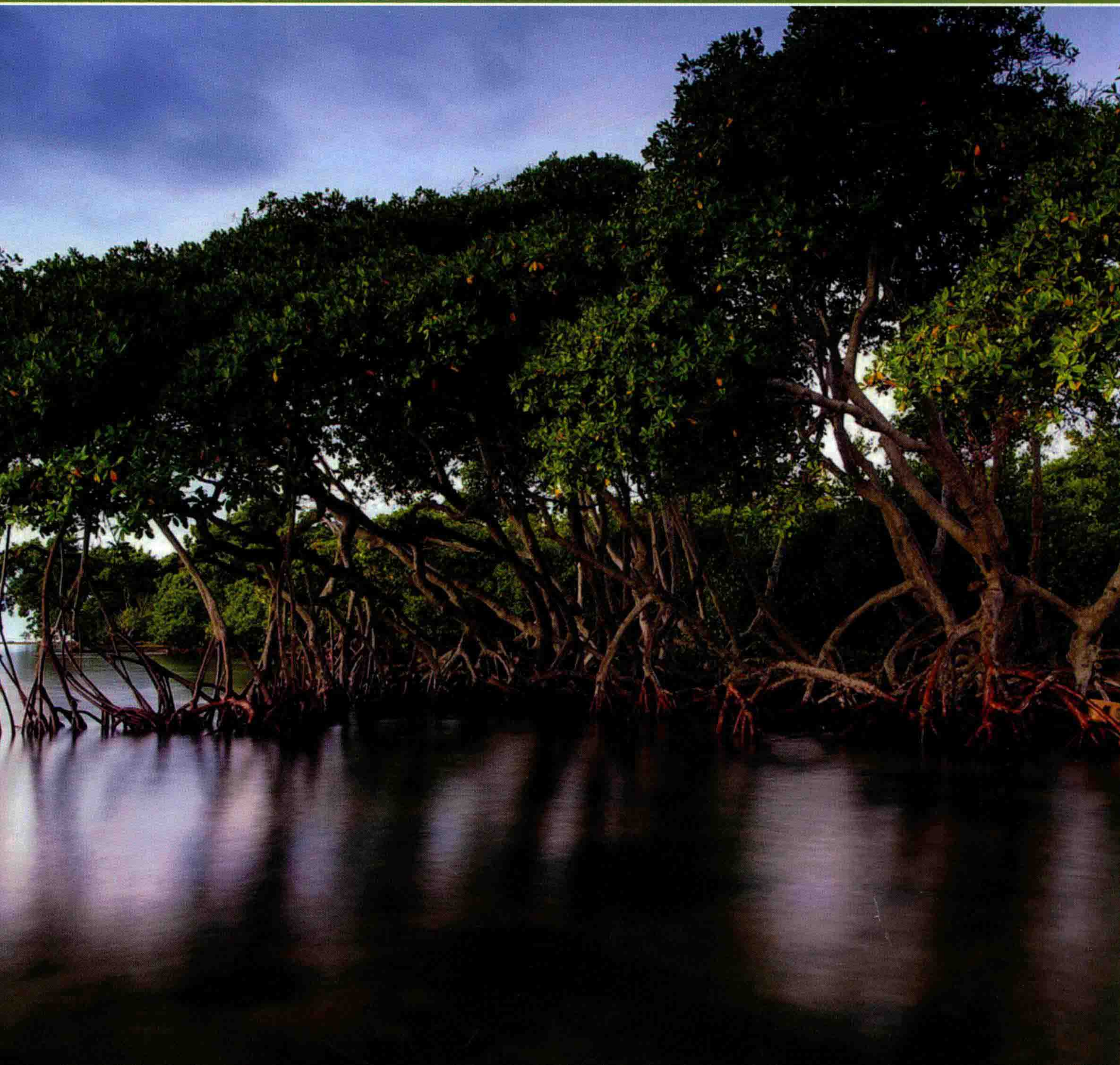
Ecology Research Handbook

Volume III

Liam Page



Ecology Research Handbook Volume III

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Volume III

Preface

The origins of the word "ecology" can be traced to the year 1866, when it was coined by the German scientist Ernst Haeckel. Ecology is an interdisciplinary field, which is the scientific study of interactions among organisms and their environment. The foundations of this subject were laid by Ancient Greek philosophers such as Hippocrates and Aristotle, who studied natural history. From the 19th century onwards, concepts such as natural selection and adaptation transformed Ecology into a more rigorous discipline.

The concepts of Ecology are premised on ecosystems, which include organisms, the communities they make up, and the non-living components of their environment. The scope of Ecology spans a wide array of interacting levels of organisms, ranging from the micro-level to planetary scale. This subject helps comprehend how the living world interacts. It provides evidence on the interdependence between the inanimate and animate elements of the ecosystem.

Ecology also covers topics of subjects like Biology and Earth Science. Topics of interest to ecologists include diversity, distribution, and population of organisms. The manner in which biodiversity affects ecological function is an important and emerging focus area in ecological studies. A better understanding of ecological systems is crucial in contemporary times, as it allows scientists to predict the consequences of human activity on the environment.

I would like to thank our researchers and writers for sharing their valuable research with us in this book.

Editor

Contents

Nesting patterns of raptors; White backed vulture (*Gyps africanus*) and African fish eagle (*Haliaeetus vocifer*), in Lochinvar National Park on the kafue flats, Zambia

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ABSTRACT

This study assessed the nesting patterns of *raptors, Gyps africanus* and *Haliaeetus vocifer* in Lochinvar National Park. The main objective of the study was to determine whether tree species, height, girth size, and habitat influenced raptor's nest placement within Lochinvar National Park. Two species were selected as indicator species for the raptors. Habitat types and tree species were identified and measurements of tree species with nests measured. It was found that the minimum height of nest placement was 10 meters above ground and Acacia woodland was found to be the most preferred habitat for nest placement. Raptors avoided human disturbance by placing their nests at least 100 meters away from human disturbance and from the National park boundary inwards or abandoning if human encroachment comes close to the nest. More research is required to assess nesting materials used, and to determine whether raptors can swap nets or return to the abandoned nests when human disturbance ceases.

Keywords: Raptors; Nest Placement; Tree Height; Lochinvar; Kafue Flats; Habitat

1. INTRODUCTION

Raptors are birds of prey which are on top of the food chain and as such play an important role in overall functioning of ecosystems. The word raptor is derived from a Latin word *raptare* meaning to seize and all raptors are biologically characterized by hooked bills and keen eyesight as well as powerful feet with sharp talons. This group of birds is facing global challenges due to habitat loss and reduction in prey species usually in competition with man. In this study, which was carried out in Lochinvar National Park, on the Kafue Flats, Zambia, two species of raptors; white backed vulture (*Gyps africanus*) (**Figure 1**) and African fish eagle (*Haliaeetus vocifer*) (**Figure 2**), were chosen as representatives of the group, as they are both susceptible to habitat conversion and loss of prey.

The white backed vulture for instance, faces similar threats to other African vultures, of being susceptible to; habitat conversion due to expanding agro-pastoral systems, loss of wild ungulates leading to a reduced availability of carrion, hunting for trade, persecution and poisoning. In East Africa, the primary issue is poisoning [1] particularly from the highly toxic pesticide carbofuran, which occurs primarily outside protected areas. The large range size requirements of this and *G. rueppellii* species puts them at significant risk as it means they inevitably spend considerable time outside protected areas [2]. Recent evidence from wing-tagging and telemetry studies suggests that annual mortality, primarily from incidental poisoning, can be as high as 25% for *G. africanus* (Kendall and Virani in press). In addition, the ungulate wildlife populations on which this species relies have declined precipitously throughout East Africa, even in protected areas [1]. In 2007, diclofenac, a non-steroidal anti-inflammatory drug often used for livestock, and which is fatal to *Gyps* spp. when ingested at livestock carcasses, was found to be on sale at a veterinary practice in Tanzania. It was also reported that in Tanzania, a Bra-

Figure 1. White backed vulture on a perch. Large tall trees are important for perching but branches must be large enough to support the weight.

Figure 2. Type of nest used by fish eagle. The nest is usually large measuring about 2 meters across and made of principally twigs.

zilian manufacturer had been aggressively marketing the drug for veterinary purposes and exporting it to 15 African countries [2]. In southern Africa, vultures are caught and consumed for perceived medicinal and psychological benefits and the decline and possible extirpation in Nigeria has been attributed to the trade in vulture parts for traditional *juju* practices. As a result of this and environmental pressures, it is predicted that the population of *G. africanus* in Zululand could be become locally extinct in 26 years, unless harvest rates have been underestimated, in which case local extinction could be 10 - 11 years away. There is evidence that it is also captured for international trade; for example in 2005, at least 13 individuals of this species being kept illegally in Italy were reportedly confiscated. Electrocution on power lines is also a problem in parts of its range, and it is vulnerable to nest harvesting or disturbance by humans [1]; perhaps more so than *G. rueppellii*, as it breeds in trees rather than on inaccessible cliffs.

The African Fish Eagles unlike the true fish eagles (Ichthyophaga) [3] are mainly fresh water birds and indigenous to sub-Saharan Africa, ranging over most of continental Africa south of the Sahara Desert and are is still quite common near freshwater lakes, reservoirs, and rivers. It requires open water with sufficient prey and a good perch. This is evident by the number of habitat types that this species may be found in, including grassland, swamps, marshes, tropical rainforest, fynbos and even desert bordering coastlines, but absent from arid areas with little surface water. Its choice of habitat, along water bodies often brings it in direct competition with humans, particularly fishing communities.

Fish eagles have a remarkable breeding behaviour. They pair up and mate for life. Pairs often maintain two or more nests, which they will frequently re-use. Because nests are re-used and built upon over the years, they can grow to be quite large, some reaching 2 m across. The nests are placed in a large tree and built mostly of sticks and other pieces of wood. Loss of habitat therefore, particularly cutting of big trees would affect the species. Like sea eagles, the African Fish Eagle has structures on its toes called spiricules that allows it to grasp fish and other slippery prey. The Osprey, a winter visitor to Africa, also has this adaptation. Should the African Fish Eagle catch a fish over 1.8 kg it will be too heavy to allow the eagle to get lift, so it will instead drag the fish across the surface of the water until it reaches the shore. If it catches a fish that is too heavy to even allow the eagle to sustain flight, it will drop into the water and paddle to the nearest shore with its wings. So if the shore line of water bodies is heavily settled by fishing camps as is usually the case in Zambia, its feeding would be affected. Preying on domestic fowl (chickens), also causes conflicts with humans and attempts to destroy fish eagles nests by humans are on record (personal obs.).

2. MATERIALS AND METHODS

2.1. Location and Description of Study Area

The study was conducted in Lochinvar National Park, Zambia which is 410 km^2 in extent and is located at Latitude 15°43' - 16°01' South, Longitude 27°11' - 27°19' East and altitude of between 970 and 1038 m above sea level.

About half of the area is part of the Kafue flood plain. The Lochinvar National Park is on the south bank of the Kafue River. Soils are dark grey and are of alluvial origin. South of the flood plain, is a flat *Terminalia* zone on sandy clay to clay soils which are water logged during the wet season. Hot springs which are indicative of a structural geologic fault occur where the woodlands meet the southern boundary of the southern edge of *Terminalia* zone. Average annual rainfall is 750 mm. Dominant grass species on the flood plain vary. However, the most common species are: *Oryza birthii*, *Vossia cuspidata*, *Echinocloa stagnina* and *Panicum ripens*. The commonest herbs are *Aeschynomone fluitans* and *Nymphaea capensis*. *Steria sphacelata* is the characteristic species in the *Terminalia* grassland. This type of grassland is due to the high water table which is in this zone. South of the National Park is a fire climax woodland of *Acacia*, *Albizia* and *Combretum* spp. In terms of large mammals, the Kafue Flats in which Lochnivar National Park is located, has about 40,000 herds of endemic species of lechwe (*Kobus leche kafuensis*), several thousands of other species and has one of the largest concentrations of cattle in the country. The Kafue River runs in between dividing the Kafue Flats into North and South banks making it suitable for this study as the fish eagle is at home with fish in the Kafue River and lagoons while the white backed vulture feasts on cattle and wild animal carcasses (**Figure 3**).

2.2. Field Methods

The National Park was divided according to vegetation communities. Line ground transects were used in both wooded and flood plain habitats. A team of six researchers walked along the transect. Two were observing on the right hand side and two on the left hand side of the transect. One carried a fire arm for the protection of the research team against dangerous game such as African buffalo (*Syncerus caffer*) and the other member was navigating the transect to ensure that it is straight from one end of the vegetation community to the other. About 17% of the National Park was sampled.

The team members had a set of Garmin GPS 45 XL each, for taking GPS locations of all trees with nests, a pair of tasco 20 × binoculars for observing the species of raptor on the nest, Bushnell Yardage pro 500 range finder to measure distance from the roads, park boundary or human disturbance where necessary, one tree height measuring rod for measuring tree height, a 5 m steel tape for measuring tree diameter at 1.3 m above ground, and a canon power shot A 470 digital camera for taking pictures of the nests, birds in the nest and other critical features. Identification of trees with nests was done with the aid of Trees of Southern Africa [4]. Identification of raptors was done based on Oberprieler and Cillie's raptor guide of Southern Africa [5]. When a tree with a nest was observed, a GPS location of the tree was taken, the tree species name was identified and recorded and the bird in the nest identified and recorded as well. Tree height

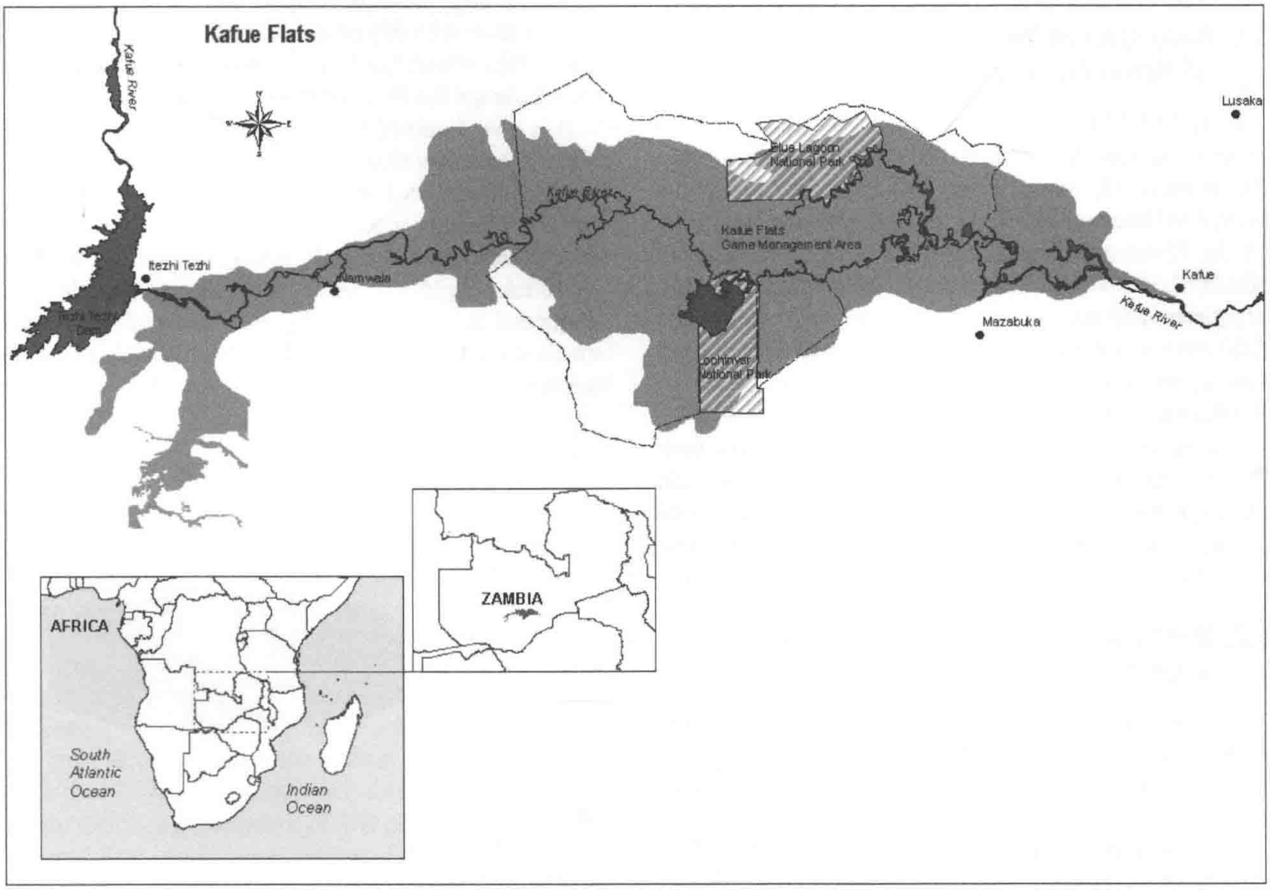

Figure 3. Location of study area, Lochinvar National park on the Kafue Flats, Zambia 2012.

was then determined and DBH taken. Distance from the park boundary was determined by the length of the transect and if the vegetation community was inside the National Park, the remaining distance was added. Since this was the breeding season, it was expected that the nest would have chicks or the parent would be present on visit to the nest or incubating eggs. Five other visits were made after the GPS locations were taken during the first visit. Where no visits of the parents were observed or chicks seen in the nest, an attempt was made to climb the nearest tall tree from which we used a pair of binoculars to see whether the nest was abandoned or not.

An abandoned nest was relatively easy to tell as there were no chicks in the nest, no parent brooding over the eggs or bringing food to the chicks, it had no fresh droppings on the ground, no fresh looking feathers which often drop from the nest or some food remains which may drop when the parent is feeding the young. Active nests had all or most of these features.

Data collected were entered on data sheets and pictures taken were downloaded at the base camp to verify the species in instances where some times only the head of the parent was seen.

3. RESULTS

3.1. Selection of Tree Species for Placement of Nests by Raptors

A total of 19 trees had raptor nests, of which 13 (68% of total) had active nests and six (6) (32%) had abandoned nests. Of the 13 nests 8 (62%) were for White backed vulture and 5 (32%) were for African Fish Eagle. Of the 13 occupied nests, 8 (62%) were on *Faidherbia albida*, 2 (15%) on *Acacia xanthophloea*, 2 (15%) on *Acacia nigrescens*, and 1 (7.5%) on *Albizia harveyii*. The difference in the placement of nests between tree species was significantly different (χ^2, P < 0.05) in favour of *Faidherbia albida* (**Figure 4**).

The mean height for the placement of nests in both species was above 10 meters above ground. In African fish eagle the mean height was 11.4 meters (n = 5) above ground and 16.6 meters (n = 8) above ground for White backed vulture.

3.2. Nest Placement with Respect to Vegetation Community

Four vegetation communities were surveyed, Acacia woodland, Mopane woodland, Shrubland, and flood plain. Of the four vegetation communities, 6 (46%) were in *Acacia* woodland, 5 (39%) in Mopane woodland, 1 (7%) in shrubland, and 1 (7%) in flood plain. The difference in nest placement was found to be significantly different in favour of *Acacia* woodland (χ^2, P < 0.05), (**Figure 5**).

3.3. Nest Placement in Relation to Distance from Human Activity

Results obtained suggest that raptors avoided human disturbance by abandoning nests. As reported above, the total number of nests observed during the study was 19. Of the 19 nests, 13 (68%) were occupied (active) and 6 (32%) were abandoned (inactive). Of the 6 that were abandoned 5 (83%) were within 100 meters of human disturbance near the park boundary, and 1 (7%) was near the main road inside the National Park. All the occupied nests were more than 100 meters away from human disturbance or National Park boundary, suggesting that human encroachment and associated activities can impact negatively on raptors by contriving them to abandon their nests.

4. DISCUSSION

4.1. Selection of Tree Species for Placement of Nests by Raptors

Large trees are important for the two species of raptors; first because the two species of birds are of large size and construct large nests to support their weight and that of their chicks. A highly placed nest also provides a vantage point from which the bird can have a wide view to scan the landscape for food.

It is also assumed that a highly placed nest would allow the nestlings to glide as they learn to fly. Such flight requires horizontal movement of air over an aerofoil surface. Perhaps it would also be easy for nestlings to take advantage of thermals, a large vortex of sun heated air to take flight [6]. Since raptor nests are made of dry twigs and an assortment of pieces of wood, it would be much safer to place a nest at a height which is out of reach of dry season fires. Placing the nest at lower height

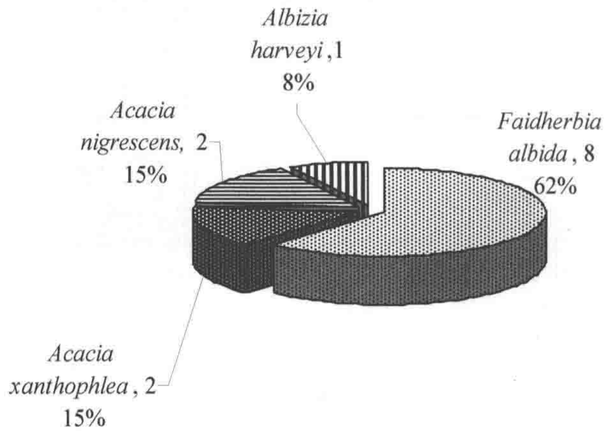

Figure 4. Selection of tree species for placement of raptor nests, Lochinvar National Park, Kafue Flats, Zambia, 2012.

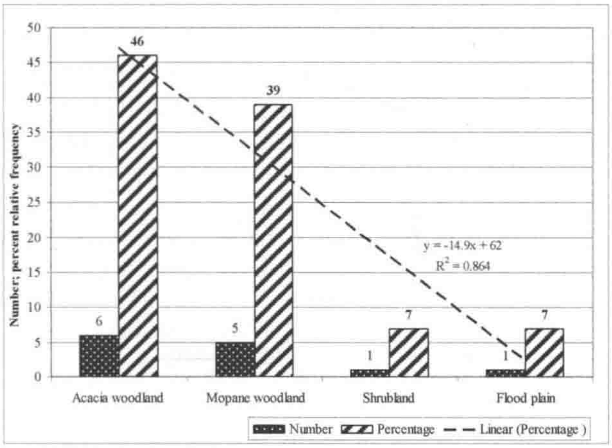

Figure 5. Raptor nest placement with respect to vegetation community selects, Lochinvar National Park, Kafue Flats, Zambia, 2012.

would expose it to wild fires, implying that the eggs or chicks would be destroyed by fire and the parents would have to repeat the task of rebuilding a new nest and re-investing energy in laying another clutch of eggs.

4.2. Nest Placement with Respect to Vegetation Community

The *Acacia* and Mopane woodlands are the only vegetation communities in Lochinvar National Park with large and tall trees which can accommodate raptor nests. Since raptors require placing their nests at least 10 meters above ground, they would only select vegetation communities with large tall trees. Additionally, the change in the flooding regime since the construction of the Itezhi Tezhi dam in 1979 [7], has contributed to the loss of some old trees and emergence of new secondary vegetation communities which may not yet have large trees suitable for raptor nest placement. The extension of agricultural activities on the periphery of the National Park coupled with charcoal production may have contributed to loss of large trees in neighbouring vegetation communities.

4.3. Nest Placement in Relation to Distance from Human Activity

The Lochinvar National Park, on the Kafue Flats is a source of fish protein from the Chunga lagoon and Kafue River. Once or twice a week, the National Park authorities permit fish traders to enter the National Park and buy fish from fisher men on the shores of Chunga lagoon. More than 30 pickup trucks each carrying more than ten people which is a minimum of 300 people may enter the National Park. Such large groups of people with the associated noise from vehicle exhaust systems and hooting would disturb the birds. Anecdotal reports also indicate that sometimes people stop to view raptor nests near the main road, which due to their size is an attraction and cannot be easily hidden from people's view. The Kafue flats is also home to more than 15,000 herds of cattle, and every day herds men bring cattle into the National Park for grazing. Such human disturbances combined are disruptive enough to force raptors to abandon their nests. Frequent visits by humans and passersby in general may reduce nest attendance by parents and may lead to the nest being abandoned. There is also a belief that fish eagle and vulture parts have magical and mythical powers and many people would need them to be used as medicine in magic spells. A nest for a vulture or eagle located in an area that is not secured would definitely be a target as people attempt to get at the parent bird or the chicks. This observation is in agreement with an observation made in Nigeria where vultures were caught and consumed for perceived medicinal and psychological benefits and the decline and possible extirpation in that country was attributed to the trade in vulture parts for traditional *juju* practices as indicated in [2] above.

5. CONCLUSION

After analyzing the data and testing the hypotheses, it was concluded as follows:

1) Tall trees of the height exceeding 10 m are critical for placement of raptor nests.
2) Human disturbance would lead to raptors abandoning their nests and thereby reducing breeding success.
3) Lochinvar National Park authorities should consider zoning key breeding areas for raptors in the National Park as low visitor use zones as frequent and unregulated visitation may lead to nest abandonment.
4) Construction of roads and other facilities for management and visitor use should take into account the need to maintain large trees for raptor nest placements.

It was therefore, established that mature trees of more than ten meters in height, located in areas with minimum human disturbance are critical to successful breeding of raptors on the Kafue Flats, Zambia. Opening of new roads, construction of new buildings as well as increaseing human activities in such habitats may lead to raptors abandoning their nests. New infrastructure in the National Park should avoid areas with high density of raptor nests as they are known to return to the same nest to lay eggs.

6. ACKNOWLEDGEMENTS

We wish to thank the Regional Manager Mrs. Marina Sibbuku for allowing the researchers to operate in the National Park un interrupted, Ms Hellen Nkole Mwaba the area ecologist, for providing logistics and participating in the exercise, Mr. Chaka Harold Kaumba for preparing the map, Microsoft Incarta Encyclopaedia for the pictures for white backed vulture and African fish eagle.

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2

Foraging habitat use of breeding barn swallow (*Hirundo rustica*) in farmland, estuary, and island

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ABSTRACT

The decline of barn swallow populations may be mainly caused by the reduction of their foraging habitat. A clear understanding of the links between proportions of available and used microhabitats of foraging barn swallows in farmland, estuary, and island habitats would enhance our understanding of the foraging habitat requirements of this species and on the effects of anthropogenic activities, such as habitat conversion (e.g., land to water, crop fields to non-arable land), on their distribution. We hypothesized that: 1) foraging swallows would be more abundant in the most common microhabitat; and 2) swallow abundance would decrease with increased foraging distance from the nest-site. As predicted by our first hypothesis, swallows were more abundant in the most common microhabitat (*i.e.*, crop fields in farmland and non-arable land on the island). Our data also support our second hypothesis that increased foraging distances from the nest-site negatively affected foraging swallow abundance. In summary, barn swallows foraged in the habitats most convenient to nest-sites, however, management of agricultural lands should include non-arable lands in the composition of available foraging microhabitats.

Keywords: Foraging Habitat; Foraging Distance; Farmland; Estuary; Island

1. INTRODUCTION

Conservation of animal populations requires information on where the populations are, why they are there, and where else they could be [1]. Therefore, temporal and spatial variation in habitat conditions may generate strong selective pressure for habitat selection [2], which in turn influences reproduction and survival of individual birds [3-5], and contributes to the regulation of bird populations [6,7].

Changes in agricultural land-use have been linked to significant declines of barn swallows in many parts of the world [8-14]. Over the last 70 years, agricultural intensification has divided historically multipurpose agriculture into specialization of livestock or row crop production [15]. Barn swallow populations have declined where livestock farming was replaced by row crop production [16,17]. The decline of barn swallow populations may have been caused by the reduction of its prey resources [18] and foraging habitat. Although foraging habitat use of barn swallows in livestock farmland has been described [19-21], to our knowledge, there have been no comparison studies of foraging habitat use among farmland and other habitat types (*i.e.*, estuary, island).

Swallows are aerial insectivores, feeding singly or gathering in large aggregations to feed on swarms of insects. The birds feed in a given patch for several minutes and move to a new patch when insect swarms disperse. In areas of high insect density, foraging swallows approach swarms slowly and then accelerates from below to capture the insects, because insects cannot escape to higher altitudes, insects are more visible against the sky than against the ground, and the counter-shaded predators themselves are less visible to the prey [22].

A clear understanding of barn swallow habitat use patterns among microhabitat of farmlands, estuaries, and islands would enhance our understanding of foraging habitat requirements for this species as well as the effects of anthropogenic activities, such as habitat conversion (e.g., land to water, crop fields to non-arable land), on their distribution. The principal objectives of this study were to compare the patterns of foraging habitat use in different land-cover areas. We hypothesized that: 1) foraging swallows would be more abundant in the most common microhabitat; and 2) swallow abundance would decrease with increased foraging distance from the nest-site.

2. STUDY AREA AND METHODS

2.1. Study Area

This study was conducted in Geoje (34°51'N, 128°34'E) and Jeju (33°57'N, 126°17'E) island, Nakdong estuary (35°7'N, 128°56'E), and Kimhae plain (35°13'N, 128°52'E) in South Korea from March 2003 to September 2004. We quantified the surface area of the different microhabitats in a radius of 400 m around the island (4 foraging sites), estuary (10 foraging sites), and farmland (5 foraging sites) because we estimated that almost all foraging occurred within this range based on previous studies [18,19]. Each foraging site was divided into four microhabitat types: crop fields, non-arable land (ungrazed grassland, small woods), water (ditch, river, shore), and human settlements. All microhabitats were identified from field visits and aerial photography and then validated by the presence of barn swallows in each habitat type during data collection.

2.2. Data Collection

The use of foraging sites by adult barn swallows was quantified using focal-nest observations (15 minutes, [23]). One hundred individuals in farmland, estuary, and island sites were observed, respectively. During observations, the observers waited until an adult left the nest and recorded what habitat types were used by the foraging swallow. The observers continued to follow the focal bird until it returned to the nest or was lost from sight. Birds were excluded from analysis if observers lost sight of the swallow in the foraging habitat before 15 minutes had expired. To prevent pseudoreplication, foraging observations were calculated only once per day for each nesting pair. The number of swallows observed was foraging individuals at 50 m distance intervals from the nest. The foraging habitats and the distance ranges (e.g., <50 m, 50 - 100 m) from nest were marked before followed foraging swallows. The density of swallows was expressed as the accumulated number of swallows recorded by each habitat type (*i.e.*, farmland, estuary, island).

2.3. Statistical Analysis

Analyses of variance (ANOVA: PROC MIXED SAS 9.3) were used to test for statistical differences in breeding swallow densities and the proportion of foraging microhabitats among habitat types. For both ANOVAs, data were tested for normality with the Shapiro-Wilks test. In the event that the residuals were not normally distributed, the data were natural log-transformed. Significant ANOVA effects were tested by post-hoc comparisons of Tukey adjusted least squared means. We also performed two generalized linear models (GLMs; PROC GLIMMIX: SAS 9.3). The first GLM compared the abundance of foraging swallows in different microhabitat types within the three larger habitat types with a cumulative logit link function and multinomial error distribution. The second GLM fit an exponential decay model's (PROC GLIMMIX: SAS 9.3) assessing the relationship between distance and natural log-transformed abundance with an identity link function and normal error distribution. For all GLMs, alternative exponential family error distributions and link functions were explored (e.g., identity or log links and negative binomial or poisson distributions) and the final combination of link functions and error distributions were selected by inspecting the Pearson chi-square/degree of freedom statistic and mean-variance plots [24]. For all analyses, significance level was set at $\alpha = 0.05$.

3. RESULTS

We found 219 breeding pairs and 921 barn swallows in 24 sites from March-September 2003 and 2004. Both breeding individual density ($F_{2,3} = 1.50$, $P = 0.35$) and breeding pair density ($F_{2,3} = 2.57$, $P = 0.22$) in farmland, estuary, and island did not statistically differ, respectively. The portion of crop fields was higher in farmland than in estuary and island sites ($F_{2,21} = 14.95$, $P < 0.001$). The proportion of human settlements and non-arable land in island was greater than farmland and estuary sites, respectively (human settlements: $F_{2,21} = 8.72$, $P = 0.002$, non-arable land: $F_{2,21} = 17.62$, $P < 0.001$). Water portion did not differ among farmland, estuary, and island ($F_{2,21} = 2.56$, $P = 0.11$).

In crop fields, foraging swallow abundance in farmland was higher than swallow abundance in estuary and island habitats but abundance over water areas was greater in island habitat than in farmland or estuary habitat ($F = 24.77$, $df = 7$, $P < 0.001$, **Figure 1**). Abundance in non-arable land and human settlements did not differ among farmland, estuary, and island habitats. The abundance of foraging barn swallows in farmland ($F = 53.88$, $df = 6$, $P < 0.001$), estuary ($F = 54.47$, $df = 6$, $P < 0.001$), and island ($F = 268.58$, $df = 6$, $P < 0.001$) decreased as distance from the nest-site increased (**Figure 2**).

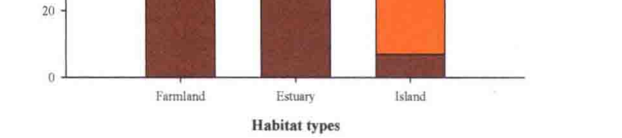

Figure 1. Distribution of 100 foraging barn swallows across four microhabitat types in three habitat types.

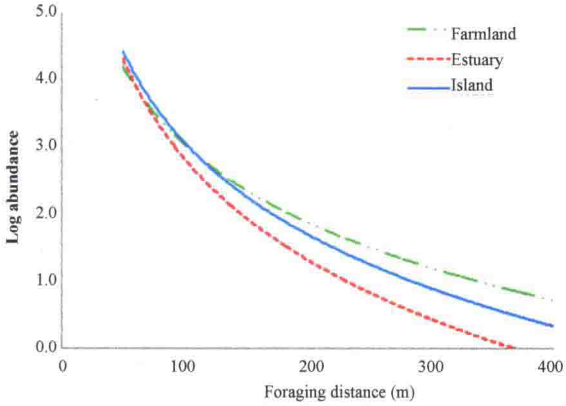

Figure 2. The log-transformed abundance of foraging swallows in relation to distance from the nest sites in farmland, estuary, and island. The log-transformed abundances were quantified using focal-nest observations.

4. DISCUSSION

The relationship between microhabitat proportion of foraging area and foraging barn swallow abundance in each microhabitat varied among farmland, estuary, and island habitat types. As predicted by our first hypothesis, crop fields (*i.e.*, dominant microhabitat) in farmland and non-arable land (*i.e.*, the highest portion) in island had larger foraging swallow abundance than in other microhabitat types. Previous study [20] noted that foraging habitat selection of breeding barn swallows followed broadly similar patterns to the distribution of aerial invertebrates because invertebrates are aggregated within fields. In this sense, our finding suggests that the higher abundances of foraging swallows in a higher proportion (*i.e.*, more available) microhabitat among different habitat types may reflect the variation of their available prey resources.

Despite different foraging swallow abundance in a microhabitat across three habitat types, the positive association between the abundance of foraging swallows and most available microhabitat portion may be associated with vegetated boundaries (e.g., hedgerows or vegetated fence lines around crop fields or separating non-arable land), which were a consistent feature among these seemingly disparate microhabitat types. Previous study noted that the increased proportion of invertebrates occurred along hedgerows presumably because these boundaries reduce wind speed, which has been negatively correlated with aerial invertebrate densities [25]. Conversely, in open areas, greater wind speed disperses aerial invertebrates increasing difficulty in capture by foraging swallows. In addition, higher wind speeds are more energetically costly for swallow foraging [26], therefore, it is possible that swallows target vegetated boundaries with higher densities of aerial invertebrates and lower flight energy expense to reduce the metabolic costs of foraging [27].

Our data also support second hypothesis that increased foraging distances from the nest-site negatively affects foraging swallow abundance. Analysis of foraging distance indicated that barn swallows prefer to forage within 100 m from their nest in all habitat types. Similar patterns of foraging behavior (*i.e.*, foraging distance from the nest) in farmland, estuary, and island may be a result of co-varying prey distribution and energy expenditure by searching flight. When foraging barn swallows require a longer distance from the nest to search their prey due to lack of prey resources, daily expenditure rates can increase due to search flight [28].

The comparison of foraging swallow abundance with microhabitat composition and foraging behavior in different habitat types can be used to assess habitat requirements for barn swallow population. Our data suggested that non-agricultural land cover types (*i.e.*, estuary, island) are also important habitat as foraging site to breeding barn swallow population. If sustained protection of the breeding barn swallow population based on foraging habitat availability is desired, maintenance of non-agricultural lands in farmland, estuary, and island should be incorporated into a comprehensive conservation and management plan.

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