AVIAN RESPONSES TO VARYING LANDSCAPE PARAMETERS IN MANGROVE FORESTS OF COASTAL GUJARAT

Thesis submitted for the partial fulfillment of
M.Sc. Degree in Wildlife Science
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CERTIFICATE

This is to certify that **Ms Devanshi Kukadia** has carried out original research work titled **"Avian responses to varying landscape parameters in mangrove forests of coastal Gujarat"** for the partial fulfilment of Master's Degree in Wildlife Science from Saurashtra University, Rajkot. The study was carried out under our supervision from December 2014 to June 2015. We hereby certify that this work has not been submitted for any other degree to any other university.

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CONTENTS

Serial no.	List of abbreviations used
1	A=Area
2	DP=Dog pugmark
3	CV%CC= Coefficient of variance of percent canopy cover
4	D=Dog presence
5	ED=Edge Density
6	MPAR= Mean Perimeter Area Ratio
7	TD= Tree density
8	XCC= mean canopy cover
9	Sp= Species
10	Obs= Observation

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Summary

1. Mangrove systems are the most productive ecosystems on the earth. The mangrove environment provides living space for dependent biota of more than two thousand species of flora and fauna of resident, semi-resident or migratory wildlife. The conversion of large contiguous tracts of the tropical mangrove forests to smaller patches embedded in a landscape matrix surrounded by human-altered habitats is one of the most serious concerns as it would affect their associated species such as birds, fishes, etc. In this context, this study was carried out aiming at discerning the responses shown by avifauna to varying landscape parameters like the mangrove patch characteristics, the level of disturbance and the structure of mangrove vegetation. Therefore, the abundance and diversity of the avifauna in mangrove forests at twenty selected sites on the coasts of Gujarat were investigated using point count surveys for a period of five months (December 2014-April 2015).

2. A total of 98 points were laid across the twenty patches of mangroves and surveyed twice during winter and summer seasons, respectively. Data were collected from the four replicates of each point during the entire study period. The total area surveyed during the study at these twenty mangrove patches was 47.97sq.km. These patches were ranging from various size classes with the smallest patch of the size of 0.125sq.km to the largest patch size was of 10.49 sq.km and were distributed throughout the coastline of 1650 km long. Habitat correlates such as structural and floristic characteristics of mangroves were quantified for each patch to establish their relationship with avifaunal abundances.

3. Despite recording only 7 species of mangroves in the twenty patches, a wide variety of birds totaling to 119 species were recorded from the mangroves during the two seasons, i.e. winter and summer during the study.

4. From the data collected by the variable-width point counts, the mean density of birds from the patches were calculated to be 6.485/ha in winter and 4.898/ha in

summer. The diversity of birds varied across the seasons. A total of 104 species of birds were recorded during the summer season as compared to 117 species of birds in winter season.

5. Large contiguous patches of mangroves were found to be supporting fewer species of birds than the smaller patches. The avian species richness of the smaller fragments were largely governed by the adjoining environment settings (matrix) of the patch. Therefore, the study found that the diversity of the birds was not found to be getting influenced by the area of the patch as the species richness was found to be increasing with the number of the surrounding matrix.

6. It was found that the structural composition of mangroves especially the canopy cover was found influence the bird density and diversity greatly as with the increase in the canopy cover, the bird species diversity and density also increased in a patch.

7. The bird assemblages in the mangroves showed a significant response towards the disturbance. The disturbed patches contained an overlapping mixed composition of the forest birds and open country birds in an equal proportion, whereas the undisturbed patches showed less number of open country birds.

8. Based on the study, it is suggested that the larger sized mangroves patches are important for their ineffable ecological services, therefore, these patches should be protected and conserved. Similarly, the smaller and fragment of mangroves patches are also equally important as they hold a good number of avifaunal species and hence, we have to adopt some strategies to conserve all the remaining - large contiguous and small fragmented patches of the mangroves from further degradation.

1. Introduction

Globally, mangroves occupy about 181, 000 km^2 of tropical and subtropical coastline. Mangrove ecosystems are among the most threatened habitats in the world (Luther and Greenberg, 2009). They are an important source of primary productivity and perform extremely important ecosystem functions and they harbour a high diversity of fauna for their relatively depauperate flora (Alongi, 2002). Mangrove forests are architecturally simple compared to rainforests, often lacking an under-storey of ferns and scrubs, and are ordinarily less species-rich than other tropical forests. Animals found within mangrove environments include a variety of taxa, many of which are vulnerable or threatened as a result of human activities in the coastal zone. Determining the value of mangroves and other estuarine habitats for these animals requires knowledge of their life history, physiology and ecology as they interact across the dynamic mosaic of available habitats (I. Nagelkerken,2008) Evidence suggests that mangroves are important to these species, but a lack of research is a major impediment to an evaluation of their mangrove dependency. Loss of biodiversity is, and will continue to be, a severe problem as even pristine mangroves are species-poor compared with other tropical ecosystems (Alongi, 2002).

1.1 The mangrove ecosystem

Mangroves are salt tolerant plant community found in tropical and sub-tropical intertidal region of the world receiving rainfall between 1,000 to 3,000mm and temperature ranging between 26-35°C. Mangroves trees are characterized by a number of interesting anatomical, morphological and reproductive adaptations (Saenger, 1992) including aerial and aboveground roots (pneumatophores), salt glands, buoyant seeds, and vivipary (where seeds germinate while attached to the parent tree). These and other distinctive features enable them to thrive in dynamic coastal environments subject to periodic tidal flooding, in substrates that may be waterlogged, anoxic, saline and unconsolidated.

Mangroves are a valuable ecological and economic resource, being important nursery grounds and breeding sites for birds, fish, crustaceans, shellfish, reptiles and mammals; a renewable source of wood; accumulation sites for sediment, contaminants, carbon and nutrients; and offer protection against coastal erosion. As high biomass forests they produce copious amounts of organic material that, when broken down into detritus, or re-cycled by crabs into micro-particulates, feeds into complex coastal food webs (Lugo and Snedaker, 1974; Hutchings and Recher, 1982; Lee, 1998) Mangroves, located at the confluence of land and sea are highly complex as well as fragile ecosystems (McLeod and Salm 2006).

Mangroves harbour a wide variety of marine and terrestrial organisms from large endangered mammals to endemic bird and ant species (Cannicci *et al.*, 2008; Nielsen, 1997). It demonstrates a unique ecological system as in no other habitat, do birds, bats and mammals co-occur with mudskippers, sea turtles, insects, marine worms and crustaceans. Despite their importance as a crucial resource for many tropical cultures, mangrove environments in most of the countries have traditionally been maligned as pestilent useless wastelands. To many, mangroves are still viewed only as insect-ridden, impenetrable swamps with strange looking trees and evil-smelling, shoe-swallowing mud.

Although mangrove ecosystems have tremendous economic and ecological value for coastal communities and associated species, coverage and quality of the mangroves are declining at an alarming rate (Duke *et al.*, 2007). The causes of this decline are mangroves are threatened by habitat loss, more so than tropical rainforests and coral reefs (Valiela et.al 2001), and it is presumed that they will be severely affected by global warming and rising sea level (Ellison and Farnsworth, 1997). Hence, there is an urgent need to understand the processes driving the assembly of floral and faunal communities inhabiting mangroves to ensure their conservation.

1.2 Avifauna of mangroves:

Birds contribute most significantly to the diversity of terrestrial vertebrates. Mangrove habitats play host to a moderate number of bird species around the globe. Mangroves, as ecosystems have been studied extensively but mangrove fauna has been little studied. Globally, 790 species of birds were recorded to be found commonly in the mangroves of which only 48 bird species are only restricted to mangroves (Luther and Greenberg, 2009).

Mangrove forest represents an important habitat for birds in many parts of the world (South America - Lefebvre and Poulin, 1997; India - Gopi and Pandav, 2007; Australia-Metcalfe, 2007). Most diverse are the Queensland mangroves of Australia, which host 186 bird species (Noske, 1996). Other records are 135 in Peninsular Malaysia (Nisbet, 1968), 125 in Guinea-Bissau, West Africa (Altenburg and van Spanje, 1989), 104 in north-western Australia (Noske, 1996), 94 in Surinam (Haverschmidt, 1965), and 84 in Trinidad (Ffrench, 1966).

In southern India, in the less floristically diverse mangroves of Pondicherry, only 14 bird species including water birds were recorded (Saravanan *et al.,* 2008). A total of 41 species of birds representing 25 families were observed in Mangalavanam mangroves in Kerala (Jayson, 2001). About 32 bird species, belonging to the 19 families were recorded from mangroves in Kundapura, Udupi district, Karnataka during the year 2010-11 (Kumar and Kumara, 2011). A total of 263 bird species belonging to 63 families were recorded from the Bhitarkanika mangroves of Orissa in the year 2007 (Gopi and Pandav, 2007). Samant (1985) recorded 121 species of birds in mangroves of Ratnagiri, Maharashtra. Another avifaunal survey in the mangroves at Borivali, Mumbai reported a record of 66 bird species belonging to 25 families (Chauhan et al, 2008)

1.3 Mangroves as a habitat

Although mangroves are not primary habitat for many terrestrial fauna, they provide additional habitat, corridors between different types of habitat, temporary island refugia and provide relatively protected breeding sites for them (Hutchings and Saenger, 1987; Kutt, 2007). Many vertebrate species have broader distributions through other habitats and only utilize mangroves intermittently (Hogarth, 1999).Terrestrial fauna may use mangroves daily or seasonally, in response to opportunities for feeding or breeding (Hogarth, 1999; Lacerda *et al.,* 2001). Mangroves may provide temporary *refugia* for visiting terrestrial birds from neighbouring habitats during and after catastrophic events by providing reliable feeding sites and cover. Seasonal changes in foliage cover, vegetation structure and climatic conditions may also cause major changes in the patterns of bird distribution between different vegetation types (Woinarski *et al.,* 1988). Small size and isolation of forest fragments may result in edge effects and other area-dependent effects coinciding to affect avian diversity (Krűger and Lawes 1997). Habitat fragmentation and isolation also cause changes to foraging behaviour and species composition and the reduction in habitat area may even cause extirpation or extinction of area-sensitive species (Stouffer *et al.,* 2006).

1.4 Mangroves of Gujarat

Gujarat state has the second largest block of tidal forests of India after Sundarbans in terms of area coverage. Gujarat mangrove forest covers 1,103 km^2; 175 km^2 are moderately dense and 858 km^2 are sparse or open mangrove forests (FSI, 2013). Mangroves in the state are mostly confined to (a) Indus deltaic region i.e. Kori creek and Sir Creek area, (b) The Gulf of Kachchh, and (c) The Gulf of Cambay. Sparse patches of mangroves are also found on the Saurashtra coast.

A total of 15 mangrove species belonging to 10 genera and 7 families have been reported from the state. (Pandey and Pandey, 2009). Both west and southern regions of the coast is surrounded by 10-13 km wide marshy zone occupying the intertidal limits and drained by the muddy channels in which the sea flows at low tide to join the main creeks (Stanley, 2004).

1.5 Avifauna in mangroves of Gujarat

An intertidal coastal system with mangroves along the coast of Gujarat offers conducive conditions for feeding, breeding and shelter to a variety of birds. Birds find the most congenial environment in the mangrove forests lining the state they are well placed to reach their food supply like the fishes, squids, mudskippers and other animals, during low tide. All along the creek and in and around several islands, mangrove trees are seen crowded with many species of birds feeding on a variety of food available in these ecosystems. A survey reported a total of 94 species of birds from the Gulf of Kutch area (V.R. Nair, 2002). Another survey in November, 1999 in the Mundra region documented 140 species of which 85 terrestrial and 55 aquatic and 71 were resident species, 44 migrant and 25 resident migrant birds (Nair, 2002). 65 bird species belonging to 17 families were recorded from the mangrove creek system at Jakhau in the surveys carried out in the winter months of the years 2011-13 (Dharaiya and Prajapati, 2014).

Eighty-six (86) avifaunal species were reported in the Kori creek region and sixty-two (62) species of birds were reported from the mangroves of the Gulf of Khambhat area by Stanley (2004). Very few studies have been carried out on the birds of Indian mangroves particularly on the coast of Gujarat. The present study compares the diversity and the abundance of the birds in 20 mangrove patches spread out throughout the coast of Gujarat. It attempts to relate the diversity and abundance of the birds with various landscape parameters like the structure of mangrove vegetation, the size of the patch and the disturbance present in the patch.

1.6 Objectives

The major difficulties in conserving the birds are the limited availability of the habitats. In a developing country like India, this is particularly true as all the available habitats are under human pressure. As a result, some habitats have totally vanished while others remain as fragments. Since we are often left with only patches of remnant habitats, we have to adopt strategies that help us to get the best out of these small and patchy fragments. In this context, this study was undertaken to study the effects of fragmentation and other habitat variables on the avifauna of the mangrove patches situated across the coastline of Gujarat.

The underlying objectives of this study were;

1. To determine the species composition of avifauna occurring in the mangrove patches in relation to the vegetation structure, composition and landscape parameters.
2. To determine the effects of the vegetation of the patch, the size of the patch and the disturbance in the patch on the avifaunal diversity and abundance.

This objective is used to answer the following research questions:

1. How diverse are the mangrove forests of Gujarat with respect to avifauna?
2. How do varying mangrove patch sizes affect avian diversity and density across different seasons?

3. How are vegetation structures related to avian diversity and density across the mangrove patches?
4. How is disturbance related to avian diversity and density across the mangrove patches?

1.7 Study Area

The study was carried out in the mangrove forests situated along the 1650 km coastline of the Gujarat State. Large and small patches of mangroves are present throughout the coastline of the entire State, spreading across the Gulf of Kutch, the Saurashtra coast and the Gulf of Khambhat extending upto South Gujarat. The selected mangrove patches for intensive sampling were spread across eleven coastal districts of the state namely Kutch, Jamnagar, Porbandar, Junagadh, Amreli, Bhavnagar, Bharuch, Surat, Navsari and Valsad. Further, three more patches were selected in the adjoining Union territories of Daman and Diu. The patches were situated far apart from each other with minimum patch isolation distance of 3 km. from the nearest patch.

1.8 Location

The study area is located within 23°37'N and 68°14'E to 20°32'N and 72°53'E. The total linear distance covered during the study throughout the coastline is approximately 1650km. The significant rivers flowing in to the Arabian sea and making estuaries are Ambika, Auranga, Damanganga, Mahi, Narmada, Ozat, Purna, Sabarmati, Saraswati, Shetrunji and Tapti. The mangrove patches covered during this study are located near some of these major estuaries. The location of the selected 20 patches are given in the Table 2.1.

Table 1.1 GPS location of selected 20 patches of mangroves

Patch no.	Name	GPS location	
Patch 1	Kandla	23°00'37.2"	70°08'24.6"
Patch 2	Mundra	22°46'43.7"	69°36'20.9"
Patch 3	Jakhau	23°13'30.3"	68°37'37.4"
Patch 4	Kori	23°33'07.0"	68°28'15.7"
Patch 5	Dwarka	22°13'38.1"	68°59'01.7"
Patch 6	Porbandar	21°39'08.0"	69°35'46.34"
Patch 7	Una Sp	20°43'09.99"	70°58'47.97"
Patch 8	Diu	20°43'00.0"	70°57'28.2"
Patch 9	Khera	20°58'22.8"	71°37'26.3"
Patch 10	Pipavav	20°55'35.5"	71°30'06.6"
Patch 11	Jafrabad	20°52'12.2"	71°23'43.9"
Patch 12	Dahej	21°46'11.4"	72°33'19.7"
Patch 13	Dandi	21°19'39.0"	72°36'58.9"
Patch 14	Dumas	21°05'41.67"	72°42'12.69"
Patch 15	Nemarai	20°56'20.36"	72°48'28.77"
Patch 16	Mendhar	20°44'35.77"	72°53'2.53"
Patch 17	Kadiya	20°27'52.7"	72°51'22.8"
Patch 18	Daman	20°24'47.5"	72°50'33.9"
Patch 19	Una FRH	20°44'30.00"	71°00'09.58"
Patch 20	Tunda	21° 7'47.88"	72°40'32.47"

1.9 Climate and Rainfall

The climate of the state is very diverse. The winters are mild, pleasant and dry with average temperature 29°C to 12°C, but it goes upto 4°C in the arid regions of Kutch. The summers are extremely hot and dry with the temperature around 49 °C to 30 °C. The rainfall varies a lot throughout the state. Though mostly dry, it is desertic in the north-west specifically in the Kutch district, the southern districts are wet due to a heavy monsoon season

1.10 Map of the study area

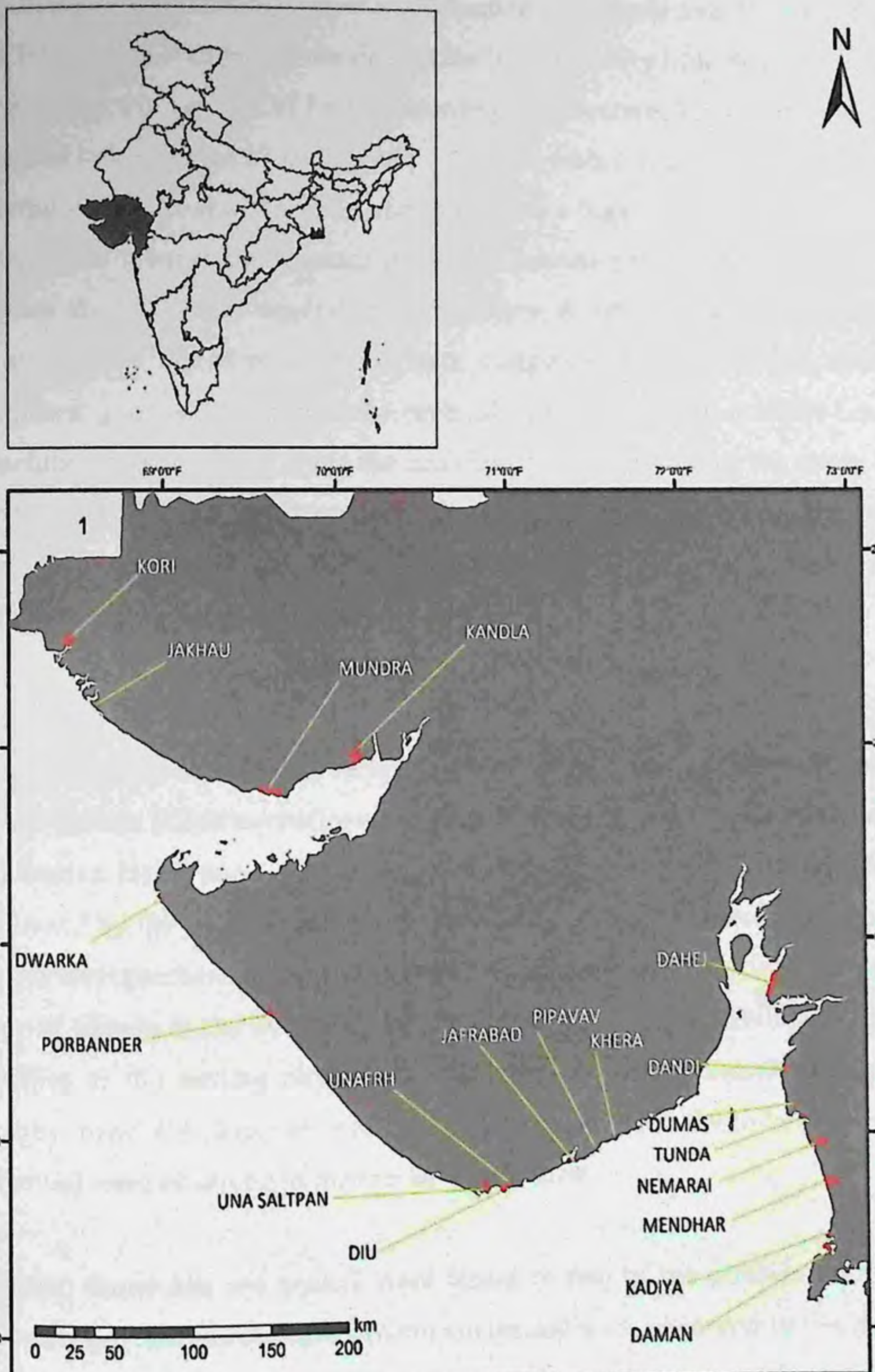


Figure 1.1 : Map showing the demarkated mangrove patches across the coastline.

1.11 Mangrove biodiversity of Gujarat

Vegetation

The mangrove forests are generally classified as Littoral and Swamp Forests (Champion and Seth, 1968). The mangrove flora of the State has very little diversity as compared to the other mangrove regions of India. According to literature, 15 mangrove species have been reported belonging to 10 genera and 7 families from Gujarat. But the species are unevenly distributed across the shoreline and they show a highly skewed distribution. The skewed distribution favours one species *Avicennia marina* predominantly, which contributes to most of the mangrove vegetation of the state. Another important species of mangroves found scantily distributed in the state comprise of *Ceriops tagal, Sonneratia apetala, Bruguiera gymnorrhiza, Aegiceras corniculatum* and *Acanthus illicifolius.* The mangrove associated species found along the coastline and noted during the study includes *Suaeda nudiflora, Salicornia brachiata, Suaeda fruticosa* and *Aeluropus lagopoides. Salvadora persica, Cressa cretica* and *Arthrocenemum indicum* were found to be occurring in the vicinity of the mangrove vegetation.

Fauna

The mangroves do not have a high density of mammalian fauna. However, during the survey, Jackals (*Canis aureus*) were encountered in a few patches like Mendhar, Una, Tunda and Dumas. Jackal pugmarks were found in several other patches and their presence was confirmed by the local people of that area. Fox (*Vulpes bengalensis*) pugmarks were found from several patches like Kori, Una and Khera. The local people claim the presence of fox on many of islands in the Gulf of Kutch where they seem to be thriving on fish, crabs and the juveniles of the nesting birds. Nilgai (*Boselaphus tragocamelus*) was seen in mangrove patches near the Pipavav port. Besides, Indo-pacific humpbacked dolphins (*Sousa chinensis*) were observed in the creeks near Jakhau.

Reptilian fauna like sea snakes were found in two of the patches i.e. Dahej and Dandi. Interestingly, saw scaled vipers (*Echis carinatus)* were observed in the mangrove patch of Kandla.

Mudskippers were recorded from most of the patches. Molluscans like *Balanus Amphitrite, Cerithidea cingulate, Telescopium*, etc, were recorded. Crabs like *Parasesarma plictum, Scylla serrata, Metapograpsus messor, Ocypode ceratophthalmus, Grapsus albioneatus*, etc. were observed during the study. Fiddler crabs belonging to genus Uca were also found from several patches. Shrimps were found from certain patches. Spiders were also found in most of the mangrove patches.

Birds

The mangroves harbor a moderate diversity of the birds. A total of 119 species of birds belonging to 47 families were observed while surveying 20 patches distributed throughout the coastline during this study.

1.12 Description of selected patches

A brief description of the 20 patches selected for the study is given below

1. Jakhau

This patch is situated in Abdasa taluka of Kutch district. *Avicennia marina* is the predominant vegetation and vegetation of the patch is sparse with some taller and denser mangroves along the creek. The total area of the mangrove forest is 0.20 sq.km tree density was calculated to be 1633/ha. The patch is located adjoining the major road that connects to Jakhau port which is 3km away. Local communities have been observed entering the patch in order to collect the mangrove leaves as fodder for their livestock. The surrounding areas of the patch are used as grounds for drying the fish catch.

2. Kori

This patch is a part of Kori creek system of Lakhpat taluka in Kutch district and is very close to the international border and a glimpse of the dense mangrove forest of Kori creek can be seen through this patch. Vegetation is dense with *Avicennia marina* as the predominant species. Very few trees of *Ceriops tagal* were also found in the patch. This patch is protected by the armed forces on the border and thus has relatively difficult accessibility and hence it gets a higher degree of protection against biotic pressures. The area of this patch is 7.54 sq.km and it shows the luxuriant growth of the mangroves which represents the mangroves of the Kori creek. This patch is a very good breeding and sheltering ground for the birds. A heronry observed on the mature trees of mangroves during the survey. Mature tree density in the patch is 1366 /ha.

3. Mundra

This patch is situated in Mundra taluka of Kutch District. *Avicennia marina* is the predominant vegetation and the vegetation is fairly dense. A large number of birds were recorded in this patch. It covers an area of 3.23 sq.km. The patch is present in the vicinity of a huge commercial port. Fishing is also done in the creeks around the mangroves during high tide and hence the mangroves of this area are under tremendous anthropogenic pressure. The tree density of the patch was found to be 2200/ha.

4. Kandla

This patch is situated in Kutch district and has a total area of 9.51 sq km, *Avicenna marina* is the only mangrove species recorded in this patch. Mangrove vegetation varies from very dense (near the creek) to quite sparse (away from the creek). The mature tree density is 1667.00/ha. Domestic sewage channel pass near to this patch. The major threat to this patch is developmental pressures like road construction, construction on a railway line and the sewage and effluent outflow from the industries nearby.

5. Dwarka

The total area of this patch is 0.0094 sq.km. This patch is located in Dwarka taluka in Dwarka district. *Avicennia marina* is the predominant vegetation and the vegetation is fairly dense. Mature tree density is 1200.00/ha. Since this small patch is found near the famous pilgrim place, the patch is highly disturbed and domestic sewage was observed getting disposed of in the patch. Humans were also seen to be collecting crabs and shells of molluscans.The highway connecting the city passes from the periphery of the patch.

6. **Porbandar**

This patch is located in Porbandar taluka of Porbandar district with a total area 0.90 sq.km. *Avicennia marina* is the only mangrove species present in the patch and the vegetation is sparse at the edges and very dense around the creeks. Mature tree density is 1933/ha, with very high human disturbance and presence of domestic sewage. The patch is adjoining the road that leads to the port. It is very good breeding and roosting ground for coastal birds and important feeding ground for migratory birds. Fishing activities are carried out in the creeks adjoining the mangroves. A small-scale boat building industry is located in the vicinity of the patch.

7. Una (Saltpan)

This patch in Kodinar taluka of Girsomnath district is relatively undisturbed and is surrounded by number of unused salt pans in with a total area of the patch 0.316sq km. *Avicennia marina* is the predominant vegetation and the vegetation is sparse. Mature tree density is 1167/ha. The patch is located away from the roads and is not easily approachable

8. Una (Forest Rest House)

This is a highly disturbed and fragmented mangrove patch and is located in the Kodinar taluka of Girsomnath district. The area of the patch is 0.5685 sq.km and tree density is 1733/ha. Vegetation is relatively dense in this patch. The patch is located adjacent to the road and in close proximity of human habitation. The lopping pressure on the mangrove trees is high in this patch. Wetlands with tall grasses are located within a proximity of 100 meters from the patch.

9. Diu

This pristine patch of mangroves is located in the Fudam Bird sanctuary, Diu. It is a small patch with very little disturbance or anthropogenic pressures. The mangroves are sparse but denser and taller near the creeks. Human beings are involved in the collection of crabs and molluscans in the sparse mangroves outside the protected area. The area of this patch is 0.5733 sq.km and the tree density was found to be 1667/ha.

10. Khera

This mangrove patch is found on both side and edge of a big creek with a total area of 0.1499 sq km in Rajula taluka in Amreli district. *Avicennia marina* is the only species of mangrove present in this patch and the vegetation is sparse and highly stunted. The mature tree density is 1800/ha. This patch is moderately disturbed as a small number of people enter the patch. The vegetation is stunted hence the extraction of resources from these stunted mangroves by the people is almost negligible.

11. Pipavav

This is a small yet dense patch of mangroves is under Pipavav port authorities in Rajula taluka of Amreli district and is surrounded by the port infrastructures. The area of this patch is 0.3203sq.km. *Avicennia marina* is the species of mangrove present in this patch and the vegetation is very dense. The mature tree density is 1466/ha. The patch is highly disturbed as a result of the ongoing developmental activities occurring around it.

12. Jafrabad

This patch of mangroves is located in the Jafrabad taluka in Amreli district. It is situated right behind a huge cement factory, a small jetty and a huge harbour. The area of the patch is 0.1364 sq.km. Moderately sparse to denser vegetation of *Avicennia marina* is present in this patch. The human dependence is high as mangrove lopping is carried out in this patch by the locals. The tree density of trees in this patch was found to be 1867/ha. The area is polluted by the cement factory present in the vicinity.

13. Dahej

This patch is situated in Vagra Taluka in Baruch district, with an area of 10.49 sq.km. *Avicennia marina* is the predominant vegetation but is sparsely distributed. The mature tree density is 1733/ha. This is the largest patch selected for the study. The patch is located after a long stretch of salt pans along the coast. The patch is also in continuity with the Gujarat Maritime Board defense research station. The mangroves are protected as the entry in the defense station is restricted and the accessibility from the salt pans is low. The vegetation structure is sparse and stunted at the edges but dense in the central region.

14. Dandi

This patch is situated in Olpad Taluka in Surat District, with an area of 0.834 km. *Avicennia marina* is the predominant vegetation with sparse distribution and few trees of *Ceriops tagal* are also found. The mature tree density of A. marina is 1900/ha. The patch is located very close to the road and there are shrimp farms along the periphery of the patch. Small scale fishing is also done along the coast of Dandi. The movement of people in this patch is high. No evidence of lopping or wood cutting was found in the patch.

15. Dumas

This patch is situated in Chorasi Taluka in Surat, with an area of 0.1256 sq km. *Avicenia marina* is the tree species occurring mainly and *Avicenia alba* and *Acanthus ilicifolius* are present with a sparse distribution. The mature tree density of *Avicenia marina* was calculated as 1900/ha. The patch is situated near the road and it is close to a very famous beach for recreation. Human movement is very high in the patch accompanied by the littering. Resources are not extracted from the mangroves.

16. Tunda

The species of mangroves found in this patch are *Avicenia marina, Sonneratia apetala* and *Acanthus illicifolius*. The mangrove structure is starkly contrasting in this patch. It is unique in the way that the A. marina trees are more than 17m tall. The area of this patch is 0.148 sq.km. The densities of mangrove trees was calculated as 950/ha. Human movement in the patch is negligible as the patch is very difficult to access.

17. Nemarai

This patch is located in Jalalpore Taluka of the Navsari district. It is undisturbed patch located far away from the human habitation. Three species of mangroves namely *Avicennia marina, Acanthus illicifolious* and *Sonneratia apetala* were found in this patch with sparse distribution. One or two trees of *Ceriops tagal* were also noted from this patch. The area covered by this patch is 6.407 sq.km. The average tree density recorded from this patch is 1400 trees/ha.

18. Mendhar

This patch have very diverse mangrove species with a total area 5.124 sq.km and lies in Gandevi taluka and Navsari district. *Avicennia marina, Acanthus illicifolious* and *Sonneratia apetala* are the mangrove species found predominantly in the patch. This patch has mature trees and the tree density is 1200/ha. This patch also has a very few trees of *Kandelia candel*. The patch has prawn farms in its periphery and some small-scale fishing is carried out in the area. It is a moderately disturbed patch.

19. Kadiya

This patch shows a very good growth of *Avicennia marina. Acanthus illicifolious* and *Ceriops decandra* are also found in this patch. This patch is located in Daman taluka in Daman District with a total area of 0.31 sq km. The mature tree density of this patch was found to be 1467 trees/ha. Human pressure is high on this patch. A lot of signs of wood cutting and lopping were found in the patch. Fishing is carried out in the creeks nearby the patch and a fish landing center also occurs in the vicinity of the patch.

20. Daman

The total area of this patch is 0.731 sq km. It lies in Daman taluka of the Daman district. *Avicennia marina, Acanthus illicifolious* and *Sonneratia apetala* are the predominant mangrove vegetation in the patch.

Mature tree density of the patch is 1650/ha. This patch is very close to the highway and has human settlements in the proximity. Medium and large scale fishing activities were observed around the patch. Anthropogenic pressure was evident in this patch. Also sewage outflow from the nearby settlements was observed in this patch.

1. *Acanthus illicifolius*

2. *Avicennia marina*

3. *Sonneratia apetala*

4. *Ceriops tagal*

5. *Rhizophora mucornata*

6. *Avicennia alba*

7. *Kandelia candel*

Figure 1.2 Mangrove species observed during the study

Figure 1.3 Pictures of some of the mangrove patches selected for the study

Jakhau

Kandla

Mundra

Kori

Dwarka

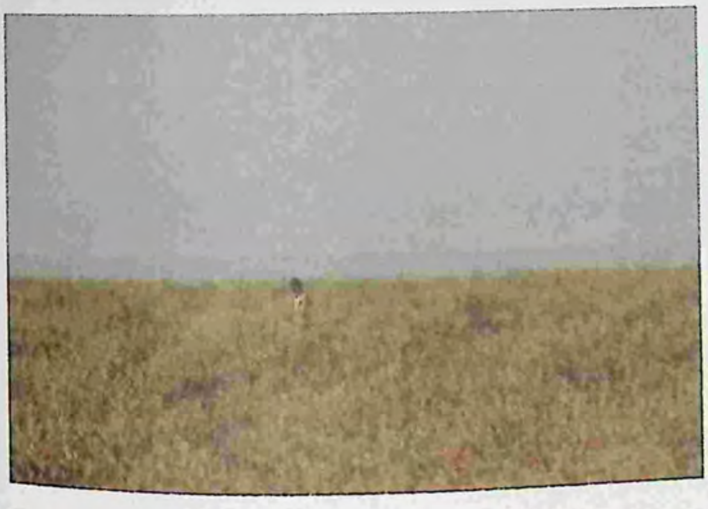
Porbandar


Jafrabad


Pipavav


Khera


Dahej


Dandi


Dumas

Tunda

Mendhar

Kadiya

Figure 1.4 Avifauna photographed at various sites during the study

Indian Roller
(Coraciasbenghalensis)

Demoiselle Crane
(Gurs virgo)

Ashy Prinia
(Prinia inornata)

Great Cormorant
(Phalacrocorax fuscicollis)

Pied Avocet
(Recurvirosta avosetta)

Pied Bushchat
(Saxicola caprata)

Black-winged Stilt
(Himantopus himantopus)

White-eye Buzzard
(Butastur teesa)

Black-headed Ibis
(Threskiornis melanocephalus)

White-breasted Waterhen
(Amaurornis phoenicurus)

Grey Heron
(Ardea cinerea)

Purple Sunbird
(Cinnyris asiaticus)

Spotted Redshank
(Tringa erythropus)

Southern Coucal
(Centropus sinensis parroti)

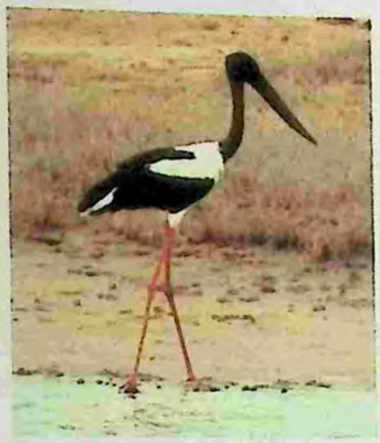
Osprey
(Pandion haliaetus)

Intermediate Egret
(Mesophoyx intermedia)

Eurasian Thik-knee
(Burhinus oedicnemus)

Large Grey babbler
(Turdoides malcolmi)

Black Drongo
(Dicrurus nacrocercus)



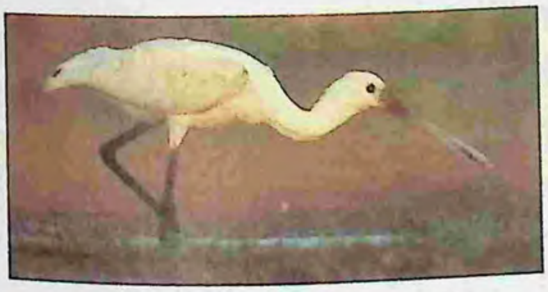
Black-necked Stork
(Ephippiorhynchus asiatcius)

Painted Stork
(Mycteria leucocepha

Purple Swamphen
(Porphyrio porphyrio)

Common Kingfisher
(Alcode athis)

Steppe Eagle
(Aquila nipalenis)



Eurasian Spoonbill
(Platalea leucorodia)

Montagu's Harrier
(Circus pygargus)

Brown-headed Gull
(Chroicocephalus brunnicephalus)

2. Study design

A reconnaissance survey was carried out throughout the coastline of the state during the month of December'14 to mid-January'15. A total of 53 patches were surveyed during this survey for the avifauna and also vegetation composition. After this reconnaissance survey, twenty mangrove patches were selected based on their species composition, the size of the patch, level of disturbance, surrounding matrix, fragmentation and accessibility. These sites were evenly spread across the entire coast of Gujarat. These 20 sites can be divided into four major groups based on their location. Of these, 4 patches were located in the Gulf of Kutch, 5 patches were selected on the Saurashtra coast, 3 patches on the western coast of the Gulf of Khambhat and 8 sites were located on the Eastern coast of the Gulf of Khambhat.

Four avifaunal surveys were carried out in the selected twenty patches after the first reconnaissance survey. The first two surveys were carried out in the winter season spanning over months of January end- February in the winter season. The second two surveys were carried out in the month of March that is the summer season.

2.1 Methodology

Bird sampling

The birds were surveyed at all the sites by a single observer at fixed points twice during each season. Point count census technique was used as the sampling technique for the study in the mangroves (Metcalfe, 2007). Point transects were preferred over line transects due to muddy terrain or vegetation types of mangroves that make it difficult to traverse a straight line while observing birds, and when conducting multispecies studies in patchy environments (Buckland *et al.*, 1993).

The point-count method, in which an observer records all birds detected within either a fixed or an unlimited distance from a point during a specified time period (Ferry and Frochot 1970, Hutto *et al.*, 1986), is the most widely used counting method in bird population studies (Ralph *et al.*, 1995, Rosenstock *et al.*, 2002).The observations were taken by entering into the patch and going to the fixed point in the patch. A short time gap of a few minutes was given before starting the actual point count in order to let the bird activities resume back to normal. Ten-minute point counts were done at each point during morning and evening. The point counts were of variable widths and all the birds seen at that point were recorded. Area proportional sampling was carried out so that the larger patches would have more points. In the patches with area less than 1sq.km, 4 points were laid. In the patches having an area of 1 sq.km to 5 sq.km, 6 points were laid and in the patches with an area greater than 5 sq.km, 8 points were laid. All the birds identified by the combination of their calls and observation. Only birds using the study plot were included. Birds merely flying through or over the site were excluded. All the point counts were done during the peak activity period of the birds that is in the morning hours from 6:30 to 10am and evening hours from 4pm to 6:15 pm. At each detection of bird species, the following variables were recorded-1) Species of the bird 2) Group size 3) Angle between the observer and the bird by using a Suunto compass 4) Distance between the observer and the bird was recorded using a laser rangefinder.

All in all, 98-point counts were laid throughout 20 patches and 2 temporal replicates were done per season and 2 seasonal replicates were done per patch. 392-point counts were done in totality, each for 10 minutes. So a total effort of 65.33 man-hours was made for the bird sampling across various patches.

Vegetation sampling

Vegetation sampling was done in each patch during December to mid-January. Vegetation sampling was done by laying 10*10 m plots in each of these patches. These plots were laid at a distance of 100m in a linear fashion perpendicular to the creek. Mangrove species and tree girth at breast height was recorded for each of the trees inside the plot. Smaller plots of 2*2m were laid inside these plots to calculate the number of seedlings and saplings. Canopy cover of each plot was measured using a densiometer.

The following habitat attributes were quantified to explain avifaunal responses to the structure of the vegetation-

Tree Density: number of live trees inside a plot were counted. A tree is defined here as a woody plant with >20cm girth at breast height.

Girth at breast height: G.B.H of all the trees were recorded in the plot by using a measuring tape.

Canopy cover: Percentage canopy cover of each plot was recorded by using a spherical densiometer. Three readings were taken in each plot and their mean value was calculated as average canopy cover.

Tree species richness: number of tree species recorded in each plot.

Disturbance

The disturbance was quantified for in each patch by noting the number of human beings and the number of stray dogs encountered in each patch. Any artisanal fisheries or collection activities from the mangroves or wood cutting and lopping were also recorded. Besides, human footprint and dog pugmarks were recorded in 3*3m plots laid in the patch and then averaged out so as to quantify the movement of humans and dogs in the patches even when they were not actually detected in the patches.

2.2 Data Analysis

Species Rarefaction curve

Species richness of birds in different mangrove patches were calculated using the Species Rarefaction Curves. Species rarefaction curves give an estimate of what the species richness or the assemblage would be if at that particular level of sampling effort. Further, species rarefaction curves can be used to make a direct comparison among assemblages differing in their sampling effort. The comparison can be directly made on the basis of number of individual in smallest sample (Maguran, 2004). This is done by taking a mean of repeated re-sampling of all pooled individuals or samples (Gotelli and Colwell, 2001). Thus sample-based rarefaction curves can be used to account for natural levels of sampling heterogeneity (patchiness) in data (Gotelli and Colwell, 2001). Therefore, the rarefaction curves of the bird species found in the patches during both the seasons, i.e. summer and winter were calculated using EstimateS 9.1.0 (Colwell, 2001) software.

Species richness estimates

Chao 1 and Jackknife estimators and one of the most popularly used estimators. Chao 1 gives an absolute number of species in an assemblage. The species richness estimates produced by Chao 1 is based on number of rare species (singletons and doubletons) in a sample and thus requires abundance data. Jackknife estimator on the other hand employs a number of species that occur only in one sample (Magurran, 2003). Therefore, the Program Estimate S 9.1.0 (Colwell, 2001) was used to estimate the Chao 1 and the Jackknife richness estimates of species in the patches across the seasons.

Dominance diversity curves (Rank abundance plots)

A dominance diversity curve (Whittaker 1965) display logarithmic species abundances against species rank order. These curves graphically represent relative species abundance data. These curves are a graph of the logarithm of relative species abundance of the species plotted on the y-axis and rank in abundance of the species on x-axis. The commonest species get plotted on the left side (low ranks) and rarest on the right side. The percentage relative abundances facilitate comparison between the different patches having different assemblages. Program BioDiversity Pro Ver 2.0 (McAleece, 1997) was used to generate rank abundance curves of the bird species across the patches in two seasons, i. e. winter and summer.

Spatial analysis of the patches

GIS and related technologies are used for a long time in studies related to the ecology. Using landscape metrics and digital data adapted with GIS have been made contributions to the landscape planning studies (Karadeniz and Gökyer 2005). Spatial analysis of the the landscape of the patches and the modelling of the attributes associated with each of the twenty patches was done using Patch analyst (Elkie *et al.*, 1999) which is an extension to the ArcGIS software system. Patch Analyst is one of the two main software programs used for landscape metrics calculation. This program was used to characterize patch pattern and assign patch values based on the combination of the patch attributes. ArcGIS 10.1 software was used.

Association of bird species with disturbance

The 119 species of birds observed during the study were divided into two classes Forest birds and Open country birds based on their general habits and by reviewing their ecology from the available literature. The increase in disturbance creates more niches for the open country birds to penetrate into the mangrove patches, and hence their number will be higher in the disturbed patches. These birds were then plotted across the patches to get a comparative idea about the disturbance in each patch. The species list of forest and open country birds can be seen in appendix 3.

Linear Correlation

The correlation coefficient (a value between -1 and +1) reveals the strength of relationship between two variables. A correlation coefficient of +1 indicates a perfect positive correlation and a correlation coefficient of -1 indicates a perfect negative correlation. In this study, a simple correlation was done to find the strength of correlation between the abundance of each species in all the twenty patches across the two seasons with the other dependent variables. MS Excel (2013) software used to find out the Pearson's correlation coefficient value *r*.

Density of the birds

Point counts are based on observed counts to estimate abundance, rely on the assumption that numbers of individuals detected (e.g. seen, heard, or captured) represent a constant proportion of actual numbers present across space and time. Density of the birds was estimated using the data from the point surveys by using the programme DISTANCE 6.0 (Thomas et.al, 2006). This programme allows for global estimates of density and also allows stratification according to sampling design and also 'post-stratification' for known subsets of data. In DISTANCE model) data sets containing clustered observations are modeled differently than are data sets consisting of single birds (Buckland *et al.*, 1993) The point survey data was analyzed for bird densities for each patch by stratifying the observations into two seasons i.e. winter and summer and then into the detection groups of low medium and high. The detection groups were made by calculating the average radial distances for each species and then classifying into bins of several classes. These bins were then plotted on a histogram and pooled together into low medium and high categories for each species. Models used by program DISTANCE are "pooling robust" to variation in detection probability (Buckland *et al.*, 1993). The underlying assumption was that the bird densities showed considerable variation across the seasons and that all the birds at that point were detected in this predominantly shrubby and stunted habitat with very little vertical habitat stratification during the 10 minute surveys and the detection probabilities decline with the increase in distance from the point.

Point count data were analyzed in the following manner:

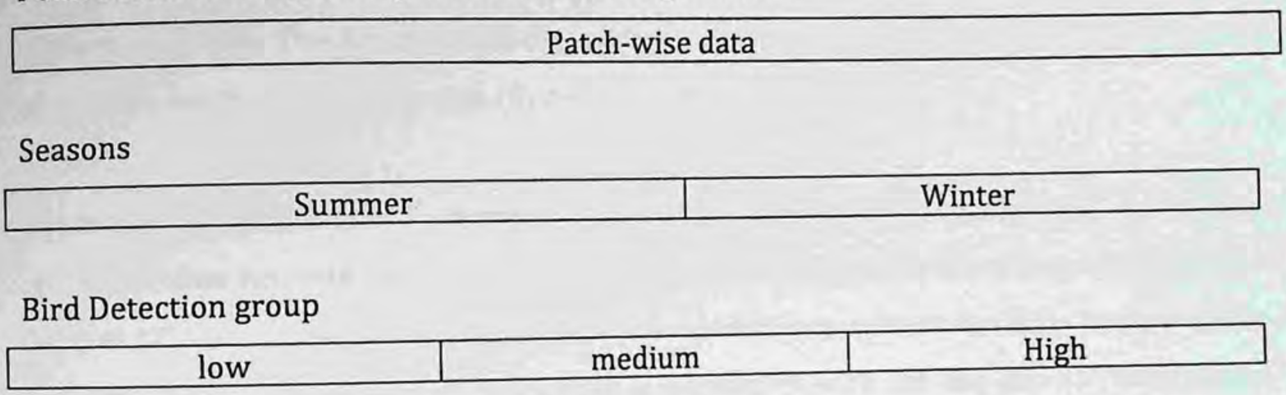


Figure 2.1 Hierarchical classification of data used in the analysis.

Relationship of Birds with Habitat variables

A data matrix of habitat heterogeneity variables like patch characteristics, vegetation characteristics and the disturbance observed were subjected to Principal Component Analysis (PCA) using software R 3.0.2 to examine the collinearity of the habitat heterogeneity variables and reduce the numbers of variables to a meaningful and orthogonal set (McCune and Grace. 2002).

Generalized Linear Models were used to examine the effect of habitat heterogeneity on bird species richness and density data from various categories using the statistical software R 3.0.2.

GLM is an extension of regression analysis and is a powerful tool for the application of regression models to a variety of non-normal response variables (Everitt and Hothorn, 2006).

GLM assumes independent or at least uncorrelated observations which were identified using PCA in the study (McCullagh and Nelder, 1983). Because the number of bird species observed are numerical counts, the GLMs were based on a Poisson distribution with a log link (Ln) function. To select among the competing models, an information theoretic approach was adopted based on Akaike's Information Criterion (AIC) (Burnham and Anderson, 2001). The AIC provides the evidence for the most parsimonious model in a set of *a priori* models that fit the data (Burnham and Anderson, 2001).

Canonical correspondence analysis (CCA) is a multivariate constrained ordination technique that extracts major gradients among combinations of explanatory variables in a dataset. CCA was done to relate bird species composition to various variables in the habitat. A multiple linear least-squares regression is performed with the site scores (determined from weighted averages of species) as the dependent variables and the environmental variables as the independent variables.

CCA is a direct gradient analysis technique and represents a special case of multivariate regression. The CCA assumes a unimodal relationship between species abundance and the relevant environmental variables. It creates synthetic variables (axes) that maximally separate (ordinate) the unimodal distribution of species. The eigenvalues associated with each axis give a relative indication of the ability of the axis to separate or order species distribution. (Bolger *et al.*, 1997). CCA was done on the species-wise data of birds for both the seasons. Since the results obtained were very clumped because of projection of 117 species in winter and 103 species in summer, along with the habitat variables and the patches, a simple linear correlation was done of each and every species with each and every variable before CCA and the species that showed the maximum positive and negative correlation with each of the variables were selected as representative species. The number of correlated species obtained in this way were considerably lower than the actual number of species recorded from the patch, but these fewer species make up the best representation of the entire dataset. A CCA was then performed on this a dataset which showed better results that could be interpreted.

3. Results

119 species of birds were observed in totality while sampling the study sites. Of these, 117 species were recorded during the winter season and 103 species were recorded in the summer season. This includes 1,369 detections in the winter season and 1,075 detections in the summer season.

3.1 Patterns in bird species richness across the mangrove patches

Winter

Species richness in winter across the patches was estimated. Chao-1 and Jack-knife 1 estimator were used to estimate the number of unsampled species in the fragment. Both observed and estimated richness showed that there were no significant trend with respect to the area of the patch in the winter season. The smaller sized Jakhau patch with an area of 0.20sq.km was found to have lowest estimated species richness while the medium sized patch with an area of 5.124 sq.km showed highest estimated species richness by the Jack-knife 1 estimator.

Table 3.1 Bird species richness across the patches in winter

Patch No	Patch Id	Area (km^2)	Obs. Richness	Chao 1 Mean	Jack 1 Mean	Shannon Mean	Density /ha
1	Jakhau	0.202993	26	25.81	23.32	2.5	7.016
2	Kori	7.548926	19	44.18	55.7	2.95	1.318
3	Mundra	3.236465	41	57.55	75.44	3.15	7.014
4	Kandla	9.511822	34	68.15	90.36	3.29	7.135
5	Dwarka	0.321297	31	76.3	100.83	3.38	8.725
6	Porbandar	0.90013	31	82.99	108.93	3.44	16.024
7	Una Sp	0.3167	11	88.2	115.84	3.51	14.610
8	Una FRH	0.568522	28	93.23	121.97	3.55	16.692
9	Diu	0.573307	16	97.89	127	3.58	7.097
10	Khera	0.149955	18	101.42	130.85	3.61	17.223
11	Pipavav	0.320345	20	103.88	132.98	3.63	23.424
12	Jafrabad	0.136487	23	106.6	135.89	3.65	8.300
13	Dahej	10.49312	33	109.05	138.34	3.66	7.084
14	Dandi	0.834936	22	111.09	140.04	3.68	9.016
15	Dumas	0.125626	23	112.7	141.5	3.68	11.200
16	Tunda	0.148184	22	113.96	142.11	3.7	6.074
17	Nemarai	6.407892	24	115.18	142.54	3.71	5.186
18	Mendhar	5.124	25	116.07	142.89	3.73	4.028

19	Kadiya	0.317748	20	116.94	142.87	3.72	2.912
20	Daman	0.731147	22	117.91	142.65	3.72	8.361

Summer

In the summer season, the estimated species richness was the lowest in the smaller sized patch Jakhau with an area of 0.20sq.km. The estimated species richness was highest in Daman patch (0.731 sq.km). Both the observed as well as estimated species richness showed there was no clear trend with respect to the area of the patch in the summer season.

Table 3.2 Bird species richness across the patches in summer

Samples	Patch Id	Area (km²)	Obs. Richness	Chao 1 Mean	Jack 1 Mean	Shannon Mean	Density /ha
1	Jakhau	0.202993	20	23.34	20.29	2.62	10.261
2	Kori	7.548926	16	40.04	46.99	3.04	2.156
3	Mundra	3.236465	21	51.66	63.07	3.25	3.504
4	Kandla	9.511822	24	60.15	76.16	3.38	9.938
5	Dwarka	0.321297	21	67.47	85.55	3.46	10.569
6	Porbandar	0.90013	26	73.39	93.23	3.51	6.8227
7	Una Sp	0.3167	11	78.01	99.35	3.56	4.73
8	Una FRH	0.568522	27	82.43	105.11	3.6	4.123
9	Diu	0.573307	14	85.39	109.6	3.63	3.875
10	Khera	0.149955	14	89.28	114.03	3.66	1.9899
11	Pipavav	0.320345	17	91.97	117.14	3.68	3.47
12	Jafrabad	0.136487	18	94.76	119.97	3.7	4.79
13	Dahej	10.49312	27	97.1	122.4	3.72	3.06
14	Dandi	0.834936	21	99.3	124.64	3.73	10.597
15	Dumas	0.125626	23	101.08	126.61	3.74	5.3308
16	Tunda	0.148184	22	102.95	128.03	3.75	6.1249
17	Nemarai	6.407892	22	103.47	128.76	3.76	1.7893
18	Mendhar	5.124592	17	104.32	129.1	3.77	3.7466
19	Kadiya	0.317748	19	104.96	129.35	3.78	2.8311
20	Daman	0.731147	21	105.5	129.6	3.79	4.7969

3.2 Comparison of species richness in the patches across the seasons

To compare species richness counts across different size classes of patches, sampling curves were generated by pooling all the similar sized patches into one size class and then by making a total of 3 size classes which includes all the 20 patches. Sample based rarefaction curves were then generated for each size class.

The rarefaction curve plots the number of species as a function of the number of individuals sampled. If one or more accumulation curves fail to reach an asymptote and sampling saturation is not achieved, the curves themselves may often be compared, after appropriate scaling using rarefaction (Gotelli and Colwell, 2001). Thus, rarefaction permits comparisons of species richness among communities when the total numbers of individuals or sample sizes and effort differ (James and Rathbun, 1981).

Sample-based rarefaction curves give a better estimate for patchy habitats, as against individual-based rarefaction curves which often tend to overestimate the number of species in such cases.

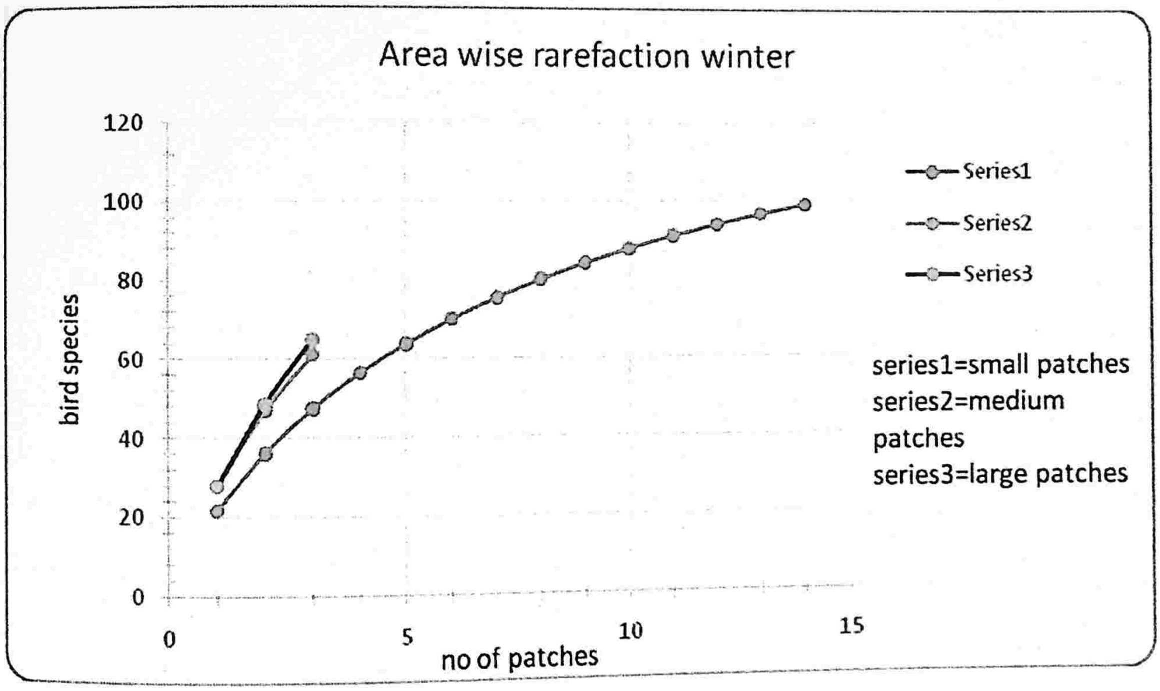


Figure 3.1 Rarefaction curve for birds in winter

Size class	Slope	S.E
1 (0-1 sq.km)	0.5491473	0.06370792
2 (1-5 sq.km)	1.65	0.9562659
3 (5-10 sq.km)	1.85	0.170544

Table 3.3 slope of rarefaction curves in winter

The rarefaction curves for species in winter showed the higher accumulation of species in the smaller patches. The medium and larger patches showed a rise because of the lack of sampling in those size classes (Fig 3.2). This is because, in the study, most of the mangrove patches considered belonged to the low size class. And hence the low size class shows certain amount of sampling saturation. The mean slope values for individual based species accumulation curves represent the rate of accumulation of species per unit individuals. The smaller size classes of patches show a maximum richness of individuals.

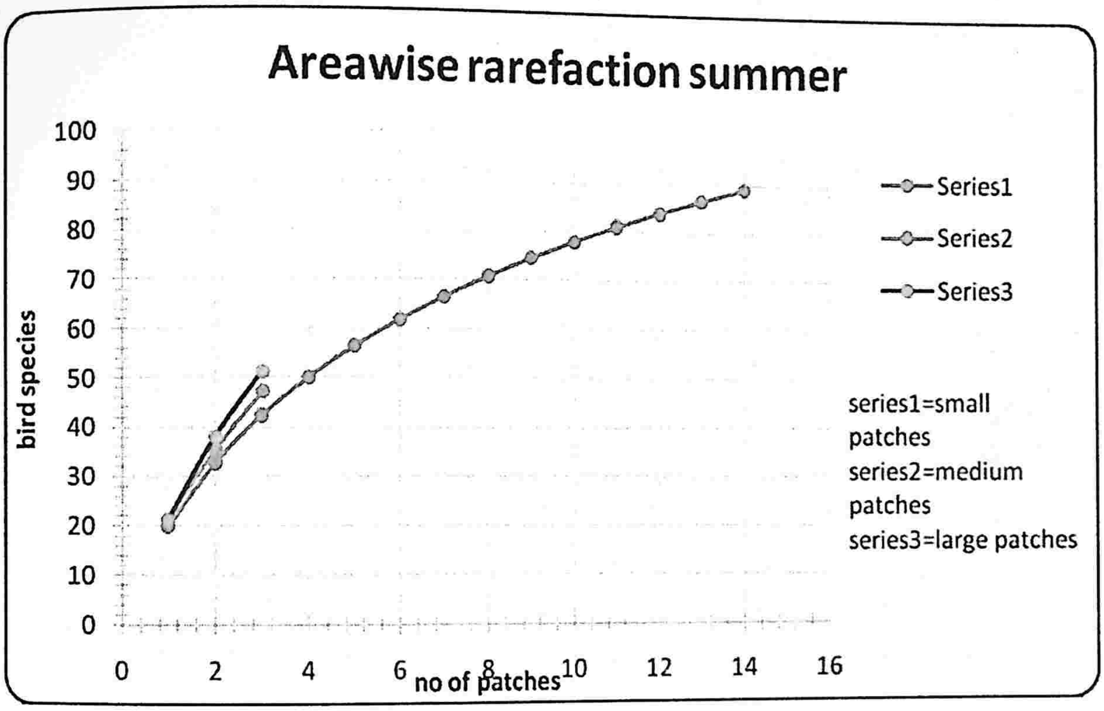


Figure 3.2 Rarefaction curve for birds in summer

Size class	Slope	S.E
1 (0-1 sq.km)	0.4906308	0.0659069
2 (1-5 sq.km)	1.2835	0.7420459
3 (5-10 sq.km)	1.4835	0.8586804

Table 3.4 slope of the rarefaction curve of summer

The rarefaction curves for summer bird species gave similar results as that of winter. The rarefaction curves for smaller patches reached almost at the asymptote, but the curves for the medium and large sized patches showed a rise because of the lack of numbers of large sized patches in the survey.

3.3 Comparison of bird species richness in each patch according to seasons

A comparison of the proportion of the forest bird species (classified on the basis of Ali, 1996) detected in various patches provided a good representation of the changes in their species diversity across the seasons. The bird species richness was noted to be considerably high in winter in some patches, whereas it was equal in some other patches (Fig 3.3).

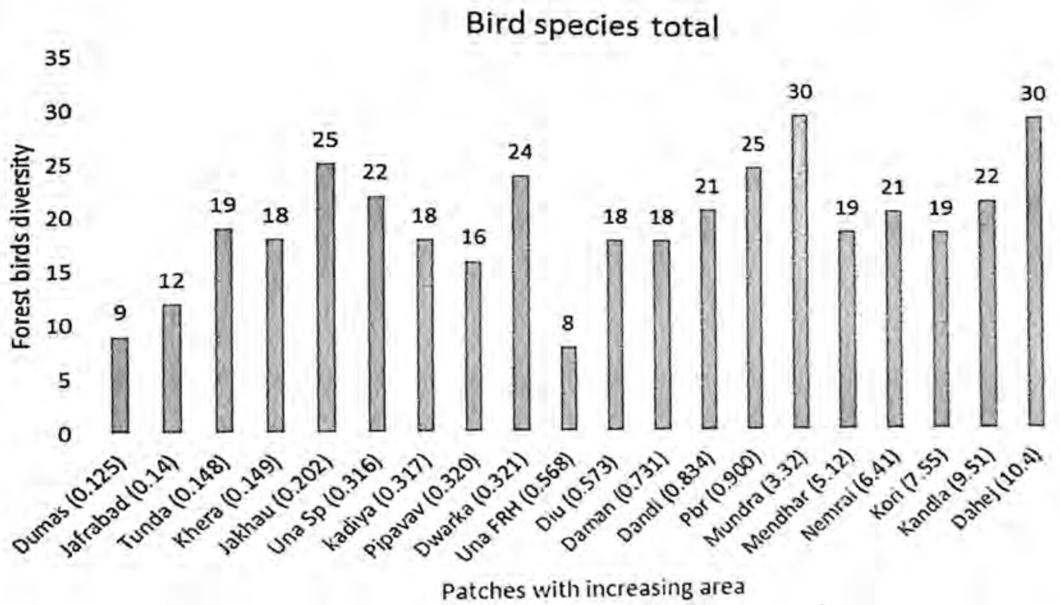


Figure 3.3 Forest bird species richness across patches in winter and summer

3.4 Rank Abundance curves

Rank abundance curves were plotted for all twenty patches for each season with bird abundance data. The rank abundance curves for the winter season depicted that the patches of Jakhau, Khera, Dandi and Jafrabad showed log-series distribution. The curve is at first steep over the low rank of the most abundant species and then shallow over the species having moderate abundances. Most of the other patches fit in the log-normal distribution pattern. Most of the communities in nature fit into the log -normal series generally. These communities represent large communities.

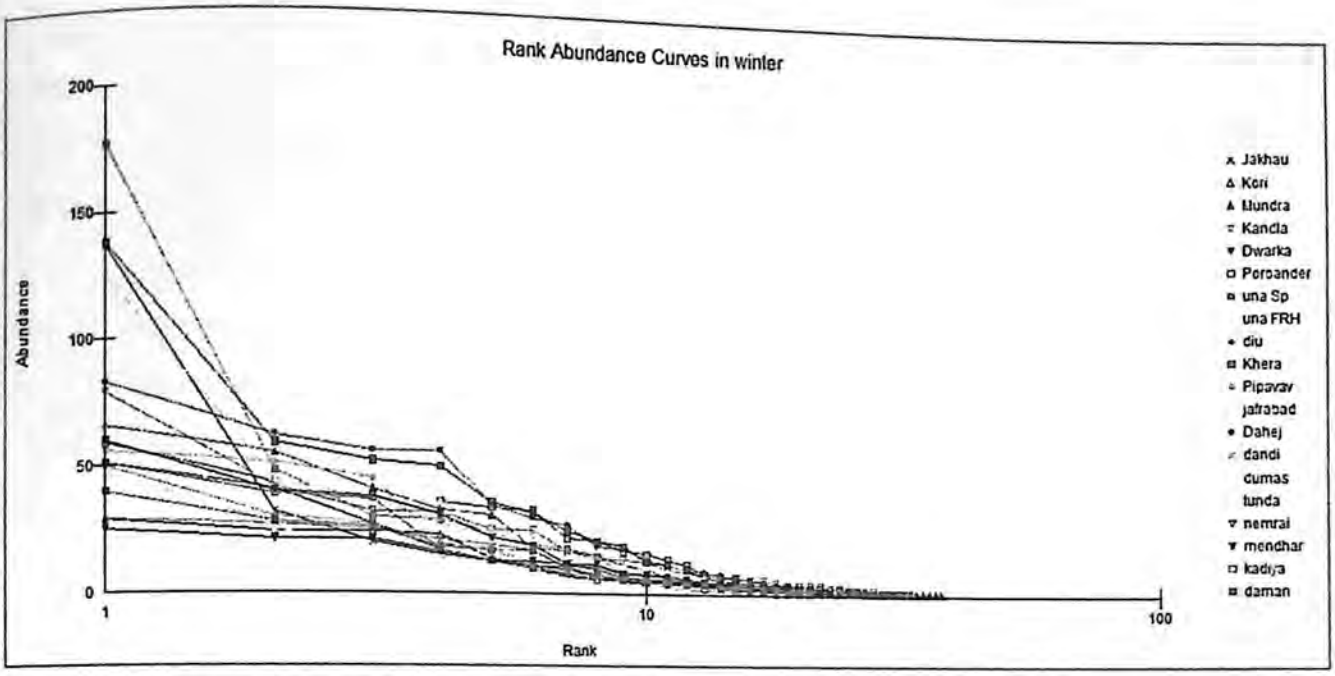


Figure 3.4 Rank abundance curves for plots in winter

Rank abundance curves for the birds in the summer season differ very little from those in the summer season. The patch kandla shows a broken stick series of distribution the broken stick model is the most equitable species abundance that happens naturally. It is biologically realistic 'uniform' distribution. The other patches follow a log normal series of distribution. The patch dwarka shows a relatively steep curve over all its abundance classes.

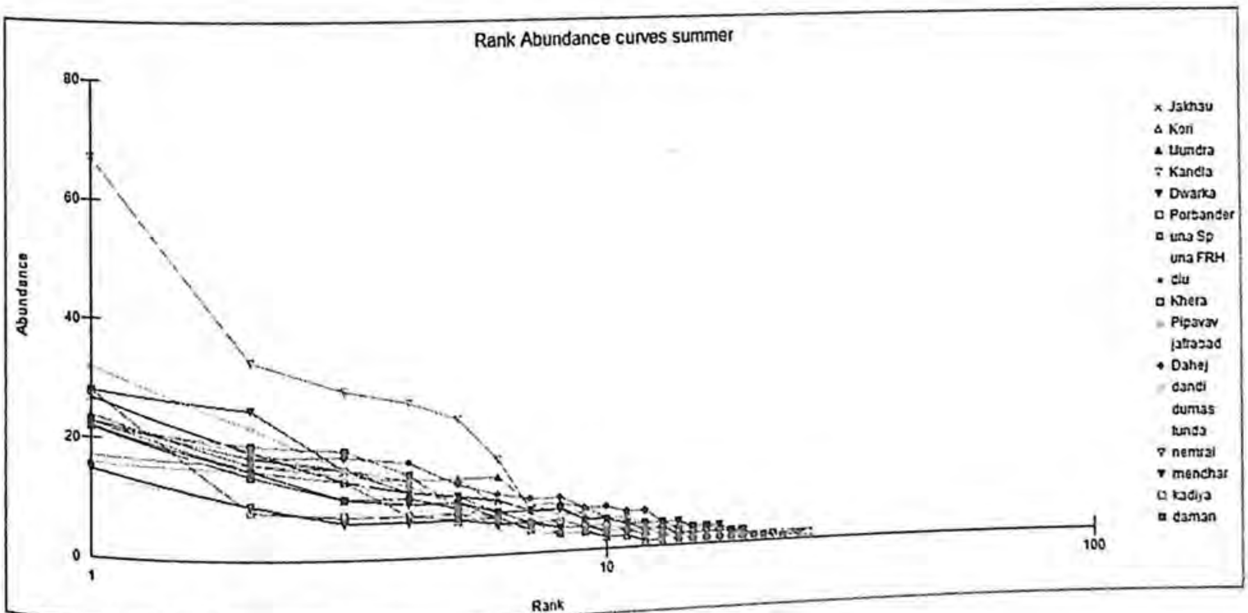


Figure 3.5 Rank abundance curves for birds in summer

3.5 Spatial analysis of the patches

Spatial analysis of each of the twenty patches was done by using Patch analyst and Area/Density/Edge metrics were calculated. There are six categories of statistics available in Patch Analyst (Paudel and Yuan, 2011), of which, two types of statistics were computed for this study 1) Patch Density and Size Metrics that reveal landscape fragmentation and configuration and (2) Edge Metrics which attribute the amount, length, and distribution of edges between specific patch types were calculated. The shapefiles were converted to a vector format before they were used to calculate the indices. Four indices as compositional measures were considered: mean patch size (MPS), edge density (ED), Mean Perimeter to Area ratio and Mean Patch Edge.

MPS is selected because it is the primary predictor of diversity within a patch. Edge Density refers to the amount of edge relative to the landscape area and is related to the degree of spatial heterogeneity (Antwi *et al.,* 2008). ED was chosen to quantify the dynamics of the abundance and attributes of specific types of edges, and infer the associated ecological effects. Mean Patch Edge shows the average amount of edge per patch.

The Mean Perimeter Area Ratio (MPAR) mean of the ratio patch perimeter. The perimeter-area ratio is equal to the ratio of the patch perimeter (m) to the area (m^2).

The computed indices for each patch are shown in the table below:

Table 3.5 Patch indices computed by using Patch Analyst

Patch No	Patch ID	Edge Density (m/m²)	Mean Patch Edge (m/m²)	Mean Patch size (ha)	Mean Peri Area Ratio m/ha
1	Jakhau	1.246	6766.949	19.531	346.500
2	Kori	15.646	84944.146	726.189	117.000
3	Mundra	5.602	30413.841	311.455	97.700
4	Kandla	10.190	55323.620	1559.820	35.500
5	Dwarka	0.860	4666.584	30.938	150.800
6	Porbandar	1.943	10551.304	86.727	121.700
7	Una Sp	3.293	17876.298	70.546	253.400
8	Una FRH	1.501	8148.501	54.807	148.700
9	Diu	6.080	33011.486	187.437	176.100
10	Khera	0.304	1648.514	14.439	114.200
11	Pipavav	0.794	4310.468	30.853	328.700
12	Jafrabad	0.796	4322.408	13.148	139.700
13	Dahej	8.840	47991.620	1007.599	47.600
14	Dandi	2.074	11262.588	80.214	140.400
15	Dumas	0.821	4458.335	12.072	369.300
16	Tunda	0.830	4506.491	14.239	316.500
17	Nemarai	9.043	49095.442	615.751	79.700
18	Mendhar	10.111	54893.274	492.561	111.400
19	Kadiya	1.201	6518.386	30.559	213.300
20	Daman	4.953	26891.867	70.327	382.400

3.6 Association of birds with disturbance

All 119 species of birds recorded during the study were divided into two classes Forest birds and Open country birds were plotted across the proportion in which they were present in all the patches as shown in the graph below. Forest birds constituted 93 species and open country birds constituted of 26 species of the birds.

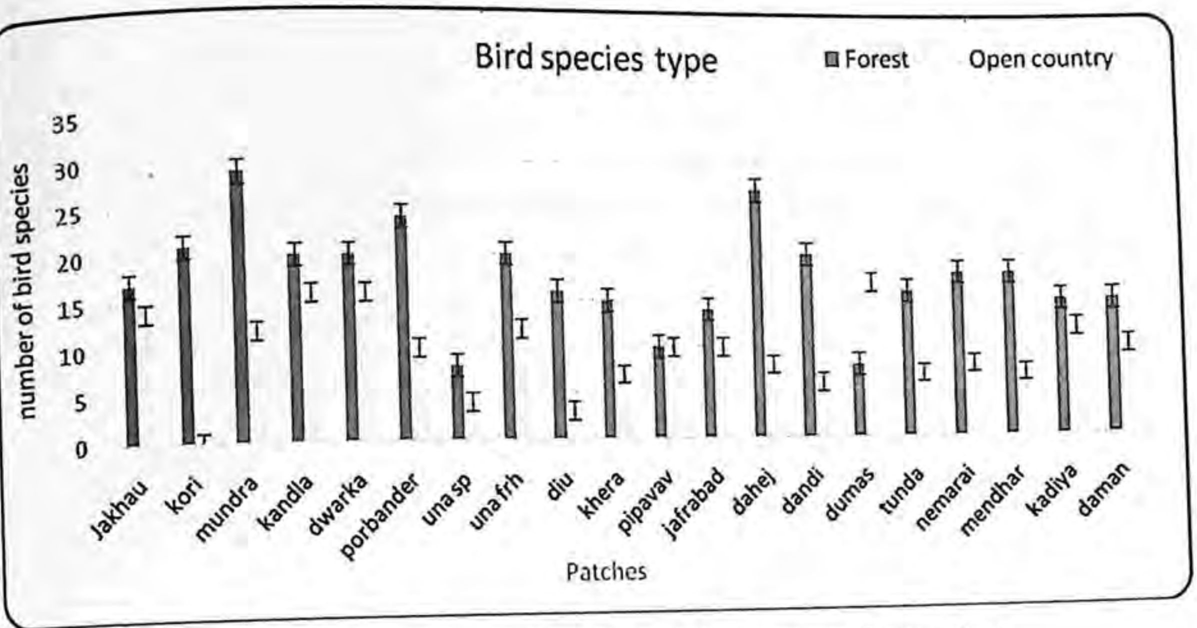


Figure 3.6 Type of bird species according to its ecology versus the patches

From the graph, it can be seen that the pristine patch Kori did not show the presence of any open country bird. The patch of Diu was located in a bird sanctuary (Fudam Bird sanctuary) and it showed very low numbers of open country birds as compared to the forest birds. Whereas in the disturbed patch Dumas, the open country birds were present in a higher number than the forest birds. In some patches like Pipavav, Jakhau and Kadiya show almost equal number of forests and open country birds. The varying numbers of species of forests and open country birds indicate how disturbed the patch is.

3.7 Density of Birds

The density of birds was estimated based on the seasons and the detection group that they fall into. Densities were calculated individually for each of the detection group i.e. low, medium and high and the following models were used and results were obtained:

Table 3.6 Showing the best Model fits to the data in DISTANCE 6.0

Serial no.	season	Detection group	Model fit	EDR	EDR SE	P value
1	winter	Low	Hazard/Cosine	65.992	8.4388	0.254
2	winter	medium	Hazard / Cosine	85.6	6.05	0.21
3	winter	high	Half-normal /Cosine	108.45	6.63	0.242
4	summer	Low	Half-normal/ Cosine	50.45	2.6	0.404
5	summer	medium	Uniform/Cosine	61.699	0.193	0.35
6	summer	high	Hazard /Cosine	105.09	5.25	0.43

Based on this, densities were calculated per patch by summation of the low, medium and high densities of each patch and hence the bird densities were obtained per patch per season. The different models fitted for different detection groups across the seasons as the detection probability of the birds varied across the seasons.

The following densities were calculated for winter season:

Table 3.7 Densities calculated for the patches in winter season

Patch Name	Winter Low	%CV	Winter Medium	%CV	Winter High	%CV	Total Density/(sq. km)
Jakhau	145.28	32.29	399.1	48.1	122.7	25.7	667.08
Kori	56.49	26.55	199.6	17.8	157.2	19.8	413.29
Mundra	290.5	30.04	489	35.2	107.3	19.09	886.8
Kandla	201.77	27.34	377.5	25.1	46	17.29	625.27
Dwarka	274.41	41.5	269.6	40.9	76.7	25.79	620.71
Porbandar	435.8	42.8	625.6	71.3	61.36	24.91	1122.76
Una SP	112.2	27.88	204.9	26.9	84.37	20.25	401.47
Una FRH	371.26	43.97	409.9	50.8	153.4	31.48	934.56
Diu	161.42	30.7	226.5	33.14	7.7	19.66	395.62
Khera	145.28	32.29	291.2	35.6	92.04	21.63	528.52
Pipavav	500	47.7	194.1	27.6	61.36	18.98	755.46
Jafrabad	225.9	32.72	323.6	42.5	69.03	22.61	618.53
Dahej	80.7	27.36	404.5	24.6	103.55	18.25	588.75
Dandi	177.5	30.31	377.5	56.4	53.6	18.99	608.6
Dumas	321.26	37.87	291.2	41.9	61.36	20131	673.82
Tunda	338.9	36.81	226	31.7	38.35	18.39	603.25
Nemarai	312	31.28	330	31.66	15.34	16.78	657.34
Mendhar	193.7	28.23	316	28.9	86.931	18.46	596.631
Kadiya	306.6	37.72	280	37.06	53.693	18.99	640.293
Daman	274.4	33.8	312	39.9	46.022	18.83	632.422

The densities calculated for summer:

Table 3.8 Densities calculated for the patches in summer season

Patch name	Summer low	%CV	Summer medium	%CV	Summer high		Total density/(sq.km)
Jakhau	33.7	16.2	422.9	39.9	12.3	15.11	468.9
Kori	50.684	14.31	160.1	10.03	28.3	13.06	239.084
Mundra	37.544	12.8	435.7	25.8	13.155	13.7	486.399
Kandla	56.3	12.8	390.8	17.3	6.1	12.21	453.2
Dwarka	6.57	14.4	461.3	44.1	12.3	15.11	480.17
Porbandar	78.8	18.17	461.3	51.08	12.3	203	552.4
Una SP	33.7	16.21	358.8	35.3	9.8	14.06	402.3
Una FRH	45.05	17.55	525.4	49.51	17.26	14.21	587.71
Diu	0	0	410	38.66	12.33	15.11	422.33
Khera	33.7	13.02	410	41.2	12.33	13.03	456.03
Pipavav	56.31	15.7	422	39.4	14.8	15.64	493.11
Jafrabad	56.31	18.11	486	48.3	12.33	17.58	554.64
Dahej	57.9	13.41	422	19.6	11.27	12.1	491.17
Dandi	22.52	13.44	460	52.9	7.39	15.61	489.91
Dumas	11.26	13.91	704	64.9	19.7	15.83	734.96
Tunda	67.57	14.46	499.7	46.3	12.3	20.3	579.57
Nemarai	105	14	410	23.7	4.9	11.6	519.9
Mendhar	0	0	427.17	24.17	11.5	12	438.67
Kadiya	45	12.6	371.6	33.6	9.8	17	426.4
Daman	78.8	14.8	435.7	43.14	4.9	12.7	519.4

3.8 Overall Densities of birds

Overall densities were remarkably higher in the winter season than that in the summer in some patches. In the other patches, the densities of the birds had very little variations for both the seasons. The following graph shows comparative bird densities/hectare across the seasons

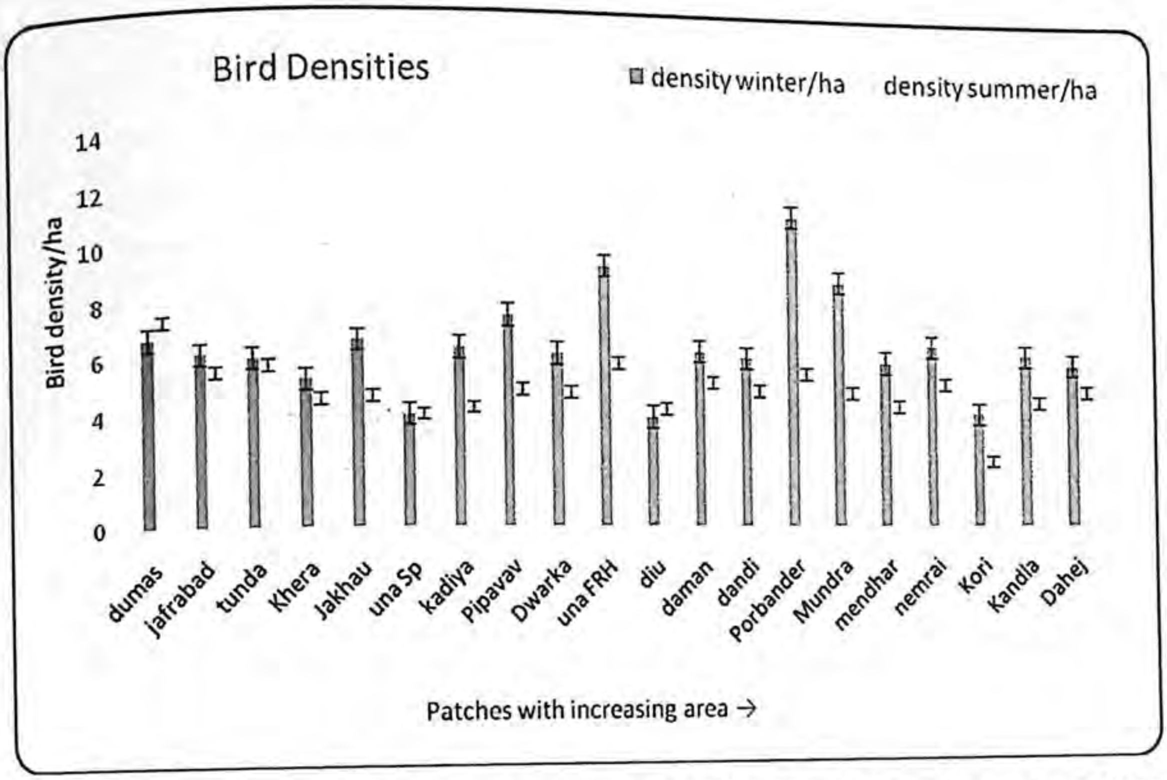


Figure 3.7 Comparison of bird densities across patches in winter and summer season

3.9 Comparison of bird abundance in each patch according to seasons

Bird abundances calculated from the software DISTANCE 6.0 in the same way as the density estimation and were compared across the patches for both the seasons, i.e summer and winter. The abundances of birds in winter season were higher than the bird abundances in the summer season in most of the patches. The difference in abundance across the seasons was higher in the large sized patches.

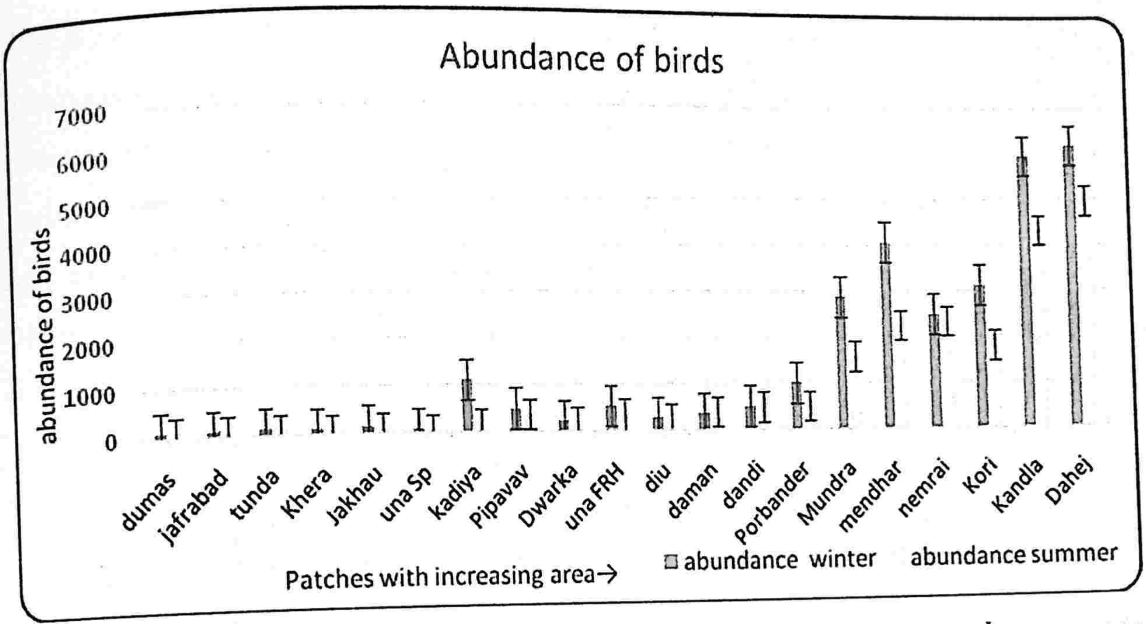


Figure 3.8 Comparison of bird abundances across patches in winter and summer season

3.10 Relationship of Birds with Habitat variables

The principle component analysis decomposed the data into five principal factors together explaining 85.74% of the variance in the dataset.

Table 3.9. Shows the contribution of each variable to the extracted factors.

Component Matrix

	Component				
	1	2	3	4	5
% Variance explained	37.80%	17.80%	11.70%	10.50%	7.72%
Mean canopy cover		0.565*	0.261	-0.175	
Coef. of variance of canopy cover		-0.446*	-0.424	0.182	-0.138
Tree density		0.372	-0.436	0.474*	
Area	-0.348	0.205	-0.152	-0.27	0.421*
Number of Humans Present	0.314	-0.246		-0.239	0.476*
Number of Dogs Present	0.269	0.316*	0.251	0.236	
Wood cutting	0.274	0.17	-0.258	-0.487*	-0.367
Human footprints (3*3m)	0.411*				0.361
Dog pugmark(3*3m)	0.374			0.251	0.407*
Lopping	0.309	0.109	-0.469*	-0.327	-0.172
Edge Density	-0.36*		-0.125	-0.283	0.323
Mean perimeter to area ratio	0.306*	-0.287	0.4	-0.195	

Table 3.9 Component matrix obtained by doing Principle Component analysis of dependent variables

Component 1 contributed to maximum variance and it was related to the disturbance factors mainly like the human footprint, edge density and mean perimeter to area ratio. Component 2 was related to mean canopy cover, the coefficient of variance of canopy cover and the number of dogs present in the patch. Component 3 was related to lopping that is again a disturbance factor. Component 4 was related to tree density and wood cutting. Component 5 was related to area, number of humans present in the patch and the dog pugmarks present in the patch.

3.11 Generalized Linear Models

The significance of predictor variables on the response variables were tested using Generalized Linear Models. Firstly, an ordinary logistic regression was performed over the data of one predictor variable (independent variable) and other response variables (dependent variables). Then a stepwise backward forward model selection was carried out on the regressed data and finally the model with lowest AIC value was chosen for Generalized Linear Modeling.

The results obtained for each independent variables are listed below:
(Here A=Area, DP=Dog pugmark, D=Dog presence, ED=Edge Density, MPAR= Mean Perimeter Area Ratio, TD= Tree density, XCC= mean percent canopy cover)
Bird Species (winter season)

The stepwise backward forward model selection after the linear regression selected the model with the lowest AIC as Bird sp.(winter)~Area + Dog Pugmark + presence of dog +Edge density + Mean Perimeter Area Ratio + Tree Density + mean of canopy cover as shown in the table below. The AIC value for this model is 51.13

Table 3.10 Stepwise backward-forward model selection for bird species richness in winter

Sr.No	Stepwise Model	backward/forward AIC
1	Bird sp.(w)~A+CVCC+DP+D+ED+HF+H+L+MPAR+TD+WC+XCC	59.51
2	Bird sp.(w)~A+CVCC+DP+D+ED+HF+H+MPAR+TD+WC+XCC	57.51
3	Bird sp.(w)~A+CVCC+DP+D+ED+HF+MPAR+TD+WC+XCC	55.51
4	Bird sp.(w)~A+CVCC+DP+D+ED+MPAR+TD+WC+XCC	53.61
5	Bird sp.(w)~A+DP+D+ED+MPAR+TD+WC+XCC	52.04
6	Bird sp.(w)~A+DP+D+ED+MPAR+TD+XCC	51.13

Table 3.11 Generalized linear model of bird species richness in winter

GLM (Bird sp.(w)~A+DP+D+ED+MPAR+TD+XCC)				
	Coefficients			
	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	3.14316	0.04816	65.26	< 2e-16 ***
Area.Z	0.2194	0.10204	2.15	0.031545 *
X.Cc.Z	0.21156	0.06333	3.341	0.000836 ***
Dog.Pugmark	0.16055	0.07062	2.274	0.022988 *
Tree.Dens.Z	0.15192	0.06319	2.404	0.016204 *
Mean.Peri.Area.Ratio	0.083	0.08142	1.019	0.308004
Edge.Dens.Z	-0.08942	0.09912	-0.902	0.366986
Dog.Z	-0.17472	0.07453	-2.344	0.019066 *
	AIC: 119.28			

The Generalized linear model of Bird species in winter with all the other dependent variables gave a result that mean of percent canopy cover β coeff =0.21156 (±0.06333)influenced this independent variable the most. Besides, the area of the patch β coeff =0.2194 (±0.10204), dog pugmarks β coeff = 0.16055 (±0.07062), tree density β coeff = 0.15192 (±0. 0.06319) and the presence of dogs β coeff =-0.1747 (±0.07) also influence this variable considerably.

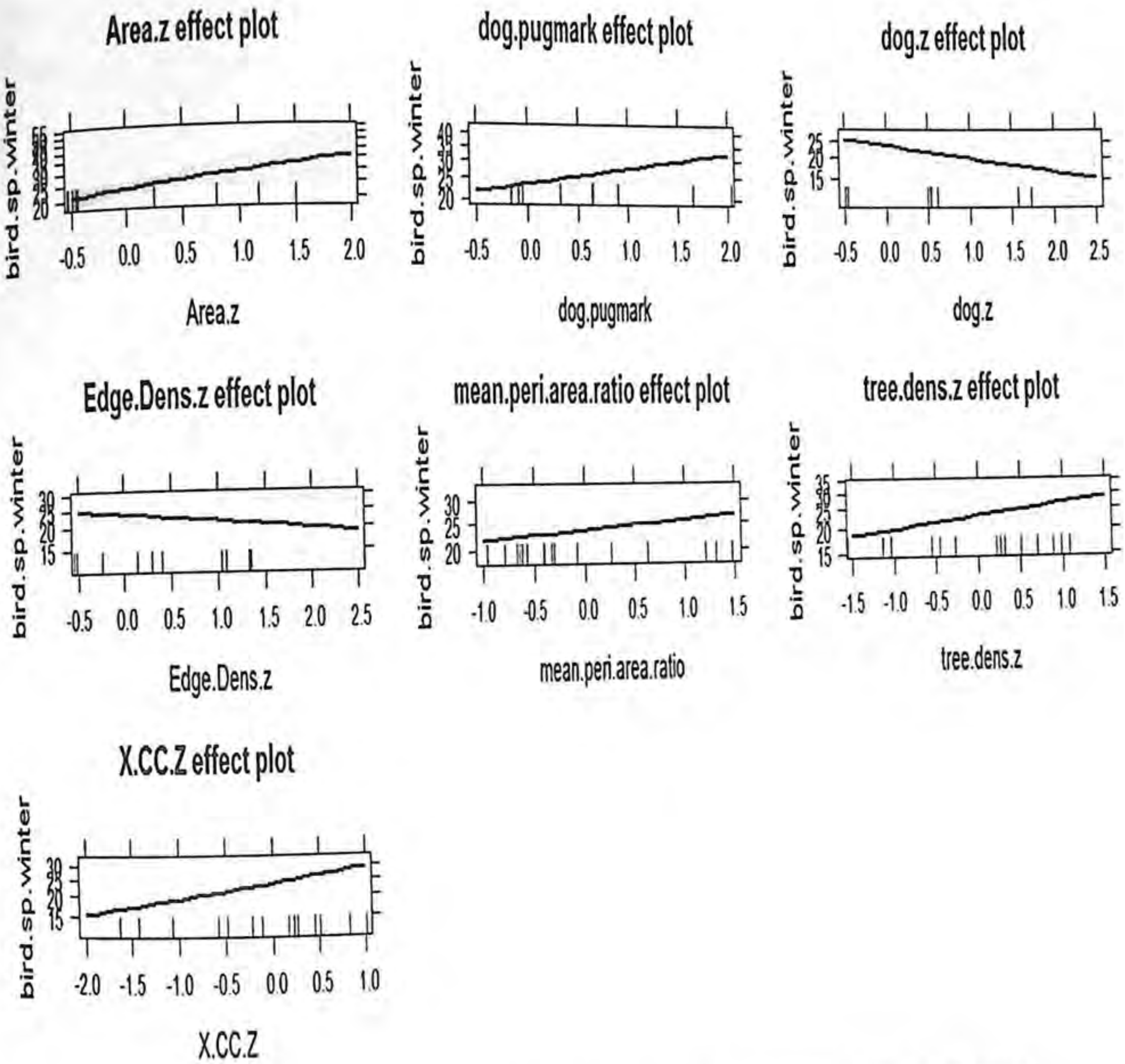


Figure 3.9 Effect plots obtained after G L Modelling of bird species richness in winter season.

2) Bird species (summer season)

For this independent variable, stepwise backward forward model selection was chosen after the linear regression for selection of the model with the lowest AIC as Bird sp.(summer)~Area + %CV of Canopy cover+ Dog Pugmark + presence of dog +Edge density + human footprints + Presence of humans and lopping shown in the table below. The AIC value for this model is 41.38

Table 3.12 Stepwise backward-forward model selection for bird species richness in summer

	stepwise	backward/forward
Sr.No	Model	AIC
1	Bird sp.(s)~A+CVCC+DP+D+ED+HF+H+L+MPAR+TD+WC+XCC	48.71
2	Bird sp.(s)~A+CVCC+DP+D+ED+HF+H+L+MPAR+TD+WC	46.71
3	Bird sp.(s)~A+CVCC+DP+D+ED+HF+H+L+MPAR+WC	44.81
4	Bird sp.(s)~A+CVCC+DP+D+ED+HF+H+L+MPAR	42.88
5	Bird sp.(s)~A+CVCC+DP+D+ED+HF+H+L	41.38

Table 3.13 Generalized linear model of bird species richness in summer

GLM (Bird sp.(s)~A+CVCC+DP+D+ED+HF+H+L)				
Coefficients				
	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	2.96328	0.05544	53.45	<2e-16 ***
Area.Z	0.17241	0.10423	1.654	0.0981 .
Human Footprint	0.102	0.117	0.872	0.383
Dog Pugmark	0.06994	0.1103	0.634	0.5263
Lopping	0.0443	0.06203	0.715	0.4746
Human Seen	-0.0475	0.07783	-0.611	0.5411
Edge Dens	-0.08829	113	-0.788	0.4307
CV.Of %CC	-0.1374	0.0685	-2.006	0.0449 *
Dog	-0.773	0.08208	-0.943	0.3459
	AIC: 117.54			

The Generalized linear model of Bird species in winter with all the other dependent variables gave a result that mean of % Coefficient of Variance of the canopy cover β coeff = -0.1374 (±0.0685)influenced this variable the most.

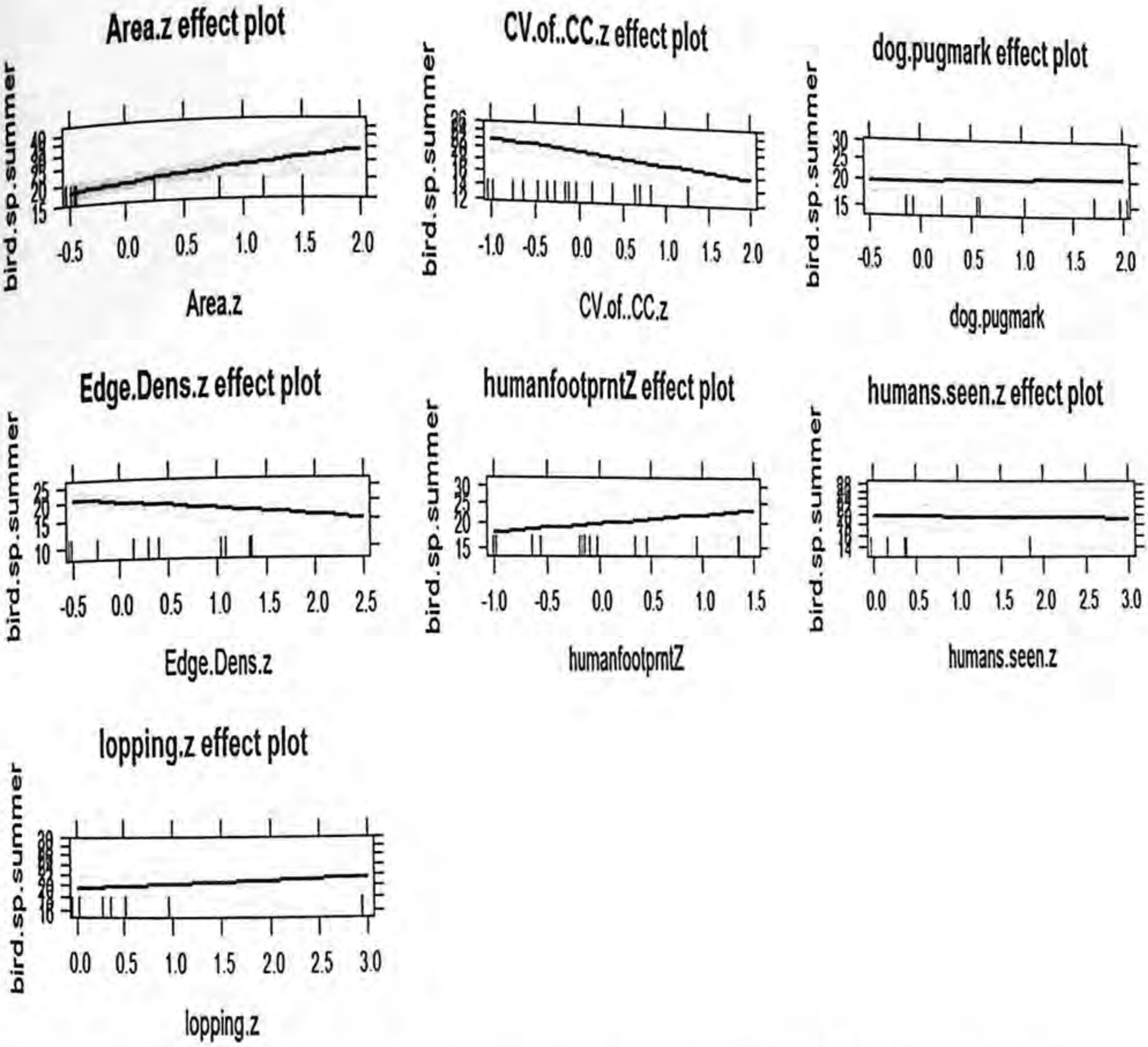


Figure 3.10 Effect plots obtained after G L Modelling of bird species richness in summer season.

3) Bird Density Winter

Stepwise backward forward model selection was done after the linear regression for selection of the model with the lowest AIC as Bird density {winter}~Area + %CV of Canopy cover+ Dog Pugmark + Dog +Edge density + human footprints + Presence of humans + lopping + tree density + woodcutting is shown in the table below. The AIC value for this model is 62.9.

Table 3.14 Stepwise backward-forward model selection for bird density in winter

Sr.No	Stepwise Model	backward/forward AIC
1	Bird dens.(w)~A+CVCC+DP+D+ED+HF+H+L+MPAR+TD+WC+XCC	66.06
2	Bird dens.(w)~A+CVCC+DP+D+ED+HF+H+L+MPAR+TD+WC	64.32
3	Bird dens.(w)~A+CVCC+DP+D+ED+HF+H+L+TD+WC	62.9

Table 3.15 Generalized linear model of bird densities in winter

GLM Bird dens.(w)~A+CVCC+DP+D+ED+HF+H+L+TD+WC				
	Coefficients			
	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	2.30204	0.09703	23.724	< 2e-16 ***
Area.z	0.42642	0.19999	2.132	0.03298 *
dog	0.38637	0.111	3.481	0.00050 ***
wood.cutting.z	0.56626	0.21614	2.62	0.00880 **
humans seen	0.38011	0.17988	2.113	0.03459 *
CV.of %CC	0.33491	0.11327	2.957	0.00311 **
tree.dens.z	0.2049	0.12293	1.667	0.09556
dog pugmark	0.18682	0.16596	1.126	0.26031
humanfootprnt	-0.4573	0.20693	-2.21	0.02711 *
edge density	-0.59427	0.20807	-2.856	0.00429 **
lopping	-0.64756	0.24145	-2.682	0.00732 **
	AIC: 62.9			

The Generalized linear model of Bird density in winter with all the other dependent variables gave a result that dog presence β coeff = 0.25907 (±0.09709) influenced this independent variable the most. Besides, wood cutting 0.56626 (±0.21614), Coefficient of variance of percent canopy cover β coeff = 0.33491 (±0.11327), edge density β coeff = -0.59427 (±0.20807) and lopping β coeff = -0.64756 (±0.24145) affect the density of the birds. Area of the patch β coeff = 0.42642 (±0.19999), human presence β coeff = 0.38011 (±0.17988) and human evidence in the patch (human footprint) β coeff = -0.4573 (±0.20693) also influence this variable considerably.

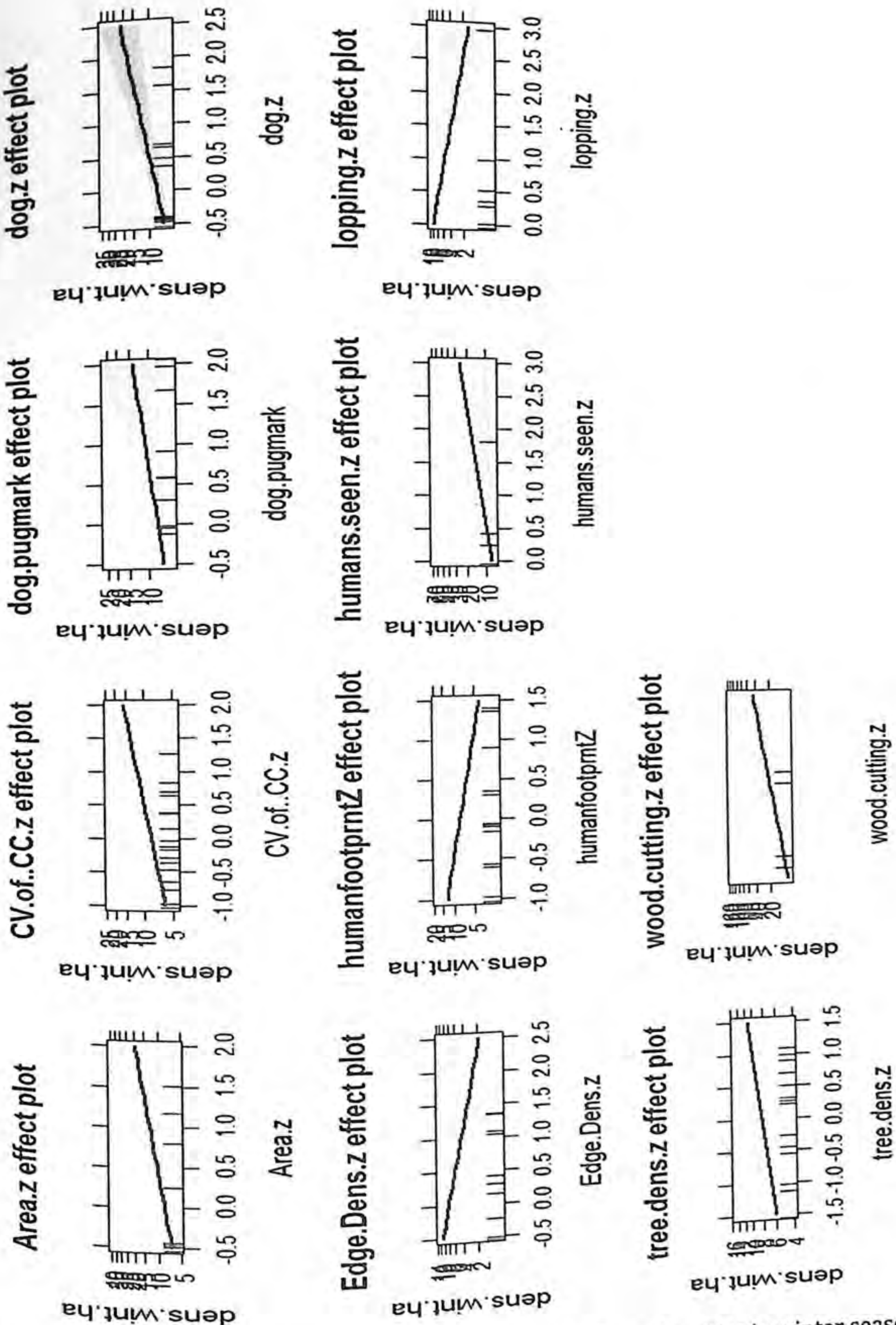


Figure 3.11 Effect plots obtained after G L Modelling of bird densities in winter season

4) Bird Density Summer

For this predictor variable, stepwise backward forward model selection was done after the linear regression for selection of the model with the lowest AIC as Bird abundance (summer)~Area + %CV of Canopy cover+ Dog Pugmark + Edge density + human footprints + mean perimeter to area ratio which is shown in the table below. The AIC value for this model is 24.58.

Table 3.16 Stepwise backward-forward model selection for bird density in summer

	Stepwise	backward/forward
Sr.No	Model	AIC
1	Bird dens.(s)~A+CVCC+DP+D+ED+HF+H+L+MPAR+TD+WC+XCC	36.74
2	Bird dens.(s)~A+CVCC+DP+ED+HF+H+L+MPAR+TD+WC+XCC	34.74
3	Bird dens.(s)~A+CVCC+DP+ED+HF+H+L+MPAR+TD+XCC	32.8
4	Bird dens.(s)~A+CVCC+DP+ED+HF+H+MPAR+TD+XCC	30.88
5	Bird dens.(s)~A+CVCC+DP+ED+HF+H+MPAR+TD	28.93
6	Bird dens.(s)~A+CVCC+DP+ED+HF+H+MPAR	27.03
7	Bird dens.(s)~A+CVCC+DP+ED+HF+MPAR	25.56
8	Bird dens.(s)~CVCC+DP+ED+HF+MPAR	24.58

Table 3.17 Generalized linear model of bird densities in summer

GLM Bird dens.(s)~A+CVCC+DP+D+ED+HF+H+L+TD+WC				
	Coefficients			
	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	1.5479	0.1078	14.36	< 2e-16 ***
Humanfootprntz	0.8307	0.1927	4.31	1.63e-05 ***
CV.Of..CC.Z	0.2224	0.1038	2.143	0.032118 *
Edge.Dens.Z	-0.1424	0.1465	-0.972	0.331124
Mean.Peri.Area.Ratio	-0.1805	0.1156	-1.561	0.118495
Dog.Pugmark	-0.5722	0.1718	-3.331	0.000866 ***
	AIC: 24.58			

The Generalized linear model of Bird density in summer with all the other dependent variables gave a result that the variables like human foot print β coeff = 0.8307 (± 0.1927) and dog pugmark β coeff = -0.5722 (± 0.1718) significantly affected this predictor variable. Besides, percent coefficient of variance in canopy cover β coeff = 0.2224 (± 0.1038) also affected the dependent variable to a lesser extent

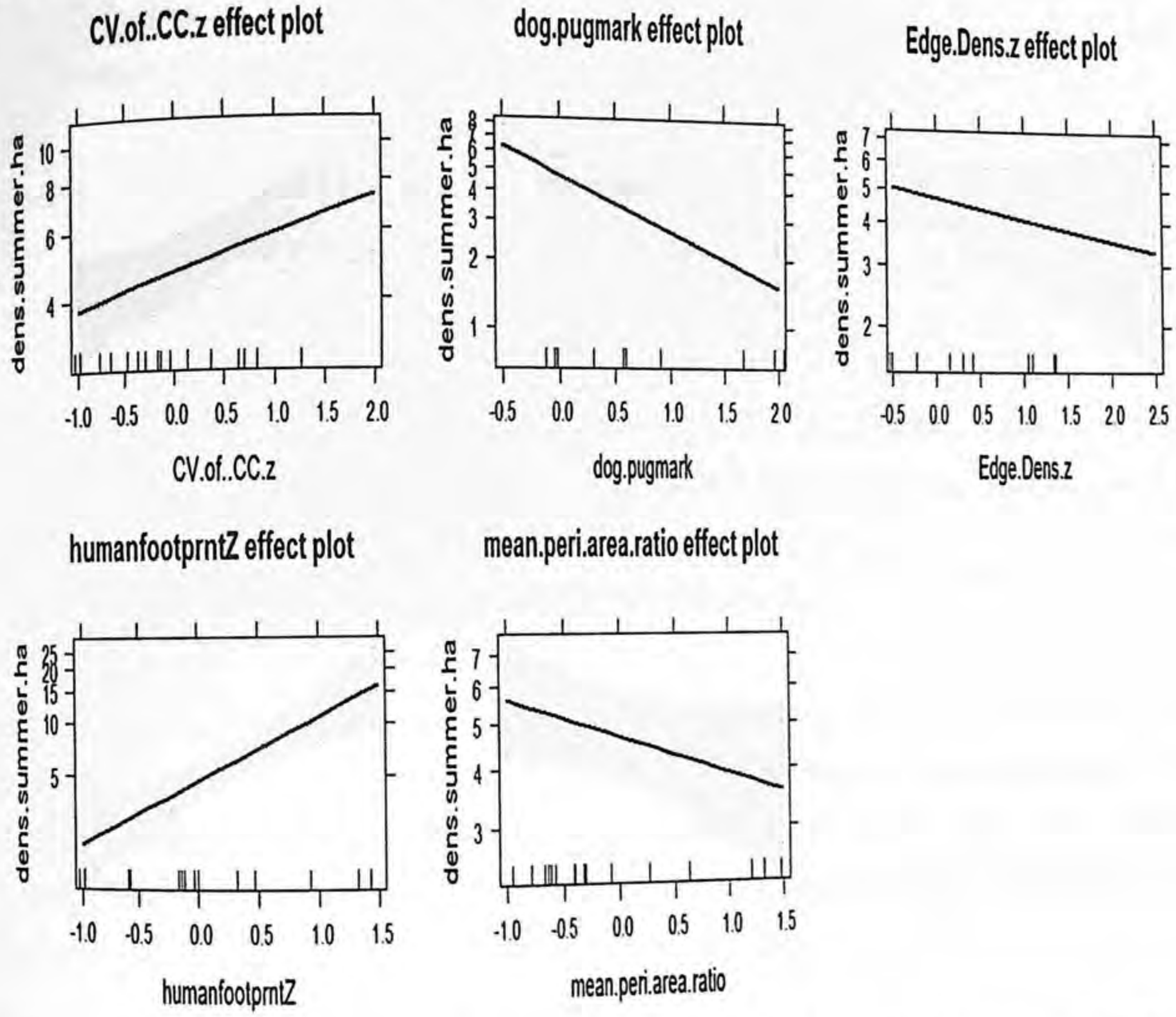


Figure 3.12 Effect plots obtained after G L Modelling of bird densities in summer season

3.12 Canonical Correspondence analysis

Canonical Correspondence Analysis was done on the patch-wise seasonal abundance data of the bird species with the habitat variables. The statistical model underlying CCA is that a species' abundance or frequency is a unimodal function of position along environmental gradients. CCA is an approximation to Gaussian Regression under a certain set of simplifying assumptions and is robust to violations of those assumptions (ter Braak and Prentice 1988) (Palmer et al, 1993). The variance of sample scores on each axis obtained reflects the importance of the axis as measured by the eigenvalue, whereas the variance of the species scores along the axes are equal.

The triplot obtained from the CCA analysis displays the major patterns in the species data with respect to the environmental variables.

Canonical Correspondence analysis (winter)

The CCA performed on the dataset with the representative species for the **winter** and the winter season and the ordination diagram is shown in Fig 3.12.

The Eigen values for the first four CCA axes were 0.402, 0.354, 0.226 and 0.161 respectively. Cumulative 73.97 % of total variability is explained by these two axes. In other words, the accuracy of correspondence between related pair of species and environment was found to be good only for the first two axes.

Human presence, presence of dog, tree density, canopy cover, human foot print, dog pugmark, mean perimeter to area ratio, wood cutting, lopping and edge density operating on the first axes while the species co - ordination for t - value biplot gave rise to the 27 species of birds that were found to be correlated with these variables during the winter season. The species of birds are represented here by numbers.

It was observed that majority of the species clumped largely into the last axis. The highly disturbed patches were arranged on one axis and the moderately disturbed patches were distributed on the other axis.

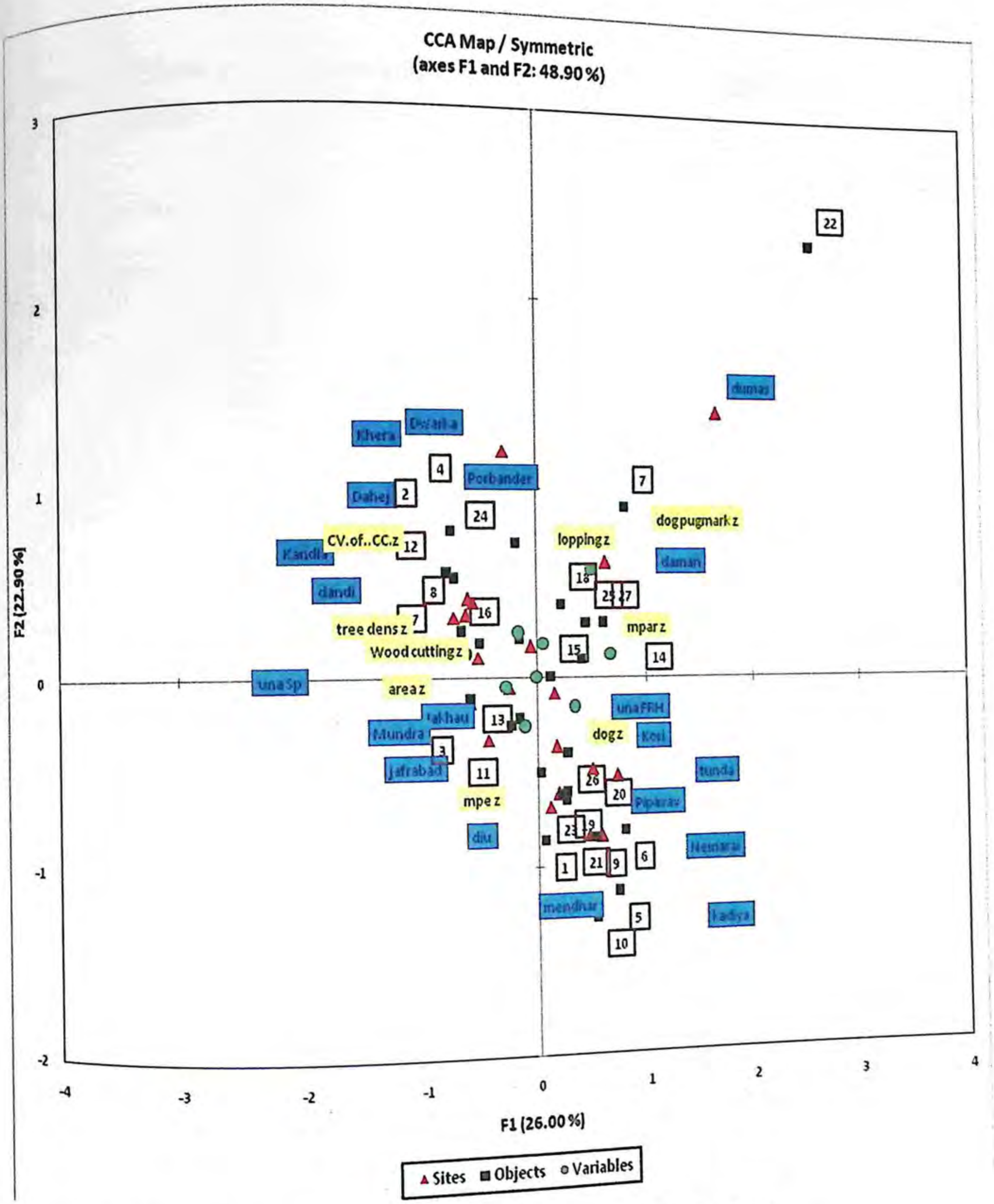


Figure 3.13 CCA of Bird Species, Patches and Habitat variables in winter

Table 3.18 Table showing the results of permutation test of Bird Species, Patches and Habitat variables in winter

Results of the permutation test:	
Permutations	100
Pseudo F	1.542
p-value	0.030
alpha	0.050

LEGEND

Black Tailed Godwit	1	Kentish Plover	6	Whiskered Tern	12	White Breasted Waterhen	18	Indian Roller	24
Common Red Shank	2	Little Egret	7	Little Cormorant	13	Ashy Drongo	19	Little Swift	25
Common Sandpiper	3	Little Ringed Plover	8	Oriental Darter	14	Black Drongo	20	Wire Tailed Swallow	26
Eurasian Spoonbill	4	Marsh Sandpiper	9	Osprey	15	Brahminy Kite	21	House Sparrow	27
Green Sandpiper	5	Spotted Redshank	10	Painted Stork	16	Barn Swallow	22		
Kentish Plover	6	Western Reef Egret	11	Red Vented Bulbul	17	Common Tailorbird	23		

MPAR=mean perimeter-area ratio

MPE=mean patch edge

CV of CC= Coefficient of variance of percent canopy cover.

This chart was further simplified in order to interpret the relation of the dependent variable with the independent variables.

From the values of the dependent variables seen from the table as well as the graph obtained on analysis, some significant results obtained were:

Tree density is located far from center of ordination axis and hence is shows a greater effect on the species. Tree density was found to be negatively related with Red-vented bulbul and little ringed plover. This is justified as both these species are edge species favouring open forests more than closed canopy forests.

Dog was found to be negatively related to Wire Tailed Swallow, Ashy Drongo, Little Swift and Brahminy Kite. The effect will be significantly negative as it is located at a greater distance from ordination axis. The dog presence in the patch causes disturbance and flushes the birds out hence it is negatively related these birds.

Coefficient of variance of percent canopy cover is positively related to the Painted stork. As the painted stork prefers strong tree branches and tree canopy to perch on, hence it is positively related to the canopy cover.

Mean patch edge shows a positive effect on the red vented bulbul and the ashy drongo. It is true as both of these species are edge species so they will increase with the increase in edge of the patch.

The variable lopping is located very close to the center of the ordination axis, it doesn't show any significant relations with majority of variables.

Wood cutting has least distance from the center of ordination axis hence is shows least relations with all the species of birds.

Barn Swallow, Spotted Redshank, Kentish Plover are not much affected by any of these variables. There is a possibility that they might be getting affected by mixed effects of several other variables.

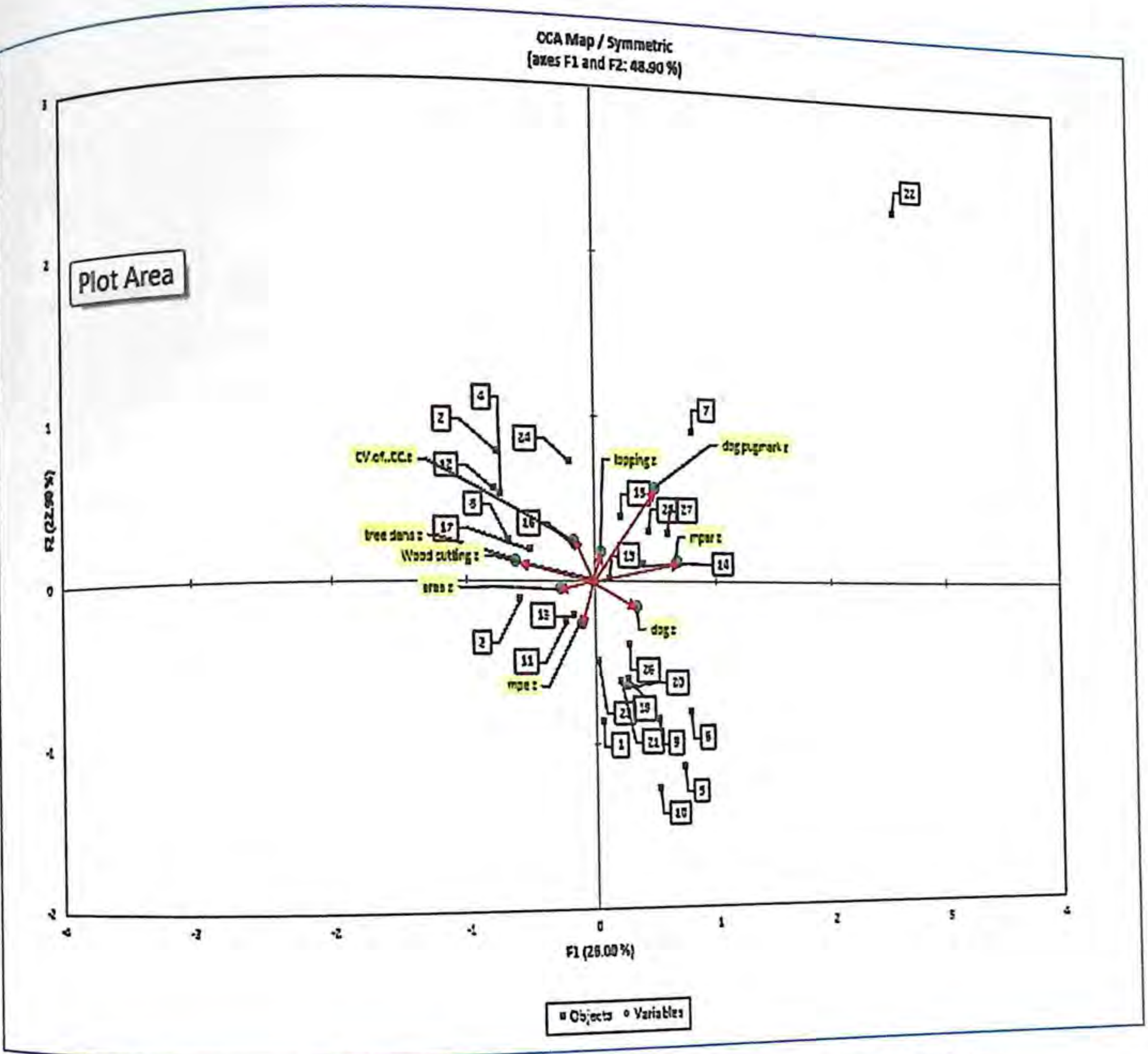


Figure 3.14 Simplified CCA showing bird species and the habitat variables in winter

LEGEND

Black tailed Godwit	1	Kentish plover	6	Whiskered tern	12	white breasted waterhen	18	Indian roller	24
Common red shank	2	little egret	7	little cormorant	13	Ashy drongo	19	little swift	25
common Sandpiper	3	little ringed plover	8	oriental Darter	14	black drongo	20	Wire tailed swallow	26
Eurasian spoonbill	4	Marsh sandpiper	9	Osprey	15	Brahminy kite	21	House sparrow	27
Green sandpiper	5	Spotted redshank	10	Painted stork	16	barn swallow	22		
Kentish plover	6	Western Reef Egret	11	red vented bulbul	17	Common tailorbird	23		

MPAR=mean perimeter-area ratio

MPE=mean patch edge

CV of CC= Coefficient of variance of percent canopy cover.

Canonical Correspondence analysis (Summer)

The Cannonical correspondence analysis of the Summer season of the bird species with other habitat variables and the patches yielded Eigen values upto first four axis as 0.420, 0.356, 0.259 and 0.181 respectively. These four axis contributed upto 79.8% variance. The CCA for summer season is shown below:

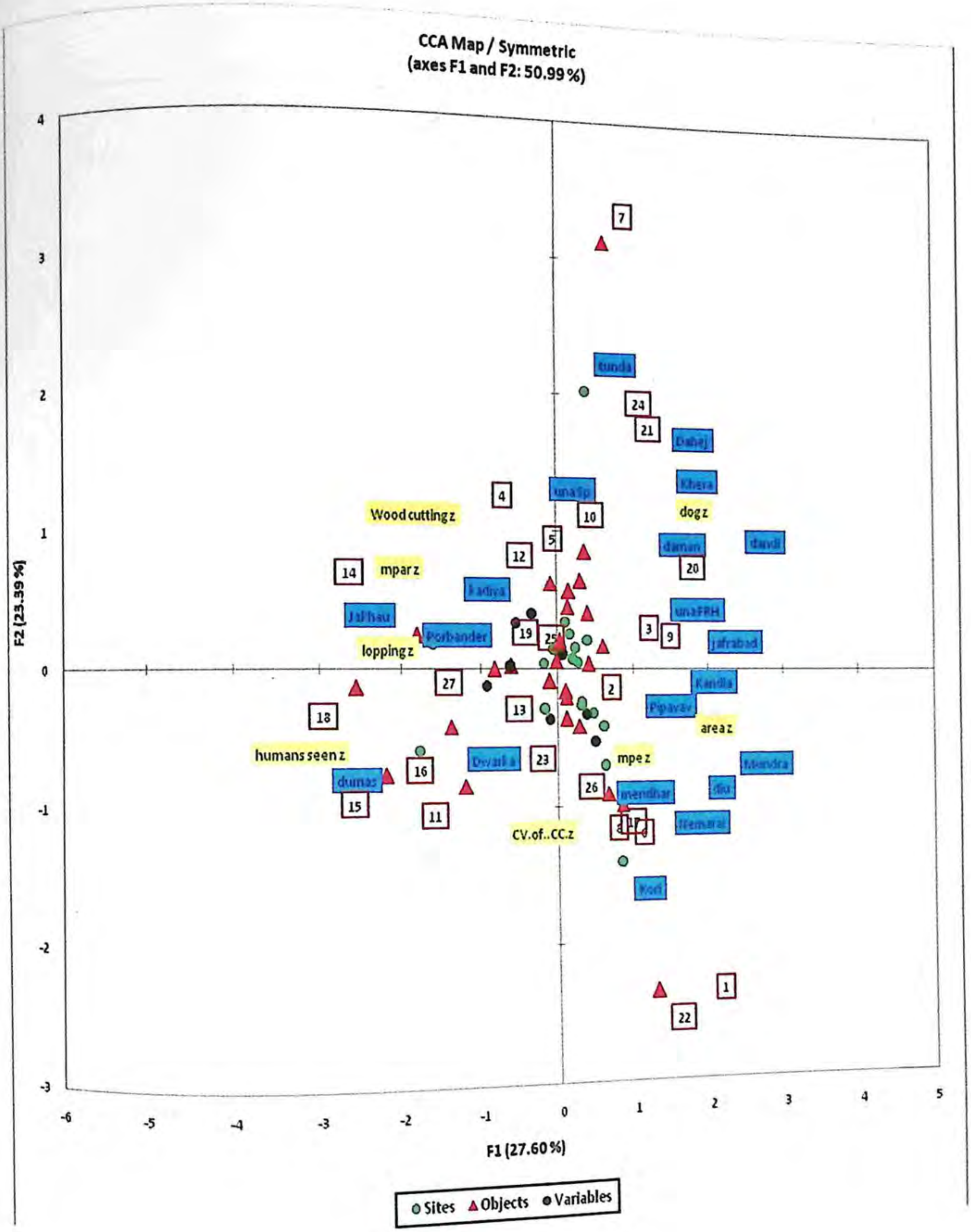


Figure 3.15 CCA of Bird Species, Patches and Habitat variables in summer

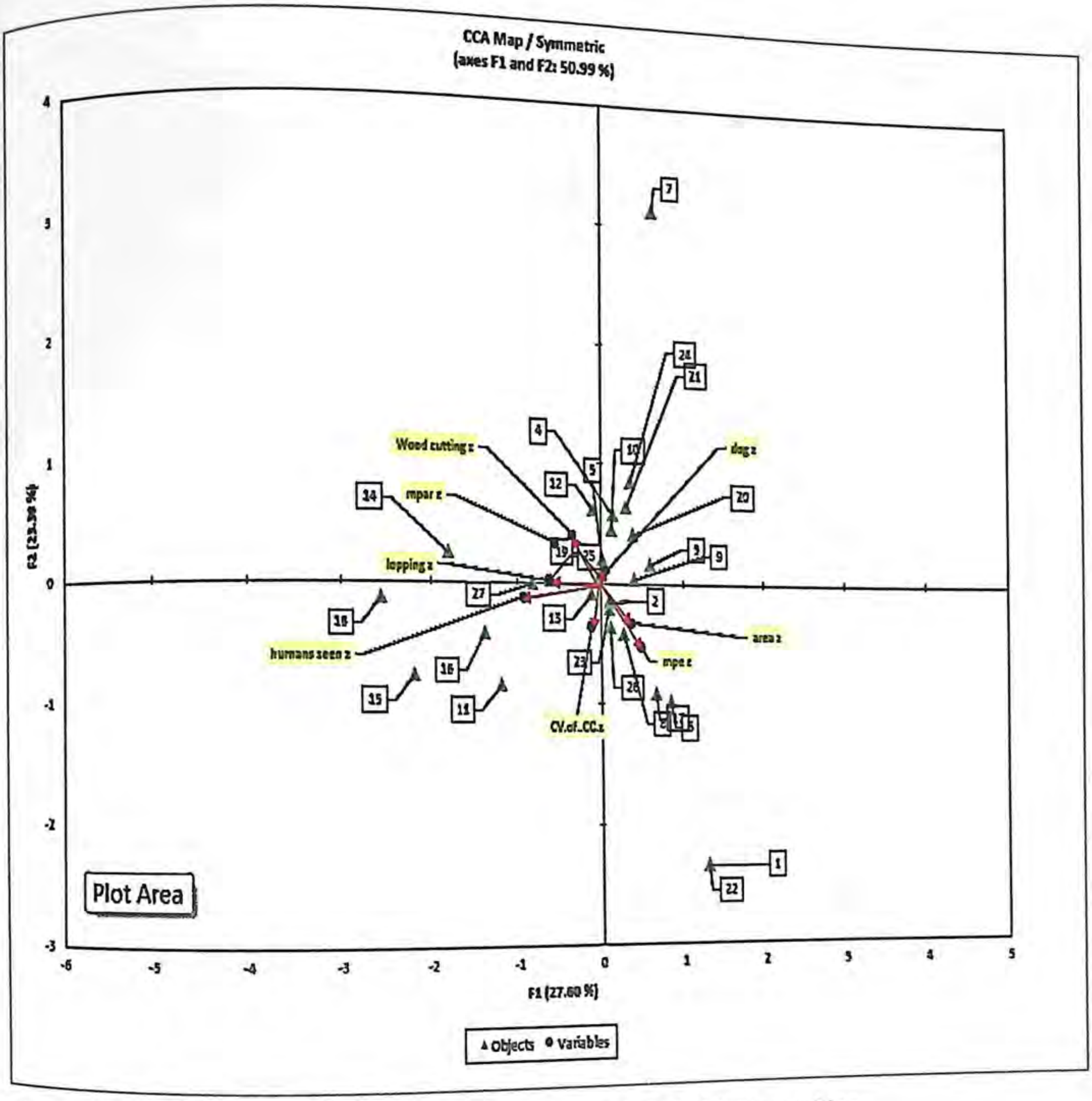


Figure 3.16 Simplified CCA showing bird species and the habitat variables

Legend

1	Bar Tailed Godwit	8	Purple Heron	15	Baya Weaver	22	Indian Thick Knee
2	Black Winged Stilt	9	River Tern	16	Rosy Starling	23	Little Swift
3	Common Kingfisher	10	Western Reef Egret	17	Eurasian Marsh Harrier	24	Plain Prinia
4	Common Sandpiper	11	Whimbrel	18	Barn Swallow	25	Wire Tailed Swallow
5	Eurasian Spoonbill	12	Red Naped Ibis	19	Cattle Egret	26	Yellow Wagtail
6	Intermediate Egret	13	Red Vented Bulbul	20	Common Tailorbird	27	Common Myna
7	Marsh Sandpiper	14	Crested Lark	21	Grey Wagtail		

MPAR=mean perimeter-area ratio

MPE=mean patch edge

CV of CC= Coefficient of variance of percent canopy cover.

The CCA analysis showed some significant results mentioned below:

From the Table 3.15, values obtained on analysis, and the graph, it was interpreted that the presence of human beings positively affects common myna, red vented bulbul and cattle egret. This effect will be strong as it is located far away from the center of the ordination axis. This is justified as these birds are generally present in periphery of human habitations.

Area strongly shows positive effects Black winged stilt, little swift and purple heron. These birds prefer peripheral edge habitats for foraging and the periphery will increase with the increase in area.

Mean patch edge was found to be positively affecting little swift, yellow wagtail and Black winged stilt. As these birds generally prefer peripheral habitats and are not found deep inside the forests, they will be positively to the increase of patch edge.

Wood cutting shows a strong positive effect on red vented bulbul, cattle egret and Eurasian spoonbill. As these birds prefer open habitats, the wood cutting will create more open habitats and more niches for them to occupy.

Mean perimeter to area ratio positively affects cattle egret and wire tailed swallow. As these birds are peripheral bird species, so increase in mean perimeter to area ratio will increase edges and more habitats for these birds.

The coefficient of variance of percent canopy cover negatively affects little swift, red vented bulbul, Wire tailed swallow and cattle egret. As these birds prefer open habitats more as compared to dense forested habitats, the increase in canopy cover will decrease their numbers.

Presence of dog shows no significant effect on any bird species as it is located at the center of ordination axis.

Plain prinia, Eurasian marsh harrier, bar tailed godwit, etc. do not get significantly affected by any of these variables. They might be getting affected by other variables or mixed effects of these variables.

4. Discussion

Most of the studies on the avifauna of mangroves show that mangrove forests support less species diversity than the other types of tropical forests. The mangrove forest provides a multitude of habitats for the resident, seasonal, and transient organisms from adjacent terrestrial and marine habitats. Globally, the range of disturbance associated with human activities, has been more significant than natural disturbance. Environmental disturbance can modify the composition, structure and function of marine plant and animal assemblages (Sousa, 1984; Skilleter, 2000; Duke, 2001; Faraco and Lana, 2003; Alongi *et al.*, 2005). Anthropogenic disturbance on mangroves include deforestation, clearing for aquaculture and other land uses, oil spills and pollution, fragmentation associated with industrial development and urbanization, selective clearing for roads and settlements, timber harvesting and grazing (Ellison and Farnsworth, 1996; Primavera, 1998; Holguin *et al.*, 2005). As a result, some habitats have totally vanished while others remain as fragments. This study found that that rich bird diversity (119 species) in the mangrove habitats of Gujarat might be due to their location in the Central Asian Flyway and also low presence of other major forest ecosystems in the adjoining areas in the State of Gujarat. Further, this study also found the presence of more bird diversity in the fragmented mangroves which are adjoining the human settlements.

4.1 Species Diversity and Density

In this study, the bird species found in the mangroves patches were largely area dependent. In very small mangrove patches, the transient species from the matrix inflated the species richness. This applied to the most of the patches covered during this study which were less than 1sq.km in area. Species composition and richness were similar among the smaller patches suggesting that species packing has led to saturated communities with dominance by species from the matrix. Larger pristine patches like Kori patch in the study had lower evenness of species richness and only a few species like Black necked stork, Green sandpiper, pied avocet were dominantly present. The total diversity of birds recorded during the entire study from the twenty patches was 119 species.

Looking at the ecology of the birds that are found in the large undisturbed patches like Kori, the Pied Avocet is a winter visitor and it's only breeding site within the Indian limits is in the Rann of Kutch where this patch is located. In India, the Black-necked Stork is very widely but thinly distributed, with the north and north-west regions forming its main strongholds (Rahmani 1989). 13 Black necked stork records were reported from Gujarat from which 6 records were from the creeks of Kutch District. (Maheswaran, 2004). Bird densities in mangroves range from 12 ind.ha-1 in Australia (Woinarski *et al.*, 1988) to 26 ind.ha-1 in Peninsular Malaysia (Noske, 1995). In the mangroves of Darwin Harbour, Australia, the mean species richness in dry season was found to be 6.8 birds/ ha (± 0.3 SE) and 5.5 birds/ha (± 0.4 SE) in wet season (Metcalfe, 2007). Average bird density in this study across the mangroves along the coast of Gujarat were found to be 6.485/ha in winter and 4.898/ha in the summer season.

4.2 Effects of seasonality on the mangrove bird community

In the tropics, the variation in bird density among communities has been attributed to variation in resource availability and requirements of the breeding season (Woinarski and Tidemann, 1991). Many of the birds recorded in mangroves of the study area are migratory birds that utilize this habitat after their migration from northern breeding grounds to southern wintering grounds. However, seasonal changes in species richness were not compensated by changes in density. Although total bird density varied among months, species richness was correlated weakly with this variation. Seasonal changes in avifauna (and richness) are minimal in the mangroves (and in rainforests) as compared to savanna woodlands, which experience a greater influx of dry season migrants. In the study, 117 species of birds were noted in the winter season and 103 species were recorded in the summer season. This seasonal influx is recorded in the diversity of birds in winter because of the migratory species present in the area during the winter season.

The birds that were exclusive to the winter season consisted of the migratory species like Black tailed godwit, Wood sandpiper, Common kestrel, Heuglin's gull, Pied avocet, etc. Looking at the ecology of some of these species, the Wood sandpiper is a winter visitor in the country and it migrates back to Europe and northern Asia and breeds in the month of May in Europe and N. Asia. Black tailed Godwit is also a winter visitor in the entire sub-continent and they emigrate back to N. Europe and E. Siberia in March/April. Common

Kestrel is a winter visitor from the Himalayas and beyond. It goes back to the Himalayas in the month of April for breeding (Ali, 1996).

4.3 Species-area relationships

The species–area relationship described by island biogeography theory has been used to suggest that bigger patches are needed to maintain species diversity (MacArthur and Wilson, 1967). In tropical rainforest, small fragments generally contain fewer bird species than that in large fragments (Lees and Peres, 2006). Contrastingly, this island effect was not as strongly observed in mangrove patches as species from the matrix tended to increase species richness, especially for smaller patches where the birds can penetrate the whole mangrove area. Contradictory to the tropical forests, large continuous mangrove patches supported fewer species than smaller fragments. Thus, patch size is not the only important determinant of bird species richness in mangroves. Several mechanisms have been proposed to explain the species-area relationship. The random placement hypothesis (Connor and McCoy, 1979; McGuinness, 1984) is often used as a null model. It assumes that individuals are distributed randomly and the chance of finding a species in a sample is simply a function of sample size. This is sometimes referred to as the passive sampling effect. The passive sampling effect did not explain species-area relationships for mangrove birds as species richness was largely independent of area and sample size.

The habitat matrix has been implicated in bird species-area relationships in several studies (Gascon *et al.*, 1999; Fisher *et al.*, 2006; Kutt, 2007; Lindenmayer and Fisher, 2006; Lindenmayer *et al.*, 2009). Lefebre and Poulin (1997) reported that bird species composition in a floristically poor mangrove forest in South America is largely determined by the type of adjacent matrix.

Species richness in mangroves increases with the number of surrounding matrix habitats. Structurally complex matrices often provide greater landscape connectivity and reduce edge effects, which in turn increase bird species richness in the matrix (Fischer *et al.*, 2006). Consistent with the latter trend, it was observed from the study that the species richness of mangrove patches within a structurally simple mudflat-creeks-mangrove system of the patch Kori was generally poorer (21 species) than those embedded in structurally complex wetlands-human habitation-agricultural field matrix like that in the Una FRH patch (32 species) or a matrix consisting of roads-human habitation-fisheries landing port-saltpan like Porbandar patch (34 species). Species-area curves for the smaller sized patches in both the seasons showed a shallow slope showing a gradually increasing trend which showed some level of sampling saturation. On the contrary, the curves were sharper in the medium sized and the large sized patches showing a lack of sampling effort as the number of those patches were very less during the sampling.

4.4 Patterns in bird responses to various variables:

Heterogeneity in habitat is a very important factor influencing species composition in the mangroves. In general, the increase in habitat heterogeneity is associated with an increase in bird species richness and diversity by accommodating more niches in a given space (MacArthur *et al.,* 1962). Although mangroves are comparatively structurally more homogeneous as compared to other tropical forest habitats, there is nevertheless structural complexity in mangroves derived from, for example, edges of the mangrove patch, the adjoining matrix of the mangrove patches, and the anthropogenic pressures on the mangrove patch. Some of the complexities increase with the area of the mangrove stand. Larger patches often have more human penetration in order to obtain resources from mangroves. The patch characteristic like edge density is affecting the density of the birds negatively. In addition to area, isolation, fragmentation and edge effects, habitat disturbance can also regulate species densities (Azlan, 2010). More the edge, more will be the disturbance in the surroundings of the patch.

It is likely that as the edge effects increases, it would limit the number forest species present in the mangroves which would subsequently create empty niches that are occupied by species from the surrounding matrix.

Habitat heterogeneity and diversity has a demonstrable role in influencing mangrove bird community composition. The total bird species composition is closely associated with the configuration of the vegetation structure. The percent canopy cover was the next most affecting variable (after patch characteristics) affecting both the species diversity and richness. The canopy cover is mostly affecting the bird density and diversity positively (except for bird diversity in summer) which shows that increase in canopy cover increases the bird diversity and abundance. As the canopy cover of a patch increases, more and more birds occupy those patches. This can be justified best for the smaller mangrove patches surrounded by a matrix of other landscapes where the birds prefer to use the mangroves as a refuge.

The presence of dogs have shown to affect the bird diversity and density negatively as the presence of dogs disturbs the birds and flush them out.

Lopping is seen to be affecting the bird diversity and density in a little lesser scale than the canopy cover. Lopping and wood cutting affect the avifauna in the patch as it creates a loss of habitat for the nesting and the foraging birds. Also, the activity of lopping and wood cutting involves penetration of human beings in the patch which further adds to the disturbance to the avifauna. Clearing, infilling and fragmentation of mangroves can juxtapose habitats that are normally widely separated, facilitating access of characteristically terrestrial birds (Metcalfe, 2007). These terrestrial birds then replace the other birds which are largely present in the mangroves.

The overall species density was highest in the patches purely dominated by *A. marina* species. Coupland, (2002) found that in Darwin harbour *A. marina* had the greatest insect species richness. High abundance of the insects and other invertebrates have been reported from the vegetation species which facilitates the diversity and the density of the insectivorous birds in the mangroves.

The vegetation structure and composition of the mangroves varied across the patches. Although, contrary to the assumptions, the mangrove species heterogeneity was found to be very low in the mangroves. Homogeneous patches had one dominant species *A. marina* and the heterogeneous patches consisted of patchily distributed species of mangroves. The maximum heterogeneity recorded from the patches was 3 species per patch. Vegetation characteristics limits and influences the variety of foraging sites supported by a habitat, and consequently the diversity of bird species which it can support (Ford, 1989). Species composition within each vegetation zone showed no clear permanent meta-community structure within the homogeneous and the heterogeneous mangrove patches. However, the factors like tree density and canopy cover were found to be influencing the avifauna found in these patches.

The mangrove bird assemblages showed a significant response towards the disturbance. The disturbed patches contained an overlapping mixed composition of forest birds generally found in the mangroves and also the birds associated with the urban habitats. The disturbance surrounding and penetrating the mangrove patches creates more niches for other terrestrial birds to occupy the same habitat. On the contrary, the less disturbed and undisturbed patches retained more of the forest birds. It appears that highly mobile species such as birds are able to utilize disturbed mangroves opportunistically, moving in and out of areas in response to resource availability. This may also have contributed to species richness and abundance remaining relatively high in the fragmented mangroves fringing developments surveyed in this study.

Area or the patch size had very little effect on the bird density and diversity as regardless of the area, it's the patch matrix of the surroundings which influence the bird diversity and density.

The bird assemblages observed in the mangroves in this study did not support many of the fundamental hypotheses of community ecology. Contrary to expectation, the total bird species richness did not show a strong species-area relationship. Many patterns were often not observed at the overall assemblage level of the birds in patches, largely because a transient element to the bird community, derived from the adjacent habitat matrices, maintains a loose spatial and temporal dynamic to the bird community.

5. Conclusions and recommendations

The smaller mangroves patches have harboured birds with high species richness and diversity in the State of Gujarat. Mangroves provide critical resources and a *refugium* to many animal species, including birds, from the surrounding matrix habitats. Therefore, small mangrove fragments should be conserved and managed wherever possible, particularly if surrounded by natural vegetation as the viability of these small fragments will be largely dependent on the surrounding neighbourhood landscape matrix. Besides, they also serve as nesting grounds for resident birds in the urban landscapes. Therefore, isolated small mangrove patches near urban areas should be restored and protected from further degradation and encroachment of developmental activities.

The results of this study highlights the potential significance of tropical mangrove forests as habitats for the avifaunal species. The mangroves patches support a huge diversity of flora and fauna which is seemingly low at a patch level but is much higher at a landscape level. There is an urgent need to protect all the remaining mangrove patches occurring across the coastline of the state. The species recorded in mangroves should be highlighted in addition to the environmental protection and ecological services offered by the mangroves to further strengthen and ensure the protection of these remanent patches of the mangroves.

The lopping, wood cutting and resource extraction from the mangroves should be checked upon as they create more edges in the already fragmented mangrove patches and this allows the penetration of other open country species into the mangrove forests leading to more competition for the limited resources.

The connectivity of the smaller patches to the nearby larger patches should be maintained. Other forest types occurring in the mangrove matrix should also be conserved as they serve as important linkages to the other mangrove patches facilitating the movement and exchange of species.

The high critical value patches of mangroves with the high species diversity of flora and fauna should be identified and must be actively protected from the anthropogenic disturbance. The flow of effluents from the industries near the mangrove forests should be checked upon to keep the water of the creeks free from the chemical pollutants.

Construction of harbours, jetties or industries on the coast in the future should be concentrated in designated areas where mangroves are already disturbed and beyond restoration.

The pressures on the coastline are ever increasing as different stakeholders have their share to exploit the coastal resources. It is the fact that the development along the coastline is imminent at a global level as well as in India. Therefore, the best strategy is to delineate the ecologically sensitive areas all along the coastline of India. In this context, the Wildlife Institute of India has already identified 106 important coastal and marine biodiversity areas (ICMBAs) (Saravanan *et al.,* 2012). While identifying ICMBAs, WII seems to have ignored the smaller sized mangrove patches due to its size without detailing its biological values especially with respect to birds. But, this study found that the smaller mangrove patches that are located in the urban landscape plays a *refugium* for birds in the region, therefore, smaller patches of mangroves with high species richness of birds also need to be considered as the important coastal and marine biodiversity areas of India.

It was observed during this study that, the mangrove patches in Gujarat are owned by various stake holders like Forest Department, BSF, GMB and private port authorities in Kachchh and Amreli Districts. The state government has notified 581.80 sq.km mangrove area as "Reserved Forests" in Abdasa, Lakhpat and Mundra talukas in Kachchhh District and 77.0 Sq. km in Maliya – Miyana talukas in Morbi district under the Indian Forest Act, 1927. However, there are no notified protected forests in other coastal districts of Gujarat, though there are distributions of the mangroves observed.

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APPENDIX 1

Species of birds observed during the study

S. No.	Species	Scientific Name	Family	Order
1	Ashy drongo	*Dicrurus leucophaeus*	Dicruridae	Passeriformes
2	Ashy prinia	*Prinia socialis*	Cisticolidae	Passeriformes
3	Bar tailed godwit	*Limosa lapponica*	Scolopacidae	Charadriiformes
4	Barn swallow	*Hirundo rustica*	Hirundinidae	Passeriformes
5	Bay backed shrike	*Lanius vittatus*	Laniidae	Passeriformes
6	Baya weaver	*Ploceus philippinus*	Ploceidae	Passeriformes
7	Black crowned night heron	*Nycticorax nycticorax*	Ardeidae	Pelecaniformes
8	Black drongo	*Dicrurus macrocercus*	Dicruridae	Passeriformes
9	Black headed gull	*Chroicocephalus ridibundus*	Laridae	Charadriiformes
10	Black headed ibis	*Threskiornis melanocephalus*	Threskiornithidae	Pelecaniformes
11	Black kite	*Milvus migrans*	Accipitridae	Accipitriformes
12	Black necked stork	*Ephippiorhynchus asiaticus*	Ciconiidae	Ciconiiformes
13	Black tailed Godwit	*Limosa limosa*	Scolopacidae	Charadriiformes
14	Black winged kite	*Elanus caeruleus*	Accipitridae	Accipitriformes
15	Black winged stilt	*Himantopus himantopus*	Recurvirostridae	Charadriiformes
16	Brahminy kite	*Haliastur indus*	Accipitridae	Accipitriformes
17	Brahminy starling	*Sturnia pagodarum*	Sturnidae	Passeriformes
18	Brown headed gull	*Chroicocephalus brunnicephalus*	Laridae	Charadriiformes
19	Steppe gull	*Larus cachinnans*	Laridae	Charadriiformes
20	Caspian tern	*Hydroprogne caspia*	Sternidae	Charadriiformes
21	Cattle egret	*Bubulcus ibis*	Ardeidae	Pelecaniformes
22	Citrine wagtail	*Motacilla citreola*	Motacillidae	Passeriformes
23	Clamorous reed warbler	*Acrocephalus stenttoreus*	Acrocephalinae	Passeriformes
24	Common babbler	*Turdoides caudata*	Leiothrichidae	Passeriformes
25	Common chiffchaff	*Phylloscopus collybita*	Phylloscopidae	Passeriformes
26	Common cuckoo	*Cuculus micropterus*	Cuculidae	Cuculiformes
27	Common green	*Tringa nebularia*	Scolopacidae	Charadriiformes

	shank			
28	Common iora	*Aegithina tiphia*	Aegithinidae	Passeriformes
29	Common kestrel	*Falco tinnunculus*	Falconidae	Falconiformes
30	Common kingfisher	*Alcedo atthis*	Alcedinidae	Coraciiformes
31	Common moorhen	*Gallinula chloropus*	Rallidae	Gruiformes
32	Common myna	*Acridotheres tristis*	Sturnidae	Passeriformes
33	Common pigeon	*Columba livia*	Columbidae	Columbiformes
34	Common red shank	*Tringa totanus*	Scolopacidae	Charadriiformes
35	Common Sandpiper	*Actitis hypoleucos*	Scolopacidae	Charadriiformes
36	Common snipe	*Gallinago gallinago*	Scolopacidae	Charadriiformes
37	Common tailorbird	*Orthotomus sutorius*	Cisticolidae	Passeriformes
38	Crested lark	*Galerida cristata*	Alaudidae	Passeriformes
39	Curlew sandpiper	*Calidris ferruginea*	Scolopacidae	Charadriiformes
40	Demoiselle crane	*Grus virgo*	Gruidae	Gruiformes
41	Eurasian collared dove	*Streptopelia decaocta*	Columbidae	Columbiformes
42	Eurasian curlew	*Numenius arquata*	Scolopacidae	Charadriiformes
43	Eurasian hobby	*Falco subbuteo*	Falconidae	Falconiformes
44	Eurasian marsh harrier	*Circus aeruginosus*	Accipitridae	Accipitriformes
45	Eurasian spoonbill	*Platalea leucorodia*	Threskiornithidae	Pelecaniformes
46	Glossy Ibis	*Plegadis falcinellus*	Threskiornithidae	Pelecaniformes
47	Great egret	*Casmerodius albus*	Ardeidae	Pelecaniformes
48	Greater short toed lark	*Calandrella brachydactyla*	Alaudidae	Passeriformes
49	Green bee eater	*Merops orientalis*	Meropidae	Coraciiformes
50	Green sandpiper	*Tringa ochropus*	Scolopacidae	Charadriiformes
51	Grey francolin	*Francolinus pondicerianus*	Phasianidae	Galliformes
52	Grey heron	*Ardea cinerea*	Ardeidae	Pelecaniformes
53	Grey wagtail	*Motacilla cinerea*	Motacillidae	Passeriformes
54	Gull billed tern	*Gelochelidon nilotica*	Sternidae	Charadriiformes
55	Heuglin's Gull	*Larus heuglini*	Laridae	Charadriiformes
56	House crow	*Corvus splendens*	Corvidae	Passeriformes
57	House sparrow	*Passer domesticus*	Passeridae	Passeriformes
58	Indian bushlark	*Mirafra erythroptera*	Alaudidae	Passeriformes
59	Indian	*Phalacrocorax*	Phalacrocoracidae	Suliformes

	cormorant	*fuscicollis*		
60	Indian golden oriole	*Oriolus (oriolus) kundoo*	Oriolidae	Passeriformes
61	Indian jungle crow	*Corvus (macrorhynchos) culminatus*	Corvidae	Passeriformes
62	Indian pond heron	*Ardeola grayii*	Ardeidae	Pelecaniformes
63	Indian robin	*Saxicoloides fulicatus*	Muscicapidae	Passeriformes
64	Indian roller	*Coracias benghalensis*	Coraciidae	Coraciiformes
65	Indian silverbill	*Euodice malabarica*	Estrildidae	Passeriformes
66	Indian thick knee	*Burhinus (oedicnemus) indicus*	Burhinidae	Charadriiformes
67	Intermediate egret	*Mesophoyx intermedia*	Ardeidae	Pelecaniformes
68	Kentish plover	*Charadrius alexandrinus*	Charadriidae	Charadriiformes
69	Large grey babbler	*Turdoides malcolmi*	Sylviidae	Passeriformes
70	Laughing dove	*Stigmatopelia senegalensis*	Columbidae	Columbiformes
71	Little cormorant	*Phalacrocorax niger*	Phalacrocoracidae	Suliformes
72	Little egret	*Egretta garzetta*	Ardeidae	Pelecaniformes
73	Little ringed plover	*Charadrius dubius*	Charadriidae	Charadriiformes
74	Little swift	*Apus affinis*	Apodidae	Apodiformes
75	Longtail shrike	*Lanius schach*	Laniidae	Passeriformes
76	Marsh sandpiper	*Tringa stagnatilis*	Scolopacidae	Charadriiformes
77	Montagu's harrier	*Circus pygargus*	Accipitridae	Accipitriformes
78	Oriental Darter	*Anhinga melanogaster*	Anhingidae	Suliformes
79	Oriental Honey buzzard	*Pernis ptilorhynchus*	Accipitridae	Accipitriformes
80	Oriental magpie robin	*Copsychus saularis*	Muscicapidae	Passeriformes
81	Oriental white eye	*Zosterops palpebrosus*	Zosteropidae	Passeriformes
82	Osprey	*Pandion haliaetus*	Pandionidae	Accipitriformes
83	Painted stork	*Mycteria leucocephala*	Ciconiidae	Ciconiiformes
84	Pallas's gull	*Ichthyaetus ichthyaetus*	Laridae	Charadriiformes
85	Pallid harrier	*Circus macrourus*	Accipitridae	Accipitriformes
86	Pied avocet	*Recurvirostra avosetta*	Recurvirostridae	Charadriiformes
87	Pied bushchat	*Saxicola caprata*	Saxicolini	Passeriformes
88	Pied kingfisher	*Ceryle rudis*	Cerylidae	Coraciiformes

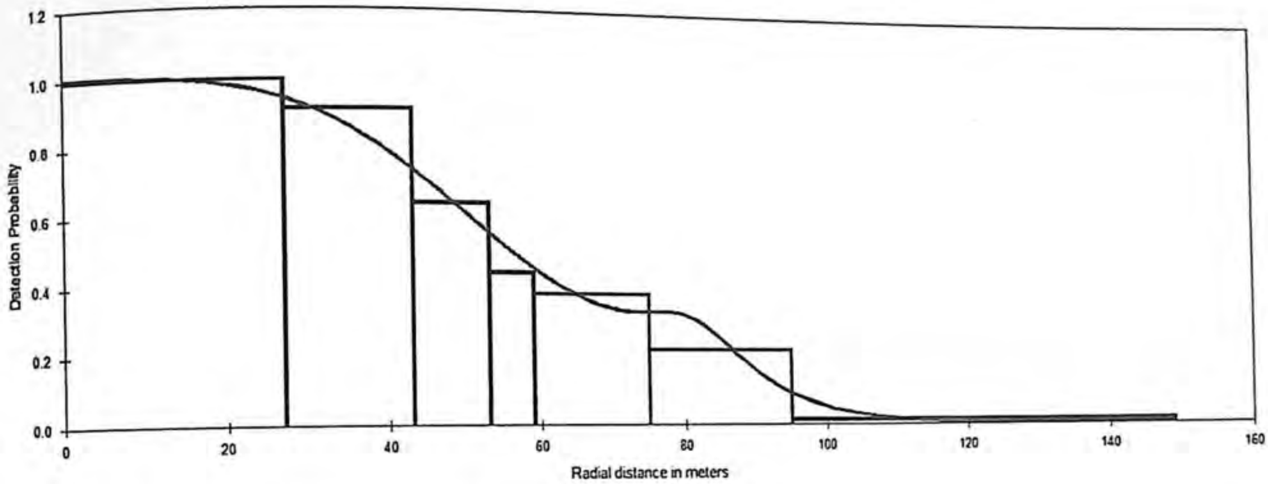
89	Plain prinia	*Prinia inornata*	Cisticolidae	Passeriformes
90	Purple heron	*Ardea purpurea*	Ardeidae	Pelecaniformes
91	Purple sunbird	*Cinnyris asiaticus*	Nectariniidae	Passeriformes
92	Red naped ibis	*Pseudibis papillosa*	Threskiornithidae	Pelecaniformes
93	Red rumped swallow	*Cecropis daurica*	Hirundinidae	Passeriformes
94	Red vented bulbul	*Pycnonotus cafer*	Pycnonotidae	Passeriformes
95	Red wattled lapwing	*Vanellus indicus*	Charadriidae	Charadriiformes
96	River tern	*Sterna aurantia*	Sternidae	Charadriiformes
97	Rosy starling	*Pastor roseus*	Sturnidae	Passeriformes
98	Ruddy turnstone	*Arenaria interpres*	Scolopacidae	Charadriiformes
99	Shikra	*Accipiter badius*	Accipitridae	Accipitriformes
100	Short toed snake eagle	*Circaetus gallicus*	Accipitridae	Accipitriformes
101	Southern coucal	*Centropus (sinensis) parroti*	Cuculidae	Cuculiformes
102	Spotted dove	*Stigmatopelia chinensis*	Columbidae	Columbiformes
103	Spotted redshank	*Tringa erythropus*	Scolopacidae	Charadriiformes
104	Steppe eagle	*Aquila nipalensis*	Accipitridae	Accipitriformes
105	Stork billed kingfisher	*Pelargopsis capensis*	Halcyonidae	Coraciiformes
106	Sulphur bellied warbler	*Phylloscopus griseolus*	Phylloscopidae	Passeriformes
107	Western Reef Egret	*Egretta gularis*	Ardeidae	Pelecaniformes
108	Whimbrel	*Numenius phaeopus*	Scolopacidae	Charadriiformes
109	Whiskered tern	*Chlidonias hybrida*	Sternidae	Charadriiformes
110	White breasted kingfisher	*Halcyon smyrnensis*	Alcedinidae	Coraciiformes
111	White breasted waterhen	*Amaurornis phoenicurus*	Rallidae	Gruiformes
112	White eared bulbul	*Pycnonotus leucotis*	Pycnonotidae	Passeriformes
113	White eyed buzzard	*Butastur teesa*	Accipitridae	Accipitriformes
114	Wire tailed swallow	*Hirundo smithii*	Hirundinidae	Passeriformes
115	Wood sandpiper	*Trigna glareola*	Scolopacidae	Charadriiformes
116	Wooly necked stork	*Ciconia episcopus*	Ciconiidae	Ciconiiformes
117	Yellow wagtail	*Motacilla flava*	Motacillidae	Passeriformes

118	Yellow wattled lapwing	*Vanellus malabaricus*	Charadriidae	Charadriiformes
119	Zitting cisticola	*Cisticola juncidis*	Cisticolidae	Passeriformes

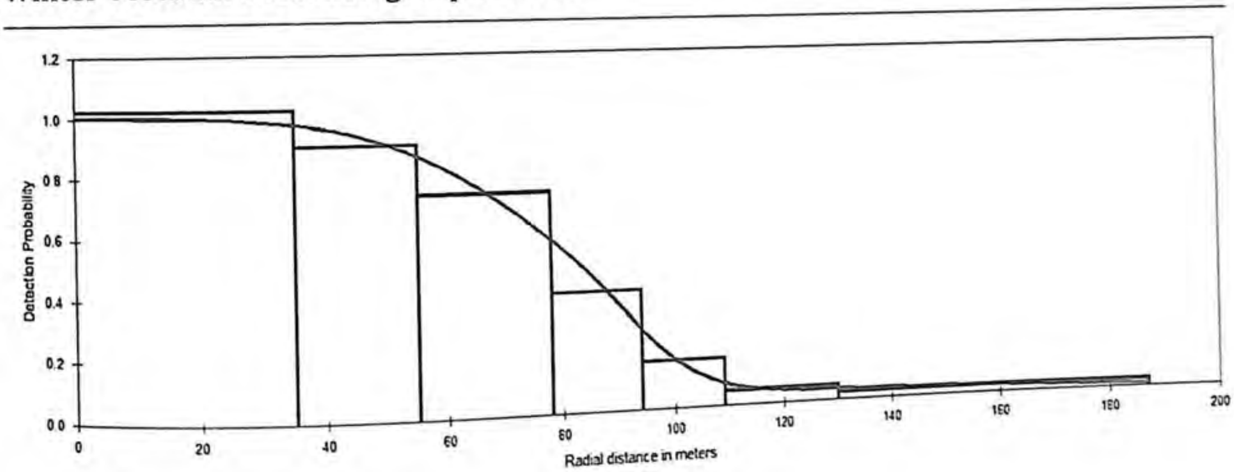
APPENDIX 2

The graphs for calculating bird densities in DISTANCE 6.0

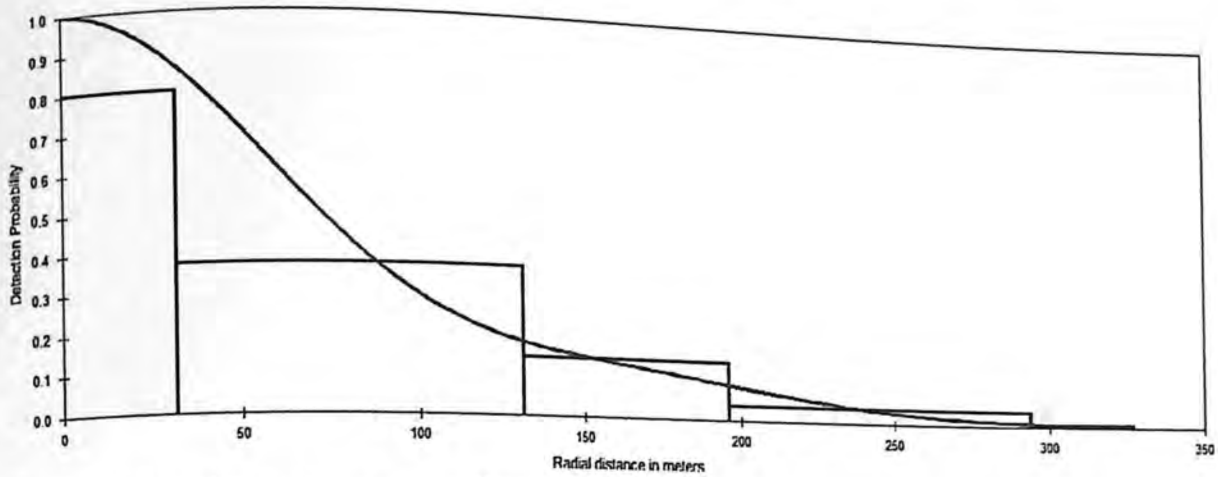
Winter – Low detection group of birds



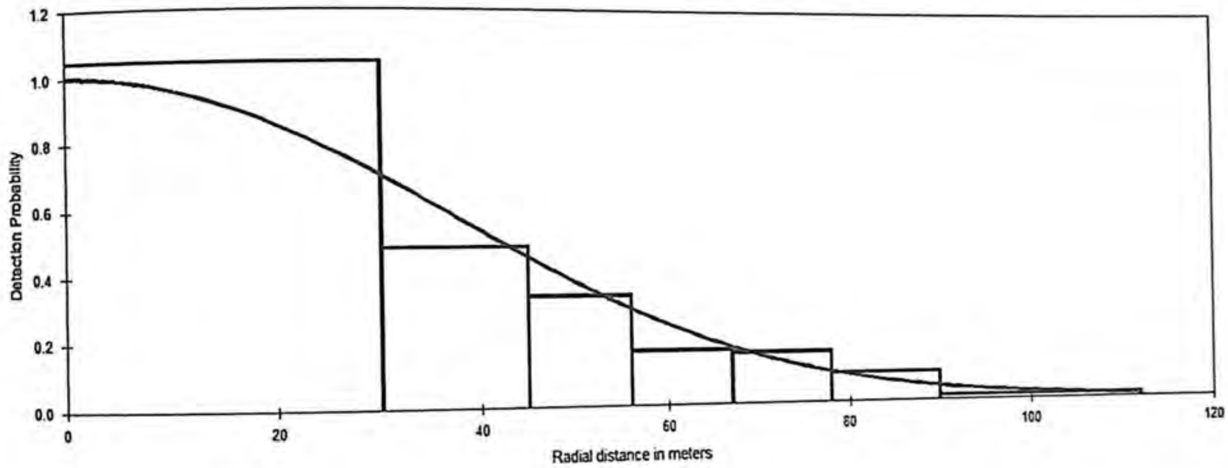
Winter-Medium detection group of birds



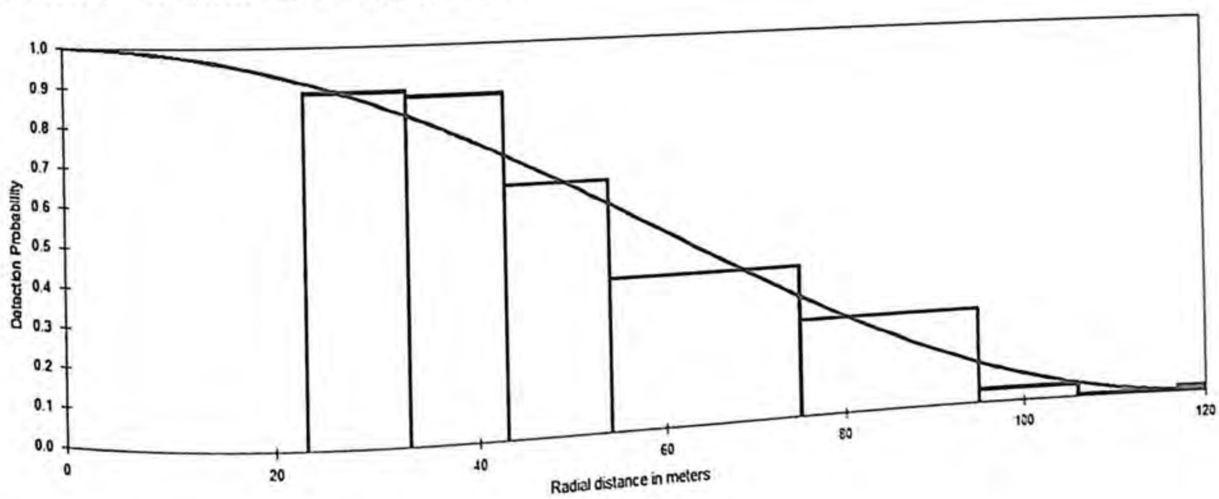
Winter- High Detection group of birds



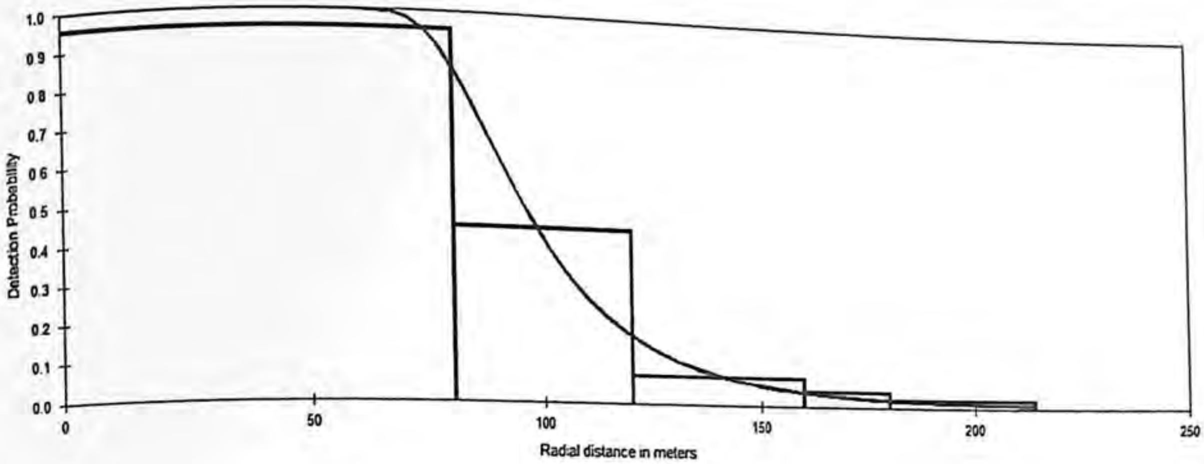
Summer-Low Detection group of birds



Summer- Medium Detection group of birds



Summer-High Detection group of birds



Appendix 3

Classification of birds into forest and open country birds

Sr no	Species of birds	bird species type
1	White Breasted Kingfisher	open country
2	Red Vented Bulbul	open country
3	Common Pigeon	open country
4	Eurasian Collared Dove	open country
5	Laughing Dove	open country
6	Rosy Starling	open country
7	Ashy Drongo	open country
8	Black Drongo	open country
9	Black Kite	open country
10	Shikra	open country
11	Barn Swallow	open country
12	Brahminy Starling	open country
13	Cattle Egret	open country
14	Common Babbler	open country
15	Common Cuckoo	open country
16	Common Tailorbird	open country
17	Green Bee Eater	open country
18	Indian Robin	open country
19	Little Swift	open country
20	Oriental Magpie Robin	open country
21	Red Wattled Lapwing	open country
22	Wire Tailed Swallow	open country
23	Purple Sunbird	open country
24	Common Myna	open country

25	House Crow	open country
26	House Sparrow	open country
1	Bar Tailed Godwit	Forest
2	Black Crowned Night Heron	Forest
3	Black Tailed Godwit	Forest
4	Black Winged Stilt	Forest
5	Brown Headed Gull	Forest
6	Steppe Gull	Forest
7	Caspian Tern	Forest
8	Common Green Shank	Forest
9	Common Kingfisher	Forest
10	Common Red Shank	Forest
11	Common Sandpiper	Forest
12	Common Snipe	Forest
13	Curlew Sandpiper	Forest
14	Eurasian Curlew	Forest
15	Eurasian Spoonbill	Forest
16	Great Egret	Forest
17	Green Sandpiper	Forest
18	Grey Heron	Forest
19	Gull Billed Tern	Forest
20	Heugins Gull	Forest
21	Intermediate Egret	Forest
22	Kentish Plover	Forest
23	Little Egret	Forest
24	Little Ringed Plover	Forest
25	Marsh Sandpiper	Forest
26	Pallas Gull	Forest
27	Pied Avocet	Forest
28	Pied Kingfisher	Forest
29	Purple Heron	Forest
30	River Tern	Forest
31	Ruddy Turnstone	Forest
32	Spotted Redshank	Forest
33	Stork Billed Kingfisher	Forest
34	Western Reef Egret	Forest
35	Whimbrel	Forest
36	Whiskered Tern	Forest
37	Wood Sandpiper	Forest
38	Wooly Necked Stork	Forest
39	Black Headed Ibis	Forest
40	Black Necked Stork	Forest
41	Glossy Ibis	Forest

42	Indian Pond Heron	Forest
43	Painted Stork	Forest
44	Red Naped Ibis	Forest
45	Indian Golden Oriole	Forest
46	White Eared Bulbul	Forest
47	Crested Lark	Forest
48	Demoiselle Crane	Forest
49	Indian Silverbill	Forest
50	Spotted Dove	Forest
51	Baya Weaver	Forest
52	Common Moorhen	Forest
53	Greater Short Toed Lark	Forest
54	Grey Francolin	Forest
55	Indian Bushlark	Forest
56	White Breasted Waterhen	Forest
57	Bay Backed Shrike	Forest
58	Black Winged Kite	Forest
59	Brahminy Kite	Forest
60	Common Kestrel	Forest
61	Eurasian Hobby	Forest
62	Eurasian Marsh Harrier	Forest
63	Longtail Shrike	Forest
64	Montagu's Harrier	Forest
65	Oriental Honey Buzzard	Forest
66	Pallid Harrier	Forest
67	Short Toed Snake Eagle	Forest
68	Southern Coucal	Forest
69	Steppe Eagle	Forest
70	White Eyed Buzzard	Forest
71	Ashy Prinia	Forest
72	Citrine Wagtail	Forest
73	Clamorous Reed Warbler	Forest
74	Common Chiffchaff	Forest
75	Common Iora	Forest
76	Grey Wagtail	Forest
77	Indian Roller	Forest
78	Indian Thick Knee	Forest
79	Large Grey Babbler	Forest
80	Pied Bushchat	Forest
81	Plain Prinia	Forest
82	Red Rumped Swallow	Forest
83	Sulphur Bellied Warbler	Forest
84	Yellow Wagtail	Forest

85	Yellow Wattled Lapwing	Forest
86	Zitting Cisticola	Forest
87	Oriental White Eye	Forest
88	Indian Jungle Crow	Forest
89	Black Headed Gull	Forest
90	Indian Cormorant	Forest
91	Little Cormorant	Forest
92	Oriental Darter	Forest
93	Osprey	Forest

Detection group of each species:

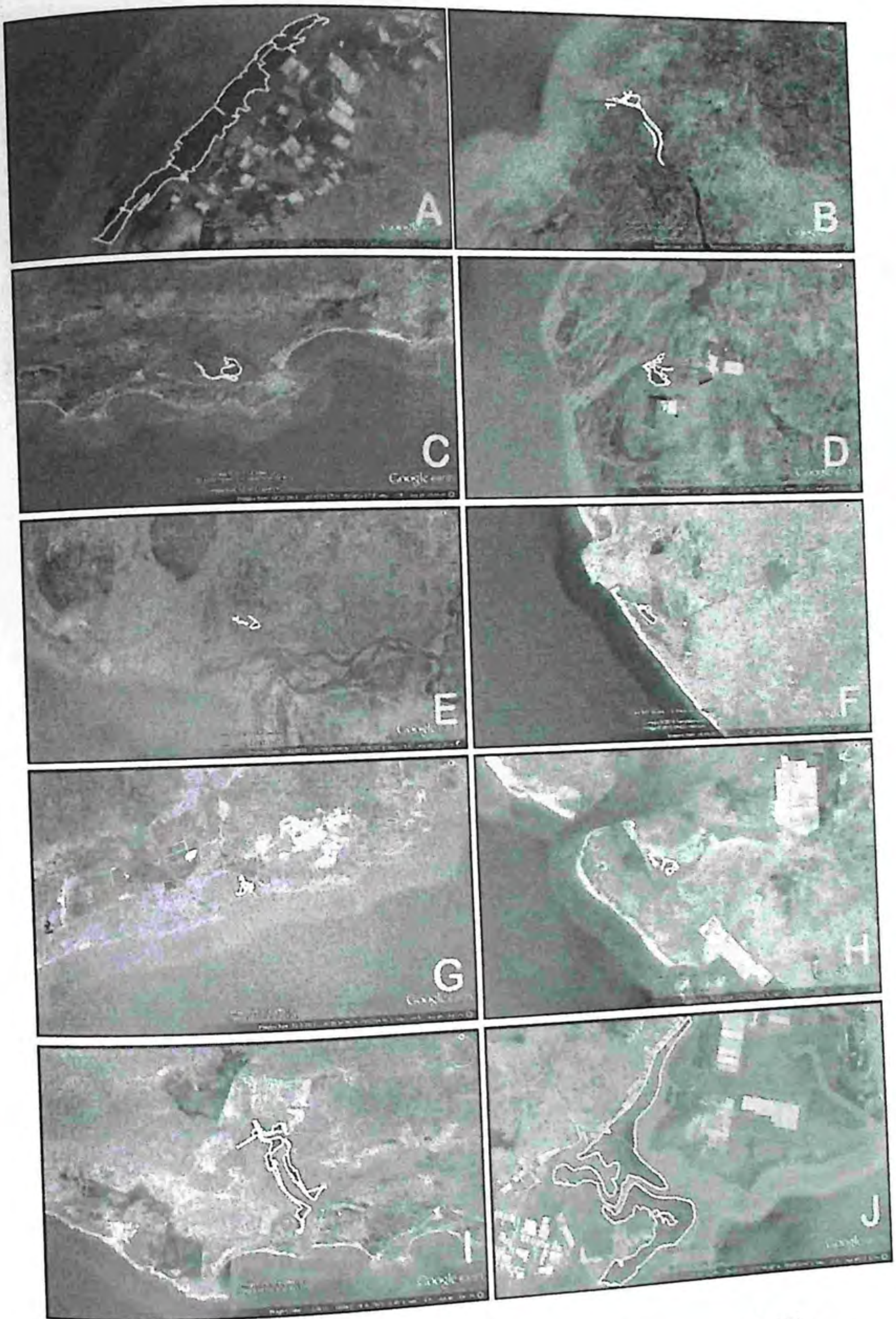
Sr No.	Species	Det. Group
1	Ashy Drongo	Low
2	Ashy Prinia	Medium
3	Bar Tailed Godwit	High
4	Barn Swallow	High
5	Bay Backed Shrike	Medium
6	Baya Weaver	Medium
7	Brahminy Starling	Medium
8	Black Crowned Night Heron	Low
9	Black Drongo	Low
10	Black Headed Gull	Medium
11	Black Headed Ibis	Medium
12	Black Kite	High
13	Black Necked Stork	High
14	Black Tailed Godwit	Low
15	Black Winged Kite	High
16	Black Winged Stilt	Medium
17	Brahminy Kite	High
18	Brown Headed Gull	High
19	Steppe Gull	Medium
20	Caspian Tern	Low
21	Cattle Egret	Low
22	Citrine Wagtail	Medium
23	Clamorous Reed Warbler	Low
24	Common Babbler	Medium
25	Common Chiffchaff	Medium
26	Common Cuckoo	Low

27	Common Greenshank	High
28	Common Iora	Low
29	Common Kestrel	Low
30	Common Kingfisher	Medium
31	Common Moorhen	Medium
32	Common Myna	Medium
33	Common Pigeon	Medium
34	Common Red Shank	Low
35	Common Sandpiper	Medium
36	Common Snipe	High
37	Common Tailorbird	Low
38	Crested Lark	Medium
39	Curlew Sandpiper	Medium
40	Demoiselle Crane	High
41	Eurasian Collared Dove	Low
42	Eurasian Curlew	Medium
43	Eurasian Hobby	High
44	Eurasian Marsh Harrier	High
45	Eurasian Spoonbill	Medium
46	Glossy Ibis	Medium
47	Great Egret	Medium
48	Greater Short Toed Lark	High
49	Green Bee Eater	Medium
50	Green Sandpiper	Medium
51	Grey Francolin	Medium
52	Grey Heron	Medium
53	Grey Wagtail	Medium
54	Gull Billed Tern	Medium
55	Heugins Gull	High
56	House Crow	Medium
57	House Sparrow	Low
58	Indian Bushlark	Low
59	Indian Cormorant	Medium
60	Indian Golden Oriole	Low
61	Indian Jungle Crow	Low
62	Indian Pond Heron	Low
63	Indian Robin	Low
64	Indian Roller	Medium
65	Indian Silverbill	Medium
66	Indian Thick Knee	Medium
67	Intermediate Egret	Medium
68	Kentish Plover	High
69	Large Grey Babbler	High

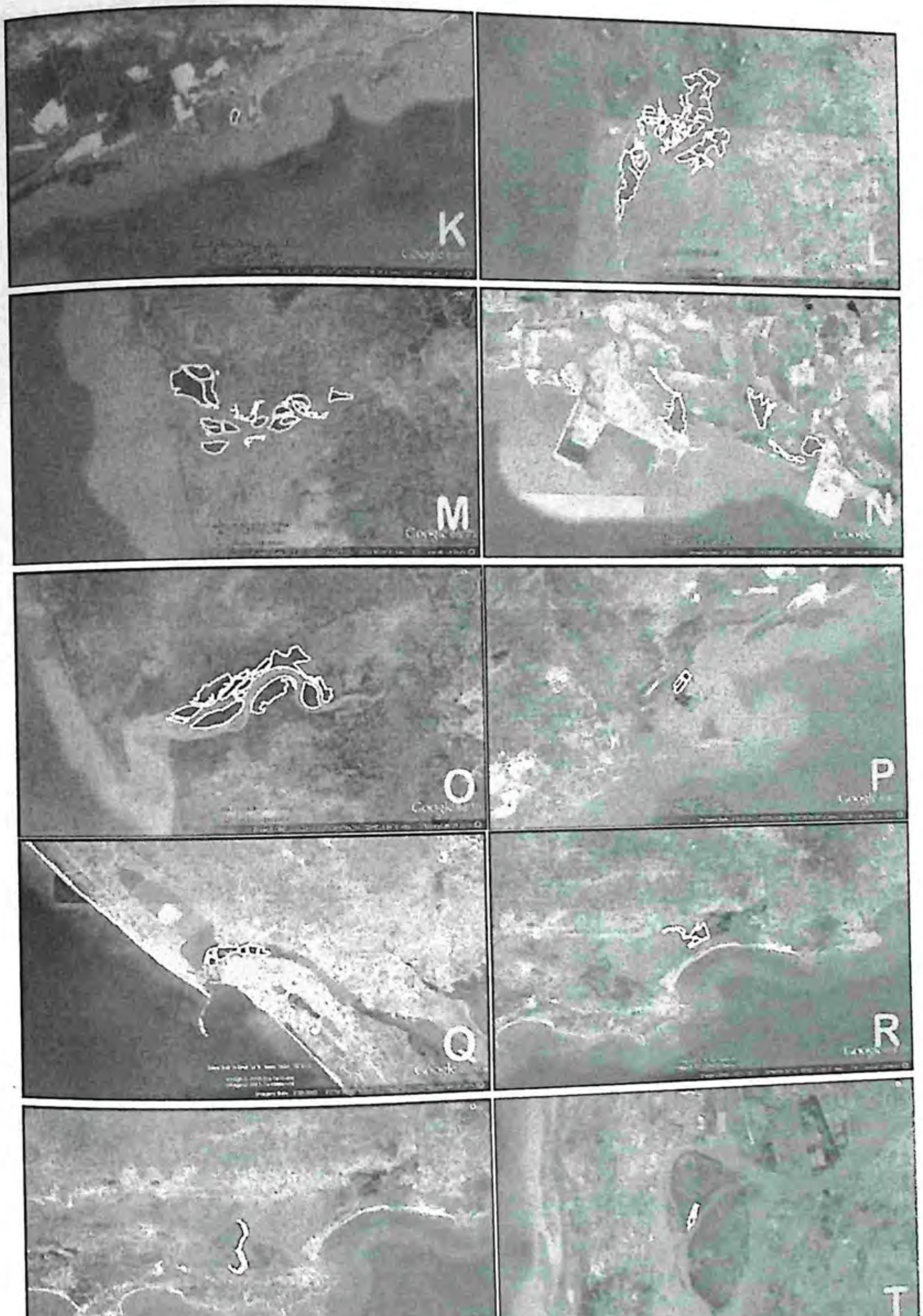
70	Laughing Dove	Medium
71	Little Cormorant	Medium
72	Little Egret	Medium
73	Little Ringed Plover	Medium
74	Little Swift	Low
75	Longtail Shrike	High
76	Marsh Sandpiper	Low
77	Montagu's Harrier	High
78	Oriental Darter	Medium
79	Oriental Honey Buzzard	High
80	Oriental Magpie Robin	Medium
81	Oriental White Eye	Low
82	Osprey	High
83	Painted Stork	High
84	Pallas's Gull	High
85	Pallid Harrier	High
86	Pied Avocet	High
87	Pied Bushchat	Low
88	Pied Kingfisher	Medium
89	Plain Prinia	Medium
90	Purple Heron	Low
91	Purple Sunbird	Low
92	Red Naped Ibis	Medium
93	Red Rumped Swallow	Low
94	Red Vented Bulbul	Low
95	Red Wattled Lapwing	Medium
96	River Tern	Medium
97	Rosy Starling	Low
98	Ruddy Turnstone	Medium
99	Shikra	Medium
100	Short Toed Snake Eagle	High
101	Southern Coucal	Medium
102	Spotted Dove	Medium
103	Spotted Redshank	Low
104	Stepper Eagle	High
105	Stork Billed Kingfisher	Medium
106	Sulphur Bellied Warbler	High
107	Western Reef Egret	Medium
108	Whimbrel	Medium
109	Whiskered Tern	High
110	White Breasted Kingfisher	Low
111	White Breasted Waterhen	Low
112	White Eared Bulbul	Medium

113	White Eyed Buzzard	Medium
114	Wire Tailed Swallow	Low
115	Wood Sandpiper	High
116	Wooly Necked Stork	Medium
117	Yellow Wagtail	Medium
118	Yellow Wattled Lapwing	Medium
119	Zitting Cisticola	Low

Google earth images of each patch.



A: Dahej
B: Daman
C: Dandi
D: Diu
E: Dumas
F: Dwarka
G: Jafrabaad
H: Jakhau
I: Kadiya
J: Kandla



K: Khera
O: Nemarai
S: Una SD
L: Kori
P: Pipavav
T: Tunda
M: Mendhar
Q: Porbandar
N: Mundra
R: Una FRH

Inter-patch distance matrix

	Jakhau	Kori	Mundra	Kandla	Dwarka	Porbander	Una Sp	Una FRH	Diu	Khera	Pipavav	Jafrabad	Dahej	Dandi	Dumas	Tunda	Nemarai	Mendhar	Kadiya	Daman
Jakhau	0	39	115	157	118	200	360	370	368	399	392	388	437	463	485	491	501	519	535	538
Kori	39	0	146	181	156	240	398	406	405	423	427	433	464	493	516	522	533	551	568	571
Mundra	115	146	0	50	85	126	259	265	266	281	280	278	320	348	369	375	386	403	421	424
Kandla	157	181	50	0	140	151	256	260	261	268	266	265	284	315	340	345	356	376	396	400
Dwarka	118	156	85	140	0	90	257	267	266	307	299	292	371	388	407	412	421	45	448	450
Porbander	200	240	126	151	90	0	163	177	175	223	213	205	306	315	30	335	343	356	364	366
una Sp	360	398	259	256	257	163	0	14	11	83	70	57	207	193	196	200	204	209	211	211
una FRH	370	406	265	260	267	177	14	0	4	69	56	43	195	178	181	186	189	194	196	196
diu	368	405	266	261	266	175	11	4	0	74	60	47	200	184	186	190	194	198	200	200
Khera	399	423	281	268	307	223	83	69	74	0	14	27	127	109	113	117	123	132	141	143
Pipavav	392	427	280	266	299	213	70	56	60	14	0	13	142	124	127	131	136	144	150	152
jafrabad	388	433	278	265	292	205	57	43	47	27	13	0	152	136	139	144	148	154	159	160
Dahej	437	464	320	284	371	306	207	195	200	127	142	152	0	48	77	80	93	117	147	152
dandi	463	493	348	315	388	315	193	178	184	109	124	136	48	0	29	33	46	69	98	104
dumas	485	516	369	340	407	330	196	181	186	113	127	139	77	29	0	5	17	40	69	75
tunda	491	522	375	345	412	335	200	186	190	117	131	144	80	33	5	0	13	36	66	72
nemrai	501	533	386	356	421	343	204	189	194	123	136	148	93	46	17	13	0	24	54	60
mendhar	519	551	403	376	435	356	209	194	198	132	144	154	117	69	40	36	24	0	30	37
kadiya	535	568	421	396	448	364	211	196	200	141	150	159	147	98	69	66	54	30	0	6
daman	538	571	424	400	450	366	211	196	200	143	152	160	152	104	75	72	60	37	6	0