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Original Article

Statistical analysis of topographic characteristics and nest-site preference of the White-Bellied Sea-Eagle (*Haliaeetus leucogaster*) in Penang National Park, Malaysia

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Abstract

Penang National Park was surveyed to model nest-site selection of the White-Bellied Sea-Eagle (WBSE) using the geographic information system of the study site (latitude $5^0\ 28'N$ and longitude $100^0\ 10'E$). Using two habitat variables (topographic and disturbance) nest-site selection analysis was carried out to examine significant differences between the sites used by the WBSE. A digital elevation model showed that the study area was characterized by high elevation (450^0) with pockets of low elevation at the edges. Higher percentages of elevation clusters were obtained at the southern region of the study area (mean elevation, 92 m) and it was significantly lower than the mean elevation of the entire park (147). The average slope of the nest sites (22.5±7.0°) was significantly higher than the general average slope of random points (18.6±9.4°) in the entire park. The occupation-model gives a parsimonious prediction of the WBSE population in an area for biodiversity conservation.

Keywords: ASPECT, slope, ruggedness, proximity, regrowth ± 6.3 m

1. Introduction

The White-bellied Sea-Eagle (WBSE) (*Haliaeetus leucogaster*), which preys on animals from the aquatic and marine environment, can be used to measure eco-system stability (Dennis *et al.*, 2011). In Malaysia, the WBSE occupies coastal environments including the coastal dipterocarp forest and other island groups (Wiersma & Richardson, 2009). The habitat-association approach in ecological studies was found to be inevitable to conservation and management (Johansson, 2001). Habitat selection analysis was widely employed to understand and manage wildlife resources. Habitat selection theory was formed based on the fact that animals have predictable habitat preferences which form part of their identity, otherwise known as 'niche' (Jones,

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2001). Habitat selection is also the foundation for the use of statistical models in assessing multivariate species-habitat relationships (Karl *et al.*, 2000; Vogiatzakis, 2003). Since the 1980s, a few studies are available on habitat selection (particularly nest site selection) by raptors in Malaysia. These studies were conducted by Andrew and Mosher (1982), Marks (1986), and Hayward and Escano (1989). However, with the advancement in computer programs and the geographic information system (GIS), such studies have become more quantitative (Bisson *et al*., 2002; Suarez *et al.*, 2000; Tapia *et al*., 2007).

A GIS organizes, synthesizes, and analyzes the habitat features from several sources relative to the species or breeding site locations and other physiographic data. This enhances the understanding of both the spatial and non-spatial relationships (Mathieu *et al*., 2006). This approach allows for the prediction of species requirements when designing strategies for the conservation and management of endangered species like the WBSE (Suarez *et al.*, 2000). The WBSE is known to construct and re-use nests in tall trees in the coastal and near coastal areas of Penang National Park. However, no known objective study has been conducted on the nest-site preference of the WBSE in Penang National Park and its environs. A nest-site selection analysis of the species may provide useful information on the relationship between the WBSE and its environment. Knowledge on the relationship would be useful for conservation and management strategies especially in the phase of dynamic habitat status. The main objective of this study was to analyze the nest-site characteristics and habitat preference by the White-bellied Sea-Eagle in Penang National Park using the GIS.

2. Materials and Methods

2.1 Study area

This study was carried out at Penang National Park (latitude $5^{0}\ 28'N$ and longitude $100^{0}\ 10'E$) between December 2007 and July 2009 (Figure 1A). It covers approximately 2562.963 ha that include 1182 ha of land, which is primarily coastal hill dipterocarp forest, coastal mangrove forest, sandy beaches, and rocky shores, and 1381 ha of sea areas (Yusop, 2004). Most of the land areas are made up of granite rocks (Chan *et al.*, 2003). The lowlands are narrow and small in size, occupying only the immediate coastal areas in the northern and western areas of Penang National Park. The reserve was designated as a Permanent Forest Reserve (PFR) under the Forestry Ordinance 1928 and as a national park since April 2003. The vegetation cover of the study area includes *Dipterocarpaceae, Leguminosae, Apocynaceae*, and *Burseraceae.* Some woody/tree species found in the area are *Shore curtisi* (Seraya), *Hope asp* (Resak), and *Agathis dammara* (Damar minyak).

2.2 Nest-site survey and GIS mapping

The nest-site survey was conducted by counting the occupied and unoccupied WBSE nests during complete breeding and non-breeding seasons from December 2007 to July 2008. Also a validation survey was conducted between October 2008 and April 2009. Two habitat variables (topographic and disturbance) were used to characterize the

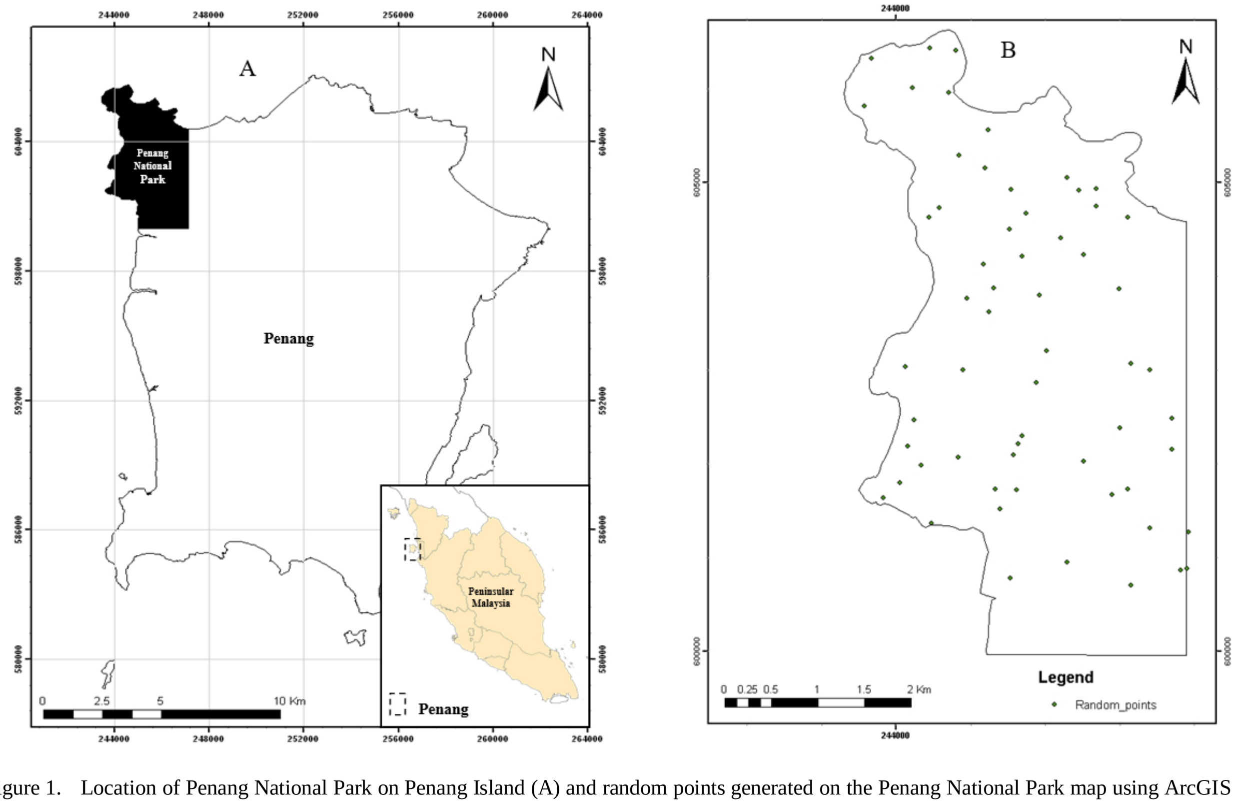

Figure 1. Location of Penang National Park on Penang Island (A) and random points generated on the Penang National Park map using ArcGIS (B).

nest site in this study (Table 1 and 2). Sixty random points were generated and placed across the landscape using Arc-GIS 9.3 software (Apriso Corporation, California, USA-Dauda *et al*., 2015) for ease of sufficient model generation (Olivier, 2006) and comparative study of the objects. These random points were measured as available habitat for the WBSE. Characteristics of each selected random point were measured, computed, and the differences between the selected habitat and available habitat (except for ASPECT variable) were tested using the student *t*-test and contingency analysis. The relationship between the assessed nest (x) and occupied nest (y) was investigated using a polynomial model:

$$y = f(x, x^2) \quad (1)$$

The ratio of the assessed nest at a particular time x_i to the mean of all the assessed nest $\bar{x}$ was obtained for each assessed nest using $x_r = x_i / \bar{x}$. Also, the ratio of the occupied nest at a particular time y_i to the mean of all occupied nests $\bar{y}$ was obtained for each occupied nest using $y_r = y_i / \bar{y}$. The relationship between the ratio of the two nesting variables (assessed and occupied) was investigated using the cubic regression model.

An algorithm for GIS study of the WBSE nest-site was constructed (Figure 2) using the 1:50000 topographic digital maps of Pulau Pinang produced by Jabatan Ukur dan Pemetaan. The topographic variables were generated using the spatial and 3D analyst extensions of ArcGIS 9.2 software and a 25 m resolution Digital Elevation Model (DEM) was produced from the digitized contour map. Height point data were extracted from the topographical digital map while elevation, slope, and aspect were derived from the DEM. ASPECT was tested with chi-square statistics while the disturbance indices, i.e. distance to road, distance to water, and distance to building, were obtained using reconnaissance survey.

3. Results

3.1 Nest occupation model and nest characteristics

Relationships between the assessed and occupied nests of the WBSE gave a parabolic model form (Figure 2A) which can be expressed as:

$$y = -0.0323x^2 + 0.298x - 0.0839 \quad (2)$$

where y is the number of assessed nests and x is the number of occupied nests. The model statistics include 3.454 (F-statistics), 0.5801 (R^2) and corrected Akaike Information Criteria (AICC) of 495.129. However, the relationship between the ratio of the assessed nests and ratio of the occupied nests (Figure 2B) produced a cubic relationship and it is expressed thus;

$$y = 0.203x^3 - 0.778x^2 + 1.5745x - 0.064 \quad (3)$$

where $y = y_r$ and $x = x_r$ as defined in Equation (1). The model statistics returned significant F statistics of 37.092 and coefficient of determination (R^2) of 0.789. The AICC returned for this model was 482.87 and it was less than the AICC returned for Equation (2). The implication of this result is that the Equation (3) model would give a more parsimonious model than the Equation (2) model. Hence, the cubic model is therefore chosen to predict the frequency of nest occupation by WBSE.

Table 1. Test of variance for different areas and mean separation for the assessed and occupied nests.

Parameters	Option	Assessed Nest	Occupied Nest
F-statistics		10.18**	4.90**
Df		7	7
Mean Separation	Teluk Bahang	0	0
	Teluk Aling	21.00[cd]	14.00[bc]
	Teluk Duyung	14.00[ed]	7.00[cd]
	Muka Head	35.00[bc]	21.00[ab]
	Teluk Ketapang	28.00[cd]	14.00[bc]
	Pantai Kerachut	56.00[a]	28.00[a]
	Teluk Kampi	35.00[bc]	14.00[bc]
	Pantai Mas	49.00[ab]	14.00[bc]

Table 2. Habitat variables used to characterize White-bellied Sea-Eagle nest-site selection.

	Variables	Description
Topographic variables	Elevation	Nest tree altitude above sea level (a.s.l. - m)
	Slope	Slope gradient (°)
	Aspect	Slope azimuth (°)
	Ruggedness index (RIX)	Density of contours (km/km²)
Disturbance variables	Distance to road	Minimum distance from nest tree to any roads (m)
	Distance to building	Minimum distance from nest tree to building (m)
	Distance to water	Distance from nest tree to nearest water body (m)

The algorithm of nest-site selection included the integration of the relevant information into a GIS database in an appropriate format like polygon, line, point or grid layers and was processed to produce a new grid layer for each criterion (Figure 3). Similarly, all WBSE nests were found in tall emergent trees of the forest. The WBSE were fond of nesting in low dipterocarp forests (0-300 m) in the study area. This dipterocarp consisted of mature trees and regrowth with a dense canopy cover. The nest-site features based on this study could be partitioned into topographic and disturbance characteristics.

3.2 Topographic characteristics of the nest sites

The DEM showed that the study area was characterized by a high elevation (450^0) with pockets of low or zero elevation at the edges (Figure 4A). Higher percentages of these elevation clusters were obtained at the southern region of the study area (Figure 4A). The mean elevation of the nest sites was generally 92±6.3 m above sea level and it

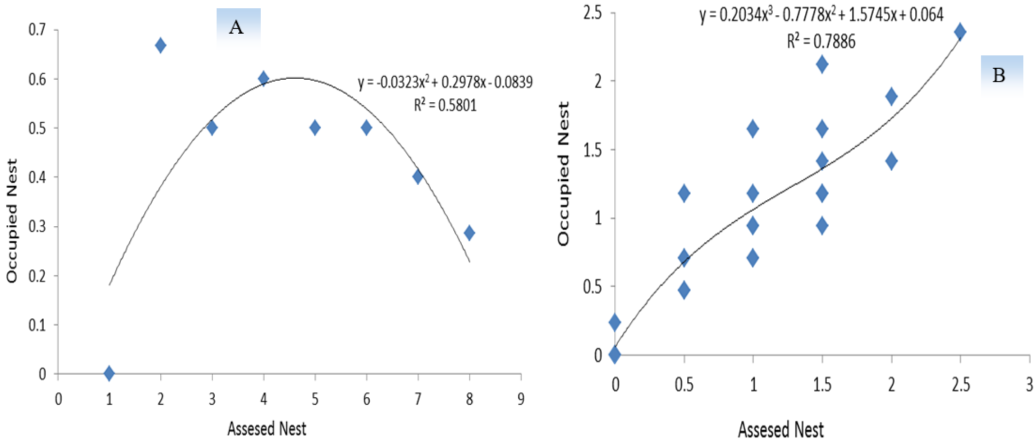

Figure 2. Polynomial model of the Assessed and Occupied Nests (A) and the assessed-nest-ratio and occupied-nest-ratio (B).

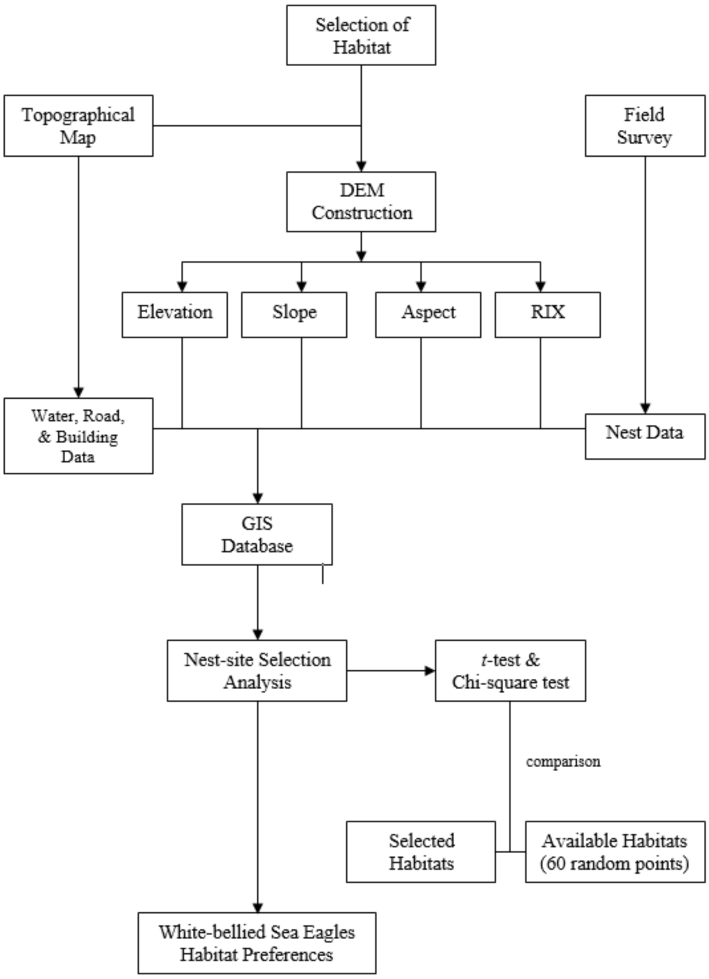

Figure 3. Algorithm of the nest-site selection analysis.

was significantly lower (P<0.05) than the mean elevation (147±9.7 m) obtained for the entire Penang National Park (Table 3). Most nests (59%) were at low altitude, i.e. below 100 meters above sea level. The elevation of the nesting points ranged between 13 m and 219 m. WBSE were found to nest in steep areas with up to 35.5° slopes. The average slope of the nest sites (22.5±7.0°) was significantly higher than the general average slope of random points (18.6±9.4°) in the entire Penang National Park. This result was also significant (P<0.05).

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The ruggedness map showed that the majority of the sections of the study area had a ruggedness index (RIX) greater than 6.5-9.8 (Figure 4B). A RIX less than 6.5 was patchy in the study area. In addition, the area supported few flat surfaces that were randomly distributed in the northern, eastern, southern, and western regions (Figure 4C). Most of the nest sites were established against the eastward direction with a bearing of 45^0-135^0. Nine percent of the nest sites were found on the eastward facing slopes while 36% were found at the southward direction. Also, 29% were found on the westward direction and 27% on the northward direction. The result of the contingency analysis of the nest directions showed there was no significant difference ($\chi^2_{3,\ 0.05} = 5.294$) between the observed nest directions against the expected nest directions ($P<0.05$).

Similarly, the slopes were generally between 20^0 and 29^0 which indicated moderate steepness of the area (Figure 4D). However, pockets of very steep and zero slopes were scattered throughout the entire study area. The steepness of the nest sites using the RIX based on the density of the contours revealed that most nests were located on steep sides of cliffs overlooking bodies of water. The contour density around the nest sites was 18.2±4.4 km/km² and it was not significantly different from the contour density (17.8±3.7 km/km²) of the entire study area ($P>0.05$). The contour density around the WBSE nests could therefore be said to be 0.225 km/km² more than the contour of the entire study sites.

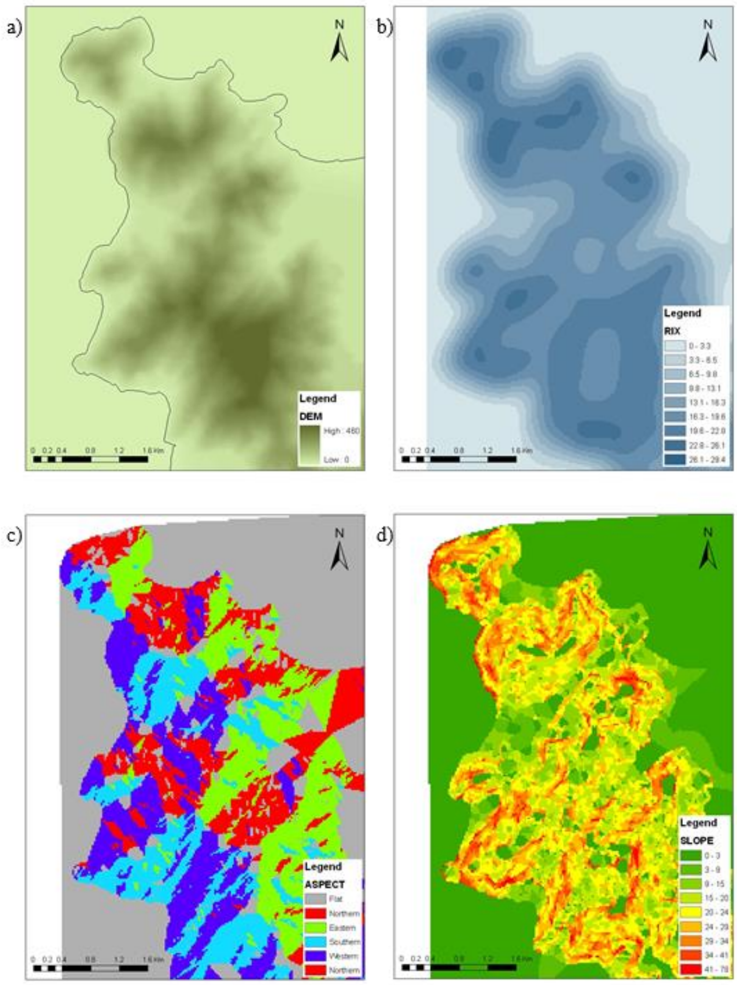

Figure 4. Topographic variables GIS layers of a) DEM, b) RIX, c) ASPECT, and d) SLOPE.

3.3 Disturbance characteristics

The average distance between nest sites and the nearest house or building was 920±60.4 m. This was also less than the average distance (1002±46.2 m) of random points to the nearest house or building in the entire study area and this result was not significant (P>0.05) (Table 3). The average proximal nest was 2083±66.1 m and the minimum was 513 m. This was, however, significantly less than the average nest distance (1557±73.0 m) to the nearest road in the study area (P<0.05) (Table 3). The average distance to the nearest water body or large river for all nest sites was 219±15.7 m with a minimum distance of 18 m. The average general distance between random sites to the nearest water (821.0±63.8 m) in Penang National Park area was significantly higher (P<0.01). The implication of this result was that nest locations were nearer to a body of water compared with other facilities, i.e. buildings and roads, in the entire study area.

4. Discussion

Topography was found to be one of the most significant landscape properties selected by the WBSE in this nest-site selection study. Altitude was found to be a topographic index that discriminated the nest sites from the entire habitat. The choice of low elevation to build a nest by the sea eagles may hinge on the need to minimize energy use in reaching their nests when returning from foraging at sea level (Thurstans, 2009). The WBSE's preference for lower altitudes and larger trees is also attributable to protection against wind speed and evaporation and these results agreed with the results by Appanah and Turnbull (1998). Similarly, WBSE nesting against the eastward possibly hinged on protection against solar radiation. It was established that southward nests (Brown & Mooney, 1997) have less solar radiation and evaporation which contributes to greater soil moisture as well as support from greater tree densities. Similarly, some of the nests were found in sheltered sections which probably served as shields against the prevailing weather. Harsh weather conditions are deleterious to the eggs and nestlings (Janes, 1985).

The preference for the WBSE to nest on the steep terrain of a cliff could be due to the dominant viewing position for catching prey. This conforms to Mathieu *et al.* (2006) which established that steep terrain provides a dominant position with good views of the surrounding landscape to observe prey. Steep terrain was also said to provide better opportunities for nest defense as well as reduce the chances of encounters with predators (Mathieu *et al*., 2006).

From this study, the proximity to water was equally found to be the best discriminating variable of the nest sites from the entire habitat. This is because the proximity to water provides better access to food. The minimum distance to a body of water from the nest sites in this study area was far below the previously recorded minimum distance of 1 kilometer (within 13 kilometers) in Victoria, Australia (Emison & Bilney, 1982). The presence of most of the nests within a 605 m radius of the coast areas of forest on cliffs near the shoreline also supported this assertion. WBSE did not tend to nest further away from houses and buildings compared to roads in the study area. Houses and buildings were present throughout the study area with a variety of human activity while roads are present only at the outskirts of the Penang National Park. The minimum distance of nests to a house or building obtained in this study was greater than 50 m reported for Kangaroo Island, Australia (Dennis *et al*., 2005). The presence of houses, however, was found to constitute a zero threat to the WBSE possibly because of a lack of physical presence of human beings. This also suggests that if other features are available, WBSE might not necessarily or actively avoid human presence, especially when the human population or density is low.

The dense forest was attractive to the WBSE because of an array of benefits, which include shade from the canopy cover and protection from the wind thereby reducing the chill factor (Thurstans, 2009) as well as protection from direct sunlight (Reynold *et al*., 1982). Although there existed a stretch of mangrove habitat at the southern part of the study area where the WBSE could be sighted, no nest was found in the area. The nest-site assessment in conclusion divulged several significant variables and well-defined ranges of parameters that were not visible from simple observation of the nests. The availability of the relatively high amount of nest data and other spatial data, along with the tools to analyze and manipulate data from several sources within the GIS systems, were vital for the assessment (Livingston *et al.,* 1990).

4.1 Implication for ecological and biodiversity conservation

This nest-site assessment provided information on the location and composition of WBSE nests in the study area. Also, the occupation model provided a parsimonious prediction of the WBSE population in any area and this is vital

Table 3. Summary of results from nest-site selection analysis tests on White-bellied Sea-Eagle habitat parameters.

Parameter	Nest sites (mean)	Random sites (mean)	Result
Elevation	92±63	147±97	*t*-test, P=0.004*
Slope	22.5±7.0	18.6±9.4	*t*-test, P=0.038*
Aspect	Southern (35.3%), Western (29.4%), Northern (26.5%), Eastern (8.8%)	Tested against random distribution (34 ÷ 4)	χ^2 = 5.294, P=0.151**
RIX	18.2±4.4	17.8±3.7	*t*-test, P=0.654**
Distance to building	920±604	1002±462	*t*-test, P=0.461**
Distance to road	2083±661	1557±730	*t*-test, P=0.001*
Distance to water	219±157	821±638	*t*-test, P=0.0001*

for biodiversity conservation through population monitoring and control. The algorithm for the GIS study of the nest-site assessment was constructed and it was found to be useful for a periodic update of WBSE nest information. Therefore, this study provided an objective basis for strategic conservation and management of the WBSE. It is therefore recommended that this study be aggregated with similar studies from other areas and countries of the world to form a global database on WBSE nest characteristics.

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