

OCCUPANCY AND POPULATION ABUNDANCE OF TWO SERPENT-EAGLES (*SPILORNIS ELGINI* AND *S. CHEELA*) IN THE ANDAMAN ISLANDS, INDIA

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ABSTRACT.—We estimated occupancy and population abundance of the Andaman Serpent-Eagle (*Spilornis elgini*) and Crested Serpent-Eagle (*Spilornis cheela*) in the Andaman Islands, India. We divided the islands that were > 100 km² into a grid of 84 cells, of which we used 34 cells (5 km × 5 km each) for surveys of two populations in the districts of (1) the North and Middle Andaman Islands, and (2) the South Andaman Islands, which includes Little Andaman Island. We performed single-season, single-species occupancy modeling independently for both regions and single-season, two-species occupancy modeling for co-occupancy in the surveyed landscapes. The estimated abundance for the Andaman Serpent-Eagle and the Crested Serpent-Eagle was 4–5 and 7–8 individuals per 25 km², respectively. The Andaman Serpent-Eagle is commonly distributed in both regions and has a high detection probability (detection probability, P = 0.8). The Crested Serpent-Eagle is widely distributed in the South Andaman Islands with a low detection probability (P = 0.5). The single-season, two-species occupancy model showed that the endemic Andaman Serpent-Eagle occupied only 22% of the area and did not co-occur with the Crested Serpent-Eagle. It also indicates the possible avoidance or exclusion of the Crested Serpent-Eagle by the Andaman Serpent-Eagle. We encountered both serpent-eagles in all the identified habitat types. The Crested Serpent-Eagle's habitat use was not restricted to the coastal forests, as previously reported, and the Crested Serpent-Eagle is probably dominating the Andaman Serpent-Eagle in the co-occupied areas. We further conclude that the occupancy dynamics and competition for space between these two *Spilornis* species might significantly affect the distribution and population of the vulnerable and endemic Andaman Serpent-Eagle in the future.

KEY WORDS: *Andaman Serpent-Eagle*, *Spilornis elgini*; *Crested Serpent-Eagle*, *Spilornis cheela*; *habitat usage*; *occupancy modeling*; *raptor conservation*; *species interaction*.

PRESENCIA DE *SPILORNIS ELGINI* Y *S. CHEELA* EN LAS ISLAS ANDAMÁN, INDIA

RESUMEN.—Estimamos la presencia y la abundancia poblacional de *Spilornis elgini* y *S. cheela* en las Islas Andamán, India. Dividimos las islas mayores de 100 km² en una retícula de 84 celdas, de las que usamos 34 celdas (5 km × 5 km cada una) para los censos en (1) las Islas Andamán del Norte y Andamán del Centro, y (2) en las Islas Andamán del Sur. Desarrollamos un modelo de presencia de una sola temporada y especie de forma independiente para ambas regiones y un modelo de presencia de dos especies de una sola temporada para la presencia compartida en los paisajes estudiados. La abundancia estimada para *S. elgini* y *S. cheela* fue de 4–5 y 7–8 individuos cada 25 km², respectivamente. *S. elgini* se distribuye normalmente por ambas regiones y tiene una alta probabilidad de detección (probabilidad de detección, P = 0.8). *S. cheela* está ampliamente distribuida en la región sur de Andamán con una baja probabilidad de detección (P = 0.5). El modelo de presencia de una sola temporada y dos especies mostró que la especie endémica *S. elgini* ocupó solo 22% del área y no se superpuso con *S. cheela*. Esto también indica que *S. elgini* excluye o evita *S. cheela*. Encontramos a ambas especies en todos los tipos de hábitats identificados. El uso de hábitat de *S. cheela* no se restringió a los bosques costeros, como se reportó previamente, y *S. cheela* está probablemente dominando a *S. elgini* en las áreas que comparten. Además, concluimos que las dinámicas de ocupación y la competencia por el espacio entre estas dos especies de *Spilornis* podría afectar significativamente en el futuro la distribución y población de *S. elgini*, una especie endémica y vulnerable.

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INTRODUCTION

The tropics are home to 76% of the world's diurnal raptors (Bildstein et al. 1998). Of the 25 diurnal raptor genera, *Spilornis* is distributed primarily in the Indo-Malayan region (Thiollay 1994, Ferguson-Lees and Christie 2001, Walther et al. 2014). Among the 12 species of *Spilornis*, India harbors three species of serpent-eagles. The Andaman Serpent-Eagle (*Spilornis elgini*) is endemic to the Andaman Islands. The Great Nicobar Serpent-Eagle (*Spilornis klossi*) is limited to the Great Nicobar Island (Ferguson-Lees and Christie 2001, Winkler et al. 2020). The Crested Serpent-Eagle (*Spilornis cheela*) is widely distributed (Amadon 1974, Stepanyan 1992) with five subspecies in India: *S. c. cheela* and *S. c. melanotis* in forests of southern India, *S. c. burmanicus* in southern and eastern Assam, *S. c. cheela* in northern and western Assam, *S. c. minimus* (endemic) in the northern group of the Nicobar Islands, and *S. c. davisoni* (endemic) in the Andaman Islands (Ferguson-Lees and Christie 2001, Naoroji 2006, Rahmani 2012).

The Andaman Serpent-Eagle and the Crested Serpent-Eagle are ecologically separated in the Andaman Islands, because the Crested Serpent-Eagle is reported to inhabit only coastal forests (mangrove swamps, littoral forest, and others; Thiollay 1994, Davidar et al. 1996, Pande et al. 2007). However, the Andaman Serpent-Eagle occurs on almost all small (< 15 km²) and large islands (> 200 km²) of the Andaman group, and at all altitudes (0–756 masl) available on the islands (Davidar et al. 1996, Thiollay 1997, Ferguson-Lees and Christie 2001, Pande et al. 2007, Clark et al. 2017). The International Union for Conservation Network's status for the Andaman Serpent-Eagle was formerly Near Threatened, but has recently been changed to Vulnerable (BirdLife International 2020).

The global population of the endemic Andaman Serpent-Eagle is unknown, but has been estimated as 1000–4000 birds (BirdLife International 2020), a value that needs further confirmation (Rahmani 2012, Clark et al. 2017). One survey found 62 individual Andaman Serpent-Eagles on 25 islands (of 45 surveyed) in 1992 (Davidar et al. 1996). A later survey estimated the population as 1000–4000 mature individuals in all islands > 10 km² (Davidar et al. 2016). A similar survey recorded 100 individuals at 78 sites and found the greatest population density in the northern and middle regions of the Andaman Islands (Rajamannan 2011) and the lowest density on Little Andaman Island (Naoroji

2006). Conversely, the National Raptor Survey, the only study focused on diurnal raptors of the Andaman and Nicobar Islands, recorded the highest abundance of the Andaman Serpent-Eagle on South Andaman Island, which was the focal region of the survey (Samant et al. 1995).

Like other raptors worldwide, the serpent-eagles face threats posed by habitat loss and fragmentation, illegal logging and burning, hunting, and the use of pesticides in agriculture and to control insect vectors of human diseases (Bildstein et al. 1998, Nijman 2006). For many tropical raptors, habitat loss and fragmentation have contributed to population declines (Thiollay 1993, Bildstein et al. 1998), though thorough studies of population density and habitat use are still lacking. Endemic species are generally at greater risk due to their restricted distribution and limited resources. Moreover, in India, serpent-eagles have been little studied, and their habitat associations, distribution, and interactions are relatively unknown. Hence, in the current study, we aimed to estimate population abundance, distribution, and occupancy of the *Spilornis* species on the selected islands in the Andaman group. We also used occupancy models to characterize the dynamics of occurrence and the interaction patterns of Andaman Serpent-Eagles and Crested Serpent-Eagles.

METHODS

Study Area. The Andaman Islands are in the northeastern Indian Ocean, and are known as the southern extension of the Arakan-Yoma Mountain range. The islands are the peaks of a submerged continuous mountain ridge arching from Arakan-Yoma in the north to Sumatra in the south, between latitudes 6°45' and 13°41'N and longitudes 92°12' and 93°57'E (Fig. 1). These islands are in a geosynclinal basin, and the highly folded rocks are due to frequent tectonic movements (Kumar 1981). The Andaman and Nicobar Islands have tropical to a subtropical climate, with relative humidity of 79–89%, air temperatures between 21–33°C, and mean annual rainfall of 2870 mm (Kedzierski and Gargol 2016). The forests of the Andaman and Nicobar Islands are dominated by tropical evergreen forest (Champion and Seth 2005). For the purposes of this study, the Andaman group of islands was subdivided into two study areas that correspond to two administrative districts: (1) North and Middle Andaman District (3483 km²); and (2) South Andaman District, which includes South (2980 km²) and Little (707 km²) Andaman Islands (Fig. 2).

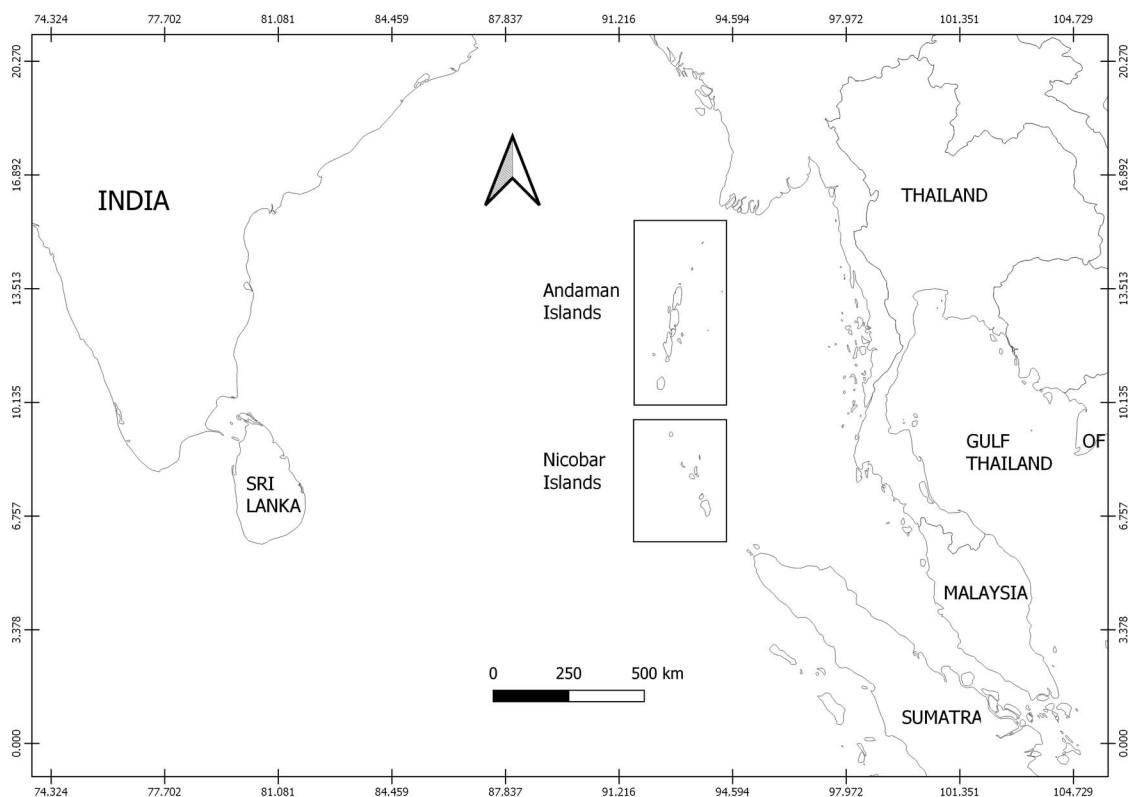


Figure 1. The Andaman Islands in the northeastern portion of the Indian Ocean.

Occupancy Survey. The study was conducted from March 2015 to November 2016, excluding the rainy days, which occurred primarily between June and September. Because smaller islands ($< 100 \text{ km}^2$) are uninhabited and cover comparatively smaller areas, we limited our study to islands $> 100 \text{ km}^2$. Based on an estimated home range size of $2\text{--}10 \text{ km}^2$ (Winkler et al. 2020), we chose a survey cell size of 25 km^2 , and used QGIS software (QGIS 2009) to create a grid of cells (each measuring $5 \text{ km} \times 5 \text{ km}$) over the selected islands. Our initial number of cells mapped was 84. We removed restricted areas from our list of available sites and then randomly chose approximately 10% of the remaining area to survey (distributed among 34 cells; Fig. 2; Sutherland et al. 2004).

To estimate species' abundance and distribution, we used open-width line transects (Sutherland et al. 2004) of various lengths between 100 and 1420 m. Transects were arranged to diagonally connect opposite corners of each cell, and the number and length of transects placed in each cell were based on

accessibility. Overall, in 77 d of field surveys, we sampled 284 transects covering about 391 km, distributed among 34 cells.

We walked each transect three times within a week for repetitive surveys; surveys were conducted from 0800 to 1300 H. To identify raptors during the survey, we used 8×40 Nikon binoculars. We documented information including raptor species, group size, activity (perched, flying, or soaring), the habitat type where Crested Serpent-Eagles and Andaman Serpent-Eagles were observed, and Global Positioning System (GPS) coordinates of the position.

Following Champion and Seth (2005), we classified the habitat in the survey area as one of six distinct types: (1) deciduous forest (irregular canopy of predominantly deciduous trees $> 40 \text{ m}$ tall, mostly very large and heavily buttressed); (2) evergreen forests (lofty, dense forests $> 45 \text{ m}$ tall, characterized by a large number of evergreen tree species); (3) semi-evergreen forest (luxuriant forest with many giant trees of deciduous and evergreen species and many vines; bamboos may or may not be

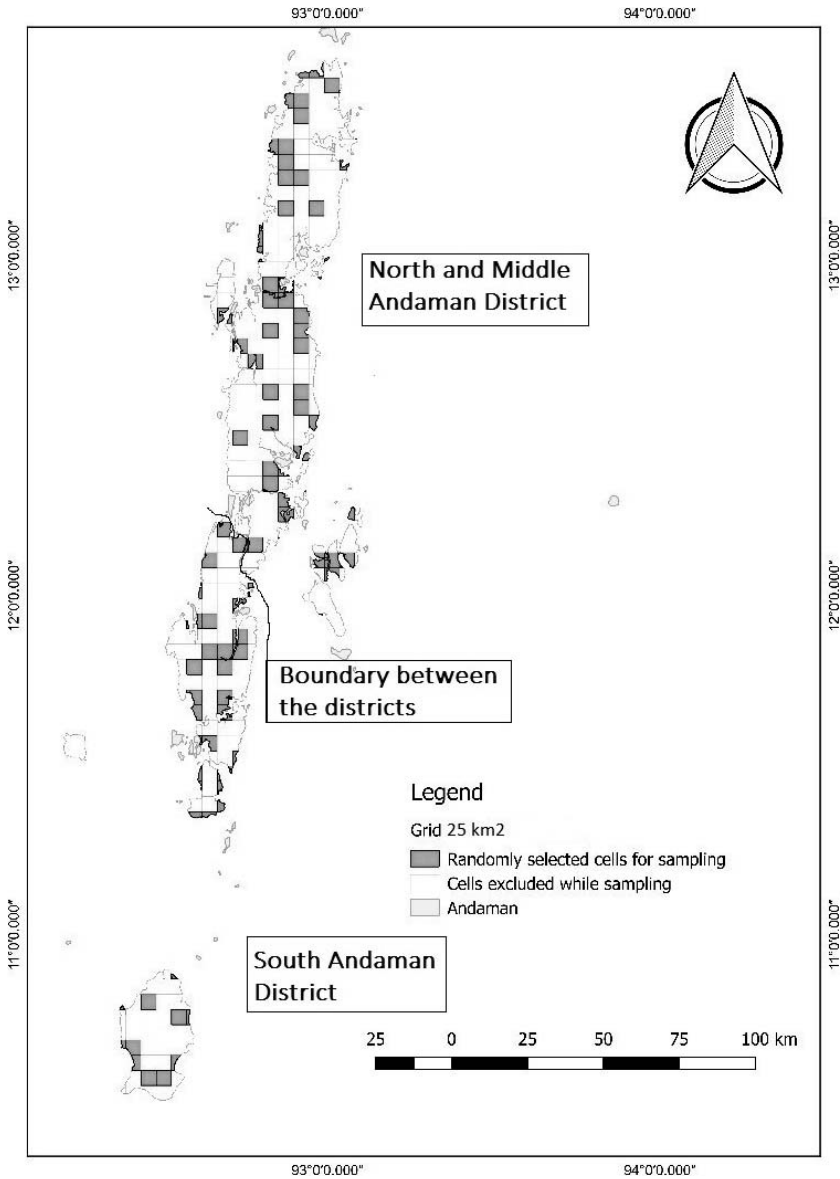


Figure 2. Grid-based (25 km²) sampling scheme for line transect survey of raptors in the study areas of North and Middle Andaman, and South Andaman Districts.

present); (4) coastal forests including mangrove forest (typically a closed evergreen forest of moderate height composed of trees specially adapted to survive on tidal mud), littoral forest, and swamp forest (typically tall evergreen trees with light foliage, on sandy beaches or dunes); (5) plantations (various monoculture patches such as teak [*Tectona grandis*]); and (6) agricultural land (primarily rice fields).

We also covered approximately 848 km off transects during random walks. Observations during these random walks were used to more fully characterize the community of raptors existing in the islands and these data were not formally analyzed.

Data Analysis. *Occupancy modeling.* For preliminary analyses of data, we used Microsoft Excel software.

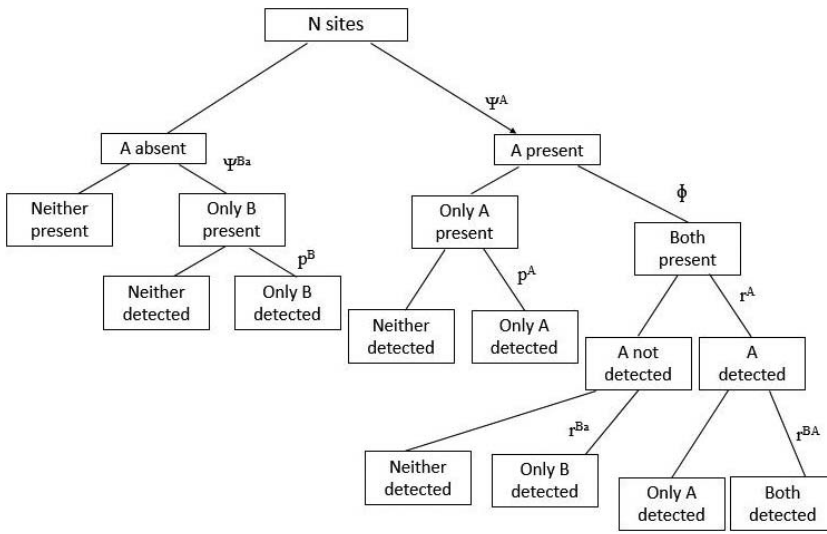


Figure 3. Hierarchical representation of the single-season, two-species occupancy model (adapted from Richmond et al. 2010).

Further, we used the XLSTAT ver. 2020.2.1 (Addinsoft 2020) and PRESENCE (Hines 2006) ver.12.7 software for detailed analyses and modeling. QGIS software (QGIS 2009) was also used to map Andaman Serpent-Eagle and Crested Serpent-Eagle distribution based on the presence locations. Further, we used the serpent-eagles’ data that represented presence/absence in the cell for the occupancy modeling. Occupancy models are used to estimate the probability of occurrence of a species among sampled sites. We used a predefined single-season, single-species occupancy model for data analysis and anticipated a detection probability (P) value of < 1 for serpent-eagles (MacKenzie et al. 2002). This occupancy model has stochastic processes that determine whether the target species will be detected at a site. The model also assumes that a site’s occupancy status (occupied or unoccupied) does not change between surveys (MacKenzie et al. 2002).

Here, a season is defined as a relevant time period (year in present case) during which the presence or absence of the species in an area is recorded. The estimates of occupancy and detection probability were obtained separately for North and Middle Andaman, and South Andaman Islands, and we also estimated the species’ occupancy for both study areas combined. The single-season, two-species occupancy model by Richmond et al. (2010) is a parameterization of MacKenzie et al. (2004) to understand the species’ co-occurrence patterns. It

is represented as a hierarchical tree (Fig. 3) of conditional occupancy and detection probabilities, where species A is assumed to be dominant, and species B is considered subordinate. The species interaction factor (SIF, ϕ) derived from the two-species model provides a measure of interaction. It allows robust inferences to be made about co-occurrence patterns (Richmond et al. 2010). If the two species occur independently, then the SIF (ϕ) = 1. An SIF < 1 indicates that species B is less likely to co-occur with species A (i.e., avoidance), whereas SIF > 1 shows that species B is more likely to co-occur with species A (i.e., aggregation). SIF was calculated as:

$$\phi = \frac{\Psi^A \Psi^{BA}}{\Psi^A (\Psi^A \Psi^{BA} + (1 - \Psi^A) \Psi^{Ba})}$$

where Ψ^A = probability of occupancy for species A; Ψ^{BA} = probability of occupancy for species B, given species A is present; Ψ^{Ba} = probability of occupancy for species B, given species A is absent. Because the Crested Serpent-Eagle (species B) is more common and has the comparatively larger body size, it was assumed to be dominant, and species A (Andaman Serpent-Eagle) was considered subordinate.

We collected data during 77 effort days, from 34 cells out of the total 84 cells mapped. Data were put in binary format (presence [1] and absence [0]), using the ψ^A , ψ^B , ϕ , p^A , p^B , r^A , r^B , δ (Table 1)

Table 1. List of parameters and their definitions used in the single-season, two-species occupancy model (ψ^A , ψ^B , ϕ , p^A , p^B , r^A , r^B , δ) in the current study, where ASE = Andaman Serpent-Eagle and CSE = Crested Serpent-Eagle.

PARAMETER NUMBER	PARAMETER AND DEFINITION	ESTIMATE (SE)	95% CONFIDENCE INTERVAL
1	Ψ^A : Probability of occupancy for ASE, regardless of the occupancy status of CSE	0.22 (0.00)	0.22–0.22
2	Ψ^{Ba} : Probability of occupancy for CSE, regardless of the occupancy status of ASE	0.78 (0.00)	0.78–0.78
3	ϕ : Species Interaction Factor likelihood ratio of co-occurrence	0.03 (0.00)	0.03–0.03
4	p^A : Probability of detecting species ASE during the survey, given only species CSE is present	0.04 (0.01)	0.02–0.07
5	p^B : Probability of detecting CSE during the survey, given only species CSE is present	0.03 (0.00)	0.02–0.05
6	r^A : Probability of detecting ASE, but not CSE, during the survey, given both species are present	0.02 (0.01)	0.01–0.05
7	r^B : Probability of detecting species CSE, but not ASE, during the survey, given both species are present	0.02 (0.01)	0.01–0.05
8	Delta	3.55 (3.22)	0.60–21.06

parameterization to fit the data set. Further, we used Student’s *t*-tests to analyze the number of observations of the two species by habitat.

RESULTS

Raptors in the Andaman Islands. During raptor surveys of the Andaman Islands, we observed 194 individuals while we were on transects and 108 raptors while off transects. We encountered seven different species of diurnal raptors. During the survey, the Andaman Serpent-Eagle was the most often observed species, followed in order by the Crested Serpent-Eagle, the Changeable Hawk-Eagle (*Nisaetus cirrhatus*), the Black Baza (*Aviceda leucophotes*), the White-bellied Sea-Eagle (*Haliaeetus leucogaster*), Oriental Honey-Buzzard (*Pernis ptilorhyn-*

chus), and Brahminy Kite (*Haliastur indus*; Fig. 4). The last three species were excluded from further analysis because the first four species mentioned represented more than 95% of the observations.

Serpent-Eagles. Based on the naïve occupancy ($\Psi = 0.77$), we estimated that the two serpent-eagles together occupy 77% of the area in the islands (detection probability, $P = 0.88 \pm 4.54$ [SD]). This statistic indicates that the Andaman Serpent-Eagle and the Crested Serpent-Eagle are widespread (Fig. 5) and are the most common raptors in the tropical islands of India.

Andaman Serpent-Eagle. The occupancy of the Andaman Serpent-Eagle did not vary ($\Psi = 0.83$) much between North and Middle Andaman, and South Andaman. However, the detection probability

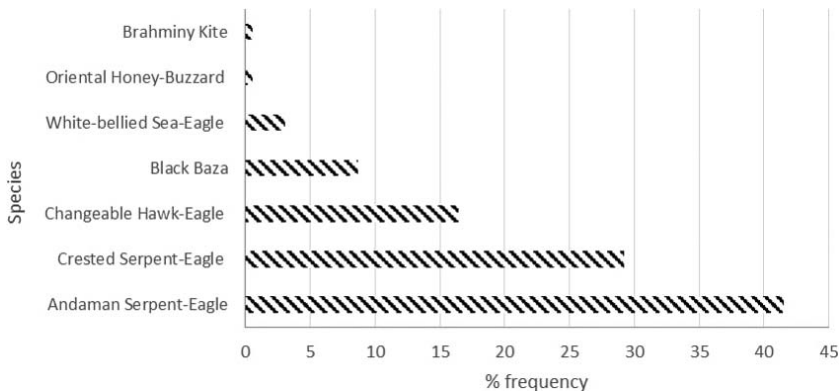


Figure 4. Encounter frequency of raptors by species in the Andaman Islands in 2015 and 2016.

Table 2. Detections of the Andaman Serpent-Eagle (ASE) and Crested Serpent-Eagle (CSE) in various habitats of the Andaman Islands.

HABITAT NUMBER	HABITAT TYPE	DETECTIONS (%)					
		NORTH & MIDDLE ANDAMAN		SOUTH ANDAMAN		ANDAMAN ISLANDS	
		ASE	CSE	ASE	CSE	ASE	CSE
1	Deciduous forest	33.4	38.46	25	30.76	29.5	34.61
2	Evergreen forest	16.7	0	15	7.69	15.9	3.84
3	Semi-evergreen forest	16.7	7.69	0	7.69	9.0	7.69
4	Coastal forest	16.7	15.38	20	30.76	18.2	23.07
5	Plantation	16.7	7.69	25	15.38	20.4	11.53
6	Agricultural land	0	30.76	15	0	7.0	15.38

of the species in South Andaman (0.88 ± 0.16 [SD]) was slightly higher than in North and Middle Andaman (0.84 ± 0.15 [SD]); this difference resulted in variation in the estimated abundance of the species in North and Middle Andaman vs. South Andaman (4.8 vs 4.0 individuals per cell, respectively). Accordingly, the estimated population of Andaman Serpent-Eagles in North and Middle Andaman was up to 613 individuals, and 524 individuals in South Andaman.

Crested Serpent-Eagle. The naïve occupancy of the Crested Serpent-Eagle was high ($\Psi = 0.83 \pm 0.15$ [SD]) throughout the Andaman Islands, indicating that the species was common and occupied more than 80% of the total area surveyed. However, the species' detection probability ($P = 0.03 \pm 0.01$ [SD]) was much lower than that of the Andaman Serpent-Eagle. Based on all data together, the estimated abundance of Crested Serpent-Eagle was 7.1 individuals per 25 km²-cell; estimated area used averaged 3.5 km² for each Crested Serpent-Eagle.

Like the Andaman Serpent-Eagle, the Crested Serpent-Eagle had the same naïve occupancy ($\Psi = 0.83$) whether the data for North and Middle Andaman, and South Andaman were analyzed separately or together. However, the probability of detecting the species in South Andaman ($P = 0.40 \pm 0.91$) differed somewhat from that of North and Middle Andaman ($P = 0.54 \pm 0.18$ SD). Estimated abundance of the species was 6.5 individuals/cell in North and Middle Andaman, and 7.6 individuals/cell in South Andaman. We estimated the total population of Crested Serpent-Eagles as 989 and 846 individuals in North and Middle Andaman, and South Andaman, respectively.

Co-occupancy of Serpent-Eagles. We used the predefined model of a single-season two-species occupancy to understand the co-occupancy of Andaman

Serpent-Eagles and Crested Serpent-Eagles. Our model estimated the naïve occupancy as 0.22 for the Andaman Serpent-Eagle and 0.78 for the Crested Serpent-Eagle across the Andaman Islands (Table 1). In North and Middle Andaman, the two eagles were encountered in deciduous forest, semi-evergreen forest, coastal forest, and plantations (Table 2). In South Andaman, the two eagles were encountered in deciduous forest, evergreen forest, coastal forest, and plantations (Table 2). When we assessed competition between these two species (following MacKenzie et al. 2004), we estimated an SIF value of 0.03, which suggested that both species co-occur less frequently than when distributed independently (e.g., possibly exclusion or avoidance).

Habitat. The Andaman Serpent-Eagle and Crested Serpent-Eagle occupied all six habitats in the Andaman Islands (Table 2). The Student *t*-test revealed that the distribution of Andaman Serpent-Eagle and Crested Serpent-Eagle in the six different habitats did not differ significantly ($P < 0.05$) from each other when analyzed between survey areas or when data was pooled for both survey areas.

Throughout the Andaman Islands, the Crested Serpent-Eagle's occurrence was higher in the deciduous forest (34.6%) than in all other habitats. We made the fewest observations of this species in the evergreen forest. For the survey areas considered separately, the occurrence of the Andaman Serpent-Eagle in North and Middle Andaman was highest in deciduous forest, and equal in evergreen forest, semi-evergreen forest, coastal forest, and plantations, but the species was absent from agricultural land. However, in South Andaman, the species was encountered in agricultural lands also (Table 2).

The Crested Serpent-Eagle, like the Andaman Serpent-Eagle, was mostly observed in deciduous

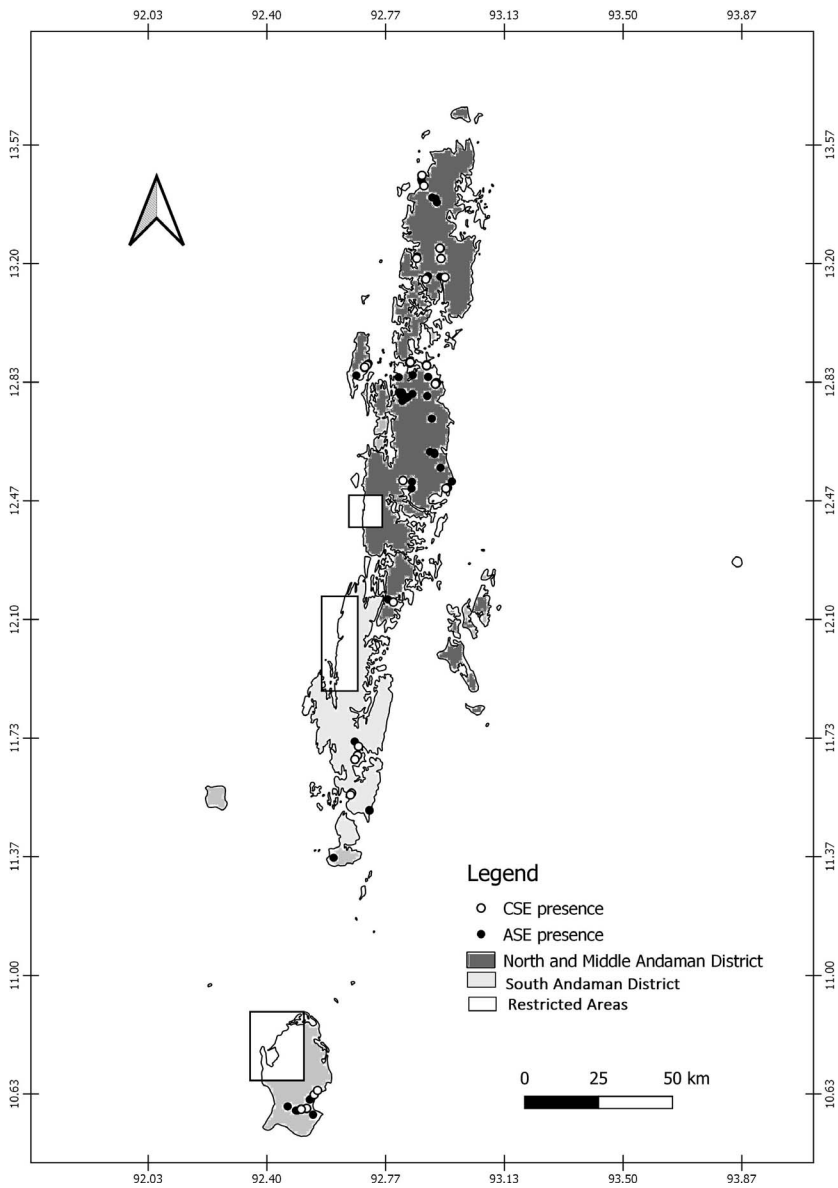


Figure 5. Distribution of Andaman Serpent-Eagle and Crested Serpent-Eagle in the Andaman Islands. Note: restricted areas depicted on the map show approximate boundaries.

forest throughout the Andaman Islands, followed by the coastal forests, agricultural lands, plantation, and semi-evergreen forest. Unlike the Andaman Serpent-Eagle, the Crested Serpent-Eagle had the fewest encounters in the evergreen forest (3.8%). For the survey areas considered separately, the occurrence of the Crested Serpent-Eagle in North and Middle Andaman was highest in the deciduous

forests and agricultural lands, with no occupancy of the evergreen forests. In South Andaman, the species was seen more in deciduous forest and coastal forests, but not in agricultural lands.

DISCUSSION

The Andaman Islands are inhabited by 22 species of diurnal raptors (Manchi and Patel 2017). Howev-

er, during the present study, we encountered only seven species while surveying transects. Although our study was the first systematic raptor-focused survey, our results support earlier general avian surveys (Butler 1899, Davidar et al. 1996, Vijayan 2009, Rajamamman 2011, Koparde and Manchi 2013) that described the Andaman Serpent-Eagle as the most common raptor species in the Andaman Islands. The commonness of the Andaman Serpent-Eagle might be because the species is derived from ancient lineages, whereas the other non-endemic species presumably descended from a more recent second wave of colonists that have been restricted by competition (Ferguson-Lees and Christie 1998). Andaman Serpent-Eagles and Crested Serpent-Eagles occupy > 80% of the survey area. This may reflect the more continuous and less disturbed forest in North and Middle Andaman (vs. South Andaman), which provides suitable conditions for these species (Thiollay 1997). We estimated the occupancy-abundance of the Andaman Serpent-Eagle as 4–5 individuals/25 km², which is low compared to the estimated abundance of 1–2 individuals/km² by Davidar (1996) but similar to the estimation of 2 individuals/13 km² by Ferguson-Lees and Christie (2001). The Crested Serpent-Eagle also tends to occupy 83% of the sampled area, which indicates that Crested Serpent-Eagles and Andaman Serpent-Eagles are sympatric species here. The overall abundance of Crested Serpent-Eagle in the Andaman Islands is 7–8 individuals in a 25 km² area, slightly more than the endemic Andaman Serpent-Eagle. Hence, based on the total sampled area (850 km²), we predict populations of 1137 Andaman Serpent-Eagle individuals and 1835 Crested Serpent-Eagle individuals in the Andaman Islands. The differences in the estimated populations between our survey and prior ones likely result from methodological differences in the surveys and data analyses (e.g., we used occupancy analysis whereas Davidar [1996] did not). Also, Davidar (1996) surveyed the small islands but we did not.

Population density for Crested Serpent-Eagles was previously reported as 2.69 (i.e., 2–3 birds/km² in Taiwan [Walther 2014] and 0.42 birds/km² for several species of raptors in southern India [Thiollay 1993]). However, the current study estimated the highest density of Crested Serpent-Eagle reported to date. Such high density might have resulted from the insular syndrome. Alternatively, a higher raptor density and possibly broader habitat niches may compensate for lower raptor species richness on

islands (Walther 2014). Compared to Taiwan, the syndrome might be a little more prominent in the Andaman Islands and smaller islands. Discussions with local people living in and around the forested area suggest that the Andaman Serpent-Eagle's population is declining (Birdlife International 2020).

The Andaman Serpent-Eagle and the Crested Serpent-Eagle occupied all six habitats in the Andaman Islands, though more were observed in deciduous forest and fewer in evergreen and semi-evergreen forests, with some slight variation between North and Middle Andaman vs. South Andaman (Table 2). The Crested Serpent-Eagle was encountered more often in deciduous and coastal forests. In habitat where the Crested Serpent-Eagle occurs commonly, the Andaman Serpent-Eagle is less common and vice versa, except in deciduous forest. The availability of the continuous less-disturbed forest in the North and Middle Andaman region may allow Andaman Serpent-Eagles to use their natural habitat and stay away from agricultural lands. Conversely, because the forest in the South Andaman region is more fragmented and disturbed than in North and Middle Andaman (Department of Environment and Forests 2013), Andaman Serpent-Eagles may be forced to use open agricultural lands, a behavior that might be an indicator of rapid habitat loss. These patterns of habitat use can result in increased competition between Andaman Serpent-Eagles and Crested Serpent-Eagles for resources. These two sympatric *Spilornis* species compete for the same prey, including frogs, rodents, reptiles, birds, crabs, and eel fishes (Ferguson-Lees and Christie 2001). This niche overlap might result in interspecific competition, in which the Crested Serpent-Eagle (47–66 cm, Grimmett et al. 2011) likely dominates the Andaman Serpent-Eagle (51–59 cm, Grimmett et al. 2011). Though body size is an essential factor affecting interspecific competition and structuring ecological communities (Leyequién et al. 2006), its influence on interactions among tropical serpent-eagles has been little studied. Competition with the Crested Serpent-Eagle could potentially result in decline of the endemic Andaman Serpent-Eagle population, as the co-occurrence of these two sympatric species is infrequent (SIF = 0.03). The low SIF value suggests that the Andaman Serpent-Eagle might be excluded from or is actively avoiding the Crested Serpent-Eagle because of the latter's dominance in the co-occupied landscape.

Studies of population density and habitat use are lacking for many tropical raptors, including some serpent-eagles. Based on our study, we suggest that the Andaman Serpent-Eagle's patchy distribution results from the ecological competition with the sympatric Crested Serpent-Eagle, and this has the potential to drive population decline. We recommend periodic population monitoring surveys and further investigation to understand the species' interactions. The Andaman Serpent-Eagle nests exclusively in the coastal forests (Naoraji 2006) but the dominance of the Crested Serpent-Eagle in the coastal forests according to our study suggests that competition for resources could occur and could influence breeding success. Understanding the competition among different raptors breeding in the coastal forests is essential for better species management. We also need to study the foraging and breeding ranges of the Andaman Serpent-Eagle to better conserve the species and manage its habitat, particularly on the uninhabited islands where these birds tend to breed. Conservation measures to avoid further forest fragmentation and coastal forest destruction on the islands are urgently needed, especially in South Andaman where rapid urbanization may occur.

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