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Distribution and nesting density of the Philippine Eagle *Pithecophaga jefferyi* on Mindanao Island, Philippines: what do we know after 100 years?

GLEN LOVELL L. BUESER,[1] KHARINA G. BUESER,[1] DONALD S. AFAN,[1] DENNIS I. SALVADOR,[1] JAMES W. GRIER,[1,2]* ROBERT S. KENNEDY[3] & HECTOR C. MIRANDA, JR[1,4]

[1]*Philippine Eagle Foundation, VAL Learning Village, Ruby Street, Marfori Heights Subd., Davao City 8000 Philippines*

[2]*Department of Biological Sciences, North Dakota State University, Fargo, North Dakota 58105, USA*

[3]*Maria Mitchell Association, 4 Vestal Street, Nantucket, MA 02554, USA*

[4]*University of the Philippines Mindanao, Bago Oshiro, Davao City 8000 Philippines*

The Philippine Eagle *Pithecophaga jefferyi*, first discovered in 1896, is one of the world's most endangered eagles. It has been reported primarily from only four main islands of the Philippine archipelago. We have studied it extensively for the past three decades. Using data from 1991 to 1998 as best representing the current status of the species on the island of Mindanao, we estimated the mean nearest-neighbour distances between breeding pairs, with remarkably little variation, to be 12.74 km (n = 13 nests plus six pairs without located nests, se = ±0.86 km, range = 8.3–17.5 km). Forest cover within circular plots based on nearest-neighbour pairs, in conjunction with estimates of remaining suitable forest habitat (approximately 14 000 km^2), yield estimates of the maximum number of breeding pairs on Mindanao ranging from 82 to 233, depending on how the forest cover is factored into the estimates.

The Philippine Eagle *Pithecophaga jefferyi* is a large forest raptor considered to be one of the three most critically endangered eagles in the world (Bildstein *et al.* 1998, Collar *et al.* 1999). The species was first discovered in 1896 (Ogilvie-Grant 1896, 1897 [published in *The Ibis*]). The eagles are not particularly secretive or shy, and in fact can be rather conspicuous, especially when flying or vocalizing during the breeding season. But they are widely dispersed, uncommon, and usually located in steep terrain and heavy forest where visibility and accessibility are limited.

The species has been reported to occur primarily on four islands: Luzon, Samar, Leyte and Mindanao. From the sizes of the islands and extent of potential habitat, the largest populations are believed to be on Luzon and Mindanao (where most of the recent information has been obtained).

Attempts to estimate the size of the populations have been beset with problems including the difficulty of access to areas where the birds may be present, insufficient or unreliable data, and inadequately reported methods. Some reports have not been clear even whether the numbers referred to individual birds, pairs, nests or some combination of them. As part of an extensive review of all available information on the species, Collar *et al.* (1999) attempted to sort through the limited population reports, although in the process they also made some unwarranted inferences of their own.[1]

Early guesses about population numbers ranged from 36 to 60 individuals (Gonzales 1968, 1971, Alvarez 1970, Rabor 1971). Territory size was also stated as about 100 km^2 (Gonzales 1968). With considerably more data, and using Gonzales' estimate of 100 km^2 as territory size, Kennedy (1977) concluded that there might have been as many as 590 birds on Mindanao in the early 1970s. Generally, however, he estimated the remaining population on Mindanao during the 1970s to be within 200–400 individuals (Kennedy 1977, 1981, 1985). Using previous reports and a range of possible eagle territory characteristics in conjunction with estimates of available habitat for 1992, Collar *et al.* (1999: pp. 134; 174–175, remark 16) derived a range for 1992 of

*Corresponding author.
Email: james.grier@ndsu.nodak.edu

26–528 pairs for Mindanao and 60–1120 pairs for the country as a whole. Including the presence of immature eagles, their estimate expands to 120–4480 birds. Their best, precautionary guess was 226 adult birds (total, for all islands) for use in IUCN criteria and 'by which the species is judged to be Critically Endangered' (p. 134, Table 18).

Raptors nesting in relatively continuous habitat are often separated from one another by roughly equal distances in a fairly regular manner (Brown 1970, Leopold & Wolfe 1970, Henny *et al.* 1973, Tubbs 1974, Newton *et al.* 1977). Such distributions permit population density and size estimates via sampling and various spatial statistics such as nearest-neighbour distances (e.g. Clark & Evans 1954, reviews in: Ripley 1985, Krebs 1999). However, many raptor species, including the Philippine Eagle under current conditions of anthropogenic habitat alteration, exist in isolated patches of very heterogeneous habitat, which creates serious statistical problems when estimating population density or size (Ripley 1985, Krebs 1999).

We have studied and documented nesting of Philippine Eagles on the island of Mindanao for the past 30 years (Kennedy 1977, 1981, 1985, Miranda *et al.* 2000). However, only a few nests were found during the first 20 years; many of them and their surrounding habitat were lost; other nests were found in other regions; and logistical, funding, and local peace-and-order problems made it difficult to maintain annual records for many sites. A further complication for understanding the number of nesting Philippine Eagles is that, unlike temperate latitude raptors, nesting is not strongly seasonal, with the initiation of egg-laying spread over several months and the period of nesting from start of egg-laying to independence of a chick from the parents requiring nearly 2 years (Kennedy 1985). During the 1990s (especially 1991–1998), although we were unable to follow every site every year, we felt more confident that birds and nests found during this period reflected the true status of the species. Active nests, and sightings of pairs for which the nests could not be located, were mapped and internest or interpair distances measured. Our goal was to use these data in conjunction with surrounding habitat measurements plus forest statistical data provided by the Philippine government and other sources to estimate the number of breeding pairs in Mindanao. On-going radio-telemetry and Geographical Information System (GIS) studies of the species should provide a better foundation for future population estimates.

STUDY AREA

This study was conducted on Mindanao (area = 97 923 km^2) located 5°30′–10°N and 122°–126°30′E. Most of the nests found were in the highlands of central and south-eastern Mindanao, which include the provinces of Agusan del Sur, Bukidnon, Cotabato, Davao, Davao Oriental, Misamis Occidental, South Cotabato, Sarangani and Davao City of Mindanao.

METHODS

We searched for Philippine Eagle nests from vantage points for several days and recruited the help of local people through a widely publicized reward-for-information campaign. To monitor reproductive success, we periodically revisited all occupied nests until the young had left the nest. Sites were located using Global Positioning System (GPS) and plotted on 1 : 500 000 aeronautical maps provided by the Philippine Air Force and overlaid with the most recent (1998) forest cover map (ESSC 1999). For more precise mapping, we also used older, but still useful 1 : 250 000 satellite image interpretation maps (NMRIA/SSC 1988).

We used nearest-neighbour distances (NNDs) between pairs as a measure of the territorial spacing required by the eagles to assess habitat in the areas occupied by them, and to estimate population sizes from the available habitat. NNDs were calculated in two ways: using only known occupied nests or by also including sites where pairs of eagles, assumed to be paired adults, were consistently seen during visits by the investigators but where the nests themselves were not found. The location for each pair without a found nest was mapped at the centre of sightings. To avoid inflating estimates with sites that were obviously not, or might not be, 'nearest' neighbours, we only used adjacent, closest or clearly neighbouring sites in contiguous or nearly contiguous habitat. We excluded nests that were separated by large expanses of open landscape or which, if within the same block of forest, were so far apart (arbitrarily defined as 2.5 times the minimum) that they might include other, undiscovered, territories.

The identities of pairs without located nests were distinguished from adjacent pairs with known nests by comparing the stages of their breeding cycles. For example, when one pair had just commenced breeding and an adjacent pair was with a juvenile, they were considered as different pairs.

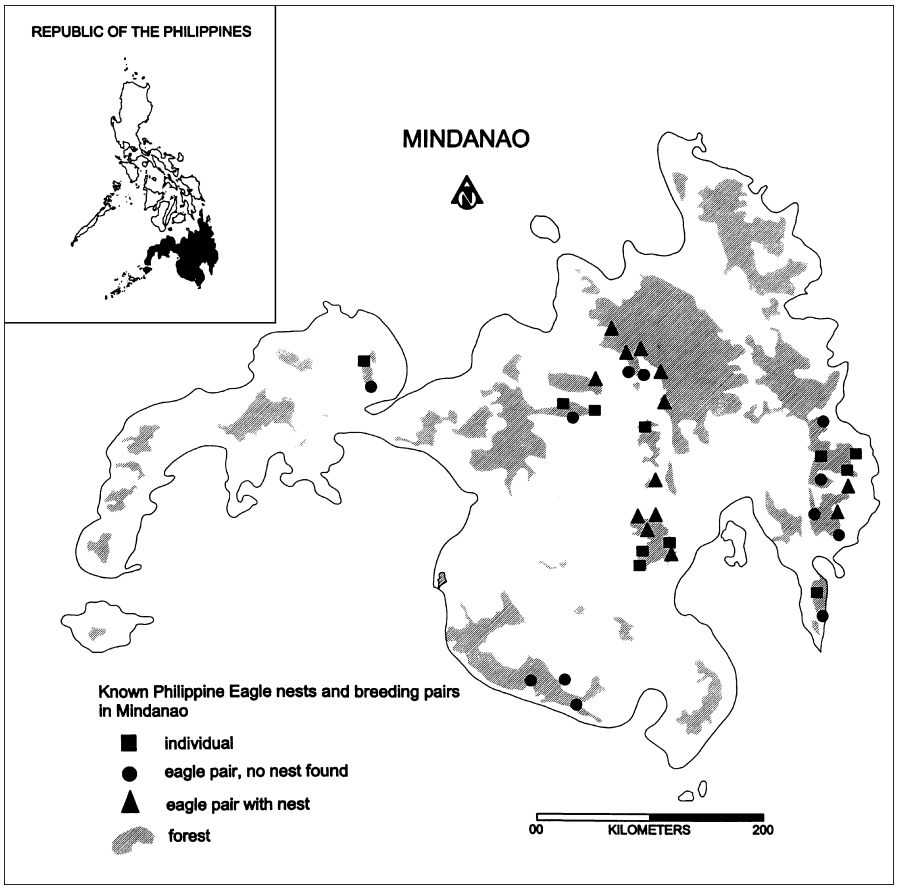

Figure 1. Locations of Philippine Eagle nests and pairs where nests were not found, 1991–1998, with remaining forest cover at the start of the time period (based on SPOT satellite images, NMRIA/SCC 1988).

A circular plot (radius = $^1/_2$NND), using the mean NND, was drawn around all nests and pair locations, including additional isolated or non-neighbouring sites. The extent of each type of vegetation cover (closed-canopy dipterocarp forest,[2] open-canopy dipterocarp forest,[2] montane-mossy forest, and non-forest landscape) was determined within each circular plot using a planimeter. Non-forest landscape included agricultural areas with corn, coffee, upland rice, orchards, tree nurseries, grazed pastures, grassland and residential land.

RESULTS

The locations of all nests, and pairs with unlocated nests, are shown in Fig. 1. Of the 13 nests, three were in primary dipterocarp forest while the remaining 10 were in mature secondary dipterocarp forest. Nine nests were within 100 m of forest edges. The remaining four located nests were deeper into the forest but still contained a large amount of open landscape within the circular NND plots. The locations of all nesting sites found during this survey support Alvarez's (1970) and Kennedy's (1977) observations that Philippine Eagle nesting areas are found near river systems or small tributaries and streams, steep slopes, ravines, and associated with mature dipterocarp forests.

NNDs for eight nests (n = 7 NNDs) averaged 12.56 km (se = ±0.89 km; range = 10.2–16.4 km) and with an additional six pairs with unlocated nests (total of 12 NNDs) averaged 12.74 km (se = ±0.86 km; range = 8.3–17.5 km). Because the distances were so consistent, whether pairs without located nests were included or not, we used the larger set for further measurements and estimates.

The resulting circular plots averaged 133 km^2 (n = 12 NNDs, se = ±17.6 km^2). These mean circular areas were then applied to all known nests or pair sites, which included additional isolated (i.e. not

neighbouring) nests (n = 5) and pairs without located nests (n = 6).

The forest cover in the circular plots averaged 69 km^2 for all known nests (n = 13, se = ±5.5) and 73 km^2 for all sites (n = 25, se = ±4.6). Closed-canopy^2 forest averaged 51.0% of the forest present for sites with located nests (n = 13) and 56.0% for all sites (n = 25). Surrounding and within the eagle areas were mosaics of dipterocarp forest at various stages of degradation and human-induced modification characterized by agricultural lands, agroforestry and grassland. Although we have frequently observed breeding pairs soaring far beyond the forest, an adequate quantitative assessment of habitat use, with a sufficient sample of nest-sites, is not yet available to report on the relative importance of various habitat types used by the Philippine Eagle.

An estimate of available suitable forest habitat of the types we found in NND circular plots on Mindanao during the 1990s was approximately 13 898 km^2 (based on statistics in DENR-FMB 1997). (Kennedy [1977: their Table 1] used an estimate of 29 000 km^2 remaining habitat for the early 1970s. Collar *et al.* [1999: 134] used an estimate of 6678 km^2 of closed-canopy forest for Mindanao for 1992.) A simple estimate of the maximum number of Philippine Eagle nesting pairs that might be fitted into this habitat, using a rounded mean estimate of 70 km^2 of forest per NND circular plot with a 95% confidence interval of ±10 km^2 (t_{24df} = 2.1, × se, Zar 1999) and rounding the available habitat to 14 000 km^2, yields a range of 175–233 adult breeding pairs. If the entire areas of the circular plots (95% CI = 96–170 km^2) are used as representing the spacing needed by territorial birds between each other, irrespective of the amount of forest included within the circles, and these are fitted into the available forest, the simple estimates for the total maximum number of breeding pairs drop to 82–146. These simple estimates assume that the birds are maximally packed into the available habitat, ignoring all 'edge' and territory shape considerations. Assuming that only 40% of this area is used (Collar *et al.* 1999: Table 18), the numbers would be proportionally lower.

DISCUSSION

The low variability of NNDs suggests that breeding Philippine Eagle pairs are regularly spaced, as are many other raptors when breeding (e.g. Newton *et al.* 1977). The circular plots of around 130 km^2, derived from NNDs, are remarkably similar to the 100 km^2 areas described by Gonzales (1968).

The simple estimates of the possible numbers of territories, based on circular plots and potential forest habitat, cannot be improved at present because many of the assumptions required for random sampling do not apply. Furthermore, it is unlikely that all available habitat could be perfectly filled with the estimated areas that we derived. Even if the number of suitable areas could be determined, it is unlikely that all would be occupied. In addition to natural reasons for suitable habitat not being completely saturated, there has probably been at least some human-related mortality which has depressed the population.

Secondly, we are faced with an extremely heterogeneous landscape of variably isolated habitat patches. This problem is compounded when many (or, in this case, all) of the sites occur at the edge of the habitat. Ripley (1985) discusses these problems and possible solutions. But the habitat problems presented by Philippine Eagles are too extreme to apply those solutions.

All the known nests and pairs have been near forest edges. It is unclear whether this reflects an edge preference by the species, their greater conspicuousness there, the result of highly fragmented habitat, or the loss of suitable habitat at lower elevations which has pushed the eagles to higher ground. A few large areas of, presumably, suitable forest remain, but we lack reports of eagles from these.

The final problem relates to sample sizes. In spite of having the best data so far available for the species, and the relatively regular spacing of neighbouring nests, there are still too few nest locations and inadequate data on eagle movements and habitat use to enable better population estimates. Thus, we conclude that it is not currently possible to derive better estimates of the number of wild nesting Philippine Eagles.

The Philippine Eagle is critically endangered. Our study suggests that Philippine Eagles require mature dipterocarp forest (at least 50% per territory). However, this may not reflect eagle densities in optimal habitat conditions as would have occurred prior to massive deforestation of the last 50 years. Some of the forest habitat where nests were located was marginal and all sites have varying degrees and forms of habitat disturbance. The extent to which eagle breeding density is limited by factors other than available habitat, such as prey populations or human-related mortality, is unknown.

Collar *et al.* (1999) closed with the statement that the Philippine Eagle probably remains the 'most important [avian] single-species conservation issue on the planet today.' We agree.

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ENDNOTES

[1]The review by Collar *et al.* (1999) unfortunately contains numerous inaccuracies and insinuations. For three examples: (1) p. 123, 'So much activity was focused on Mindanao that it often appears as if the eagle had no range or potential for conservation elsewhere.' and p. 128, '… province still largely ignored as a target of investigation …' Luzon has been very much of interest. It was not studied as much as Mindanao because of logistical and organizational problems, insufficient funding and lack of available, trained personnel. (2) In reference to Kennedy (1977), which is best viewed in retrospect as an early report based on the best available, albeit limited information, Collar *et al.* repeatedly infer implications that are not justified, e.g. (p. 128) ' "the last known record …" … , as if implying its probable extinction there.' and (p. 133) 'preferred the most conservative of his three population estimates (309); he did not give a reason for this choice, although it was possibly in order not to appear too seriously out of line with previous assessments …' Kennedy simply stated that the one instance was 'the last known record', nothing more and nothing less, and he chose his preferred estimate based on his own, best judgement at the time. (3) Collar *et al.* (1999) misunderstood or misrepresented the role of captive breeding of Philippine eagles (pp. 151, 153–160, 168–170). Captive breeding has been only one (important for several reasons, in our opinion) component of an integrated programme by the Philippine Eagle Foundation (formerly Philippine Eagle Conservation Program, PECP) and planning by the Philippine Eagle Working Group (PEWG) that equally include *in situ* work with the wild populations as well as important educational and socio-economic efforts.

[2]We used the definitions of closed canopy and open canopy dipterocarp forest provided and mapped by the (Philippine) National Mapping and Resource Information Authority (NMRIA) and the Swedish Space Corporation (SSC) whereby 'closed canopy' included mature dipterocarp and other broad-leaved forest covering over half the area, 'open canopy' had mature forest cover of less than half the area, and, in both cases, with less than 10% cultivated and other open areas.

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