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Habitat Suitability of Eastern Sarus Crane (*Antigone Antigone sharpii*) in Ayeyarwady Delta, the Union of Myanmar

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Abstract: The eastern sarus crane (*Antigone antigone sharpii*; ESC) is a species related to wetland ecosystems in Southeast Asia. The habitat suitability of the eastern sarus crane in Ayeyarwady Delta was surveyed between March 2018 and February 2019. Eastern sarus cranes were found at 73 locations and Maximum Entropy (MaxEnt) was used to classify the habitat suitability among different seasons. MaxEnt showed the largest total area of highly suitable habitat was in the winter season (2450 km^2, AUC = 0.968), while the least amount of available suitable habitat was evident during the rainy season (1028.7 km^2, AUC = 0.979). A difference in the assessment of home range areas using the Minimum Convex Polygon (95% MPC) and the Kernel Density Estimate (95% KDE) was found. The total area in the winter season was highest at 95% KDE (13,839.5 km^2) and lowest in the rainy season (1238.1 km^2), while 95% MCP was highest in the rainy season (7892.9 km^2) and lowest in the summer season (7014.6 km^2). Analysis of the environmental parameters indicated that low temperature in the summer season and high precipitation in the rainy season and winter season are important for ESC habitat suitability. These climatic parameters were important for ESC in all seasons (AUC > 0.9). Important parameters influencing ESC habitat suitability were elevation, slope, distance to road in the summer season, elevation, distance to road and village and slope in the rainy season, and elevation and slope in the winter season. Annual precipitation was the main parameter influencing ESC habitat suitability in both summer and winter, while in the rainy season it was mean diurnal range (>90%).

Keywords: Ayeyarwady Delta; bird habitat preference; climatic parameters; eastern sarus crane; MaxEnt

Citation: Latt, T.N.; Chaiyarat, R.; Choowaew, S.; Thongtip, N.; Stewart, T.N. Habitat Suitability of Eastern Sarus Crane (*Antigone Antigone sharpii*) in Ayeyarwady Delta, the Union of Myanmar. *Diversity* **2022**, *14*, 1076. https://doi.org/10.3390/d14121076

Academic Editors: Michel Baguette and Huw Lloyd

Received: 31 August 2022
Accepted: 29 November 2022
Published: 6 December 2022

1. Introduction

Habitat degradation remains one of the greatest threats to the survival of wild animal populations. It is, therefore, critical to gain a better understanding of the degree of habitat suitability and diverse habitat use by threatened bird populations for their conservation, particularly in highly heterogeneous landscapes [1,2]. Information on the diverse habitat use of birds within landscapes is critical for avian ecology and conservation [3]. Climate is a key parameter of habitat suitability, as it influences the structure and composition of plant and animal communities. Variability in climate drives many aspects of species ecology either directly or indirectly through changes in habitat type and structure [1,4,5]. Many crane species (family—Gruidae) are considered to be globally threatened, and the loss of their preferred natural wetland habitat threatens the extent and degree of habitat suitability. For example, populations of red-crowned cranes (*Grus japonensis*) in the Yancheng National Nature Reserve, China are threatened by the conversion of wetlands to cropland and aquaculture [6,7]. The eastern sarus crane (*Antigone antigone sharpii*; ESC) is currently listed

as vulnerable on the IUCN Red List of Threatened Species, and the total population of the three subspecies is estimated to be between 13,000 and 15,000 individuals [8].

The ESC is distributed in the Union of Myanmar, Thailand (where it has been reintroduced), Cambodia, southern Laos (PDR) and Vietnam [9–11], but the GBIF Secretariat reports occurrences only in Cambodia and Thailand [12]. The ESC is almost completely dependent on natural wetlands in both the wet and dry season [13]. Breeding ESC pairs seem to prefer nest site areas located along the borders between man-made paddy fields, or along borders between paddies and uncultivated fields [14]. The trends in the Mekong River and Myanmar populations are difficult to determine, but are presumed to be declining [15]. In Vietnam, the ESC population became extinct following the destruction of reed vegetation habitat in a region of the Mekong Delta known as the Plain of Reeds by draining and burning during the Vietnam War. In addition, there are reports of cranes elsewhere in their range being persecuted for food or for sport. Although cranes have returned to the Plain of Reeds, the high rate of human population growth in this area has led to rapid and extensive conversion of the wetlands to intensive rice production. At the regional scale, human population growth and the restoration of peace in the region have increased pressures to pursue large development projects within the Mekong River system, with profound implications for the wetlands associated with the river [16].

The Ayeyarwady Region (~82,256 km^2) is widely believed to be one of the most important areas for ESC conservation in Myanmar. To date, little is known about the degree of habitat suitability, since few data exist regarding crane home range and the key environmental parameters that influence ESC habitat preferences, as these have not been assessed previously. Identifying the key environmental parameters (e.g., climatic, land use, anthropogenic infrastructure such as roads, water sources, slope, and elevation) associated with suitable habitat areas is therefore important for future conservation planning for ESC populations [17]. The development of species distribution models (SDMs) has proven critical for identifying, characterizing, and predicting animal habitats at the scales that are more relevant for on-ground biodiversity conservation planning [18], but SDMs have, to date, not yet been used to assess habitat preferences and suitability for ESC populations. In this study, we aimed to identify the suitable habitat range and the key environmental parameters that influenced suitable habitat areas for ESC in the Ayeyarwady Delta. This information can help in prioritizing areas as conservation sites where Myanmar's eastern sarus crane population can be effectively restored, maintained, and protected.

2. Materials and Methods

2.1. Study Area

The Ayeyarwady Delta is located in the southern part of the Union of Myanmar and consists of three regions with a total of 85,540 km^2 of land at an elevation range between 0 and 1900 m (amsl) (Figure 1). The total wetland area is 57,574 km^2 [19]. A previous survey of the ESC population between June 2017 and May 2018 estimated the population to be 299 individuals, with 78 active nests also recorded [20]. Geographically, the delta is bordered by Rakhine State on the northwest, the Bay of Bengal in the west, and the Andaman Sea in the south (Myanmar Information Management [21]). The area contains more than 30 species of endangered flora and fauna, including the Ayeyarwady dolphin (*Orcaella brevirostris*), estuarine crocodile (*Crocodylus porosus*), mangrove terrapin (*Batagur baska*), ESC, and spoon-billed sandpiper (*Eurynorhynchus pygmeus*). The three types of forest found in the Ayeyarwady Delta are tropical evergreen forest, mixed deciduous forest, and mangrove forest [22].

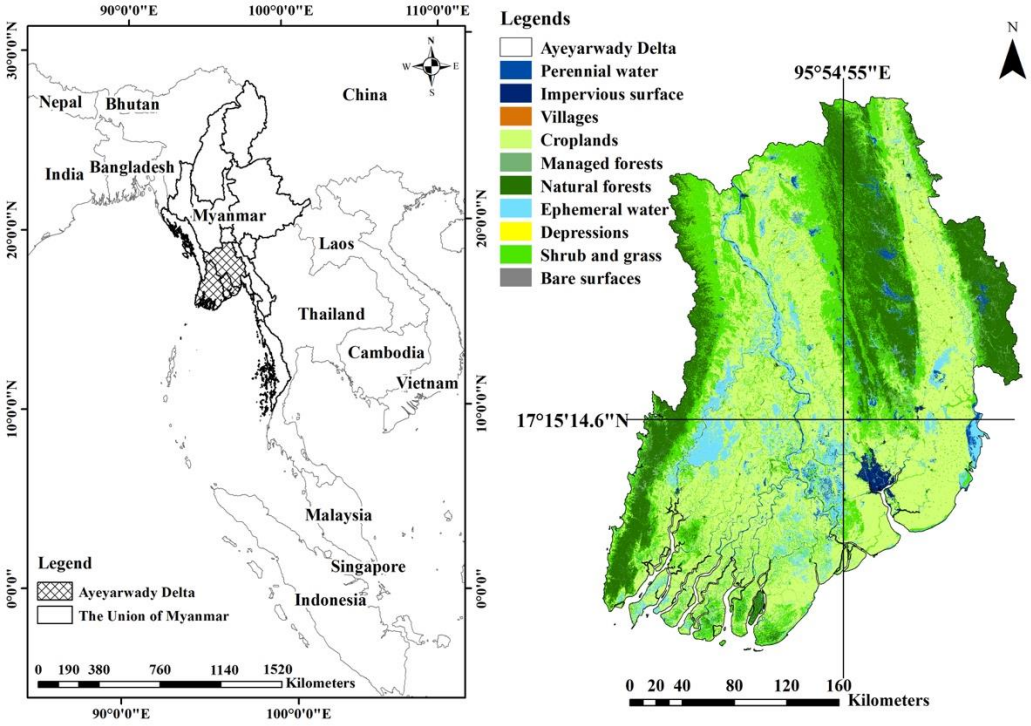


Figure 1. Land use and land cover within the study area in Ayeyarwady Delta, the Union of Myanmar.

2.2. Data Collection

A preliminary survey was carried out in the study area in partnership with consultation with local leaders to prepare a local map marking survey routes and zones to obtain a complete coverage of the distribution pattern of ESC. The feasibility areas, comprising the townships of the Ayeyarwady Region (10 townships in Yangon Region, and four townships in Bago Region) were selected, based on a previous study [14–16,23,24]. The locations of ESC in the field were recorded using a hand-held GPS (Garmin e-Trex 20, Schaffhausen, Switzerland) reported by local residents during the rainy season, winter, and summer (Supplementary Table S1). The climatic parameters used to create the distribution models (Figure 2) were based on the work of Fick and Hijmans [25].

2.3. Land Use and Land Cover Identification

Land use and land cover (LULC) classifications in the study area were assigned to identify habitat suitability. In this study, LULC polygons were drawn and analyzed using Landsat 8 paths 132 and 133, as well as rows 47, 48, and 49 in January 2019. Those images were ordered from the United States Geological Survey, Earth Resources Observation, and Science Center.

Supervised classification was applied to seven LULC habitat types in this study: wetland, water body (lake, river, creek, or reservoir), reservoir, settlement, grassland area, forest area, cropland, and barren area. The wetland or mixed wetlands grass species and aquatic vegetation were usually established as seasonal or perennial along the boundary of the croplands [26]. Water bodies included floodplain lakes of the large river systems, rivers, creeks, and other linear water bodies. Settlement land use included cities, villages, strip developments along highways, transportation, power, communications facilities, areas such as those occupied by mills, factories and commercial complexes, and institutions [27]. Grasslands were primarily comprised of herbaceous spermatophytes of grasses (family—Poaceae), as well as grass-like vegetation, particularly sedge (family—Cyperaceae). Forests were defined as areas that had a tree–crown areal density greater than 10%, stocked with trees capable of producing timber or other wood products. Croplands were areas used for growing crops in the growing season and growing grasses and legumes in other seasons.

Barren areas had limited ability to support life, and less than one-third of the area had plants or other cover.

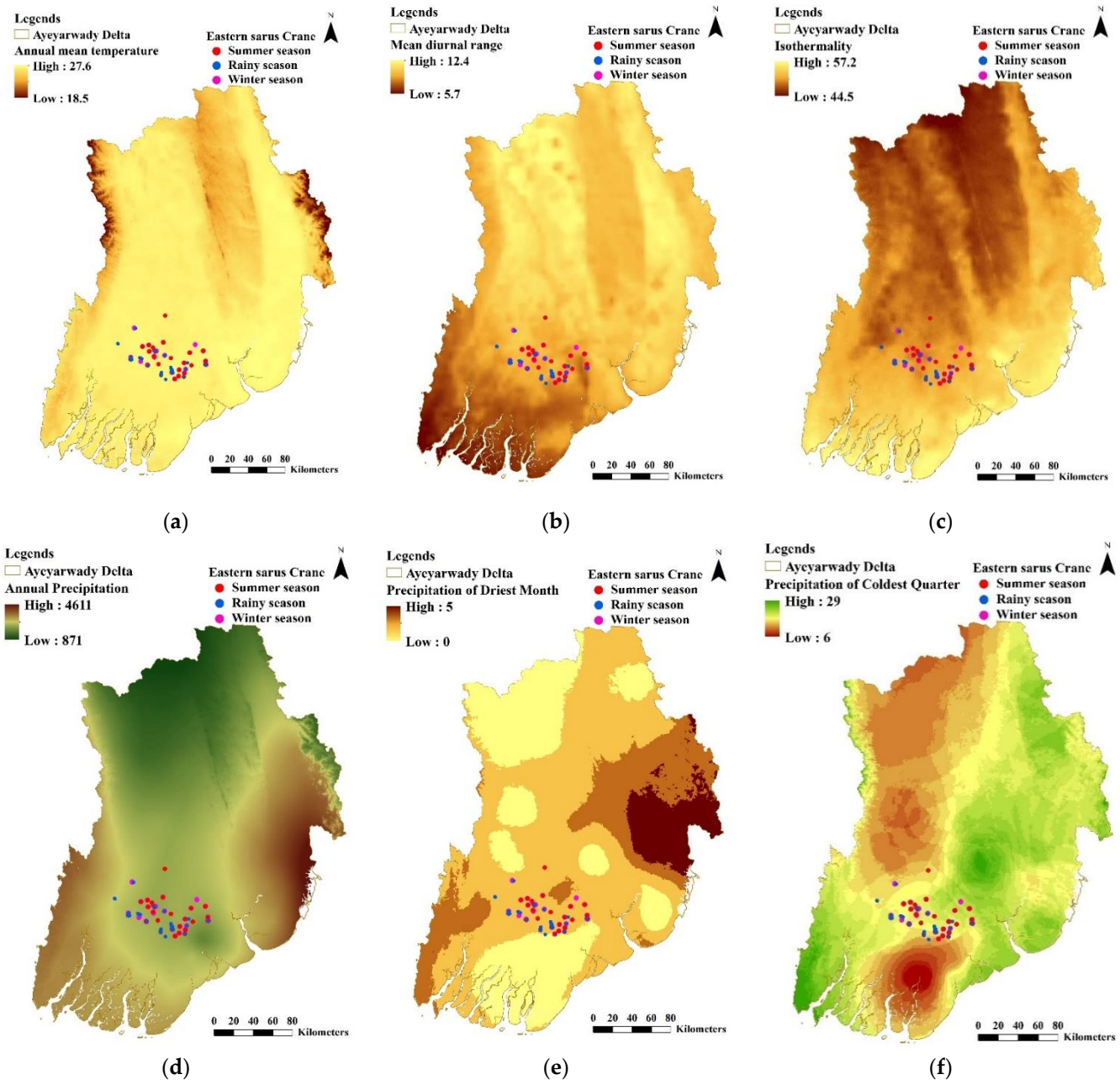


Figure 2. Climatic parameters used to create the distribution model of eastern sarus crane (*Antigone antigone sharpii*) in Ayeyarwady Delta, the Union of Myanmar; (**a**) annual mean temperature, (**b**) mean diurnal range, (**c**) isothermality, (**d**) annual precipitation, (**e**) precipitation of driest month, and (**f**) precipitation of coldest quarter.

2.4. Environmental Variables and Species Occurrence Data

The seven LULC types (wetland, grassland, forest, cropland, water body, barren, and settlement) were used in the MaxEnt species distribution model. Although ESCs are tolerant of people and depend on natural wetland, they are rarely found near settlement areas [14].

An ecological model was designed using a set of suitable features, such as environmental parameters and species geographical distribution, and fit with five attribute types: linear,

quadratic, hinge, product, and threshold [28]. Important parameters used in the model were elevation (m), land cover (km^2) (perennial water, impervious surface, villages, croplands, managed forests, natural forest, ephemeral water, depressions, shrub and grassland, and bare surfaces), distance to river (m), road (m), village (m), and slope (degree) (Figure 3). The predictors include the following climatic datasets: annual mean temperature (°C), mean diurnal range (hours), isothermality (°C), annual precipitation (mm), precipitation of driest month (mm), and precipitation of coldest quarter (mm) (Figure 2 and Supplementary Table S2). The Pearson correlation coefficient *r* statistic was applied to compare between the pairs of environmental parameters, and autocorrelation was searched for at significance levels of 0.05 [29], and then only parameters that did not have the autocorrelation were selected to avoid overfitting. Elementary data and layers were prepared from fieldwork and data available from the appropriate organizations. Digital maps were converted to raster maps in ArcGIS (version 10.4.1).

2.5. Eastern Sarus Crane Suitable Habitat

Maximum entropy (MaxEnt) creates better models from small sample sizes compared to other modeling methods [29–32]. MaxEnt uses presence-only data to predict the distribution of a species [33]. The estimation of species distribution probability is most accurate when the species occurrence is closest to uniform environmental limitation [34]. In this study, the four habitat categories were divided into highly (>75–100), moderately (>50–75), low (>25–50) and unsuitable habitats (<25). The anthropogenic parameters chosen as one of the classification units was settlement area because farmers living at the paddies and linseed fields were within 500 m of eastern sarus crane nests found in some of the study areas. The predictors included climatic datasets that were downloaded from related websites [35].

Biophysical variable data were acquired from the digital elevation model (DEM) [36]. Classifications were assigned using a combination of field data and data from Google Earth. Mapping preparation using ArcGIS (version 10.4.1) resampled the variables to 30 m high spatial resolution, and pixel type was assigned an integer to match the grid size of other environmental layers. The spatial resolution of all environmental layers was 30 m × 30 m.

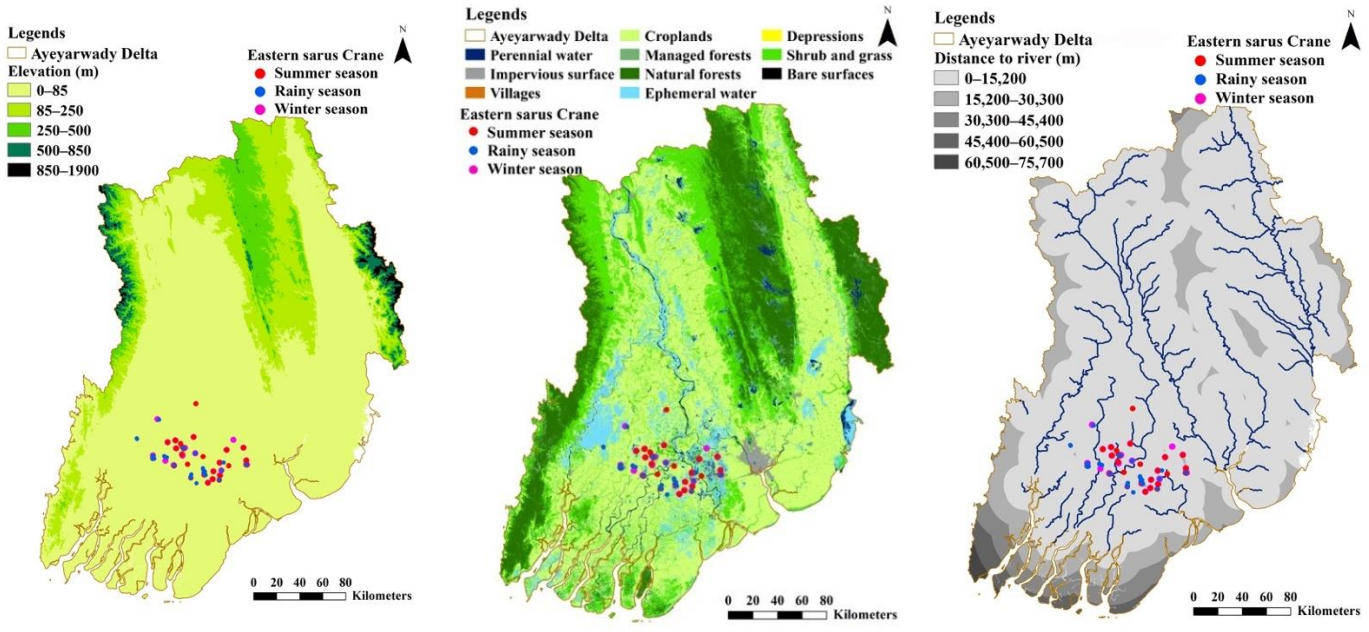


Figure 3. *Cont.*

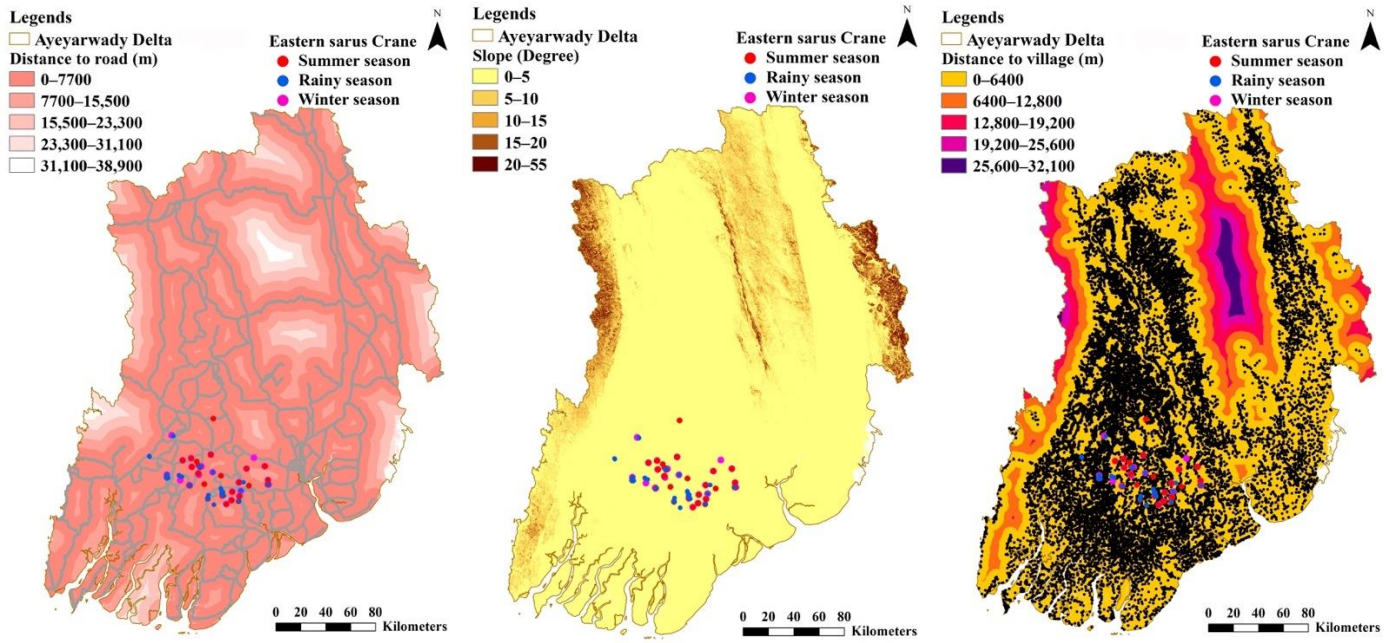


Figure 3. Geographic parameters used to create the distribution model of eastern sarus crane (*Antigone antigone sharpii*) in Ayeyarwady Delta, the Union of Myanmar; (**a**) elevation, (**b**) land cover, (**c**) distance to river, (**d**) distance to road, (**e**) slope, and (**f**) distance to village.

Species Distribution Models (SDMs) are usually evaluated by suitable significance with cross validation. The AUC value is the most generally used statistic to evaluate SDM results and is classically used with climatic variables that are strongly interrelated with each other. In general, The AUC ranges from 0 to 1, where a score of 1 indicates perfect discrimination, a score of 0.5 implies predictive discrimination that is no better than a random guess, and values < 0.5 indicate performance worse than random [29–37]. There is a strong relationship between AUC and the sensitivity (the proportion of correctly predicted presence locations) equivalent to specificity (the proportion of correctly predicted absence locations) [38].

2.6. Model Performance

The replicates test omission rate and predicted areas as a function of the cumulative threshold averaged over replicated runs were computed. The receiver operating characteristic (ROC) curve was produced with the same data, again averaged over the replicated runs, and received lower, median, minimum, maximum, average and standard deviation from all runs [39].

2.7. Population Home Range

The population home ranges were grouped to understand their overall home ranges. The MCP and KDE bounds on the innermost 95% of the density of the presence data points in the summer, rainy, and winter season were used to estimate the population habitat use areas [40] of ESC. The model derived from this equation was used to create a habitat use map in ArcGIS.

3. Results

Eastern sarus cranes were not found in unsuitable habitats and were detected in all three seasons (rainy, summer, and winter) at 32, 33, and 29 GPS locations, respectively (Figure 4 and Table 1).

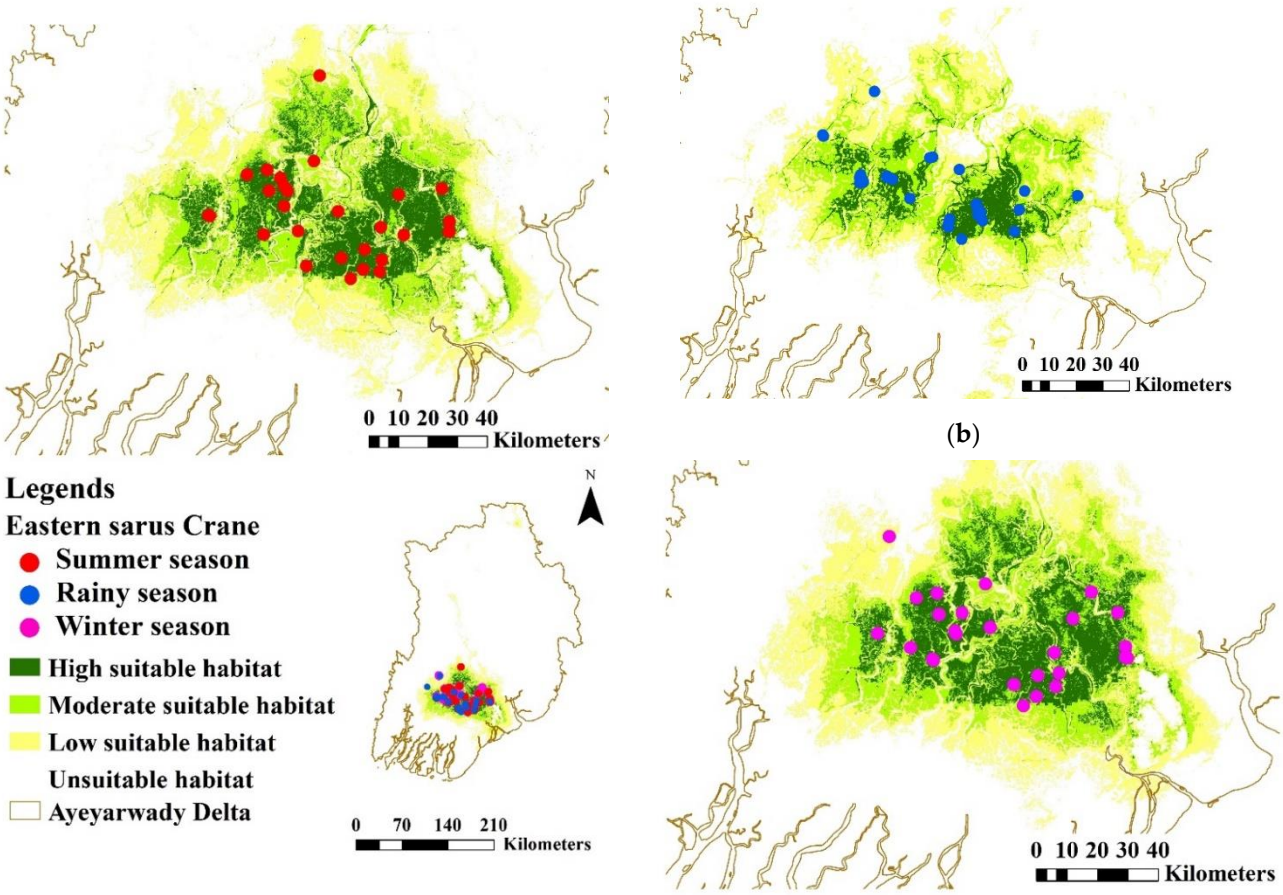


Figure 4. Locations of eastern sarus crane (*Antigone antigone sharpii*) in Ayeyarwady Delta, the Union of Myanmar in (**a**) the summer season, (**b**) the rainy season, and the winter season (**c**).

Table 1. Suitable habitat analysis for the summer season, the rainy season, and the winter season by using MaxEnt and population home ranges by using the Minimum Convex Polygon (95 % MCP) and the Kernel Density Estimate (95% KDE) for eastern sarus cranes (*Antigone antigone sharpii*) in Ayeyarwady Delta, the Union of Myanmar.

Habitat Suitability	Summer Season		Occurrence		Rainy Season		Occurrence		Winter Season		Occurrence	
	km^2	%	Point	%	km^2	%	Point	%	km^2	%	Point	%
MaxEnt												
High	2155.8	2.62	28	85	1028.7	1.2	26	76	2450	3	24	80
Moderate	2275.4	2.8	5	15	2011.3	2.5	6	18	2513.5	3.1	5	17
Low	3627.1	4.4	0	0	3734.3	4.5	2	6	4788.4	5.8	1	3
Unsuitable	74,673.5	90.8	0	0	75,482.4	91.8	0	0	72,504.6	88.1	0	0
95% MCP	7014.6	N/A	N/A	N/A	7892.9	N/A	N/A	N/A	7783.9	N/A	N/A	N/A
KDE												
100	28,867	N/A	N/A	N/A	3601.3	N/A	N/A	N/A	43,780.1	N/A	N/A	N/A
95	9761.9	N/A	N/A	N/A	1238.1	N/A	N/A	N/A	13,839.5	N/A	N/A	N/A
90	7710.9	N/A	N/A	N/A	953.4	N/A	N/A	N/A	10,774.1	N/A	N/A	N/A
50	2485.2	N/A	N/A	N/A	223.2	N/A	N/A	N/A	3274.8	N/A	N/A	N/A

N/A = Not analysis.

3.1. Eastern Sarus Crane Habitat Suitability

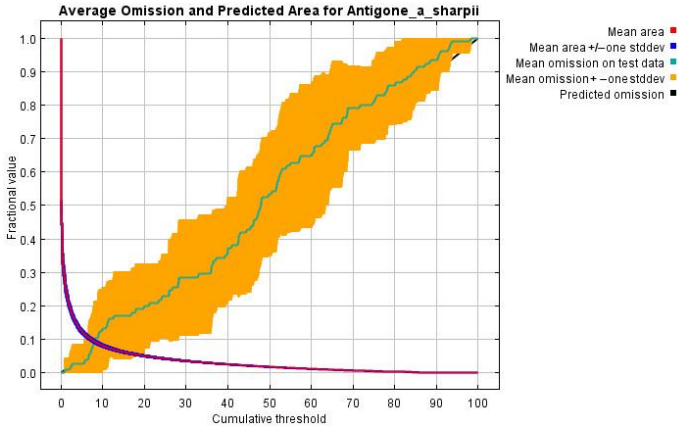
The largest area of highly and moderate suitable habitat for ESC in Ayeyarwady Delta was in the winter season (2450 km^2 and 2513.5 km^2). The largest area of low suitable habitat for ESC in Ayeyarwady Delta was in the winter season (4788.4 km^2) (Table 2 and Figure 2).

From the model performance results, the cumulative thresholds and average omission and predicted areas performed well in all seasons (AUC > 0.9) (Figure 5 and Table 2).

Table 2. MaxEnt special distribution model output for training area under curve (AUC), test gain, and test AUC for eastern sarus crane (*Antigone antigone sharpii*) in the Ayeyarwady Delta in the summer season, the rainy season, and the winter season in Ayeyarwady Delta, the Union of Myanmar.

Model	Summer (Training Sample = 24, Test Sample 7, Background Point = 10,024)			Rainy (Training Sample = 26, Test Sample 8, Background Point = 10,026)			Winter (Training Sample = 21, Test Sample 7, Background Point = 10,021)		
	Training AUC	Test Gain	Test AUC	Training AUC	Test Gain	Test AUC	Training AUC	Test Gain	Test AUC
0	0.987	3.034	0.987	0.988	3.96	0.994	0.989	2.08	0.959
1	0.986	2.295	0.968	0.988	2.814	0.977	0.986	2.293	0.967
2	0.988	1.749	0.976	0.991	2.73	0.975	0.987	2.241	0.964
3	0.984	2.269	0.977	0.988	2.911	0.981	0.986	2.351	0.968
4	0.986	2.829	0.982	0.99	2.352	0.973	0.986	2.39	0.97
5	0.987	2.265	0.985	0.989	3.603	0.989	0.984	2.467	0.971
6	0.989	2.327	0.955	0.989	2.81	0.981	0.983	2.358	0.97
7	0.988	2.34	0.992	0.988	3.63	0.993	0.99	1.297	0.942
8	0.989	2.086	0.983	0.99	2.697	0.978	0.985	2.438	0.97
9	0.988	1.551	0.948	0.988	3.243	0.989	0.982	2.888	0.985
10	0.988	2.59	0.977	0.988	2.999	0.986	0.986	2.358	0.967
11	0.985	2.74	0.968	0.991	2.487	0.974	0.985	2.134	0.962
12	0.988	2.083	0.973	0.993	2.283	0.97	0.98	2.794	0.983
13	0.988	2.8	0.967	0.992	2.712	0.97	0.984	2.492	0.974
14	0.989	2.253	0.989	0.994	1.94	0.96	0.984	2.483	0.971
Average	0.987	2.348	0.975	0.99	2.878	0.979	0.985	2.337	0.968

The climatic parameter associated with ESC habitat suitability above 90% in the summer season was annual precipitation. Habitat suitability in the rainy season was associated with mean diurnal range. Habitat suitability close to 90% in the winter season was associated with annual precipitation. The geographical parameters associated with ESC habitat suitability above 70% in the summer season were elevation, percentage slope, distance to village, and distance to road. While parameters in the rainy season were elevation, distance to road, distance to village, and percentage slope, and in the winter season they were elevation and percentage slope (Figure 6). The land covers associated with the summer season were village and cropland. During the rainy season, they were cropland and shrub and grass, while in the winter season, they were cropland and perennial water (Figure 7).



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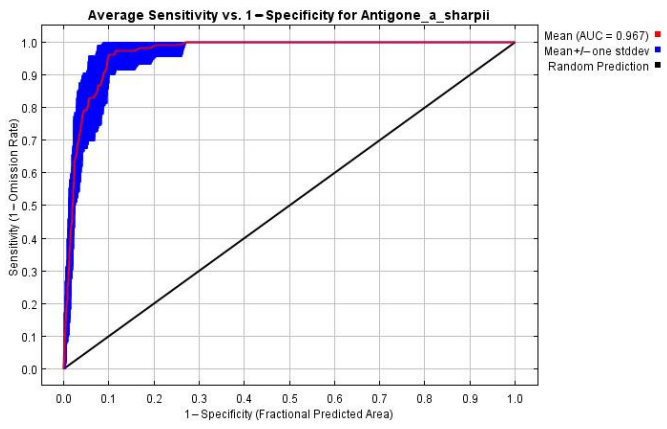

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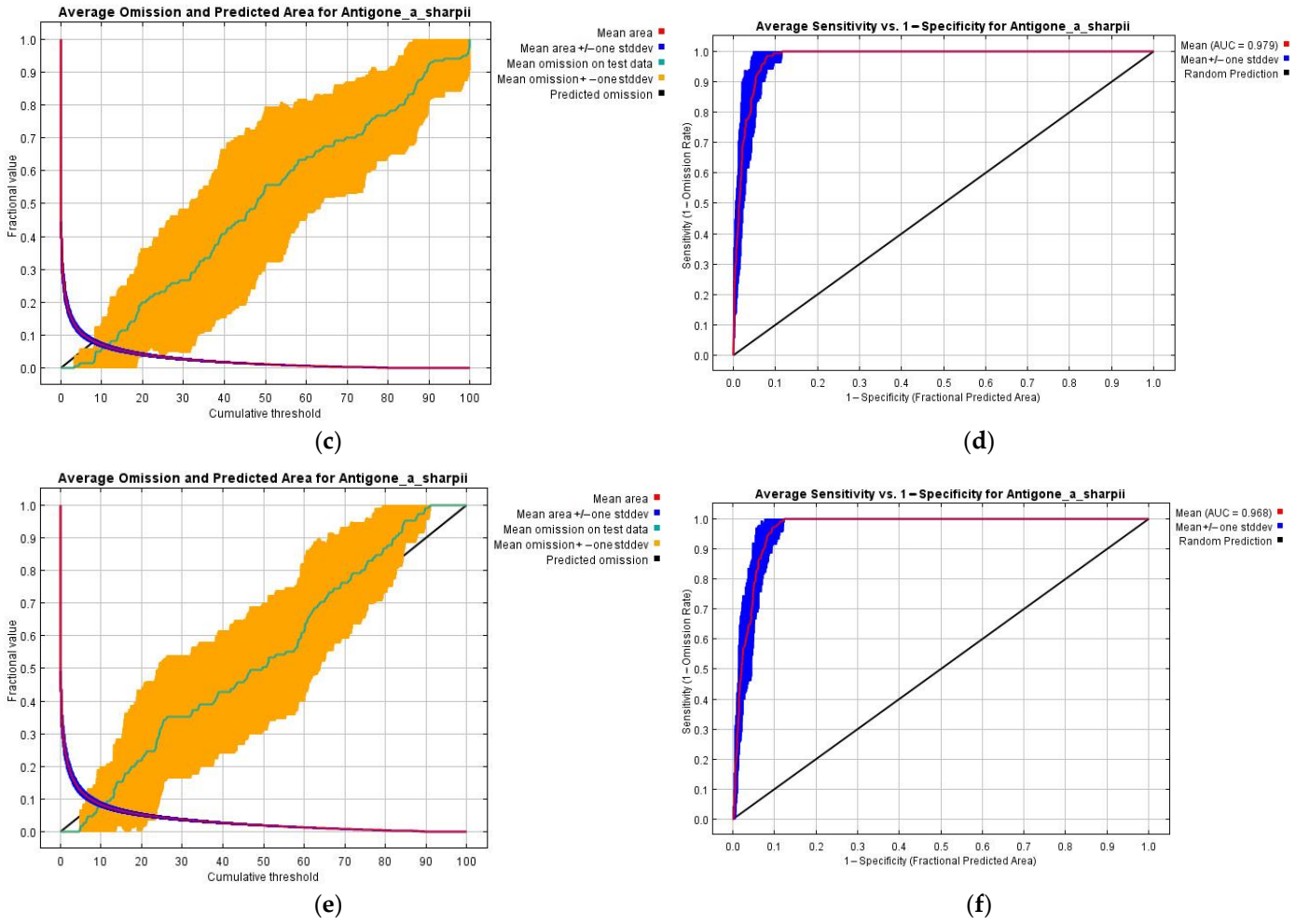
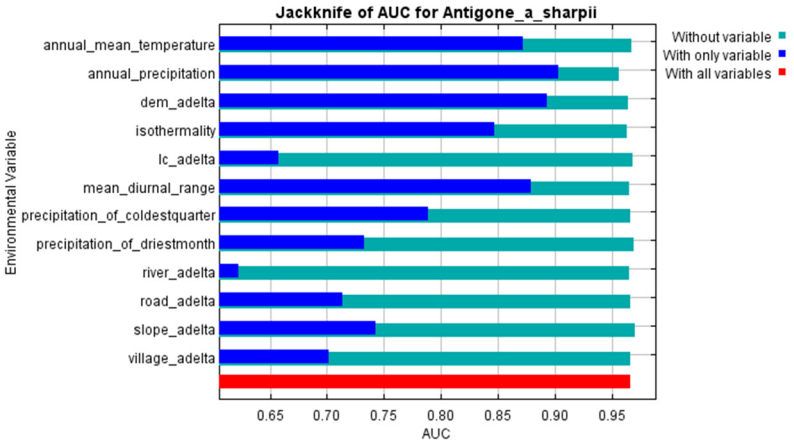


Figure 5. Average omission and predicted areas in (**a**) the summer season, (**c**) the rainy season, and (**e**) the winter season; and average sensitivity vs. 1—specificity in (**b**) the summer season, (**d**) the rainy season, and (**f**) the winter season for eastern sarus cranes (*Antigone antigone sharpii*) in Ayeyarwady Delta, the Union of Myanmar.



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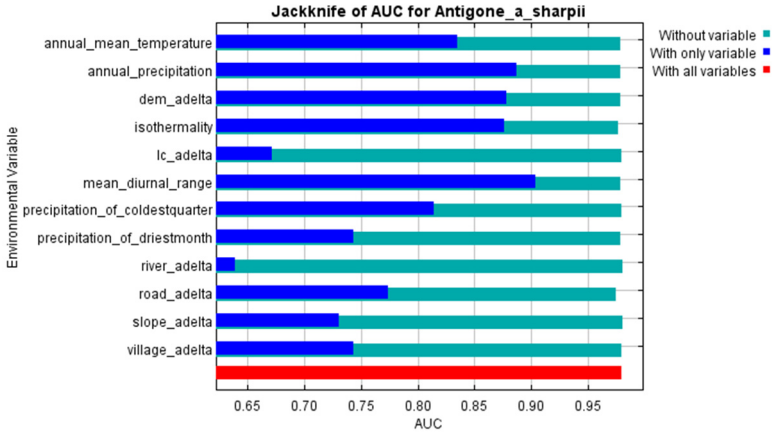

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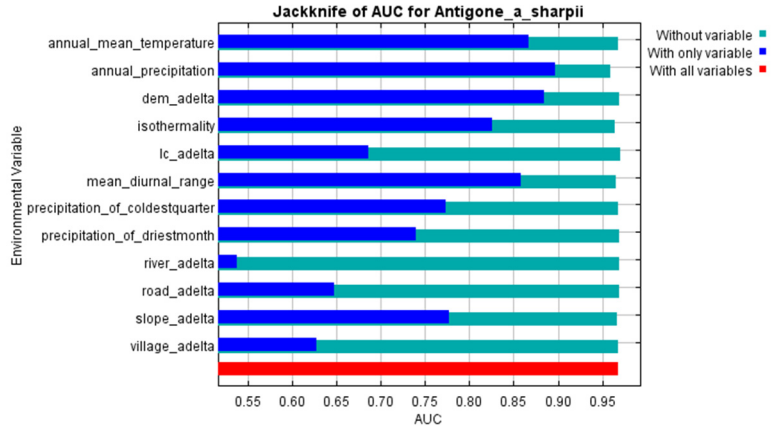
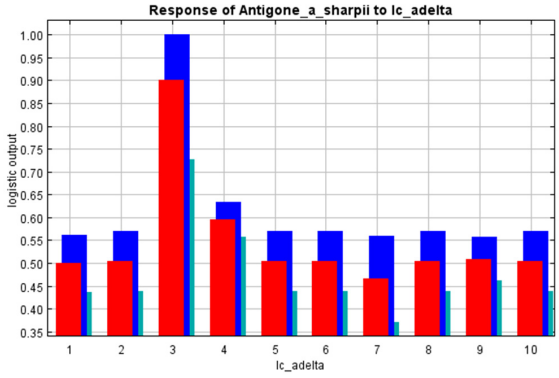


(**c**)

Figure 6. The Jackknife test for evaluating the relative importance of environmental variables for eastern sarus crane (*Antigone antigone sharpii*) in Ayeyarwady Delta, the Union of Myanmar in (**a**) the summer season, (**b**) the rainy season, and (**c**) the winter season.

3.2. Habitat Use Area

The habitat use area estimated using 95% MCP was largest in the summer season (3135.5 km^2) and smallest in the rainy season (2568.8 km^2). The 95% KDE was highest in the summer season (11,670.4 km^2), followed by the winter season (1549.5 km^2), and smallest in the rainy season (316.5 km^2) (Figure 8 and Table 2).



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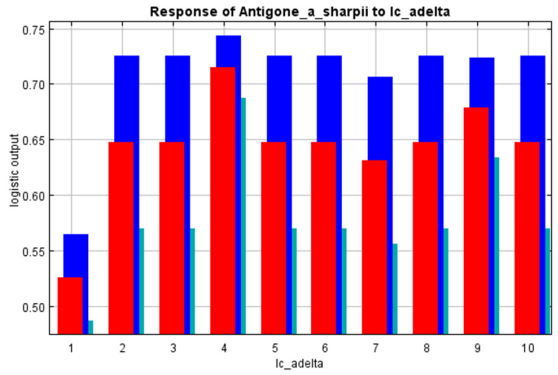

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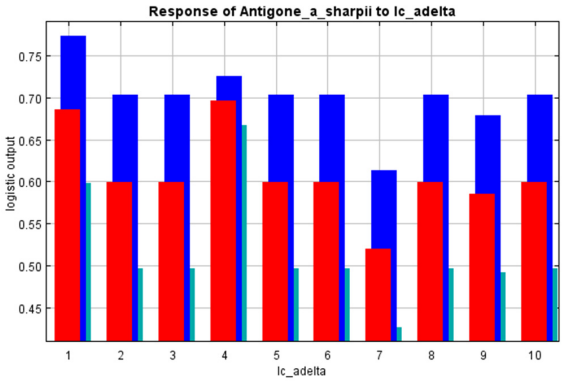

(**c**)

Figure 7. The response of eastern sarus crane (*Antigone antigone sharpii*) to land covers in Ayeyarwady Delta, the Union of Myanmar in (**a**) the summer season, (**b**) the rainy season, and (**c**) the winter season; 1 = perennial water, 2 = impervious surface, 3 = villages, 4 = croplands, 5 = managed forests, 6 = natural forests, 7 = ephemeral water, 8 = depressions, 9 = shrub and grass, and 10 = bare surfaces; the red indicate the mean values, the blue (positive) and the green (negative) denote the one standard deviation limits, resulting from cross validation model runs.

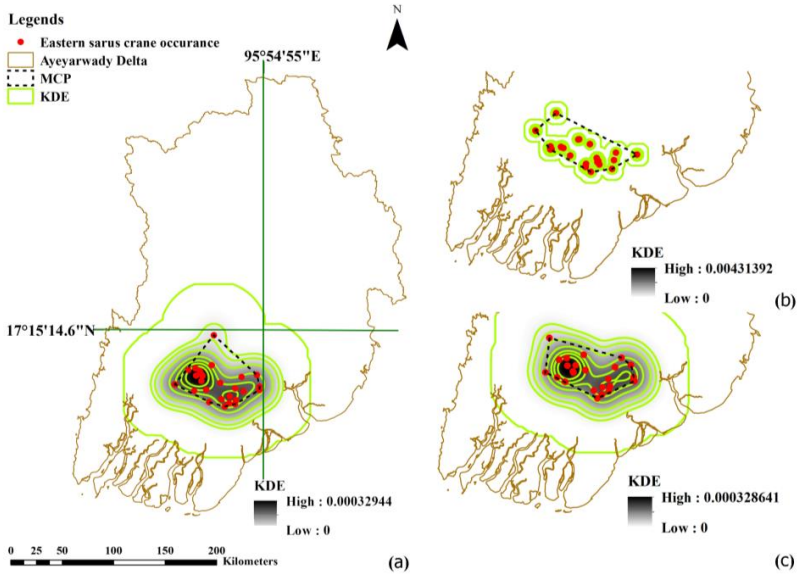

Figure 8. Estimating population home range and density of eastern sarus crane in Ayeyarwady Delta, the Union of Myanmar by using the Minimum Convex Polygon (95 % MCP) and the Kernel Density Estimate (95% KDE); (**a**) the summer season, (**b**) the rainy season, and (**c**) the winter season.

4. Discussion

From the MaxEnt analysis, habitat suitable models showed that the lower part of the Ayeyarwady Delta is suitable for supporting ESC in all seasons with the high score of AUC (>0.9) [29,37] with >10,000 background points [18] or pseudo-absences [41]. The habitat suitable area of ESC was reduced in the summer season due to a reduction in wetlands, especially perennial water sources, and the rainy season due to flooding in the area and cultivation of the wetland outside the protected areas, as found in Nepal [42]. The ESCs were found close to human settlements, especially in the summer season and the rainy season, as their suitable habitats were threatened by drainage of wetlands, conversion of farmlands to settlements, and other developmental activities [43]. Some shallow-water wetland areas disappeared in the summer because of high temperatures and reduced precipitation; consequently, crop plants that are the main food source of the sarus crane (*Antigone antigone*) were limited, similar to the findings in Uttar Pradesh, India [44]. Regarding LULC, enclosed lakes and reservoirs have seriously damaged some wetlands by making water levels too low in the summer season or too high in the rainy season. This has been reported to affect the cranes' foraging and roosting activity [45].

The ESC population in the Ayeyarwady Delta region is faced with anthropogenic land use practices, in particular rice farming. Typically, the main rice crop is sowed between May to early June, grows until September, and is mostly harvested during November and December in some regions. A second rice crop can potentially be sown during November, with harvest by May the following year. Maize, potatoes, wheat, and a mix of cash, food, and rotation crops can be grown outside of the main rice season. Rotations, failed crops, fallow land use, and yield can vary tremendously spatially within season, and making season-to-season assessments was very challenging [46].

The land use and land cover types have changed in the Ayeyarwady Delta since the 20th century and can affect the distribution of ESC due to the deciduous forests in the Ayeyarwady Delta being replaced by agriculture and aquaculture [23]. Other activities, such as the development of the Nyanungdon Oil and Gas Field, which covers 181.3 km^2, have reduced the suitable habitat area for ESCs. Afforestation in Ayeyarwady Delta may also affect ESC habitat. ESCs may partially move or disappear when the wetlands and crop lands are converted to human settlements, polluted by environmental contamination, or lost due to drought [47].

Some areas of Twantay were highly suitable for ESC in the rainy season, but no ESC was present during this time. Further studies may find the environmental impact parameters involved. Another substantial environmental issue since 2010 has been the reduction of freshwater bodies [48].

The ESC habitats were found to be highly suitable in the winter seasons in the Ayeyarwady Delta, when the croplands were ready to support ESCs as food sources, especially the ripened rice in paddy fields. In the rainy season, the KDEs did not perform well because of disruption across the home range area due to flooding and rice cultivation activities. It is noteworthy that, while ESCs have already been observed in the Moeyungyi Wetland Wildlife Sanctuary, no breeding has been recorded in this sanctuary since the 19th century when it was observed irregularly during winter and summer periods [24]. However, ESCs did not visit this wildlife sanctuary during the present study, between March 2018 and February 2019, likely due to environmental anthropogenic parameters, such as increased visitor traffic and noise and water pollution from motorboats [49] used inside the park.

In the future, systematic monitoring of species is essential to building up a comprehensive database on the population trends and suitable LULC types. Upgraded public awareness, strict law enforcement, close habitat protection and restoration management, and tracking genetic diversity are major conservation concerns for the animal population [50,51].

5. Conclusions

ESCs were observed in the study area during all three seasons. MaxEnt analysis revealed that precipitation, elevation, slope, distance to village, and distance to road and crop lands were the most significant parameters for suitable ESC habitat. ESCs can adapt when natural habitat areas of the Ayeyarwady Delta of the Union of Myanmar are replaced with crop lands. However, continued monitoring and protection of natural wetlands and other habitats should be performed to ensure the conservation of ESC in the Ayeyarwady Delta. In this framework, it will be useful to consider human pressures affecting ESC distribution routes, which may change in the protected areas. These results could help support policies and management plans for species conservation in priority areas. Conservation efforts in the Ayeyarwady Delta should include the protection of ESC in the traditional crop lands in the low elevation areas.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/d14121076/s1, Table S1: Location of the eastern sarus crane in the Ayeyarwady Delta, the Union of Myanmar, in the summer season, the rainy season, and the winter season; Table S2: The Pearson correlation coefficient rank *r* statistic between the pair of environmental parameters.

Author Contributions: Conceptualization, T.N.L. and R.C.; methodology, T.N.L. and R.C.; software, T.N.L.; validation, R.C., S.C. and N.T.; formal analysis, T.N.L. and R.C.; investigation, T.N.L.; resources, T.N.L.; data curation, R.C.; writing—original draft preparation, T.N.L.; writing—review and editing, R.C. and T.N.S.; visualization, R.C.; supervision, R.C.; project administration, T.N.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of the Ministry of Environmental Conservation and Forestry, Forest Department, Nature and Wildlife Conservation Division, The Union of Myanmar (Park—Lakaya/Research/870/2018), and it was also approved by the Mahidol University—Institute Animal Care and Use Committee (COA.No.MU—IACUC 2018/019).

Data Availability Statement: Not applicable.

Acknowledgments: We appreciate Theerawut Chiyanon, Faulty of Environment Resource Studies, Mahidol University, as well as Namphung Youngpoy, Wildlife and Plant Research Center, for their assistance in processing the ArcGIS data for presentation in this manuscript. We also thank Soe Thein, Twantay, Yangon Region, Khin Kyaing, Einme, Than Lwin, Pantanaw, Khaing Myint, Maubin, Zaw Moe, Wakema, and Kyaw Myo Maung, Kangyidaunt, Ayeyarwady region, Kyaw Thu and Zar Zar Khaing, Waw Township, Bago region, Zaw Htoo Aung, Meinmahla Kyun Wildlife Sanctuary, Thin Thin Yu, Moeyungyi Wetland Wildlife Sanctuary, and field assistants for permission to work in the protected areas, for sharing data, and for helping to collect data at the Ayeyarwady Delta, the Union of Myanmar.

Conflicts of Interest: The authors declare no conflict of interest.

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