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NESTING AND PERCHING HABITAT USE OF THE MADAGASCAR FISH-EAGLE

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Abstract.—We documented Madagascar Fish-Eagle (*Haliaeetus vociferoides*) nest and perch use on lakes and rivers and compared parameters of used trees to unused reference trees. Nest and perch trees were broader and taller, had more unobstructed branches, and were less obstructed by adjacent trees compared to reference trees. Perch trees also were more often deciduous than reference trees. Nest sites had more shoreline perch trees than reference sites. Logistic regression models with tree height as the independent variable distinguished nest and perch trees from randomly selected reference trees. Models with number of perch trees along a 1.25 ha (50 m width) shoreline section distinguished nest sites from reference sites. These models suggest that the presence of trees ≥15 m tall within 50 m of the shoreline is a good predictor of Madagascar Fish-Eagle habitat use.

Key Words: *Madagascar Fish-Eagle;* Haliaeetus vociferoides; *habitat; Madagascar; nest tree; perch tree; shoreline.*

USO DE HABITAT DE ANIDACIÓN Y PERCHA DEL AGUILA PESCADORA DE MADAGASCAR

Resumen.—Documentamos el uso de nidos y perchas para el águila pescadora de Madagascar (*Haliaeetus vociferoides*) en lagos y ríos y comparamos parámetros de árboles usados con árboles no usados de referencia. Los nidos y árboles percha fueron mas anchos y mas altos, tenían mas ramas despejadas, y estaban menos obstruidos por árboles adyacentes en comparación con los árboles referencia. Los árboles percha fueron además algunas veces más deciduos que los árboles control. Los sitios nido disponían de mas árboles percha costeros que los sitios de referencia. Los modelos de regresión logística con la altura de los árboles como variable independiente distinguieron los nidos y árboles percha de árboles control seleccionados aleatoreamente. Los modelos con números de árboles percha cerca a 1.25 ha (50 m de ancho) de la sección de costa distinguieron los sitios nido de los sitios referencia. Estos modelos sugieren que la presencia de árboles ≥15 m de alto dentro de 50 m de la línea costera es un buen pronosticador del uso de hábitat del águila pescadora de Madagascar.

[Traducción de César Márquez]

With a population estimate of 99 breeding pairs (Rabarisoa et al. 1997), the Madagascar Fish-Eagle (*Haliaeetus vociferoides*) is one of the rarest birds of prey in the world (Meyburg 1986). Until recently, little was known about the species' ecology and status. Langrand and Meyburg (1989) noted that the Madagascar Fish-Eagle used tall trees near water for nests and foraging perches, but prior to this study, there had been no detailed quantitative studies of Madagascar Fish-Eagle nesting or perching habitat use.

Nelson and Horning (1993) estimated from satellite data that Madagascar's forest cover had been reduced to 10.4% of the island by 1990. Nest-site availability is a key limiting factor for raptor populations (Newton 1979). Also perch-tree distribution is a reliable predictor of Bald Eagle (*Haliaeetus leucocephalus*) distribution on the Chesapeake Bay (Chandler et al. 1995). Thus, we focused our study on both nest and perch trees, along with the surrounding habitat conditions. The objectives of this study were to determine characteristics of nest trees, nest sites, and perch trees used by Madagas-

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Table 1. Sites where Madagascar Fish-Eagle nests and perches were investigated in the region of Antsalova, Madagascar, 1994. Site names are lakes unless otherwise indicated.

SITE	LATITUDE, LONGITUDE	NUMBER OF EAGLE PAIRS
Masiadolo	18°41′S, 44°28′E	1[a]
Besara	18°41′S, 44°16′E	1
Soahanina River	18°46′–48′S, 44°16′–19′E	3[a]
Antsahafa	18°48′S, 44°29′E	1[a]
Masama	18°50′–51′S, 44°28′–29′E	2
Tsiandrora	18°58′S, 44°38′E	1
Andranolava 1[b]	19°0′S, 44°21′E	1
Befotaka	19°1′–2′S, 44°24′–25′E	3
Soamalipo	18°59′–19°2′S, 44°26′–27′E	3[a]
Ankerika	19°1′–2′S, 44°27′–44°28′E	4
Andranovorimirafy	19°3′S, 44°27′E	1
Andranolava 2[b]	19°4′S, 44°25′E	1
Antsakotsako	19°6′S, 44°33′E	1[a]
Ampozabe	19°9′S, 44°40′E	1
Bevoay	19°9′S, 44°25′E	1
Manambolo River	19°8′–9′S, 44°44′–49′S	2
Maromahia	19°11′–12′S, 44°37′–38′E	1
Bejijo	19°12′–14′S, 44°32′–33′E	1

[a] No nest was found for one of the fish-eagle pairs at five of the sites.
[b] Two of the lakes in the study had the same name.

car Fish-Eagles and to develop predictive models to identify fish-eagle nesting and perching habitat.

STUDY AREA AND METHODS

We conducted the study during the first half of the Madagascar Fish-Eagle breeding season from 21 May–14 August 1994. We investigated fish-eagle nesting and perching habitat in a 3000 km² area in the Antsalova region of western Madagascar (18°40′–19°15′S, 44°15′–44°50′E) that included the drainages of the Manambolo, Beboka, and Soahanina rivers west of the Bemaraha Plateau. Topography consisted of coastal plains and low rolling hills with elevations ranging from sea level to 126 m. Soils were shallow and sandy, and the vegetation was a patchwork of dry deciduous forest, savanna, wetlands, mangrove swamps, and rice paddies. The climate was subhumid and tropical with a dry season from April–October and a wet season from November–March. Mean annual rainfall in the region ranged from 1000–1500 mm (Donque 1972).

We defined a nest tree as any tree in which we observed nest construction, incubation, or brood rearing. A nest site was the area within 300 m of the nest tree. A perch tree was any tree in which we observed adult fish-eagles perching. We measured nest and perch trees of every known Madagascar Fish-Eagle pair in the study area (Table 1). Our perch-tree sample ($N = 29$) was larger than our nest-tree sample ($N = 24$) because we did not find a nest for five of the fish-eagle pairs.

We measured characteristics of fish-eagle nest trees and randomly selected reference trees to determine if trees used by fish-eagles differed from average large trees (>20 cm diameter at breast height [DBH]) near the same bodies of water. To compare nest and perch trees to available large trees, we randomly selected a reference tree for each nest or perch tree. We selected trees at the same distance from the water as the nest or perch tree To do this, we measured with a hip chain the distance from the nest tree to the nearest water (nest-water distance), from perch tree to nearest water (perch-water distance), and the distance along the shore between the nest and perch trees (nest-perch distance). We then randomly selected a shoreline reference point on the same body of water as the nest tree that we had measured (within 1.5 km along the banks for nest trees on rivers)

To select each nest reference tree, we went to the shoreline reference point and moved inland a distance equal to the nest-water distance and selected the nearest tree >20 cm in DBH as our nest reference tree. We used the same shoreline reference point to select a perch reference tree by moving the nest-perch distance in the same direction (left or right) along the shoreline as that between the used nest and perch trees. We then moved inland the perch-water distance and selected the nearest tree >20 cm in DBH as our perch reference tree. We used 20-cm DBH as a minimum size for reference trees based on the minimum size of Bald Eagle perch trees on the Chesapeake Bay (Buehler et al. 1992).

We measured DBH of nest trees to the nearest cm and used a clinometer to measure height to the nearest meter. We counted branches in the tree canopy that we estimated to be >5 cm in diameter and unobstructed for 1 m above and below. We recorded arc of accessibility by standing at the base of the tree and using a compass to measure the total arc (0°–360°) that was unobstructed by other trees for an estimated distance of 10 m from the trunk and 3 m below the tree's crown (Buehler et al. 1992). We recorded nest-tree species and classified growth form following Keister and Anthony (1983). Our classification was based on the location of the lowest fork in the trunk, and whether the tree was dead. We classified growth form as large if the lowest fork was in the lower third of the trunk, medium if the lowest fork was in the middle third of the trunk, and small if the lowest fork was in the upper third of the trunk. We recorded growth form as dead top if the top third of the crown was dead and as snag if the entire tree was dead and leafless, regardless of the location of the lowest fork in the trunk.

We measured minimum distance of each nest tree to water with a hip chain and minimum distance to human disturbance, building, road, and fish-eagle nest from maps and aerial photos. Human disturbances included agricultural clearings, rice paddies, villages, tombs, and fishermen's camps. Temporary, seasonal shelters that were not used during the fish-eagle breeding season were not considered buildings. There were no paved roads and few motor vehicles in the area, and the most traveled roads were traversed by less than one motor vehicle per day, even in the dry season. Oxcarts frequently were used to transport materials, so we recorded any oxcart track as a road.

We considered trees ≥6.1 m high and with ≥30° accessibility from the shoreline to be potential perch trees based on the smallest recorded perch tree used by Bald Eagles on the Chesapeake Bay (Buehler et al. 1992). We counted perch trees within 50 m of the water along a 250 m shoreline section centered on the nest tree or reference tree (Chandler et al. 1995). We classified mean surrounding canopy height to 5-m intervals ranging from 0–25 m based on visual observation.

We measured the perch tree that we saw fish-eagles use most frequently for foraging for each of the 29 fish-eagle pairs in the study area. Eleven (37.9%) of the pairs were observed for at least 6 hr, at least once per week during the breeding season (May–October) in 1992, 1993, and 1994 as part of a related study (Watson et al. 1999). The remaining 18 (62.1%) pairs were observed for at least 6 hr, at least three times per breeding season from 1992–94. We measured the same tree characteristics for perch trees that we measured for nest trees.

We tested the null hypothesis of no difference between trees or sites used by breeding Madagascar Fish-Eagles and reference trees or sites for each of the numerical variables using the Wilcoxon signed-ranks test. We paired each fish-eagle nest or perch tree with the randomly selected reference tree on the same water body. We did not test for differences in distance to water because this was a criterion for selecting reference trees. We used the chi-square test of equal proportions to determine if fish-eagle habitat use was different from expected use for the following categorical variables: tree species, deciduous versus evergreen trees, growth form, and surrounding canopy height. If >20% of expected values were <5, we used the likelihood ratio chi-square test statistic (Agresti 1990).

We developed logistic regression models to predict the probability of fish-eagle use of trees and sites based on the measured habitat variables using stepwise analysis Our significance level for variables to both enter and exit models was $P = 0.05$. We used dummy variables for growth form categories in the logistic regression (Hosmer and Lemeshow 1989). We constructed classification tables for each logistic regression model by using the estimated logistic probabilities for each tree or site to predict fish-eagle use (Hosmer and Lemeshow 1989). We considered trees or sites as correctly classified as used by fish-eagles if the predicted probabilities were ≥0.5.

RESULTS

Nest-tree Characteristics. Nest construction, incubation, or brood rearing was observed at 21 (87.5%) of the 24 measured nest trees in 1994. The remaining three nest trees were used in 1993, but not in 1994. Nest trees were taller, had more unobstructed branches, and a greater arc of accessibility than reference trees (Table 2). Mean nest-tree DBH was more than twice that of reference trees. Twenty-two of 24 (91.7%) nest trees versus only 14 of 24 (58.3%) reference trees had a >270° arc of accessibility.

Nest-tree species included *Tamarindus indica* ($N = 7$), *Cordyla madagascariensis* ($N = 4$), *Adansonia* sp. ($N = 2$), *Colvillea racemosa* ($N = 2$), *Neobeguea mahafaliensis* ($N = 2$), *Acacia* sp. ($N = 1$), *Albizia greveana* ($N = 1$), *Alleanthus greveanus* ($N = 1$), *Foetidia* sp. ($N = 1$), *Pandanus* sp. ($N = 1$), and unidentified ($N = 2$). *T. indica* was the most frequently recorded species of nest reference tree ($N = 6$). Its proportion among nest trees (29.2%) was not different from its proportion among reference trees (20.8%) ($\chi^2 = 0.44$, df = 1, $P = 0.51$). Proportions of nest trees and reference trees in each growth form class were similar ($\chi^2 = 4.58$, df = 4, $P = 0.33$). Eight of the nest trees (33.3%) and three (12.5%) of the reference trees were deciduous ($\chi^2 = 2.95$, df = 1, $P = 0.09$).

Fish-eagle nest-tree use was positively associated with tree height, producing a logistic regression model of

$$\theta = 1 \Big/ \left(1 + \exp\left[5.52 - \sum_{i=1}^{n} 0.38x_i\right]\right)$$

where θ is the probability of fish-eagle use and x_i is the height of tree i. This model correctly classified 83.3% of 48 trees measured.

Nest-site Characteristics. Number of shoreline perch trees was greater at nest sites than at random sites (Table 3). There was a positive relationship

Table 2. Characteristics of Madagascar Fish-Eagle nest trees, perch trees, and paired reference trees in the region of Antsalova, Madagascar in 1994.

VARIABLE	NEST TREES (N = 24) $\bar{x}$ ± SE (RANGE)	PAIRED REFERENCE TREES (N = 24) $\bar{x}$ ± SE (RANGE)	P^a	PERCH TREES (N = 29) $\bar{x}$ ± SE (RANGE)	PAIRED REFERENCE TREES (N = 29) $\bar{x}$ ± SE (RANGE)	P^a
DBH (cm)	87.8 ± 11.8 (29–245)	38.4 ± 4.2 (22–114)	<0.001	65.3 ± 7.2 (27–270)	36.9 ± 3.3 (21–120)	<0.001
Height (m)	18.7 ± 0.8 (10.7–25.9)	10.5 ± 0.9 (5.0–23.3)	<0.001	16.7 ± 0.8 (9.4–30.3)	9.8 ± 0.4 (4.9–15.8)	<0.001
No. of branches[b]	5.5 ± 0.7 (1–14)	3.2 ± 0.8 (0–19)	0.021	7.9 ± 1.2 (2–39)	1.8 ± 0.4 (0–15)	<0.001
Arc of accessibility (°)[c]	346.7 ± 5.4 (265–360)	260.2 ± 25.0 (0–360)	<0.001	336.7 ± 7.1 (190–360)	231.4 ± 21.4 (0–360)	<0.001

[a] Wilcoxon signed-ranks test significance level.
[b] Number of branches in the tree canopy >5 cm in diameter and unobstructed for 1 m above and below.
[c] Arc (0°–360°) that was unobstructed by other trees ≤10 m of the trunk and ≤3 m below the crown (Buehler et al. 1992).

between fish-eagle nest-site use and the number of shoreline perch trees. The model was

$$\theta = 1 \bigg/ \left(1 + \exp\left[3.49 - \sum_{i=1}^{n} 0.15x_i\right]\right)$$

where θ is the probability of fish-eagle use and x_i is the number of perch trees within a 1.25 ha (50 m wide) shoreline section centered on the point on the shoreline nearest nest tree i. Correct classification of fish-eagle use for this model was 72.9% of 48 sites. Minimum distance to human disturbance, minimum distance to nearest road, minimum distance to nearest building, and minimum distance to nearest fish-eagle nest did not differ between nest sites and random sites (Table 3). The proportion of nest sites in each 5 m canopy height interval did not differ between nest sites and random sites (χ^2 = 4.93, df = 4, P = 0.30). Mean distance to water of nest trees was 70.8 m (SE = 12 6, range = 6.8–199.2 m).

Perch-tree Characteristics. Perch trees were larger (DBH and height), had more unobstructed branches, and had a greater arc of accessibility than reference trees (Table 2). Twenty-six of 29 (89.7%) nest trees versus only 16 of 29 (55.2%) reference trees had a >270° arc of accessibility.

Perch-tree species included *Colvillea racemosa* (N = 5), *Ficus cocculifolia* (N = 4), *Neobeguea mahafaliensis* (N = 3), *Tamarindus indica* (N = 3), *Albizia lebbeck* (N = 2), *Borassus madagascariensis* (N = 2), *Cordyla madagascariensis* (N = 2), *Acacia* sp. (N = 1), *Adansonia* sp. (N = 1), *Cedrelopsis grevei* (N = 1), *Pandanus* sp. (N = 1), *Raphia* sp. (N = 1), and unidentified (N = 3). *T. indica* was the most frequently recorded perch reference tree species (N = 10). Its proportion among perch trees (10.3%) was smaller than among reference trees (48.3%) (χ^2 = 5.96, df = 1, P = 0.02).

Perch trees and reference trees had similar growth forms (χ^2 = 8.04, df = 4, P = 0.09). Proportion of deciduous trees among perch trees (34.5%) was greater than among reference trees (10.3%) (χ^2 = 4.86, df = 1, P = 0.03).

There was a positive association between fish-eagle perch-tree use and tree height, producing a logistic regression model of

$$\theta = 1 \bigg/ \left(1 + \exp\left[8.68 - \sum_{i=1}^{n} 0.71x_i\right]\right)$$

where θ is the probability of fish-eagle use and x_i is the height of tree i. This model correctly classified 84.5% of 58 trees measured.

DISCUSSION

Nest-tree Use. Madagascar Fish-Eagles used nest trees that were taller and had a greater DBH, more unobstructed branches, and a greater arc of accessibility than reference trees. The substantial difference between nest trees and reference trees in mean height and DBH suggests that the fish-eagle selects nest trees from among the largest trees available near water. By placing its nests in the tops

Table 3. Characteristics of Madagascar Fish-Eagle nest sites (N = 24) and paired reference sites (N = 24) in the region of Antsalova, Madagascar in 1994.

VARIABLE	NEST SITES $\bar{x} \pm$ SE (RANGE)	PAIRED RANDOM SITES $\bar{x} \pm$ SE (RANGE)	P[a]
Minimum distance to human disturbance[b] (km)	0.8 ± 0.2 (0–2.8)	0.9 ± 0.1 (0–2.8)	0.742
Minimum distance to building (km)	1.8 ± 0.4 (0.1–7.7)	1.8 ± 0.3 (0–5.6)	0.814
Minimum distance to road (km)	1.7 ± 0.4 (0–8.4)	1.3 ± 0.3 (0–5.4)	0.055
Minimum distance to fish-eagle nest (km)	4.8 ± 0.9 (1.3–20.3)	4.3 ± 0.9 (0.4–20.1)	0.104
Number of perch trees[c]	30.8 ± 2.3 (10–53)	16.6 ± 1.9 (0–33)	<0.001

[a] Wilcoxon signed-ranks test significance level.
[b] Human disturbances included agricultural clearings, rice paddies, villages, tombs, and fishermen's camps.
[c] Number of perch trees within a 1.25 ha (50 m wide) shoreline section centered on the point on the shoreline nearest the nest tree We considered trees that we estimated to have a height ≥6.1 m and ≥30° accessibility from the shoreline to be perch trees.

of these trees, it maximizes accessibility and visibility for foraging and territorial defense. These results were consistent with those reported for other nesting *Haliaeetus* species (McEwan and Hirth 1979, Andrew and Mosher 1982, Anthony and Isaacs 1989, Shiraki 1994).

Nest-site Use. Number of shoreline perch trees was the only variable that differed between nest sites and random sites. This suggests that the Madagascar Fish-Eagle, like the Bald Eagle (Chandler et al. 1995), may avoid areas without a sufficient number of foraging perches.

Perch-tree Use. Perch trees were larger in height and DBH, and had more unobstructed branches, and had a greater arc of accessibility than reference trees. Such trees probably have greater access and provide better visibility over water than other trees. This is consistent with Bald Eagle perch-tree use (Stalmaster and Newman 1979, Steenhof et al. 1980, Buehler et al. 1992). Madagascar Fish-Eagle perch trees were more often deciduous than reference trees. In contrast with the nest-tree results, the fish-eagles in this study appeared to avoid *T. indica* for perching. *T. indica* is evergreen and often has a dense crown; therefore fish-eagles may use this species less often for perching than leafless trees or snags.

Model Applications. The models we developed may be used to identify Madagascar Fish-Eagle nesting and perching habitat along lakes, rivers, and estuaries in western Madagascar. They do not apply to a sub-population of at least 16 fish-eagle pairs that nest on offshore islands at the north end of the species' range (Rabarisoa et al. 1997). Although our sample size was limited, the 29 breeding sites sampled represent 29.3%, of the 99 known remaining Madagascar Fish-Eagle breeding sites (Rabarisoa et al. 1997). Bald Eagle management guidelines recommend conserving mature forest around existing and potential nest sites (Anthony et al. 1982, Wood et al. 1989). We offer guidelines that are more specific to the range of tree sizes and densities found in the tropical dry forest and savanna habitats that surround the lakes where Madagascar Fish-Eagles occur.

We recommend that areas with a ≥32/ha density of trees ≥15 m tall should receive high priority for Madagascar Fish-Eagle conservation. Probability that a shoreline tree would be used by Madagascar Fish-Eagles for nesting or perching can be calculated by inserting tree height into the corresponding logistic equation (Fig. 1). Similarly, number of perch trees along a 1.25 ha (250 × 50 m) shoreline section can be used to estimate the probability that Madagascar Fish-Eagles will use the shoreline section for nesting (Fig. 1). These models are best used under the conditions that were present during this study (e.g., same eagle population density, same time of year) and apply to eagles nesting on lakes, rivers, and estuaries.

Presence of tall trees close to shoreline is the best predictor of Madagascar Fish-Eagle nest-site use. The eagles often used the tallest trees near water both for nesting and for foraging perches. Rabarisoa et al. (1997) conducted Madagascar Fish-Eagle surveys from 1991–95, and found areas

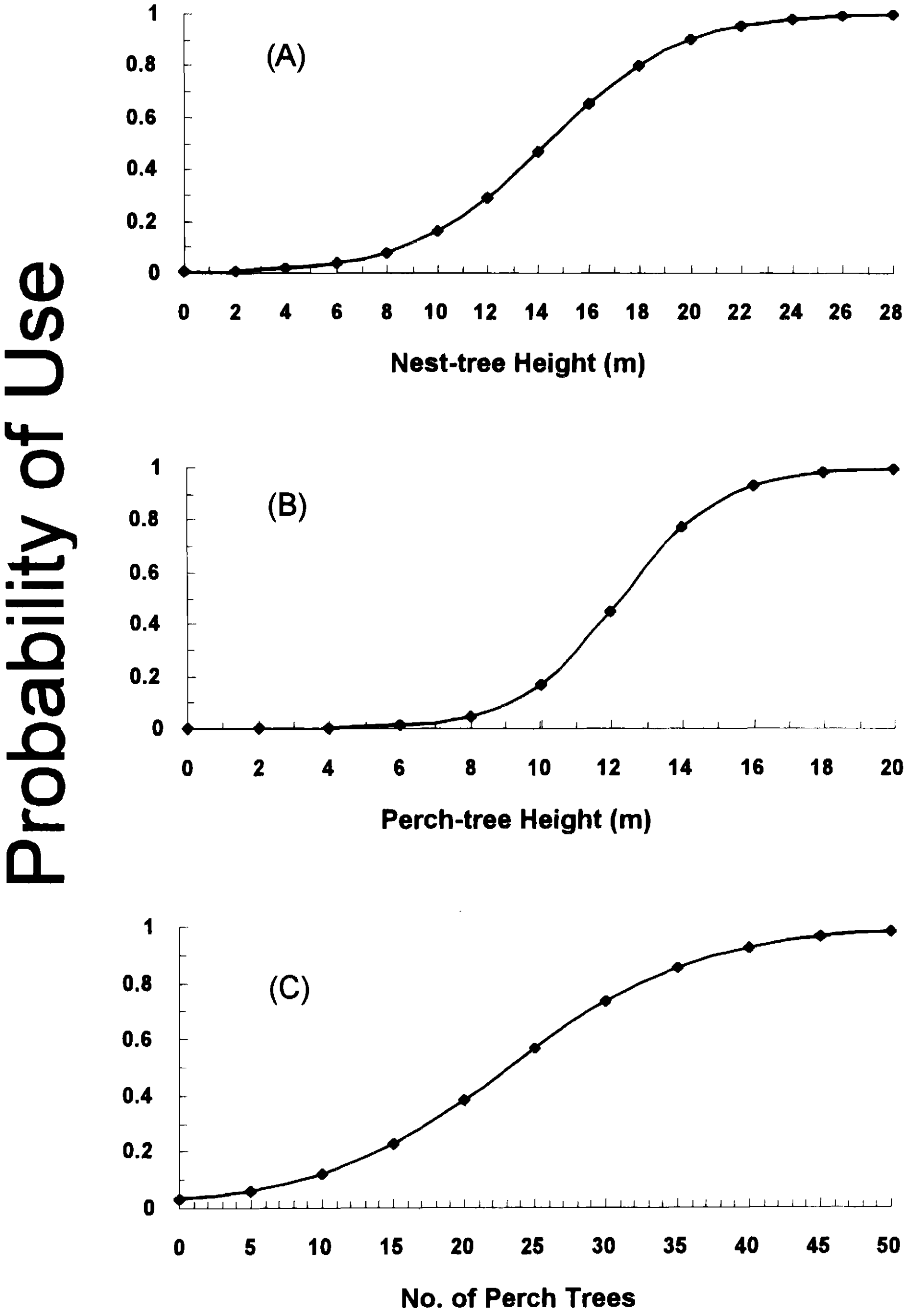

Figure 1. Probability of Madagascar Fish-Eagle use of nest trees, perch trees, and nest sites as a function of nest-tree height (A), perch-tree height (B), and number of shoreline perch trees (C), in the region of Antsalova Madagascar, 1994. Probabilities were calculated by inserting different values of the explanatory variable (tree height or number of perch trees) into the equation resulting from stepwise logistic regression analysis.

with dense forest adjacent to water that were unoccupied by fish-eagles. Watson et al. (1996) are developing means to augment the fish-eagle population and seek areas of unoccupied fish-eagle habitat where young eagles may be released. Our models may be used both to identify areas of suitable, but unoccupied, fish-eagle habitat and high conservation priority areas of occupied habitat.

The Tsimembo Forest surrounding Lakes Befotaka, Soamalipo, and Ankerika, where the highest density of fish-eagles is found (Rabarisoa et al. 1997), should receive highest conservation priority. The human population density around the lakes was low until recent years when large numbers of fishermen began to migrate to the region (Watson and Rabarisoa 2000). Increased harvesting of tall shoreline trees by migrant fishermen will have a negative impact on the fish-eagles. People use the tallest trees available for dugout canoes and building materials (Watson and Rabarisoa 2000) and may prevent regeneration of tall trees by harvesting large amounts of fuel wood to preserve fish by smoke drying. Deforestation probably has already substantially reduced the amount of fish-eagle habitat available, and as the human population continues to increase, available habitat will continue to decrease unless steps are taken to conserve fish-eagle habitat.

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