	68	35	67
Maximum	12.60	11.94	9.10	9.54	21.50	15.80
Minimum	3.90	4.00	3.20	3.31	3.60	1.70
Average	7.03	7.09	5.21	5.60	8.50	7.61
Std. dev.	1.77	1.36	1.27	1.17	3.50	3.00
P	P=.78		P=.13		P=.23	

B. `Elepaio nest tree measurements for koa.

Measurements	Tree Height(m)		Nest Height(m)		Nest Tree DBH(cm)	
koa	1993	1994	1993	1994	1993	1994
N	13	25	12	25	13	25
Maximum	16.20	15.01	8.50	8.65	74.40	80.20
Minimum	4.90	5.12	4.30	3.25	6.40	9.30
Average	10.00	9.30	6.23	6.32	35.43	29.07
Std. dev.	3.20	2.16	1.33	1.29	20.52	18.47
P	P=.44		P=.85		P=.35	

C. Comparision of combined `Elepaio nest trees data for 1993 and 1994 between`a`ali`i and koa.

Measurements	Tree Height(m)		Nest Height(m)		Nest Tree DBH(cm)	
all species	`a`ali`i	koa	`a`ali`i	koa	`a`ali`i	koa
N	101	38	12	25	102	38
Maximum	12.60	16.20	8.50	8.65	21.50	80.20
Minimum	3.90	4.90	4.30	3.25	1.70	6.40
Average	7.08	9.54	6.23	6.32	7.90	31.20
Std. dev.	1.51	2.62	1.33	1.29	3.21	19.50
P	P<.0001		P=.0004		P<.0001	

Table 4. 1994 Grid tree measurements compared to 1993 and 1994 `Elepaio nest tree measurements from the Keamoku study grid. Comparisons were made using a two-tailed t-test.

A. Tree measurements for `a`ali`i

Measurements `a`ali`i	Grid Tree Height (m)	`Elepaio Tree Ht (m)	Grid Tree DBH (cm)	`Elepaio Tree DBH (cm)
N	132	101	132	102
Maximum	9.80	12.60	16.50	21.50
Minimum	2.27	3.90	0.80	1.70
Average	5.35	7.08	5.27	7.90
Std. dev.	1.90	1.51	3.09	3.21
P	P<.0001		P<.0001	

B. Tree measurements for koa.

Measurements koa	Grid Tree Height (m)	`Elepaio Tree Ht. (m)	Grid Tree DBH (cm)	`Elepaio Tree DBH (cm)
N	155	38	155	38
Maximum	12.04	16.20	64.00	80.20
Minimum	2.00	4.90	1.20	6.40
Average	4.90	9.60	8.70	31.20
Std. dev.	2.37	2.60	10.70	19.50
P	P<.0001		P<.0001	

Table 5. Nest measurements from `Elepaio nests collected in the Keamoku study grid during 1994. Comparisons were made using a two-tailed t-test.

Nest Measurements	Side Thickness (mm)	Bottom thickness (cm)	Cup Depth (cm)	Nest Ht Highest (cm)	Nest Ht Lowest (cm)	Inside Diameter (cm)	Outside Diameter (cm)	Branch Diameter (cm)
`a`ali`i								
N	18	18	18	18	18	18	18	18
Maximum	14.77	6.60	4.40	15.70	7.40	6.45	8.16	2.47
Minimum	8.21	2.10	3.20	4.80	1.20	5.09	6.84	0.48
Average	10.82	4.03	3.88	10.38	3.28	5.58	7.57	1.15
Std. dev.	1.86	1.24	0.36	2.55	1.71	0.32	0.37	0.56
koa								
N	6	6	6	6	6	6	6	6
Maximum	12.47	4.00	4.50	9.20	6.80	5.95	7.89	4.30
Minimum	8.02	1.00	3.20	4.40	1.20	5.05	6.92	1.84
Average	10.28	2.05	4.02	6.98	4.60	5.38	7.46	2.86
Std. dev.	1.24	0.96	0.41	1.52	1.89	0.32	0.30	1.04
P	0.5200	0.0024	0.4500	0.0073	0.1400	0.2200	0.5100	0.0001
Similarity	same	diff.	same	diff.	same	same	same	diff.

Table 6. Resighting results of `Elepaio pairs in the Keamoku study grid, October 1994.

Pair Description	# of Territories Found
New female	4
New male	1
New pair	3
Same pair	24
Male not observed	1
Female not observed	1

Table 7. Number of nesting attempts by `Elepaio in the Keamoku study grid for 1993 and 1994 breeding seasons.

1993

# of nest attempts	# of Pairs	Total # of nests	# of pairs Successful	# of pairs Failed	# of nests Successful	# of nests Failed	Nests failed due to: Predation	Weather	Unknown abandoned	Egg/chick failure
1	10	10	9	1	9	1	0	0	0	1
2	13	26	8	5	13	13	2	0	2	9
3	3	9	2	1	3	6	3	0	1	2
4	1	4	1	0	1	3	0	0	1	2
	27	49	20	7	26	23	5	0	4	14

1994

# of nest attempts	# of Pairs	Total # of nests	# of pairs Successful	# of pairs Failed	# of nests Successful	# of nests Failed	Nests failed due to: Predation	Weather	Unknown abandoned	Egg/chick failure
1	8	8	7	1	7	1	1	0	0	0
2	10	20	8	2	9	11	2	6	2	1
3	4	12	4	0	4	8	3	1	1	3
4	4	16	0	4	0	16	13	2	1	0
5	1	5	0	1	0	5	1	1	0	3
6	2	12	1	1	1	11	7	0	4	0
7	1	7	0	1	0	7	6	1	0	0
8	1	8	0	1	0	8	7	1	0	0
	31	88	20	11	21	67	40	12	8	7

Table 8. Types of nest failures for 1993 and 1994 at the Keamoku study grid.

	1993		1994		
Type of Failure	# of Nests	%	# of Nests	%	Total %
Egg failure	8	35	9	13	19
Chick failure	3	13	0	0	3
Predation suspected-egg stage	7	30	35	52	47
Predation suspected-chick stage	1	4	4	6	6
Abandoned after construction complete	2	9	8	12	11
Weather suspected-construction stage	0	0	8	12	9
Weather suspected-egg stage	1	4	2	3	3
Unknown	1	4	1	1	2
Totals	23	100	67	100	100

Table 9. Physical sign observed for `Elepaio nests that failed due to predation during the 1993 and 1994 nesting seasons in the Keamoku study grid.

	1993		1994		
Predation at Egg stage	# of nests	%	# of nests	%	Total %
(Eggs Missing)					
A. No sign left, nest empty.	2	29	20	57	52
B. Egg shells at base of nest tree.	0	0	6	17	14
C. Egg shell fragments in nest.	4	57	7	20	26
D. Nest empty and torn at bottom.	1	14	2	6	7
Totals	7	100	35	100	100
Predation at Nestling stage	# of nests	%	# of nests	%	%
(nestlings missing)					
A. Nest empty.	0	0	3	75	60
B. Pin feathers in nest.	1	100	1	25	40
Totals	1	100	4	100	100

Pair Number	1993 Breeding Season	1994 Breeding Season
A4	This pairs nests were not found in the 1993 nesting season, but two juveniles were found being attended to within this territory.	Pair are not banded but appear to be the same pair as previous year. They produced one juvenile this year with one nest. Renested in the same nest, but second nest failed. Female - U/B, Male - U/B
A9	Built 4 nests with the 4th one being successful and producing 2 juveniles. Female - U/B, Male - U/B	Appears to be the same pair. Built 2 nests with the 2nd being successful and producing 2 juveniles. Female - U/B, Male - U/B
A16	Was not successful this year after 2 nesting attempts. First nest juvenile fledged but then disappeared. Second nest failed. Female - U/B, Male - U/B	New juvenile looking female in this pair. Successfully fledged 1 juvenile this year after 2 nesting attempts. Female molting into full adult plumage. Female - U/B, Male - PNK/YEL
C7	Produced two nests. The first nest fledged two juveniles but both were presumed to have died shortly after fledgling. The second nest produced one successful juvenile. Female - GRN/MAG, Male - MAG/GRN	Same pair as last year, both male and female banded. Were not successful after 4 nesting attempts. Female disapppeared shortly after the fourth nest failed. Male appeared later to have taken YEL/WHT from F5 pair as new mate. Female - GRN/MAG then YEL/WHT, Male - MAG/GRN
D2	Successfully fledged two juveniles after two nesting attempts. Female - WHT/MAG, Male - MAG/ORG	Same pair as last year, both male and female banded. Were not successful after 6 nesting attempts. The sixth nest produced one juvenile which fledged but was not observed in the area and thus was presumed to have died. Female - WHT/MAG, Male - MAG/ORG
D9	Produced one juvenile in one nesting attempt. Female - GRN/YEL, Male - YEL/GRN	Same pair as last year, both male and female banded. Succeeded in producing one juvenile after 3 nesting attempts. Female - GRN/YEL, Male - YEL/GRN
D13	Fledged one chick after 2 nesting attempts. After chick fledged, it was not observed in area and presumed to have died. Female - U/B, Male - U/B	May be a different male than previous year, female appears to be the same. Successfuly fledged two chicks from third nest. Female - U/B, Male - U/B
E15	Produced two successful nests. First nest had one fledgling and second nest also produced one fledgling. Female - MAG/BLU, Male -YEL/YEL	Same pair as previous year, both male and female banded. Were not successful after 6 nesting attempts. Female - MAG/BLU, Male -YEL/YEL
F5	Were not successful this year. Found only one nest which was active but then failed. Female - YEL/WHT, Male - U/B	Same pair as last year. Female banded and male appears to be the same as previous year. Succeded in fledgling two chicks. Female appears to have left mate to join C7 male. New female is an adult/juvenile looking bird. Female - YEL/WHT then U/B, Male - U/B
F12	Found only one nest which fledged one juvenile. Later on this pair was observed tending to two recently fledged juveniles. Female - LAV/YEL, Male -ORG/GRN	Same pair as previous year. Not successful after 8 nesting attempts. Female - LAV/YEL, Male -ORG/GRN
G17	Succeded in fledging one chick after second nesting attempt. Female - U/B Male -YEL/MAG	Same pair as previous year. Not successful after 4 nest attempts. Female - U/B, Male -YEL/MAG
I2	One successful juvenile with one nest. Female - RED/ORG, Male -U/B (chin/throat 95% black)	Same pair as previous year. Produced one juvenile with one nest. Female - RED/ORG, Male -U/B (chin/throat 95% black)
I7	Three nesting attempts with no success. Female - GRN/LAV, Male -GRN/WHT	Same pair as previous year. This year they had four nests with no success. Female - GRN/LAV, Male -GRN/WHT
J11	Fledged two juveniles from first nest. Female - WHT/LAV, Male -WHT/YEL	Same pair as previous year. Did not succeed in fledging any juveniles after 4 nests. Female disappeared after 4th nest. Male seen with another female shortly thereafter. Female - WHT/LAV then U/B, Male -WHT/YEL

Appendix 1 Nesting History for ʻElepaio in the 1993 and 1994 Breeding Season

Pair Number	1993 Breeding Season	1994 Breeding Season
K12	Not successful after two nesting attempts. Female - U/B Juv., Male - GRN/ORG	Pair looks like a different pair than from the previous year. Territory also seams to have changed somewhat. Their first nest of this year was successful and produced 2 fledglings. Female - MAG/PNK, Male - ORG/MAG
K17	Found one nest with no successful fledglings. Observed pair feeding a juvenile at end of season. Female - U/B, Male - U/B	This could be a new pair. Last years female was not banded, this year she is. The male does not match the description of last year's male. Could not find any nests or fledglings in this territory but near end of season a fledgling was heard. Female - RED/BLU, Male - U/B
L8	Fledged two juveniles from their second nest. About 2 months later, neither of these adults or juveniles were seen in the territory. Female - ORG/WHT, Male - BLU/ORG	For most of the breeding season, no Elepaio pair were seen in this territory. Elepaio from neighboring territories were seen foraging in the area, but no nesting activity. In May, a juvenile pair of Elepaio moved into the area. Female - MAG/MAG, Male - U/B Juv.
L13	Two nesting attempts with no success. Female - U/B, Male - U/B	The female in this pair may be the same as the previous year. The male last year had full adult plumage, but this year looks like a juvenile. There was one juvenile this year from one nest. Female - U/B, Male - U/B-Juv.
N1	Three nesting attempts, with the third one producing 1 juvenile. Female - U/B, Male - U/B	Cannot be certain that this pair is the same as last year. The male was banded late in the summer and their descriptions are not close enough to be certain that they are the same birds. They were successful with two juveniles from their second nest Female - U/B, Male - GRN/PNK
N13	Found only one nest which did not produce any juveniles. Female - YEL/RED, Male - U/B	The same pair as last year. They succeeded in fledging three birds of their second nest, but one was missing a few days later. Female - YEL/RED, Male - U/B
N15	Two nesting attempts but none of them were successful. Female - U/B, Male - U/B	The same pair as last year. They had two successful nests, each producing one fledgling. Female - BLU/MAG, Male - LAV/LAV
O4	Had one nest that produced two juveniles. Could find only one juvenile, presumed the other one had died. Female - U/B, Male - RED/GRN	Female last year was juvenile looking, but this year she has adult plumage so it's hard to tell if it is the same bird. Produced 2 juveniles from their second nest. Female - U/B, Male - RED/GRN
O17	Produced one juvenile from their second nest. Female - U/B, Male - U/B	Probably the same pair as last year. Male was banded mid-spring. This pair succeeded in producing two juveniles from their first nest. This male also had a second female in another nest nearby, but this nest failed. Female - U/B, Male - PNK/YEL
P6	During the incubation period of their first nest, the male of this pair was seen with pox lesions on its foot. After about two weeks, the bird was never seen again, and the terrirory was deserted. Female - U/B, Male - U/B	A new pair moved into this area, the male banded and the female not banded. They were not successful with their first and only nest. Female - U/B Juv., Male - RED/WHT
P12	One successful juvenile with one nest. Female - U/B, Male - U/B	This could be the same pair from the previous year, but not certain. The male was banded this spring. They were not successful with any of their 4 nests that they built. This pair is very suspicious to people. Female - U/B Juv., Male - PNK/GRN

Appendix 1. Nesting History for 'Elepaio in the 1993 and 1994 Breeding Season (Continued)

Pair	1993 Breeding Season	1994 Breeding Season
P14	Successful juvenile with one nest. Female - BLU/LAV, Male - ORG/ORG	Same pair as the previous year. First nest was successful, producing two juveniles. This pair went on to build two more nests but neither of them were successful. Female - BLU/LAV, Male - ORG/ORG
Q2	Area not covered in 1993.	Produced two juveniles from their first and only nest. Female - U/B Male - U/B
Q11	Were successful in fledging one juvenile from their third nest. A month or so later later, neither adult or juvenile were seen in the area. Female - U/B, Male - BLU/YEL	Appears to be a new pair in this territory. This pair built two nests, but neither one were successful. Female - U/B Juv., Male - LAV/MAG
R1	Area not covered in 1993.	Built seven nests, but none were successful. Female - U/B Male - U/B
R5	Area not covered in 1993.	Built two nests, but none were successful. Female - U/B Male - U/B
R12	Successful juvenile with one nest. Female - U/B, Male - MAG/WHT	Appears to be a new pair in this territory. This pair was successful with their first and only nest, fledging one juvenile. Female - BLU/PNK Male - U/B
R14	Fledged one juvenile from one nest. Juvenile was banded. Female - U/B, Male - MAG/LAV	Probably same pair as last year. Female was banded in the early spring of this year. Succeded in fledging one juvenile from their third nest. Female - ORG/PNK, Male - MAG/LAV
A11	Saw and heard juveniles in this area in late spring. Never found a nest.	Saw the same pair in the area on numerous occasions. Did not find any nests or detect any juveniles. Spent very little time in this area searching for nests. Female - U/B Adu/Juv., Male - ORG/YEL

Appendix 1. Nesting History for 'Elepaio in the 1993 and 1994 Breeding Season (Continued)