

Article

Nesting Habitat Suitability of African Jacana (*Actophilornis africanus*) in Lake Hawassa, Ethiopia

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Abstract

The African jacana (*Actophilornis africanus*, family Jacanidae) is a sex-role-reversed waterbird inhabiting tropical and subtropical open wetlands across Africa. Identifying environmental factors that influence nest site distribution and suitable nesting habitats is crucial for protecting species and habitat management; however, studies addressing these factors remain limited for this species. This study aimed to map suitable nesting habitats and identify the main environmental variables influencing the nest site distribution of the African jacana in Lake Hawassa, Ethiopia. We mapped nesting habitat suitability using a Maximum Entropy (MaxEnt) model and ArcGIS Pro 3.2.2 based on 78 field-collected nest data points and ten environmental variables. The model predicted a total suitable nesting habitat area of 1.25 km² with high accuracy (AUC = 0.90, CBI = 0.8, and omission rate = 0.22), representing about 1.2% of Lake Hawassa's total area. In general, suitable nesting habitats were relatively small, fragmented, and mainly clustered along the south-eastern shore of Lake Hawassa. The mean precipitation and temperature during the breeding season, slope, elevation, and distance to shoreline were the main predictors of the African jacana's nesting habitat suitability. The results of the present study provide valuable insights into local wetland management and the conservation of African jacanas and other breeding waterbirds in Lake Hawassa. Moreover, this study establishes baseline information for assessing how future climate and habitat changes may influence breeding habitat suitability in similar Ethiopian wetlands. The present study was limited to nesting habitat suitability based on limited environmental factors and did not include nest success, pollution parameters or predation; future studies incorporating these factors may improve ecological interpretation.

Keywords: African jacana; nesting habitat suitability; environmental variables; Lake Hawassa; MaxEnt



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1. Background

The African jacana (*Actophilornis africanus*) is a sex-role-reversed waterbird distributed in sub-Saharan Africa, from West Africa to Ethiopia and southern Africa. The African jacana breeds in shallow freshwater wetlands with floating vegetation. It breeds mainly during the rainy season [1] and exhibits female-biased sexual size dimorphism [2]. Females usually lay a clutch of four eggs in a nest built on floating vegetation. The mean incubation period is 23.4 ± 0.8 days (SD) following clutch completion (Wondimu Ersino et al. unpublished data). The species has a polyandrous mating system in which one female mates with multiple males over the course of a single breeding season. The male provides sole parental care, including incubating the eggs, caring for the chicks, and building nests [1–3].

The African jacana is currently classified as Least Concern by the IUCN, and its global population trend appears to be stable. However, the species is strongly dependent on shallow freshwater wetlands with floating vegetation, which are among the most threatened ecosystems in Africa [4–6]. In Ethiopia, freshwater lakes, including Lake Hawassa, are increasingly exposed to anthropogenic and climatic pressures.

Lake Hawassa is one of the Rift Valley lakes in Ethiopia and is classified as an Important Bird Area (IBA), identified by the code ET053 [7]. It provides a critical habitat for the African jacana and supports diverse aquatic organisms, including 103 bird species [8–10]. However, the lake is facing potential local threats such as wetland degradation, water level fluctuations, habitat fragmentation, urban expansion, chemical pollution, shoreline vegetation loss, and climate change [11–13]. Such threats can alter vegetation structure, reduce the availability of floating vegetation, and disrupt suitable nesting and feeding habitats for African jacanas.

The reproductive behaviour and nest success of the African jacana are influenced by environmental factors such as ambient temperature, precipitation, food resource availability, and predation pressure. Because African jacanas build nests on floating vegetation within seasonally dynamic wetlands, their nesting sites are vulnerable to environmental changes, including fluctuations in water depth, climatic variability, and changes in vegetation structure, which can directly affect nest stability and breeding success [1,14].

Across much of sub-Saharan Africa, including Ethiopia, existing studies of the African jacana have primarily focused on abundance, distribution, mating system and feeding behaviour in various wetlands [15–18]. Despite the ecological sensitivity of African jacanas and the conservation importance of Ethiopian wetlands, the environmental drivers of nesting habitat suitability for this species remain poorly understood, and no spatially explicit modelling based on field-collected nest data has been conducted in Ethiopia [19–22].

Nesting habitats consist of environmental features that support the successful breeding of species [23–25]. They play an important role in maintaining population persistence [26], and their availability often limits breeding density and success in bird populations [27]. Nesting habitat suitability is affected by both fine-scale environmental conditions, such as vegetation cover, water depth, and microclimates, and broad-scale landscape attributes, including slope, elevation, and human disturbances [28,29]. Understanding the spatial distribution of suitable habitats is essential for the effective conservation and management of wetland birds [30,31] as wetland species often depend on specific microhabitat conditions for breeding and are highly sensitive to habitat changes [32–36]. Ecological niche models, also known as species distribution models (SDMs), are useful tools that relate species' occurrence with environmental variables to predict the potential geographic distribution and identify factors shaping habitat suitability across landscapes [37–39]. They have been widely applied in avian studies to identify suitable habitats, assess the impacts of climate and land-use change, and guide biodiversity conservation strategies [40–43]. SDMs are par-

ticularly useful in data-limited regions, as this approach predicts species distribution and identifies potential suitable habitats [44]. The integration of remotely sensed environmental data further enhances this capability, providing spatially continuous and cost-effective information in regions where empirical ecological data are scarce [45,46]. Among the available species distribution modelling approaches, the Maximum Entropy (MaxEnt) algorithm is widely used to model species distribution because it generates reliable predictions from presence-only data while minimizing overfitting [47,48]. Additionally, this algorithm can produce accurate results using a large set of randomly generated pseudo-absence points and remains robust even with a small number of occurrence records [49].

Given the lack of spatially explicit information on the environmental drivers shaping the nesting habitat suitability of the African jacana and other Jacanidae species in tropical and subtropical wetlands, this study aimed to map nesting habitats and identify key environmental factors influencing the nesting habitats of African jacanas in Lake Hawassa, Ethiopia. Understanding these drivers provides new insights into breeding habitat requirements at a fine scale, which is crucial for conserving wetland-dependent species. This study also provides baseline data and a methodological approach that could guide similar nesting habitat assessments for other tropical and subtropical wetland birds.

We hypothesized that variables such as distance to shoreline, precipitation, temperature, NDVI and proximity to conspecific nests are expected to predict suitable nesting sites, providing a basis for habitat protection and management strategies.

2. Materials and Methods

2.1. Study Area

Lake Hawassa is one of the eight major Rift Valley lakes located in the Sidama Region in southern Ethiopia, covering a total area of approximately 94 km². It lies between 6°49' and 7°15' N latitude and 38°17' and 38°44' E longitude, with an elevation of 1685 masl, to the west of Hawassa town (Figure 1). The lake is encircled by various mountains, such as Mount Tabor with an elevation of 1810 m above sea level and Mount Alamura reaching 2019 m above sea level [50]. The areas around the lake are bordered by flat to gently sloping terrain. The lake is also surrounded by multidirectional faults, collapse calderas, ground cracks, and other hidden structures that reflect the lake's geological complexity. Since the lake lacks an outflow, its morphology may be affected by inflow, rainfall, temperature, and evaporation. The climate of the Hawassa area is sub-humid with an average annual precipitation of about 960 mm, mainly occurring during the eight-month rainy season. Generally, the region experiences a mean annual air temperature of 19.8 °C [51]. The shoreline regions of Lake Hawassa have several floating aquatic plant species, such as water lilies, floating grass *Paspalidium germinatum*, and cattails. Lake Hawassa provides nesting and foraging habitats for many waterbird species, including the African jacana *Actophilonis africanus*, the common moorhen *Gallinula chloropus*, the long-toed lapwing *Vanellus crassirostris*, and the great cormorant *Phalacrocorax carbo*, which are among the most dominant breeding waterbird species. Fieldwork was conducted under permission granted by the Sidama Regional State of Ethiopia, Office of Environmental Protection, Forest and Climate Change.

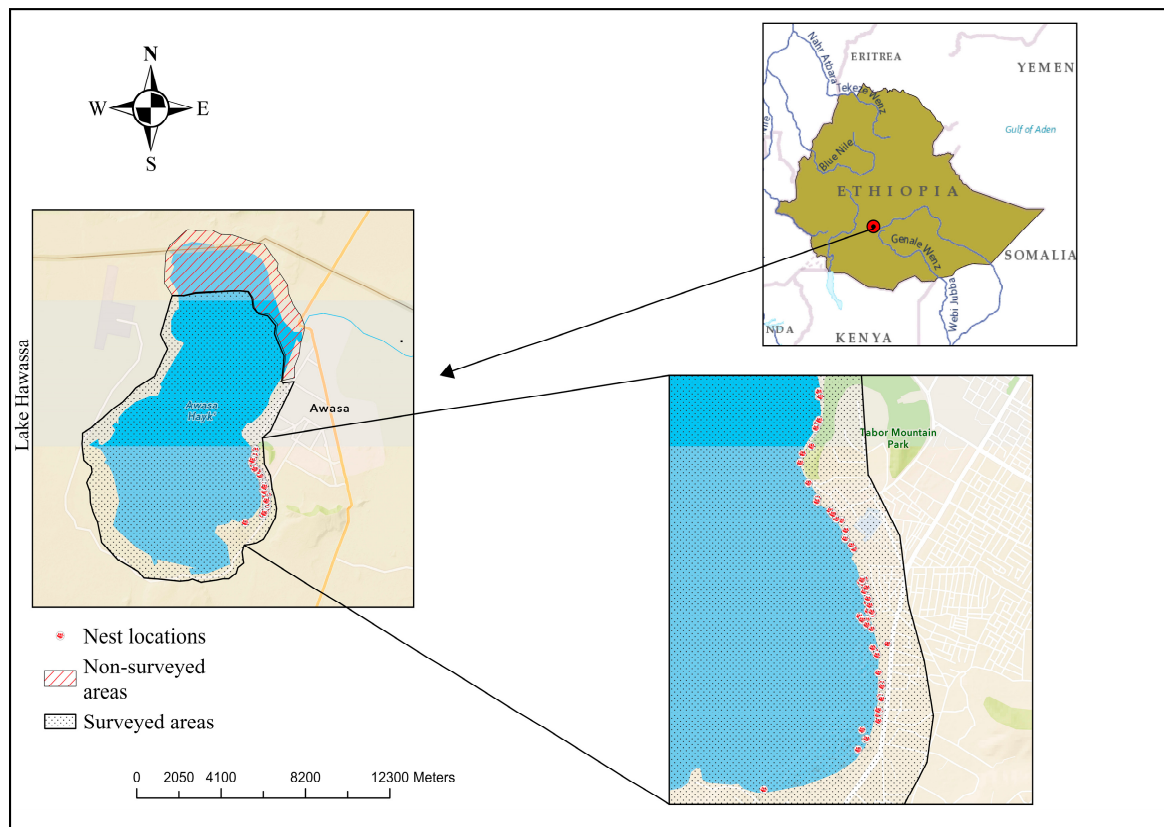


Figure 1. Study area of Lake Hawassa, showing surveyed and non-surveyed areas and locations of African jacana nests. Total shoreline length is approximately 47 km, of which about 37 km was surveyed, and 10 km remained non-surveyed.

2.2. Nest Occurrence Data

A field study was undertaken during the same breeding season from June to October 2022–2024. We followed the standard protocol of our group [52] during nest data collection. We searched for African jacana nests along transects of 1 km each, spaced at 50–100 m intervals, in Lake Hawassa using a small, non-motorized boat and two field assistants. The nest survey covered all accessible shorelines areas of Lake Hawassa, except for most of the northern part of the lake (Figure 1), due to limited safe boat access and the presence of hippopotamuses, which posed safety risks. The detection range for each transect was about 5–10 m on either side of the boat. The detection distance was sometimes varied, as some nests were difficult to detect due to dense aquatic vegetation and the naturally concealed nature of African jacana nests. Nests were identified by either incubating African jacanas or observing nests with eggs. The surveys were conducted every 3–4 days throughout the breeding season. The observers maintained an approximate distance of 10 m from incubating nests and limited the time spent nearby to minimize disturbances and reduce predator attraction [53]. The latitude and longitude of each nest found were recorded using a Garmin eTrex SE handheld GPS receiver, Garmin, Würzburg, Taiwan. A total of 80 nest presence locations were identified during our study periods (Figure 1) and were combined to increase sample size and model robustness. However, this approach may mask interannual variation in environmental conditions affecting nest distribution. Nest occurrence locations were binned into a grid with a 10 m × 10 m (100 m²) area, retaining only one presence point per cell to reduce spatial autocorrelation and ensure consistency with the spatial resolution of the environmental raster layers [53–55]. This procedure was done using the SDM Toolbox in ArcGIS Pro 3.2.2 [56], resulting in a total of 78 nest occurrence records for the nesting habitat suitability analysis. Publicly available

data sources, such as the Global Biodiversity Information Facility (GBIF), record species occurrences (which could be foraging, resting, nesting or even accidental sightings) rather than nesting locations for the African jacana (*Actophilornis africanus*). There is also a lack of important information related to habitat features, such as water depth. Therefore, our study relied only on confirmed field-based nest locations.

2.3. Selection and Processing of Environmental Variables

We included fifteen environmental variables obtained from various remote sensing sources to build a nesting habitat suitability model of the African jacana based on previous studies. The sources and details of the environmental variables are provided in Table S1. Environmental variables, such as short-term or localized changes in temperature, rainfall, and wind, can strongly influence avian individual behaviour, life history, physiology, and morphology, with consequences at the population and species levels [57,58]. In shorebirds, ambient temperature and precipitation can modulate breeding by affecting parental behaviour and food availability [59], as well as flooding risk and nest initiation, which in turn affect nesting site selection [60]. Therefore, we included mean precipitation and temperature during the breeding season. June to October is the confirmed main breeding season for the African jacana. Accordingly, we downloaded precipitation and temperature data at 2 m resolution and wind speed (m/s) and wind direction (°) at 10 m resolution for the 2022–2024 breeding season from POWER NASA (<https://power.larc.nasa.gov/> (accessed on 30 October 2024)) to match the nest survey period. We then calculated the mean values of precipitation (mm/day), temperature (°C), wind speed (m/s), and wind direction (°) to represent generalized environmental conditions.

We included vegetation indices, such as the normalized difference vegetation index (NDVI), Normalized Difference Aquatic Vegetation Index (NDAVI), and Global Environmental Monitoring Index (GEMI), which are used to represent aquatic and overall vegetation conditions influencing waterbird nesting habitat suitability [61,62]. The NDVI reflects vegetation cover and is a relative measure of forage for waterbirds [63,64]. The satellite-derived normalized difference vegetation index (NDVI) is usually used to estimate green cover and food availability [65], as well as waterbird habitat suitability. To calculate these three vegetation indices (NDVI, NDAVI and GEMI), Sentinel-2 Level-2A imageries (with a spatial resolution of 10 m) were downloaded from the Copernicus Data Space (<https://browser.dataspace.copernicus.eu/> (accessed on 30 October 2024)) for the breeding season. Blue (band 2), green (band 3), red (band 4), and near-infrared (band 8) images were post-processed; scenes with more than 93% cloud cover were excluded; and overall cloud contamination was reduced to below 7% using cloud-masking tools such as FMask. Finally, we calculated the multi-year average vegetation indices using algebraic map expressions in ArcPy.

Topographic variables, such as elevation, slope, and aspect, are important factors for species distribution or habitat modelling as they can shape microclimate, soil moisture, and biogeochemical processes, which directly affect vegetation type, productivity, and resilience [66,67]. Therefore, we included these topographic variables in our model, which were derived from the digital elevation model (DEM) with a spatial resolution of 30 m. The DEM was downloaded from the Alaska Satellite Facility (<https://asf.alaska.edu/> (accessed on 30 October 2024)) based on Shuttle Radar Topography Mission (SRTM) data. Topographic variables were standardized (z-score normalization) for further use as inputs for the MaxEnt model.

Distance to shoreline influences access to foraging area, predation risk and nest site selection and nest success in waterbird species [68,69]. Nesting habitat is also influenced by anthropogenic activities [36]; therefore, distance to human settlements and roads was

included as a predictor to account for the influence of anthropogenic activities on waterbird habitat use [23,70]. In addition, proximity to conspecific nests, reflecting spacing patterns driven by social or competitive processes, may influence nest site selection [71]. Distances to shoreline, human settlement, conspecific nests, and roads were calculated using the Euclidean distance tool in ArcGIS Pro 3.2.2, accounting for the Earth's curvature [72]. Water depth and wetland vegetation are also known to influence waterbird nest site suitability and the distribution of waterbirds [73]. Because jacana nests are built on floating vegetation, they may be subject to changes in water level [3,74].

All the environmental variables (rasters) used in this study were resampled to a 10 m resolution to ensure consistency before modelling, cropped, and masked to match the study area's boundary. Fine-scale spatial resolution was used to capture microhabitat features relevant to the African jacana's breeding habitat selection. Such fine-scale resolution is appropriate for investigating breeding habitat characteristics at local scales, as demonstrated via high performance in previous small-scale SDM studies of bird species [75]. Rasters were also projected to the WGS84/UTM Zone 37N coordinate reference system (EPSG:32637) using ArcGIS Pro 3.2.2 before running the MaxEnt model. These steps ensured that all our variables shared the same extent, projection, and spatial resolution. For visualization, maps of each environmental variable used in this study are provided in (Figure S1).

2.4. Multicollinearity Test

Before running the MaxEnt model, we checked multicollinearity among the environmental variables using the packages “car”, “correlation”, and “rvif” [76] in R version 4.4.3 (Core Team, 2025), as shown in the Supplementary Material (Figure S2). If pairs of variables had a high Pearson correlation coefficient ($|r| > 0.7$), we excluded one from the final model, given their biological or ecological relevance (Figure 2). Accordingly, three variables (GEMI, NDAVI, and distance to the road) were excluded due to high collinearity ($|r| > 0.7$). Furthermore, multicollinearity among the remaining twelve variables was tested using the Variance Inflation Factor (VIF) with the car package in R Version 4.4.3. Generally, a $VIF < 10$ is an acceptable threshold. Values greater than 10 show an unacceptably large amount of collinearity and should be excluded [77]. Consequently, wind direction and wind speed were excluded one by one using a stepwise procedure as they had a VIF value greater than 10. Finally, ten environmental variables were selected for modelling the nesting habitat suitability of the African jacana using MaxEnt (Table S2; Figure S2).

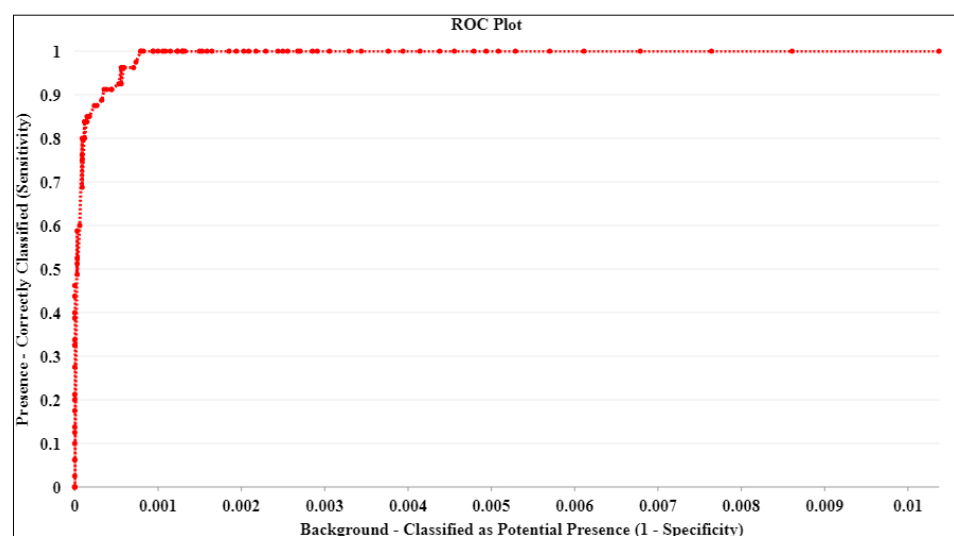


Figure 2. A ROC curve of MaxEnt prediction, based on a series of misclassification matrices computed for a range of cutoffs from 0 to 1.

2.5. Fitting the Model

We used Maximum Entropy (MaxEnt) modelling to predict nesting habitat suitability for the African jacana in Lake Hawassa, Ethiopia. The nest occurrence data and the final set of 10 variables remaining after multicollinearity testing were used as model inputs. We selected the cloglog output, as the dataset consisted of confirmed nest-only presence records verified in the field. Ten-fold cross-validation was applied to evaluate model stability and predictive performance. Out of 78 nest presence records, 80% were randomly selected for the model training set, and the remaining 20% were used for testing. A total of 30,000 random background (pseudo-absence) points across the study area were generated by MaxEnt to contrast with our presence data (Supplementary Figure S3). Finally, a nesting habitat suitability map was produced as a continuous surface ranging from 0 (unsuitable) to 1 (highly suitable).

2.6. MaxEnt Model Evaluation

MaxEnt model performance was assessed using the Area Under the Curve (AUC) derived from the Receiver Operating Characteristic (ROC) curve. In general, models were assessed as follows based on AUC values: 0.5–0.6 indicates failed, 0.6–0.7 indicates worthless, 0.7–0.8 indicates poor, 0.8–0.9 indicates good, and >0.9 indicates excellent model performance [78]. Model accuracy was also assessed using the omission rate (proportion of known occurrences not predicted as suitable), where lower values indicate better performance, as the model correctly predicts most known occurrences [48]. A low omission rate is a necessary (but not sufficient) condition for a good model. Furthermore, the predictive performance of the MaxEnt model was also assessed using the Continuous Boyce Index (CBI), which provides insight into the model's robustness and deviation from randomness [79]. CBI values range from −1 to +1, where values near +1 indicate that the model predicts species habitat suitability very well, values around 0 suggest that the model performs no better than random, and negative values indicate that the model's predictions are contrary to actual observations [80]. It should be noted that since this study aimed to assess nesting habitat suitability within Lake Hawassa, model evaluation relied on internal validation metrics rather than independent validation in distant habitats due to a lack of verified nest records.

Finally, the relative contribution of each environmental variable to nesting habitat suitability was determined using the permutation method using the “enmttools.vip” function, which uses the *vip* package in R [81]. Then, we were able to present the results of the MaxEnt variables' permutation importance and percentage contribution ranking, followed by the Variance Inflation Factor (VIF) [82].

3. Results

3.1. MaxEnt Model Evaluation

The MaxEnt model accurately predicted suitable nesting habitats for the African jacana, with a training AUC value of 0.9 (Figure 2), a Continuous Boyce Index (CBI) value of 0.8 (Figure 3) and an omission rate less than 0.2 at a cutoff of 0.5 (Figure 4), indicating that the MaxEnt model successfully predicted all known nesting habitats of the African jacana.

3.2. Nesting Habitat Suitability Map

We identified that 1.25 km² of Lake Hawassa can act as a suitable nesting habitat for *Actophilornis africanus* (Figure 5). The areas with high nesting habitat suitability for the African jacana had predicted occurrence probabilities ranging between 0.803 and 0.962. These habitats are mainly concentrated along the shoreline areas of Lake Hawassa in southeast villages, such as Sallaka, Referral, and Loqe. Overall, suitable nesting habitat areas were fragmented and exhibited a clustered spatial distribution pattern (Figure 5).

Accordingly, the reported habitat associations are representative of the surveyed portions of the lake and should not be generalized to non-surveyed areas (Figure 1).

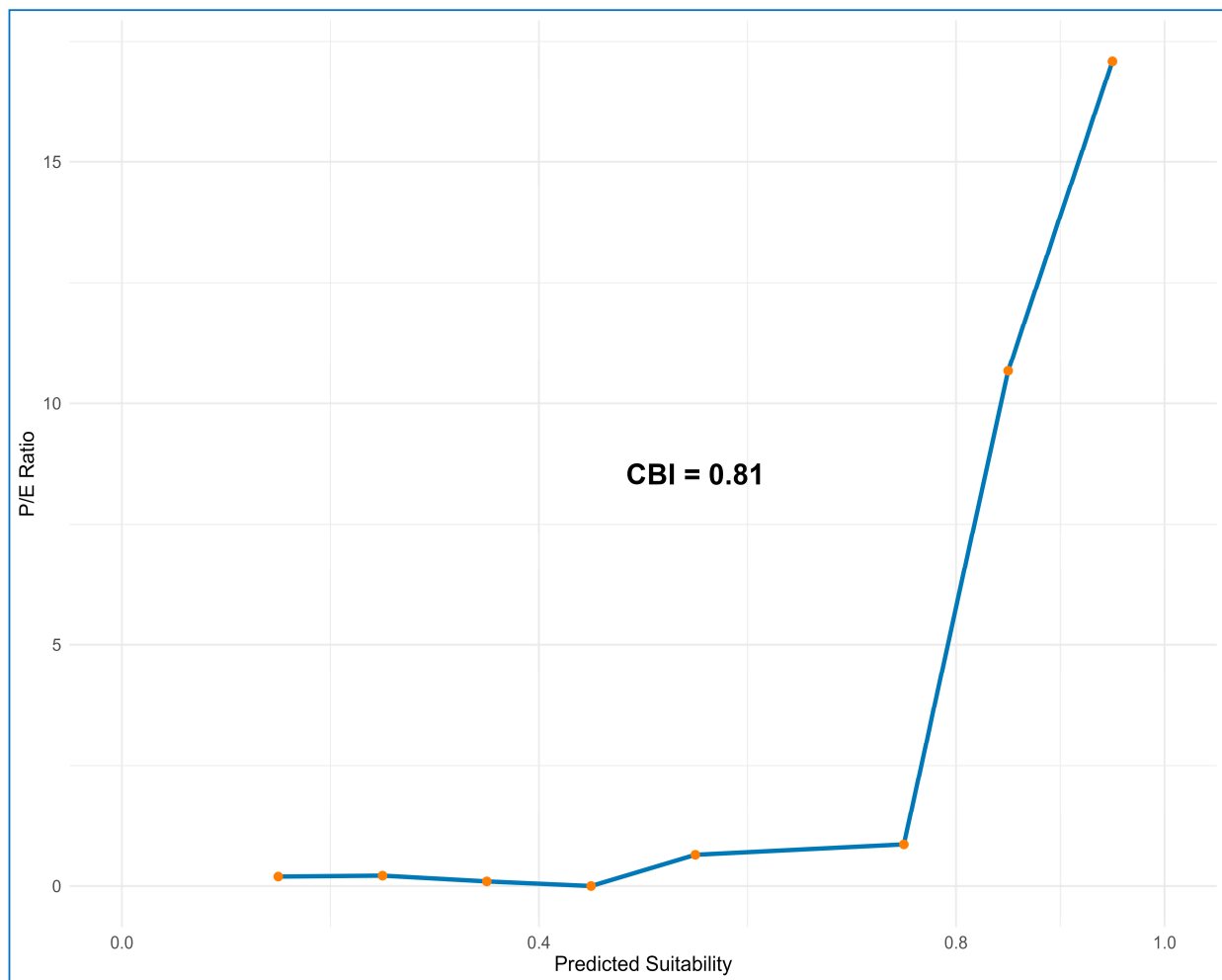


Figure 3. Evaluation of MaxEnt model performance using Continuous Boyce Index (CBI). Note: P indicates predicted fraction of observed presences in each suitability range. E = Expected fraction of area predicted to have that suitability range.

3.3. Main Environmental Predictors of Nesting Distribution

An analysis of the model's variable importance suggests that precipitation, with a contribution of (18%), was the most influential predictor in MaxEnt model prediction, followed by temperature (15%), distance to conspecific nests (13%), elevation (11%), distance to human settlement (11%), and slope (10%). The aspect (8%), distance to shoreline (5%), NDVI (5%), and depth of water (4%) were relatively less influential in determining the nesting habitat suitability of the African jacana (Table S2).

The response curve showed how the predicted probability of habitat suitability varies with environmental variables while keeping all other variables constant (Figure 6). The response curve indicated a positive relationship between precipitation and nesting habitat suitability, with suitability reaching its maximum around 4.9 mm. The aspect curve indicated a general increasing trend, with the probability of suitable nesting habitats peaking at around an aspect value of 360°. Based on this trend, it is suggested that *Actophilornis africanus* prefers slopes oriented to the east and south, but it avoids north- and west-facing slopes. This pattern suggests that slope orientation may influence microclimatic conditions favourable for nesting. The response curve indicates a negative relationship between elevation and nesting habitat suitability. Nesting habitat suitability reached an optimum at

1647 m elevation within the study area. Water depth, distance from human settlement, and nearest conspecific nest did not affect nesting habitat suitability. Nesting habitat suitability was positively correlated with the normalized difference vegetation index (NDVI; Figure 6).

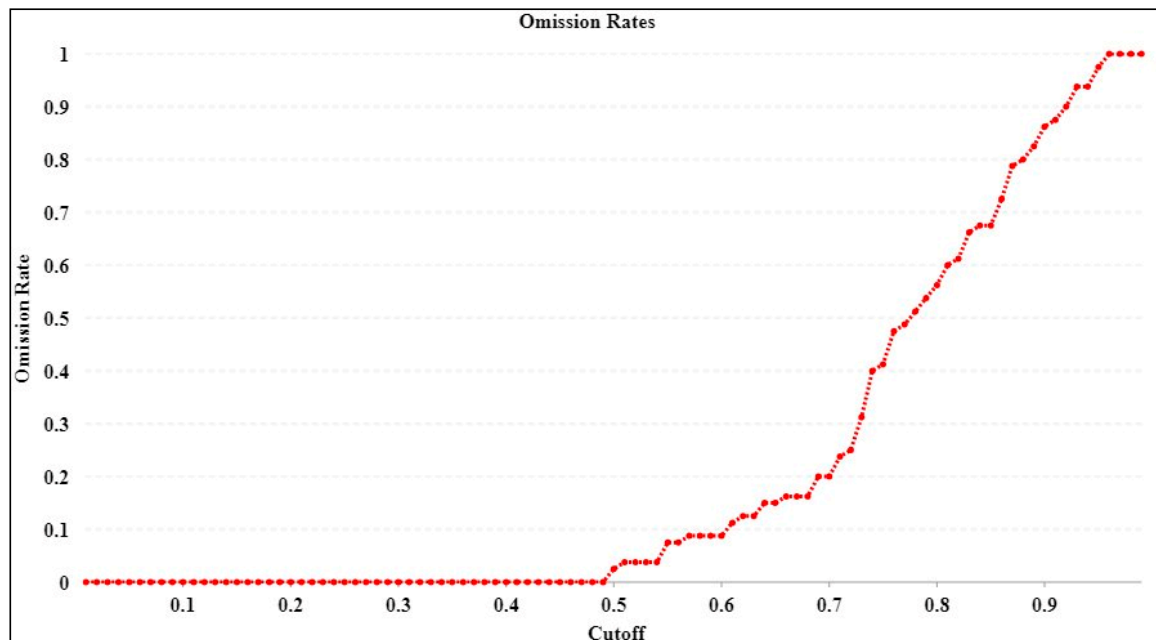


Figure 4. Curve showing omission rate.

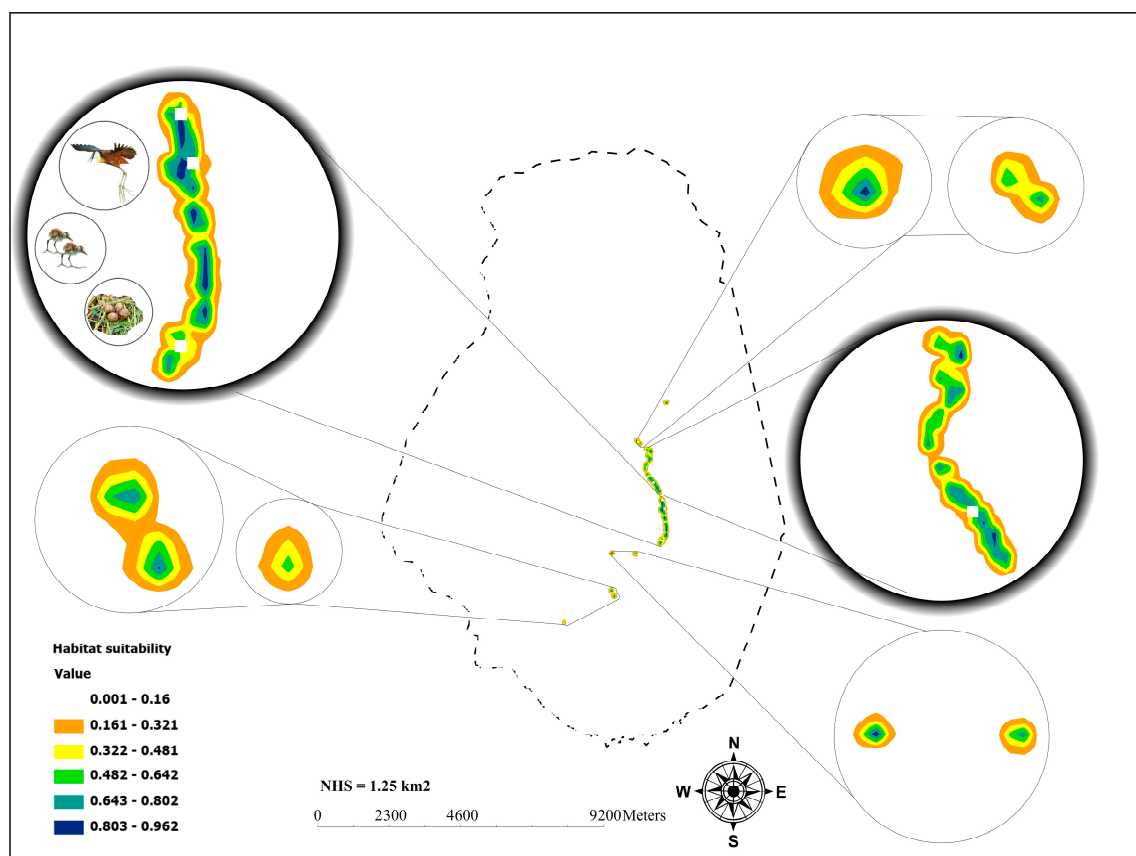


Figure 5. A map of the nesting habitat suitability of the African jacana in Lake Hawassa. The dotted polygon indicates a study area boundary. Colours represent different ranges of predicted nesting habitat suitability, from low (yellow) to high (blue).

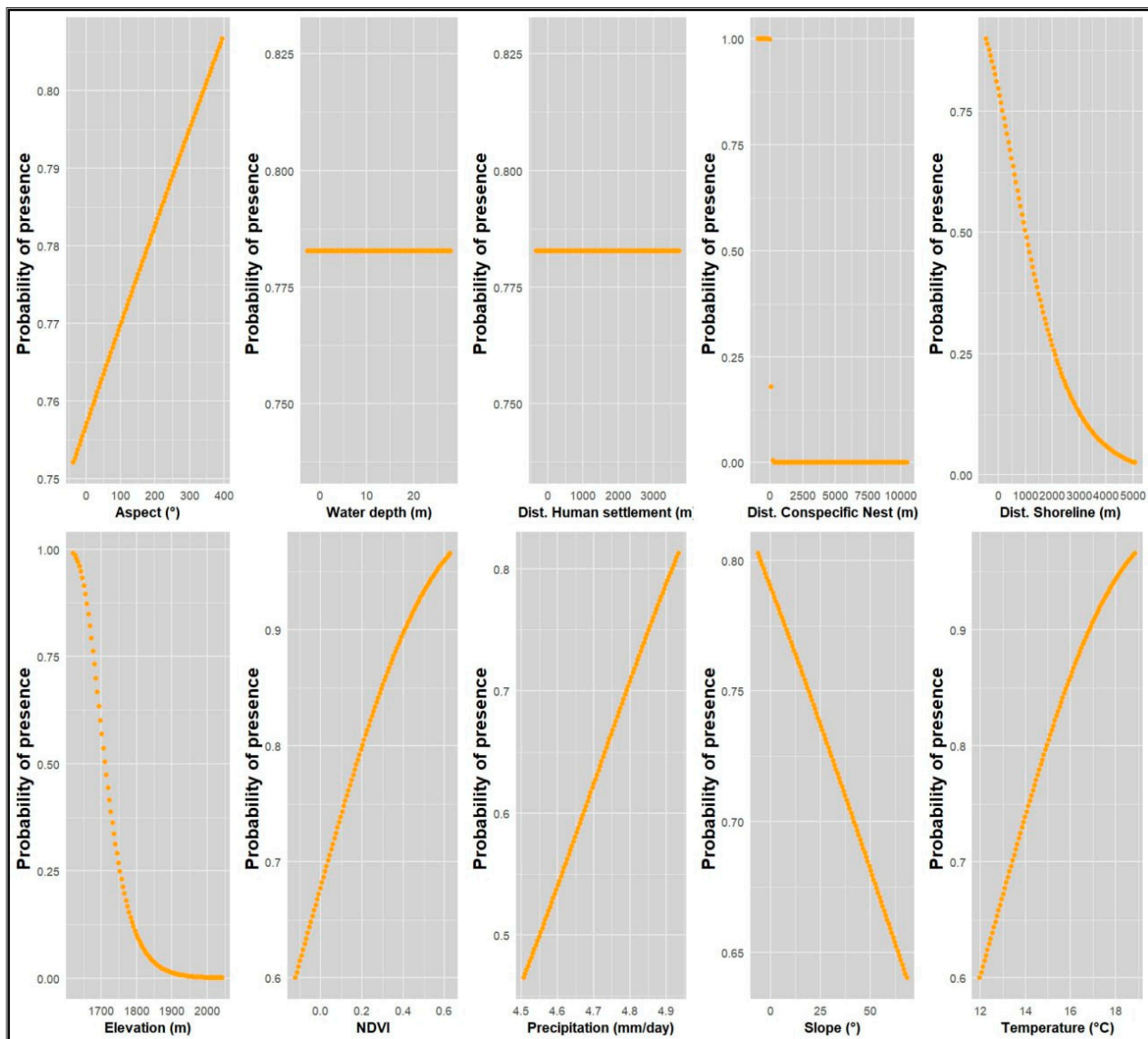


Figure 6. Response curves of environmental variables predicting nesting habitat suitability of African jacana.

4. Discussion

The MaxEnt model in this study showed high predictive accuracy in identifying suitable nesting areas and identified key predictors influencing the nesting habitat suitability of the African jacana. The most important predictors of African jacana nesting habitat suitability were precipitation, temperature, normalized difference vegetation index (NDVI), distance to shoreline, slope, aspect and elevation. The results obtained help us to understand the breeding habitat requirements of the African jacana and the usefulness of MaxEnt for assessing nesting habitat suitability in wetlands.

Precipitation plays a key role in determining nesting habitat suitability in breeding birds by affecting water levels, food availability, and vegetation growth [22]. In this study, the nesting habitat suitability of the African jacana increased as precipitation during the breeding season progressed, likely because moderate precipitation increases foraging opportunities [83]. Since the African jacana is highly dependent on wetlands, it demands floating vegetation and shallow water for nesting, and moderate rainfall can enhance the quality and extent of suitable nesting sites. Higher precipitation during the breeding season promotes the growth of aquatic vegetation and enhances arthropod abundance, thereby

improving foraging opportunities for adults and chicks [84,85], which likely enhances the nesting habitat suitability of the African jacana. Nest site selection by African jacanas has been described as a trade-off between minimizing predation risk and reducing exposure to adverse weather conditions [2,14]. The positive relation between ambient temperature and nesting habitat suitability in our study (Figure 6) may be linked to warmer rainy seasons which are typically associated with peak food availability and breeding activities in the African jacana [75,86]. A similar pattern has been reported in other waterbirds, where increases in seasonal temperature have been related to earlier nest initiation and higher nesting density in wetlands [87], suggesting that climatic conditions are important drivers of nesting nest site selection and breeding phenology in waterbirds.

Topographic factors can alter microclimatic conditions and influence the distribution of land cover types [88]. In the present study, elevation, slope, and aspect contributed about one-third (29%) to the MaxEnt model predicting the nesting habitat suitability of the African jacana. The higher nesting habitat suitability observed was associated with relatively lower-altitude areas, which is consistent with typical shorebird habitat requirements: low-altitude sites with gentle slopes near water bodies favour slow water flow or reduce the risk of nest flooding, leading to large shallow-water areas and rich wetland vegetation, which provide optimal nesting and foraging grounds [89]. Moreover, several studies have shown that elevation influences species diversity distribution patterns by influencing local climatic conditions, the distribution of water systems, and vegetation community types [24,90,91].

While elevation was identified as an important predictor of nesting habitat suitability of the African jacana, it likely reflects variation in surrounding topographic conditions, such as slope and proximity to the shoreline, rather than differences in the lake surface itself. Slope has been believed to determine nesting habitat suitability for shorebirds by influencing environmental variables such as solar radiation, soil moisture, and microclimatic conditions [66,92], which in turn affects vegetation structure and resource availability. In this study, we noticed that an increase in slope had a negative influence on nesting habitat selection. A similar pattern has been reported in other shorebird species, such as the Kentish plover (*Charadrius alexandrinus*) in the Arid Lands of Xinjiang, China [32], and Asian woollyneck (*Ciconia episcopus*) in Nepal [33].

This may be because steep slopes reduce the availability of flat, stable surfaces important for nest construction, thereby increasing the risk of egg rolling or nest flooding, particularly in wetland-associated species. Specifically, an elevation of about 1647 m and a slope of 0° (flat terrain) in Lake Hawassa represented the most preferred nesting habitat for the African jacana. Our finding is consistent with previous reports that the African jacana occurs in freshwater wetlands across a broad elevational range, extending to approximately 2000 m (<https://birdfact.com/birds/african-jacana> (accessed on 7 November 2025)). Furthermore, studies reported on piping plovers, which are ground-nesting birds, show that they preferred relatively flat areas for nesting, even in topographically variable habitats [93]. These findings suggest that gently sloping shorelines should be conserved to maintain suitable nesting habitats.

This probably suggests that a flat microhabitat keeps nests stable and reduces the risk of egg rolling for the African jacana, which often lays its eggs on floating aquatic vegetation. We recommend that local communities conserve the gently sloping shoreline areas of Lake Hawassa, which are critical for maintaining suitable nesting habitats for African jacanas. Although the topographic variables used in this study were derived from a 30 m DEM and resampled to 10 m for modelling, the effective resolution remains 30 m. Therefore, some fine-scale microhabitat variation may not be fully captured.

Distance to the shoreline was an important factor influencing the nesting habitat suitability of the African jacana. The nesting habitat area of the African jacana decreased as the distance from the shoreline increased (Figure 6). This pattern likely occurred because, based on our field observations, African jacanas prefer shallow wetlands with floating or emergent vegetation (e.g., waterlilies, Kissimmee grass) for nesting, and these are the most abundant near the water's edge. Additionally, the water's edge or shoreline areas of Lake Hawassa provide relatively stable water levels and suitable substrates for nest anchorage, which are likely important for successful incubation and chick survival. This supports earlier findings that African jacanas rely on the shoreline areas of Lake Hawassa to forage for aquatic invertebrates [16,94]. Moreover, similar trends were observed in other waterbird species, where birds preferentially nest near shallow shorelines [95,96]. The findings of this study indicate that proximity to the shoreline plays a key role in African jacanas' nest site selection. This underscores the importance of conserving and effectively managing the shoreline areas of Lake Hawassa.

Although the contribution of the NDVI in predicting the nesting habitat suitability of the African jacana was relatively low, a previous study showed that areas with higher aquatic vegetation, which is reflected by higher NDVI values [97], provide suitable nesting sites and foraging opportunities for the African jacana by hosting insects, worms, and other invertebrates. Moreover, based on our field observations in our study area, we confirmed that African jacanas typically use floating vegetation, such as water lilies and *Paspalidium geminatum*, for nesting, foraging, and nest camouflage. This is consistent with previous studies in other regions of waterbirds, where the NDVI has been shown to serve as a useful predictor of habitat suitability, likely reflecting food availability or habitat structure [97,98].

However, predicted nesting habitat suitability for African jacanas does not necessarily equate to high reproductive success. Ecological trap theory suggests that animals may preferentially select habitats that appear suitable based on environmental cues but actually lead to lower fitness (e.g., reduced breeding success) due to changes in conditions, often anthropogenic habitat change [99,100]. Therefore, we suggest that future studies combine habitat suitability modelling with direct measures of nesting success to more comprehensively evaluate habitat quality.

The total area predicted to be a suitable nesting habitat for the African jacana was relatively small (1.25 km²) and should be interpreted with caution. Consistent with previous studies on wetland birds, including the Bronze-winged Jacana (*Metopidius indicus*), suitable habitats were found to be limited and show a patchy distribution; however, comparisons should be interpreted with caution due to differences in study regions and species [34]. Despite this limited extent and model evaluation metrics, the MaxEnt model demonstrated high predictive accuracy and is a reliable tool for estimating the nesting habitat suitability of the African jacana. The restricted availability of suitable nesting habitats may reflect ongoing habitat degradation. In addition to our predictor variables tested, this may be caused by the nutrient enrichment and water pollution previously reported by researchers in Lake Hawassa [50,101,102].

In shallow tropical lakes such as Hawassa, moderate nutrient enrichment and effluent inputs can initially increase floating macrophyte cover and thereby expand the type of nesting substrate preferred by African jacanas, even when the source is anthropogenic. Only at higher levels of eutrophication, or when combined with intense disturbance, turbidity, or heavy litter accumulation, would we expect a net decline in stable floating vegetation and a corresponding reduction in nesting habitat. Future studies should incorporate spatial information on water quality and eutrophication metrics (e.g., chlorophyll-a, nutrient concentrations, turbidity, or mapped macrophyte cover) to test these mechanisms. Fur-

thermore, human activities along the shores of Lake Hawassa, such as waste disposal (including significant litter buildup) and disturbances from fishing practices [101], may further restrict the extent of suitable microhabitats for African jacanas.

Predicted habitat suitability maps can serve as an important tool for scientific management and implementing conservation actions [34,103]. Therefore, conservation measures should prioritize the protection and management of these identified nesting areas to ensure the long-term persistence of the African jacana in the region. Moreover, we recommend that future studies include the effects of anthropogenic activities, food resource availability, predation pressure, and longer temporal datasets (such as several breeding seasons) when modelling the suitable nesting habitats of the African jacana in the wetlands of this region.

5. Conclusions

The nesting habitat suitability of the African jacana in Lake Hawassa is strongly influenced by climatic and topographic variables. MaxEnt modelling revealed that precipitation, temperature slope, elevation and distance to shoreline were key predictors of nesting habitat distribution. This study identified a total potential suitable nesting area of 1.25 km², accounting for 1.2% of Lake Hawassa's total area. Although nest surveys covered much of the lake, recorded occurrences were spatially restricted, suggesting that suitable breeding habitats may be limited. Protecting and managing the identified suitable nesting sites of African jacanas could contribute to sustaining the local breeding population in the face of ongoing anthropogenic and climatic pressures. Future studies should incorporate temporal variability, breeding success, pollution parameters, and predation effects, which may improve the ecological interpretation of nesting habitat suitability.

Supplementary Materials: The following supporting information can be downloaded at <https://www.mdpi.com/article/10.3390/ecologies7020054/s1>, Figure S1: Maps of the raster layers for each environmental variable used in this study; Figure S2: Correlation analysis of environmental variables; Figure S3: Graph showing presence points and background points used in MaxEnt modeling; Table S1: Predictor variables used to model the nesting habitat suitability of *Actophilornis africanus*, Lake Hawassa (June–October 2022–2024); Table S2: Predictor variable contributions (%) in the MaxEnt model for nesting habitat suitability of the African jacana at Lake Hawassa. References [104–114] are cited in the supplementary materials.

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Abbreviations

The following abbreviations were used in this manuscript.

NDVI	Normalized difference vegetation index
Temp	Mean temperature of the breeding season
Prec	Mean precipitation of the breeding season
Elev	Elevation
Dist_S	Distance to shoreline
Dist_N	Distance to conspecific nest
Depth_W	Depth of water
Dist_H	Distance to human settlement
ASP	Aspect
Slop	Slope

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