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ESTIMATING THE BREEDING POPULATION OF BOOTED EAGLES IN THE CAPE PROVINCE, SOUTH AFRICA

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ABSTRACT.—Data on the breeding range of Booted Eagles (*Hieraaetus pennatus)* were collected over 25 yr in the Northern, Western, and Eastern Cape Provinces, South Africa, to estimate the breeding population. Based on the distribution of 150 known nest sites, we used information from digital terrain models to define topographical characteristics of nest sites. This information was used to identify the total suitable nesting habitat in the study area. By calculating the mean inter-nest distance, we estimated the total nesting population through extrapolation. With a mean inter-nest distance of 9.7 km, we arrived at an estimate of 702 nests. In core areas that we have studied intensively, we found even higher breeding densities and therefore consider our estimate to be conservative.

KEY WORDS: *Booted Eagle*; Hieraaetus pennatus; *breeding density*; *South Africa*; *GIS habitat delineation*; *population estimation.*

Estimación de la población reproductiva de *Hieraaetus pennatus* en la provincia del Cabo, Surafrica

RESUMEN.—Recopilamos datos sobre el rango de reproduccion de *Hieraaetus pennatus* durante 25 años en el norte, oeste y este de la Provincia del Cabo, Suráfrica para estimar la población reproductiva. Con base en la distribución de 150 sitios de nidos, utilizamos información de modelos digitales del terreno para definir las características topográficas de los sitios de anidación. Esta información fue utilizada para identificar el total del habitat propicio para anidación en el área de estudio. Al extrapolar el cálculo de la media de la distancia entre nidos, estimamos el total de la población anidante. Con una media de distancia entre nidos de 9.7 km, llegamos a un estimativo de 702 nidos. En las áreas centrales que hemos estudiado intensivamente, encontramos densidades aún mas altas, por lo tanto consideramos que nuestro estimativo es conservador.

[Traducción de César Márquez]

In contrast to the Palearctic region, where the biology of the Booted Eagle (*Hieraaetus pennatus*) is well-known (Cramp and Simmons 1980, del Hoyo et al. 1994, Suárez et al. 2000), only its breeding biology has been studied in southern Africa (Steyn and Grobler 1981, 1985). This breeding population was only recently discovered (Martin and Martin 1974, Brooke et al. 1980) and the first modern breeding record was confirmed in 1973 (Martin and Martin 1974). The extent of the breeding range was clarified by models of seasonality and associated breeding by Boshoff and Allan (1997) and Harrison et al. (1997) but the range is complicated because there appear to be three separate populations of Booted Eagles in southern Africa (Boshoff and Allan 1997). These populations consist of nonbreeding summer migrants from the Palearctic region, a relict breeding population from the Waterberg in Namibia, and a breeding population in the Cape Province (del Hoyo et al. 1994, Brooke et al. 1980). To further complicate the situation, some eagles overwinter in the southwestern Cape Province (Pepler and Martin 1997). To date, only one estimate of breeding population (400

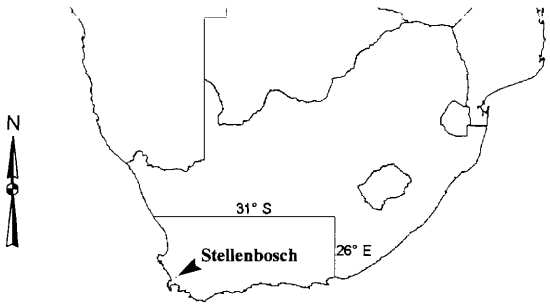

Figure 1. The study area in southern Africa.

pairs) has been made for the Cape Province (Martin and Martin 1991).

We collected data on the breeding range and density of the Booted Eagle population in the Cape Province over the past 25 yr through direct observations. We used elevation information from digital terrain models to define the topographical characteristics of Booted Eagle nesting sites based on the distribution of 150 known sites to determine the total area of suitable habitat. To estimate the total nesting population, we established the nesting density within suitable habitat by calculating the mean inter-nest distance following the method of Pepler et al. (1991). In this method a plot of the cumulative sum of deviations from the running mean (Lombaard 1989) indicates changes in density with distance. This method is more typically used in the analysis of time-series data but is applied in this case to the distance series. A systematic deviation from zero is indicative of a change in trend, in this case inter-nest distance.

Study Area and Methods

The study area covered the portion of southern Africa south of 31°S and west of 26°E (Fig. 1). The total land area was 263 532 km^2. The town of Stellenbosch (33°55′S, 18°52′E) was used as our base. Our study area covered most of the perceived breeding range as described by Steyn (1982) and Boshoff and Allan (1997). The study was conducted annually from 1975–93. Timing of fieldwork was restricted to the breeding season, which was typically from September to December.

Within our study area, Booted Eagles hunted and bred in both hilly and open country, preferring habitats consisting of nama karoo, succulent karoo and fynbos (Low and Rebelo 1996) and, especially, the ecotones between these habitat types (Boshoff and Allan 1997). In recent years, however, we observed Booted Eagles hunting in suburban areas (Pepler and Martin 1996), and it is reasonable to assume that records of breeding from within these areas will be found in due course.

We searched for nests from roads that gave access to mountainous areas, and strategic vantage points were selected that afforded the greatest possible field of view. The total distance covered during the course of the fieldwork was in excess of 500 000 km (approximately 2 km traveled per km^2 of the study area or 0.1/km per yr). Occupied nest sites were confirmed when one or both adults were seen carrying nesting material to a specific site, prey items were seen being carried to sites, or young were observed at sites before they fledged. Nests were typically situated behind small trees or shrubs growing on cliffs. Whitewash around occupied nest sites has a unique streaked appearance that helped us locate them from greater distances.

Breeding sites were plotted on 1:250 000 topographical maps and subsequently digitized into a format compatible with an ARC/INFO Geographic Information System (Environmental Systems Research Institute, Inc., 380 New York Street, Redlands, CA 92373-8100, U.S.A.). Elevation data for the study area were obtained from national digital elevation data (Department of Land Information Systems, Private Bag X10, Mowbray 7705, South Africa) and these data were also imported into the GIS. The vertical interval for the elevation data was 250 m.

Booted Eagle nest sites are associated with mountainous country with broken terrain (Steyn 1982). Elevation alone was not a good indicator of suitable habitat because the eagles do not nest on high plateaus. Steep slopes were also indicators of suitable habitat but evenly sloping areas are not used for nesting. The broken terrain used by Booted Eagles was identified using the rate of change of slope which was determined from the second derivative of the function describing the surface. The function was calculated for each point from the eight elevations immediately adjacent to a point as well as the elevation of the point itself. The value referred to a point at the center of a grid of nine points with a total dimension of 678 × 678 m. High values of this parameter indicated the rapidly changing slopes associated with broken hilly country while excluding plateaus and smooth inclines. Low values indicated constant slope. A number of values of this parameter were tried until one, which by inspection of the area covered on the map just included the distribution of the majority of the known nests, was found. The term "mountainous," in the context of this analysis, was taken as any area with a second derivative of height greater than, or equal to, 0.2. The cell size for the analysis was fixed at 226 × 226 m (51 076 m^2) since this was the scale at which the second derivative was calculated. Finally, we calculated the total number of cells in the mountainous and nonmountainous areas and the percentage of the study area that was mountainous.

Since the survey was carried out from roads, it was possible that undetected nests in areas isolated from roads might cause an overestimate of the inter-nest distance and an underestimate of the density. Similarly, the survey was spread over a wide area and it was likely that nests closer to our base in Stellenbosch could have been more likely to be found. To determine if this was the case, we calculated the cumulative sum of deviations from the running mean (CUSUM, Lombaard 1989, Pepler et al. 1991) for inter-nest distances based on the observations ordered in increasing distance from a road and also on increasing distance from Stellenbosch.

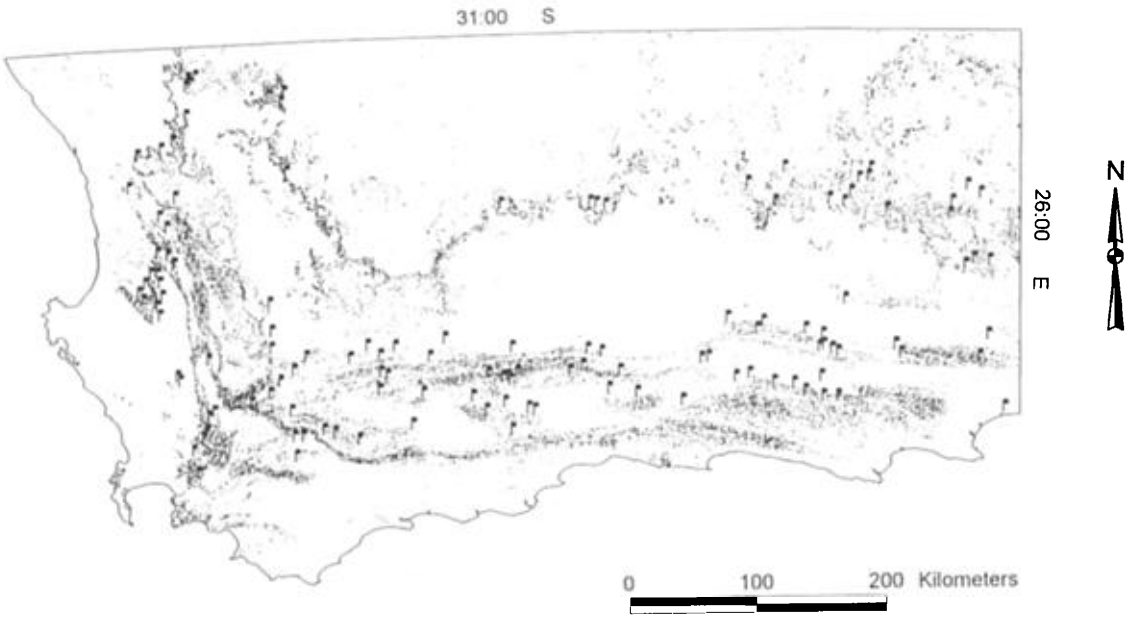

Figure 2. Breeding distribution of Booted Eagles in southern Africa. Nest sites are flagged and areas with second derivatives of the surface function >0.2 are shaded.

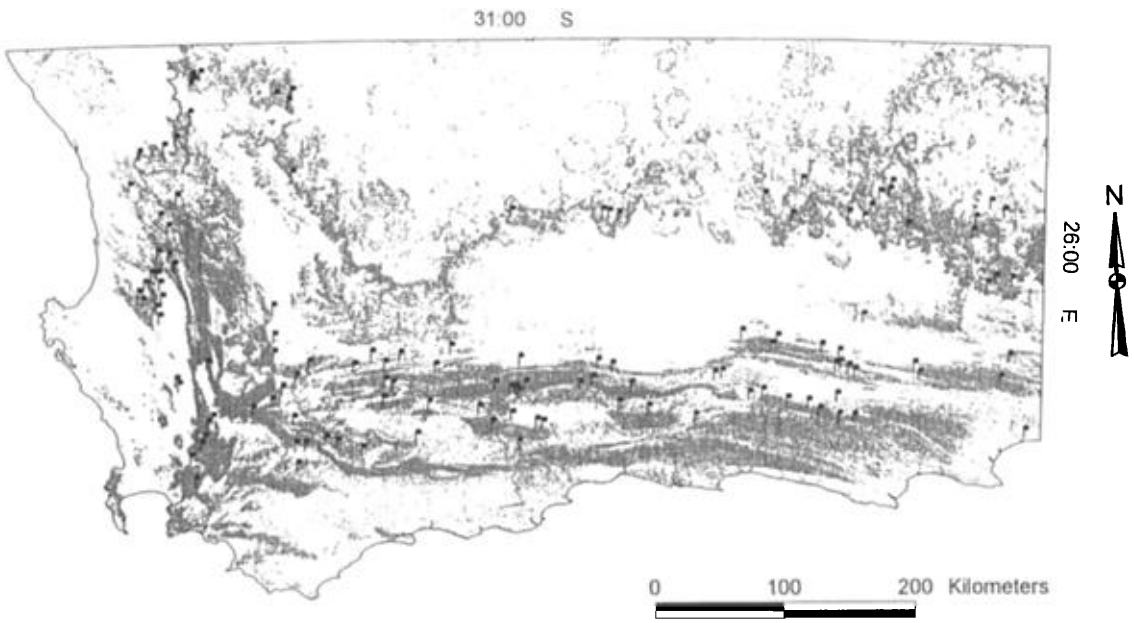

Figure 3. Breeding distribution of Booted Eagles in southern Africa. Nest sites are flagged and areas of steep slope with first derivative values >6.5 are shaded.

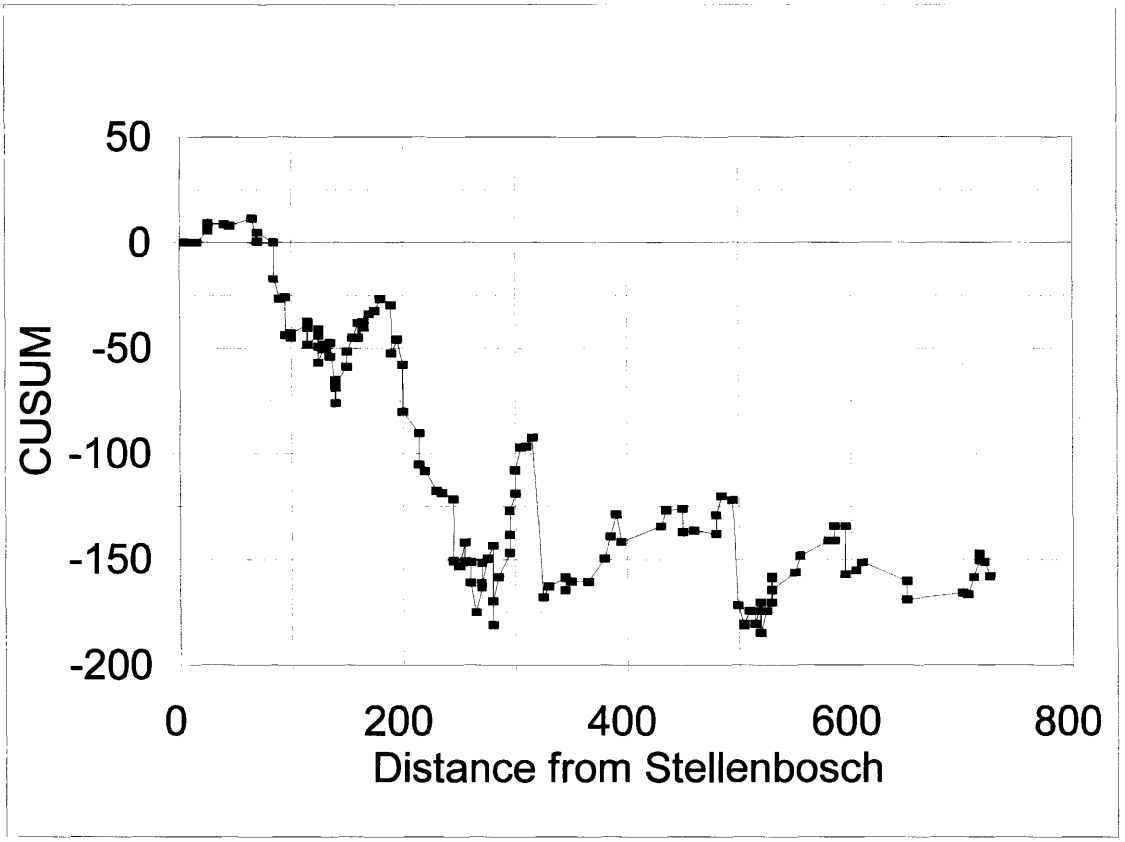

Figure 4. Cumulative sum of deviations from the running mean (CUSUM) plot for Booted Eagle inter-nest distances (km) and distances from Stellenbosch (km).

RESULTS

The breeding distribution of Booted Eagles corresponded closely with areas where the second derivative of the surface function had values >0.2 (Fig. 2). This differed from areas of steep slopes where first derivative values were >6.5 (Fig. 3). The total area of the habitat identified is 61 663 km^2.

CUSUM showed a possible change in inter-nest distance for sites in excess of 200 km from Stellenbosch (Fig. 4), so we based our calculations of inter-nest distances on nests at distances <200 km from Stellenbosch. There was no evidence that nest detection was based on distance from roads since no change point was evident in the CUSUM plot. Therefore, we used observations within 200 km of Stellenbosch to calculate our estimate of breeding density. Calculation of this estimate was based on two crucial assumptions. First, that the area included in our survey was representative of the entire area in terms of the average inter-nest distance and, second, that the estimate of inter-nest distance was accurate. The mean inter-nest distance was 9.677 km (95% CI = 9.17–10.18) and the estimate of the total breeding population for the study area was 702 pairs (95% CI = 576–879).

DISCUSSION

The results of our analysis were comparable to the atlas data of Harrison et al. (1997), especially with their models of breeding rate based on seasonality and breeding in zones four and eight.

Our study was carried out over 25 yr and we assumed that all the recorded nests remained occupied throughout the study period. We made this assumption because we have, in a number of cases, observed the continuous occupation of particular nesting sites for periods ranging from 1972–99. Be-

cause our observations were made from roads, we made no attempt to sample many of the mountain massifs. Therefore, it was possible that densities within these massifs were lower than we estimated.

Given the very high breeding density of four pairs of breeding Booted Eagles in a 3 km^2 area that was recorded by Martin and Martin (1988, 1995) in parts of our study area, we considered our calculation of the total population to be a substantial underestimate. This did not imply that such a high density is evenly maintained throughout the entire breeding range, but the severe constraints of time and logistics placed on a study of this nature preclude saturation sampling. An example of such an undersampled area is the mountain range of the Great Escarpment between Beaufort West (32°20′S, 22°38′E) and Calvinia (31°27′S, 19°50′E).

We believe that our data present the first attempt at an estimation of an entire breeding population of Booted Eagles in Africa. It has been suggested that this southern breeding population may be a subspecies of the northern Booted Eagle (R. Yosef and G. Verdoorn pers. comm.), but this needs confirmation. Elsewhere in its range only "fairly approximate estimates" of breeding density exist (del Hoyo et al. 1994). With time, we are confident that additional data will expand our database and increase the accuracy of our breeding density calculations.

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