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# Assemblage of Shorebirds in the Sindhudurg District Maharashtra

THESIS TO BE SUBMITTED TO
MANIPAL ACADEMY OF HIGHER EDUCATION

FOR FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE
OF

**DOCTOR OF PHILOSOPHY**

BY

**GOLUSU BABU RAO**
Reg. No. 159000049

UNDER THE GUIDANCE OF

**Dr. S. BABU**

Senior Scientist
Division of Ornithology, SACON
Anaikatty, Coimbatore - 641108
Tamil Nadu, India

SÁLIM ALI CENTRE FOR ORNITHOLOGY AND NATURAL HISTORY (SACON)

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डॉ. एस बाबु / Dr. S Babu
वरिष्ठ वैज्ञानिक & सहायक पाठ्यक्रम निदेशक (पीजी)
Senior Scientist & Asst. Course Director (PG)
सालिम अली पक्षिविज्ञान एवं प्रकृति विज्ञान केन्द्र
Sálim Ali Centre for Ornithology and Natural History
आनैकट्टी, कोयम्बटूर – 641 108
Anaikatty (Post), Coimbatore – 641 108.

**Dr. S. Babu**
Senior Scientist
Division of Ornithology
Sálim Ali Centre for Ornithology and Natural History (SACON)

Place: SACON, Coimbatore
Date: 25th February 2022

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I declare that this thesis, submitted for the degree of Doctor of Philosophy to Manipal Academy of Higher Education, is my original work, conducted under the supervision of my guide **Dr. S. Babu**. I also wish to inform that no part of the research has been submitted for a degree or examination at any university. References, help and material obtained from other sources have been duly acknowledged.

**Candidate**

Signature
**Golusu Babu Rao**
Reg. No. 159000049
Division of Ornithology
Sálim Ali Centre for Ornithology and Natural History (SACON)

**February 2022**

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# CERTIFICATE

This is to certify that the work incorporated in this thesis “**Assemblage of Shorebirds in the Sindhudurg District Maharashtra**” submitted by **Mr. Golusu Babu Rao** was carried out under my supervision. No part of this thesis has been submitted for a degree or examination at any university. References, help and material obtained from other sources have been duly acknowledged.

**Research Guide**

डॉ. एस बाबु / Dr. S Babu
वरिष्ठ वैज्ञानिक & सहायक पाठ्यक्रम निदेशक (पीजी)
Senior Scientist & Asst. Course Director (PG)
सालिम अली पक्षिविज्ञान एवं प्रकृति विज्ञान केन्द्र
Sálim Ali Centre for Ornithology and Natural History
आनैकट्टी, कोयम्बटूर - 641 108
Anaikatty (Post), Coimbatore - 641 108

Signature
**Dr. S. Babu**
Senior Scientist
Division of Ornithology
Sálim Ali Centre for Ornithology and Natural History (SACON)

**February 2022**

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**Babu Rao**

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**Abstract:**

Migratory shorebirds are the most threatened waterbird species around the world. Shorebirds in India have received little attention, particularly on the west coast. Thus, this study was conducted in the coastal areas of the Sindhudurg district, Maharashtra. The coastal habitats in the district are dominated by beaches, mudflats, and mangroves, which have been identified as potential habitats for shorebirds. Thus, the distribution, abundance, and factors influencing habitat use of shorebirds were studied from these three habitats across seven sites and five seasons. Among the three habitat types, mudflat was an important area for shorebirds thus fine-scale habitat selection for select shorebird species was carried out in the mudflats. Total count and photographic methods were used to count the birds. A total of 36 species of shorebirds were recorded, of which 21 and 10 species used Sindhudurg coast as stopover and wintering sites respectively. Mudflats had a higher species richness (21) than the beach (20) and mangroves (14) habitats. Plovers were the most common and abundant species in the study area. nMDs showed various pattern of shorebird species composition across the habitats and seasons. The cluster analysis revealed five distinct migratory seasons in shorebirds along the Sindhudurg coast: 1) arrival phase, 2) wintering phase, 3) early departure and late arrival phase, 4) departure phase, and e) breeding phase. The physiochemical parameters of water and prey varied significantly between habitats and seasons. Salinity showed decreasing trend from beach (34.67±5.94) towards the mangroves (28.07±7.66). Prey abundance was higher in mudflats and during the wintering season. BIO-ENV analysis showed that among the measured environmental parameters salinity was the key factor influenced prey distribution (ρ=0.51). The shorebird richness ($X^2$=56.5, P=0.00) and abundance ($X^2$=32.6, P=0.00) positively influenced by crustacean density, salinity and bivalve density. Prey availability and accessibility had a major impact on the fine-scale habitat selection of the studied species. The Lesser Sand Plover and Kentish Plover avoided areas with oyster beds and preferred fine sand substrates with higher crab densities. Eurasian Curlew selected high profitable foraging sites close to the waterline with increased surface penetrability.

**Keywords:** Shorebirds, Sindhudurg, Mudflats, Plovers, West coast, Accessibility

# Chapter 1

# Introduction

## 1.1. GENERAL OVERVIEW

Shorebirds are members of the order Charadriiformes belonging to the class Aves. More than 200 species of shorebirds occur around the world (Message & Taylor, 2005). Most of these species are typically associated with wetlands, especially in coastal habitats hence they are referred to as 'waders or shorebirds. Shorebirds are a divergent group of birds among the avifauna because of their prodigious migration journeys between breeding and wintering grounds (Message & Taylor, 2005). They mostly breed in the Northern hemisphere in the Arctic tundra and winters in Australia, Africa, and South Asia (CMS, 2019). Shorebirds generally form large flocks during feeding and migration but are solitary while breeding. These are easily distinguishable because of their long conspecific beaks and legs (Message & Taylor, 2005).

During migration, shorebirds stage at several sites to acquire energy reserves, typically using estuarine intertidal mudflats for foraging (Watkins, 1993). Estuarine intertidal mudflats are dynamic coastal ecosystems largely influenced by tides (Dias et al. 2006). Intertidal habitats of the estuarine ecosystem usually exposed during low tide provide foraging space for shorebirds. The availability and accessibility of intertidal foraging space to the shorebirds are largely governed by tidal cycles. During high tide mudflats are filled with high tide water as a result species are forced to move from these places to high tide roost sites. In this way, the available foraging space changes over the different temporal gradient on intertidal mudflats. Shorebirds developed various morphological and behavioural adaptations to exploit the prey in these dynamic coastal ecosystems. The two basic strategies used by shorebirds to capture the prey are pecking and probing (Jiang et al. 2007). Shorebirds capture the prey either by sight or touch and sometimes use both techniques. The bill shape and size of each shorebird species are specially designed to capture particular prey items from a unique substrate. Generally, the short-billed shorebirds like Plovers primarily use the pecking type of foraging method. The long-billed Bar-tailed Godwit and Eurasian Curlew use the probing method. Foot-trembling and stitching (repeated probing in the sediment) behaviour is the few examples of behavioural adaptation followed by the shorebirds to capture their prey. All these specialized characters make the species share the resources equally in their wintering grounds (Message & Taylor, 2005).

The non-breeding season is the most crucial period for shorebirds because energy demands are high at this stage (Alerstam & Hedenström, 1998). Tracking and finding of suitable stopover and wintering sites for refuel energy resources are critical for successful migration journeys (Petit, 2000). Further, most shorebird mortality occurs outside their breeding range therefore strong selective forces shape the species to use suitable stopover and wintering grounds (Brindock & Colwell, 2011). On the wintering grounds, shorebirds use intertidal mudflats and mostly prey upon the benthic invertebrates. (Lunardi et al. 2012; Aarif et al. 2021). The major shorebird diet consists of polychaetes, bivalves, crustaceans, and gastropods (Yates et al. 1993; van de Kam et al. 2004). Shorebird migration strongly coincides with the local and regional abundance of food resources (Moore et al. 1995; Aarif et al. 2021). In addition to prey, multiple factors influence shorebird habitat use during non-breeding season such as predatory pressure (Lank et al. 2003), suitable high tide roost sites (Dias et al. 2006), and anthropogenic disturbances (Yasue, 2006).

Migratory shorebirds use specific paths to complete their migration between breeding and wintering grounds these specific routes are called flyways (International Wader Study Group, 2003). Among the shorebird populations across the globe, many shorebird populations are declining (International Wader Study Group, 2003). The main reason for shorebird population declines is degradation or loss of habitat, hunting, climate change, and increasing human pressure that collapsed most of the shorebird populations (Norris et al. 2005; Stroud et al. 2006). To conserve the migratory shorebird population across the globe, nine migratory flyways are identified by CMS (Convention on the Conservation of

Migratory Species of Wild Animals). Out of nine, three flyways are found in India viz., Central Asian Flyway (CAF), West Asian/East African Flyway (WAEAF), and East-Asian Australian Flyway (EAAF). Central Asian Flyway is the smallest shorebird flyway in the world, lying exclusively in the Northern Hemisphere, which extends from the northernmost breeding site, Siberia to the southernmost non-breeding areas of South Asia and West Asia (CMS, 2019). The CAF is one of the least known flyways, most of shorebird population trends and size are being unknown (CMS, 2019; Balachandaran, 2006). CAF spread across the 30 countries, India is one of the major countries in the CAF which supports 171 species, including 5 Critical Endangered, 5 Endangered, 13 Vulnerable, and 14 Near-Threatened species (CAF National Action Plan, 2018).

India has a long coastal line, which is broadly categorized into two types i.e., east coast (extends from Kanyakumari-West Bengal) and west coast (stretches between Kerala-Gujarat) consists of diverse coastal habitats (beach, mangrove, mudflats, rocky shore, saltpans, and aquaculture ponds) supports around 60 species of shorebirds. Ecological studies on shorebirds in India are scarce (Urfi, 2015); and available studies are mainly concentrated on the east coast in sites like Sundarbans, Chilika, Coringa, Pulicat, Pichavaram, Point Calimere, and Gulf of Mannar (Balachandran, 2006). Not much attention is given to the shorebirds on the west coast except few locations. The major research gaps identified with reference to shorebirds in India are highlighted below.

**1.2. Gaps Identified**

- Distribution pattern, density, and habitat utilization of shorebirds has been well explored in the east coast of India compared to that of north-east coast, and west coast (Sampath, 1987; Balachandran, 1990; Nagarajan, 1990; Nagarajan & Thiyagesan, 1996; Pandiyan, 2002; Sandiliyan, 2009; Kannan & Pandiyan, 2012; Pandiyan & Asokan, 2016).

- West coast of India is poorly explored (Kurup, 1991; Vijayan et al. 2008; Sivaperuman, 2004; Aarif et al. 2014) with respect to shorebirds except with some site-specific information (for example Kadalundi & Kole wetlands).
- The relationship between shorebirds and prey has been poorly explored along the Indian coast (Sampath, 1987; Nagarajan & Thiyagesan, 1996; Aarif, 2014)
- Sindhudurg district lies on the west coast of India having diverse coastal habitats, support several waterbird species, but there is no baseline data available on shorebird population and their distribution pattern with respect to biotic and abiotic factors.

### 1.3. Importance of proposed research investigation

Shorebirds are indicators of wetland ecosystems as they use multiple sites, any major disturbances in sites they use significantly impact their population trends. Therefore, conservation of the shorebird population is very difficult because of their broader distributional range. To conserve their population, it is necessary to safeguard their potential wintering and stopover sites along with the flyway system. Therefore region and site-specific conservations are vital to protect shorebirds from population decline. India is one of the main countries in CAF and a lot of shorebird studies in India focused on the east coast compared to the west coast. These existing studies are site-specific not covered on a large spatial scale. Further, the major portion of the Indian coast is unprotected undergoing tremendous development activities e.g., construction of tetrapods and increasing tourism related activities. Thus, to prioritise important coastal sites along the Indian coasts, identification of important coastal regions for the conservation of shorebirds and other waterbirds populations are not available. Hence this study was designed to document the avifauna in the coastal talukas of Sindhudurg district to address the following objectives.

### 1.4. Objectives

1) To assess the distribution pattern, abundance and diversity of shorebirds in the Sindhudurg district
2) To study effect of environmental variables on habitat use of shorebirds
3) To study habitat selection of select shorebirds in Sindhudurg coast

### 1.5. Study area

The coastal zone of Maharashtra is popularly known as 'Konkan', comprising Thane, Raigad, Ratnagiri, and Sindhudurg districts. Sindhudurg district (15.37-16.40 0N & 73.19-74.18 0E) is situated geographically in south-western Maharashtra (Fig. 1.1). The district is boardered by Ratnagiri district in the north, Goa in the south, Arabian Sea in the west, and Kolhapur district in the east. The district has a total area of 5,207 $km^2$ with a 121 km-coastline (~2% of India’s total coastline). The district constitutes eight talukas viz., Dodamarg, Kankavali, Sawanthwadi, Kudal, Vaibhavwadi, Vengurla, Devgad, and Malvan. Out of 8 talukas, Devgad, Malvan, and Vengurla are coastal talukas. Vengurla rocks (Burnt Island) in this area have been identified as an IBA that has a population of Edible nest-swift lets (*Aerodramus unicolor)* and breeding terns. With the presence of, one of India's most famous tourist hotspots Goa, the influx of tourists has been increasing every year. Therefore in 1997, Maharshtra government declared Sindhudurg as tourism district. Coastal areas in the districts hold wide array of natural (beach, mangroves, rocky shore, and intertidal mudflats) and man-made habitats (aquaculture ponds, agriculture lands and saltpans). Small-scale saltpans are located in the Vengurla taluka. Aquaculture ponds are common along the coast. The most common aquaculture practices include the cultivation of prawns (*Litopenaeus vannamei, Penaeus indicu*s), crabs (*Scylla serrata*), and fish (*Chanos chanos*, and *Mugil cephalus*).

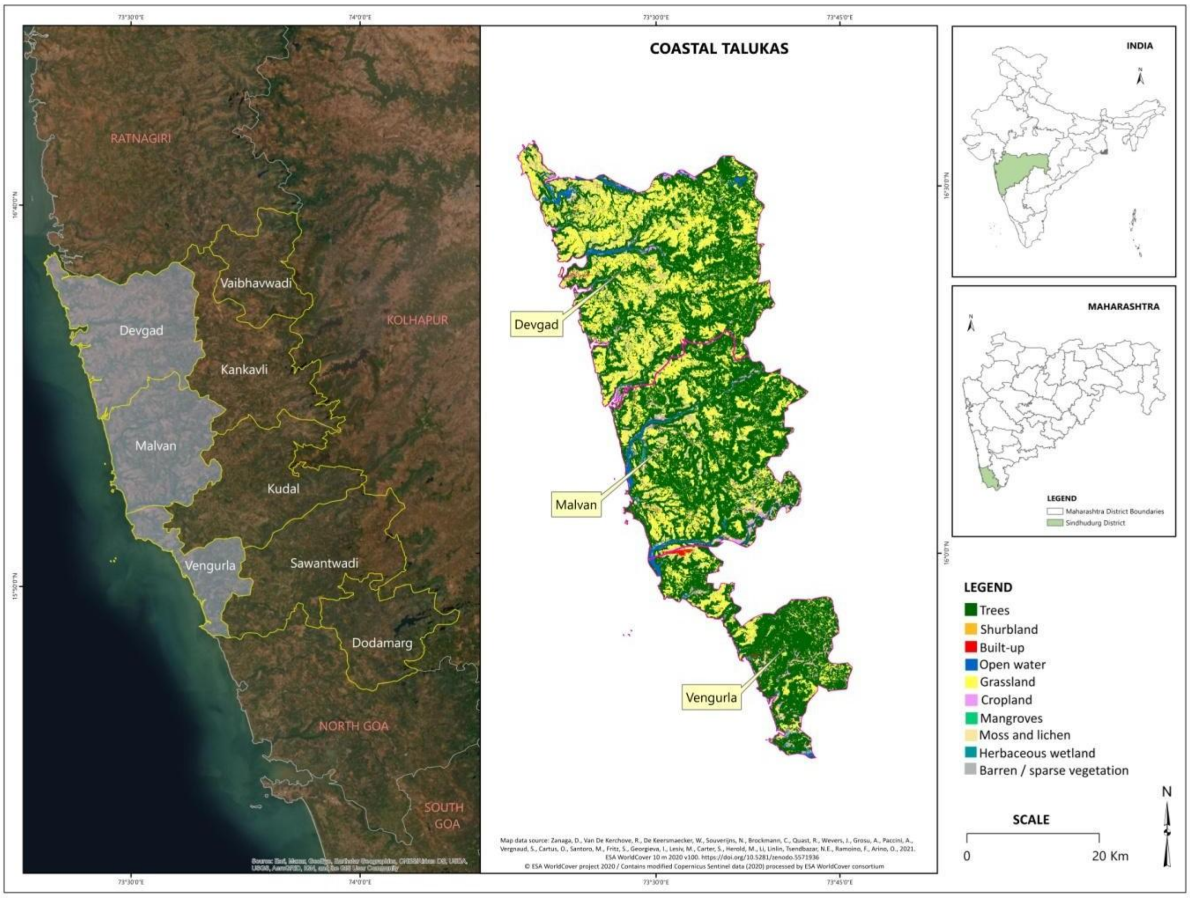



**Figure 1.1.** Map of Sindhudurg district

### 1.5.1. The major habitat types in coastal areas of the district described below in detail

#### a) Beach

Beaches, located adjacent to estuaries, are composed of fine sand sediments, gravel, and shells that cover the shoreline in many places along the Sindhudurg coast. Additionally, the exposed rocky substrate is common along the coast. Beach is characterized by five distinct zones 1) foreshore/wet covered zone – the area with continuous surf action from running tide below the high tide 2) Wet to dry sand – influenced by last high tide watermark between foreshore to wrack zone 3) Wrack zone – characterized by debris settled by high tides 4) back shore – the area extending inland towards sand dunes 5) Sand dunes – areas characterized by dune vegetation such as *Ipomea prescapre* and *Spinifex* sp. and some other beach binders which reduce beach erosion.

**b) Sandy mudflats**

Sandy mudflats (hereafter mudflats) are mostly sandy in nature with small amounts of mud influenced by semi-diurnal tides. Mudflats are exposed in the low tide and, submerged at high tides. This region, between the highest point of the high tide and the lowest point of the low tide, provides an ideal substratum for several invertebrates that reside and form a part of the food chain.

**c) Mangroves**

Muddy patches (hereafter mangroves) around the mangrove vegetation are ideal habitats for shorebirds. Mangroves are distinct vegetation types that can grow in saline conditions, are mostly located further from the shore but on the banks of the river and estuarine ecotone. Mangroves of the Sindhudurg coast are characterized by exposed mudflats and large portions of oyster beds *Crassostrea madrasensis*, *Crassostrea cuttackensis* and *Saccostrea* sp., which are exploited by locals for consumption. Mangroves provide foraging, roosting, and nesting sites for several bird species. Furthermore, it serves as an important habitat for shy and skulking bird species such as crakes and rallids. Mangrove plants recorded in these stretches include *Rhizophora mucronata*, *R. apiculata*, *Kandelia candel, Ceriops tagal*, *Avicennia marina*, *A. officinalis*, *Sonneratia alba*, *Sonneratia caseolaris*, *Lumnitzera racemosa*, *Xylocarpus granatum*, *Excoecaria agallocha*, *Cynometra iripa*, *Aegiceras corniculatum*, *Acanthus ilicifolius*, *Heritiera littoralis*, and *Dolichandrone spathacea*.

**d) Laterite grasslands**

These grasslands were formed during the mid-tertiary period and are part of the Deccan Trap floodplain (Seshadri et al. 2016). The overall habitat comprises grasses, herbs, shrubs, and stunted trees interspersed with agricultural fields and habitation. Grasslands are found along with the coastal areas of the Sindhudurg District. Some of the meadows are extensive in size and, offer potential foraging ground for raptors (e.g., Harriers *Circus sp*.), and nesting ground for grassland birds (e.g., Lapwings *Vanellus sp.* and Larks Alaudidae).

**e) Woodlands including plantations**

Fragmented patches of moist deciduous forest and plantations (mango, coconut, cashew, and Casuarina) are found in mosaics among the human settlements. The natural forests are not intact but possess dense upper-story and mid-story cover.

**f) Vengurla rocks**

It is a group of small rocky offshore islands located around six kilometers from the Kochara village in Vengurla taluka. In one of the islets, breeding activities of the Greater Crested Tern *Thalasseus bergii*, Bridled Tern *Onychopriyon anaethetus* and Roseate Tern *Sterna dougallii* have been reported (Lainer, 2003). This rocky islet is partially covered with combinations of tall grasses and short herb species. The terns exploit the bare rocky portions of the island for nesting.

**g) Man-modified habitats**

Man-modified wetlands such as agriculture fields (largely paddy), saltpans, and aquaculture ponds are found in patches throughout the coastal areas. The saltpan is practiced in Vengurla taluka on a minor scale. Aquaculture ponds are common along upstream regions of the district. Common aquaculture species are prawns and crabs.

**h) Pat Lake**

Pat Lake is a freshwater lake located amid populated Pat Parule village in Vengurla taluka. This shallow lake with floating vegetation and mature trees on one side makes it a suitable habitat for several water-associated birds including ducks and geese.

### 1.6. Climatic condition

Sindhudurg district is generally moist and humid throughout the year, humidity ranging between 63 to 88%. The area receives maximum rainfall during the South-West monsoon (May to August) with a mean annual rainfall of 3,070 millimeters. Temperature ranges from 19.9 °C (post-monsoon) to 34.5 °C in summer.

### 1.7. Materials and methods

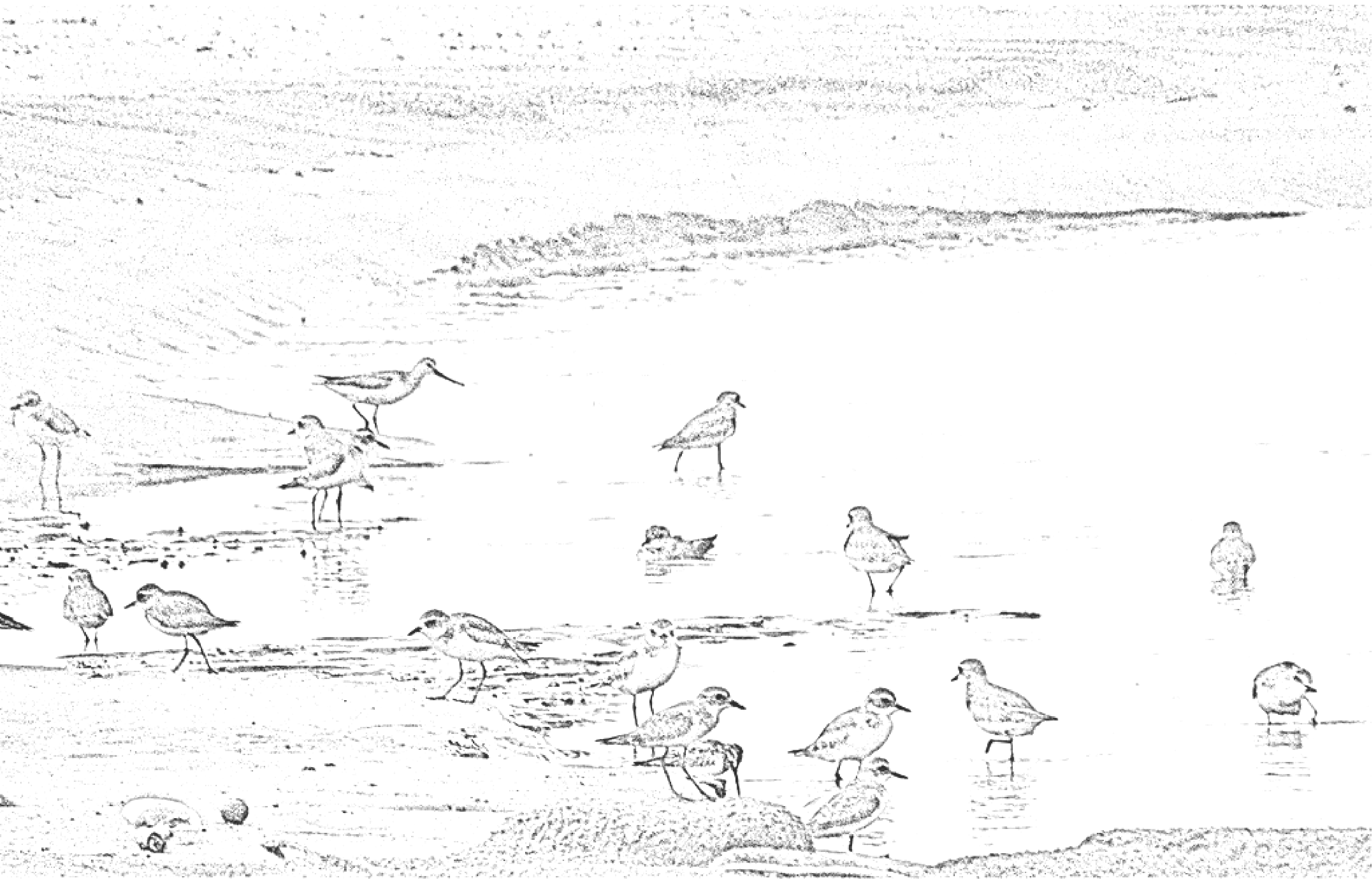
Reconnaissance surveys were conducted in all estuaries and coastal habitats within the coastal zones of Sindhudurg district between October and December 2014, the peak wintering time for shorebirds. Three natural habitats namely mangroves, mudflats, and sandy beaches were observed to be ideal habitat for shorebirds in the region. Hence, seven estuaries were selected for sampling based on the area availability and accessibility. Intensive sampling was conducted between 2015-2019 in all selected estuaries. Methodology and efforts put in were described in detail in corresponding chapters.

### 1.8. Organization of the thesis

This thesis represents a step towards the understanding of shorebird wintering ecology in the unexplored coastal areas of India. **The first chapter** provides a general overview of the study; the objectives, specific questions and arguments, and details of the study site. **The second chapter** includes an extensive review of the literature. **The third chapter** primarily address the avifaunal diversity in the coastal area. **The fourth chapter** examines the spatio-temporal patterns of shorebird assemblage. **The fifth chapter** describes the population structure and abundance of wintering gull species. **The sixth chapter** examines the relationship between shorebirds and their prey, and discuss factor that influences shorebird habitat use. **The seventh chapter** primarily covers the habitat selection of select shorebird species in the Sindhudurg district. Chapter eight culminates into the summary chapter which summarizes the results of earlier chapters.

Chapter 2

# Literature Review



## 2.1. Wintering ecology of shorebirds

Shorebirds are widespread; there are more than 200 species occur around the world (Message & Taylor, 2005). The monitoring of the shorebird population in India started four decades back. Since 1980 the bird ringing data shows a drastic decline of migratory shorebirds, especially that of Curlew sandpiper (*Caladris ferruginea*), Pied Avocets (*Recurvirostra avosetta*), and Little Stint (*Calidris minuta*) due to poaching and habitat alteration (Balachandran, 2006). Thus, it is very much essential to monitor the shorebird population in order to elucidate the population trend and to document the distribution and abundance in their non-breeding range (*i.e.* wintering grounds). Wintering period is the most crucial part of the shorebird migration, any change in their wintering grounds directly affects its population and reproductive success (Henkel & Taylor, 2015). Therefore, shorebirds need to select high-quality wintering sites for their survival. During migration, shorebirds depend on several habitats and their duration of stay varies at sites in different species (Stutzman, 2012). Thus, understanding stopover and winter ecology of each species provides useful information for the conservation of the shorebird's population (Stutzman, 2012). The characteristics of the shorebird population have been well studied along the east coast of India as compared to that of the west coast (Sampath & Krishnamurthy, 1990; Nagarajan & Thiyagesan, 1996; Balachandran, 2006; Kannan & Pandiyan, 2012). The most abundant shorebird species in the east coast are Curlew Sandpiper, Black-tailed Godwit, Little Stint, and Lesser Sand Plover (Balachandran, 2006; Kannan & Pandiyan, 2012) whereas Lesser Sand Plover for the west coast (Aarif, 2014).

## 2.2. Influence of biotic and abiotic factors on shorebirds

Physico-chemical parameters of water and soil, and benthic organisms play an essential role in understanding habitat quality of birds and in the management and conservation of wetlands. The function of aquatic ecosystems and their ability to support life forms largely depends on the water parameters (Mittal et al. 1990).

Therefore it is essential to understand the role of hydrological parameters on benthic invertebrates and waterbirds. Habitat variables such as sediment, turbidity, Dissolved Oxygen, temperature, and pH affect the habitat use of waterbirds (Nagarajan & Thiyagesan, 1996). The presence of organic matters in water and sediment influences the algal growth and abundance of benthic invertebrates (Rehfisch, 1994). Among the several water parameters salinity is the key variable that influence invertebrate distribution. Balasubramanian (2004) reported that increased salinity decreased the gastropods abundance in Pichavaram mangroves, Tamil Nadu. Sandiliyan et al. (2010) found that increased salinity would severely influence the planktons, fungi, benthic organisms, and birds. The sediment particle size is also the prime factor that determines the invertebrate prey (Yates et al. 1993).

In India, studies on the ecology of shorebirds are limited but few studies have been done on the role of environmental variables in determining the shorebird communities (Nagarajan & Thiyagesan, 1996; Sandiliyan, 2009; Aarif et al. 2021). The variation in water levels and pH of sediment, mud phosphorous, salinity, temperature, and nutrients influenced the shorebird richness, diversity, and density in Pichavaram and Kadalundi (Nagarajan & Thiyagesan, 1996; Aarif et al. 2014; Aarif et al. 2021). The rising salinity in Pichavaram affected the number of migratory shorebirds, especially larger and smaller waders (Sandiliyan et al. 2010). The increased levels of nutrients make waterbodies unsuitable for waterbirds. The altered nutrient conditions decreased shorebird numbers and made the species to use less profitable sandy beaches in Kadalundi (Aarif et al. 2014).

Shorebirds generally forage on benthic invertebrates during the low tide and take rest at high tide (Spencer, 2010). Shorebirds select sites where they can maximum their feeding opportunities (Rippe & Dierschke, 1997; Rogers et al. 2006a; van Dusen et al. 2012). Spatial-temporal variation in food availability largely influences the habitat utilization by waterbirds, and it is considered as an indicator of habitat status (Hartke et al. 2009). Preference of food and habitat by shorebirds vary with site and season (e.g., Red knots *Calidris canutus* prey on soft-bodied arthropods in summer and hard-shelled mollusks in winter Dekinga et al. 2001). The associations between shorebirds and its prey have not been studied extensively in India except few studies (Sampath & Krishnamurthy, 1990; Nagarajan & Thiyagesan, 1996; Aarif et al. 2021). Therefore the studies focusing on the role of water parameters and invertebrate densities on wintering habitat use of shorebirds analyzed is warrented.

Shorebirds forage mostly on invertebrates buried (e.g., crustaceans, bivalves, polychaetes, and gastropods) in the intertidal coastal areas. Shorebirds develop various strategies to forage in this unique substrate for example; the large eyes of plovers even detect the prey during the night and most of the species in the Scolopacidae (Sandpipers) contain long bills, which enable them to probe deeper inside the sediment (McNeil et al. 1992). On the basis of methods used for capturing the prey, shorebirds are broadly categorized into two type's viz., visual and tactile foragers. Plovers mainly use visual cues to detect the prey whereas most of the Scolopacidae species detect the prey by using tactile cues (Barbosa, 1997; Jing et al. 2007). The presence of heavy stomach muscles in mussel eaters like Great Knot and Purple Sandpiper (*Calidris maritime*) enable them to crush hard mussel shells (Piersma et al. 1993a). All these behavioral and morphological adaptations allow species to use a variety of habitats for foraging.

The selection of suitable wintering habitat is very important for migratory shorebirds (Brindock & Colwell, 2011). On the intertidal mudflats, prey availability and accessibility change over different spatial and temporal gradients (Chang & Fang, 2004). The selection of suitable foraging sites is the principal factor for shorebirds to manage with changing resource availability (Colwell & Landrum, 1993). There are several factors that influence shorebirds' habitat selection. Several studies have reported that the choice of site selection by migratory shorebirds is largely governed by prey abundance (Colwell & Landrum, 1993) and sediment types (Myers et al. 1980; Kelsey & Hassall, 1989; Finn et al. 2007; van Dusen, 2012). Factors influence habitat selection by shorebird varies on the different spatial scales (Finn et al. 2007; Schlacher et al. 2013). On a large spatial scale between multiple estuaries, prey is the fundamental factor that determines the habitat selection by shorebirds (Finn et al. 2007; Schlacher et al. 2013). On smaller spatial scale, the physical features of the sediment act as a major determining factor (Finn et al. 2007). Substrate type and soil grain size directly influence types and abundance of invertebrate prey in a site, which in turn determines shorebird habitat selection (Yates et al. 1993). Therefore, understanding foraging site selection by migratory shorebirds at both the levels (micro and macro scale) will provide better insight for effective management actions. Shorebirds studies in India are mainly confined to single wetlands but not studied on a large spatial scale (Nagarajan & Thiyagesan, 1996; Pandiyan, 2002; Sandilyan, 2009, Aarif, 2014). Further, the wintering site selection for many shorebird species is not studied.

## 2.3. Threats to the shorebird populations

Around the world, many waterbird populations are declining (Stroud et al. 2006). The causes for their decline are diverse; the most noticeable reasons are loss of breeding and wintering habitats (Goss-Custard & Yates, 1992), anthropogenic disturbances (Cayford, 1993), and climate change (Norris et al. 2005). The problems related to climate change are the loss of nesting habitat and decreasing intertidal feeding areas due to sea-level rise (Rehfisch & Crick, 2003; Crooks, 2004). Among the other disturbances, decreasing intertidal feeding areas is the major threat to the shorebird population. Over the last few decades, most of the intertidal feeding areas have been drastically reduced (van de Kam et al. 2004). This reduced feeding area creates competition among individuals and a reduction in their intake rates (Durell et al. 2005). Human disturbances are also considered as a major threat to the shorebird population decline. At the southeast coast of India, most of the wintering shorebird populations are drastically decreased due to the expansion of salt-based industries in the region (Balachandran, 2006). Clearing of mangroves and increasing shrimp farming along the east coast of India reduced many waterbird populations in several sites (Nagarajan & Thiyagesan, 2006). The combined effect of human disturbance and habitat loss will be a severe threat to the shorebird populations.

## 2.4. Population characteristics of gulls

India attracts several species of gulls and a large congregation of these species occurs every year during winter. Among the several species of gulls, Black-headed Gull, and Brown-headed Gull are highly abundant along the Indian coast (Lainer & Alvares, 2013; Sathiyaselvam & Sreedhar, 2014; Aarif et al. 2015). In several countries, gulls are treated as disease transmitters (Fenlon, 1981, 1983; Ferns & Mudge, 2000) and contaminators of water supply reservoirs (Hatch, 1996, Nugent & Dillingham, 2009). The important aspects of wintering gulls on the Indian coast are population trend is lacking for most parts of the Indian coast except few sporadic observations (Lainer & Alvares 2013; Sathiyaselvam & Sreedhar, 2014; Aarif et al. 2015). Available literature indicates that the gull population is relatively higher on the west coast as compared to that of the east coast; the reason for this pattern has yet to be identified.

Chapter 3

# Bird Diversity in the Coastal Talukas of Sindudhurg District

## 3.1. INTRODUCTION

Sindhudurg district is located geographically on the southwestern side of the state of Maharashtra and recognized as one of the principal tourist destinations in the western coast of India. The increasing inflow of tourists to Sindhudurg coast and subsequent change in land use and land cover of the coastal area increase the pressure on coastal and marine biodiversity. Therefore this study compiled primary and secondary bird occurrence data along the Sindhudurg coasts to signify bird diversity wealth and to identify crucial bird areas for the conservation of coastal birds.

Southwestern Maharashtra (Ratnagiri and Sindhudurg) received much attention for bird studies from both the early-time British ornithologists and post-independence workers. Studies in Sindhudurg district can broadly be grouped into three categories based on the extent of focal area and target birds, viz., Sindhudurg as a landscape level (Vidal, 1880; Gole, 1994; Prasad, 2006; Mahabal et al. 2011), small regions or localities level (Hume, 1876; Abdulali, 1940, 1942, 1983; Madsen, 1988; Pande, 2002a; Lainer, 2003; Katdare et al. 2004a; Patil, 2015) and single or small group of birds level (Katdare, 2001; Pande, 2001, 2002b; Pande et al. 2001; Katdare et al. 2004b; Mahabal et al. 2007; Kambale et al. 2011; Rao et al. 2015). Vidal (1880) prepared the first comprehensive checklist on the birds of the Konkan region that included Sindhudurg district. Prasad (2006) included the Sindhudurg coast in his book on birds of western Maharashtra, though he did not specifically cover their local status. Studies by Khot (2016) included Malvan and Malagaon-Bagayat from Sindhudurg district but did not cover large parts of coastal zones in the Sindhudurg district. Patil et al. (2015) published a checklist for a single wetland (Pat Lake) in the district.

Considering this information and significance of the Sindhudurg coast, this chapter attempted to assess the local status, habitat association, sighting frequency and taluka-wise distribution of birds from the coastal talukas of Sindhudurg district based on primary and secondary observations from this region.

### 3.2. METHODS

For this study seven estuaries selected: Achara and Karli in Malvan taluka, Mitbav and Wadatar in Devgad taluka, and Mochemad, Vengurla Bandar and Nivati in Vengurla taluka for observing the coastal birds (Fig. 3.1). These sites were sampled once a month and thus, visited the whole stretch of Sindhudurg coast either by bike or jeep covering diverse terrestrial habitats (moist deciduous forest, grasslands, agriculture fields, commercial plantations) and inland wetland habitats (pat lake and puddles in grasslands during the monsoon) in the area.

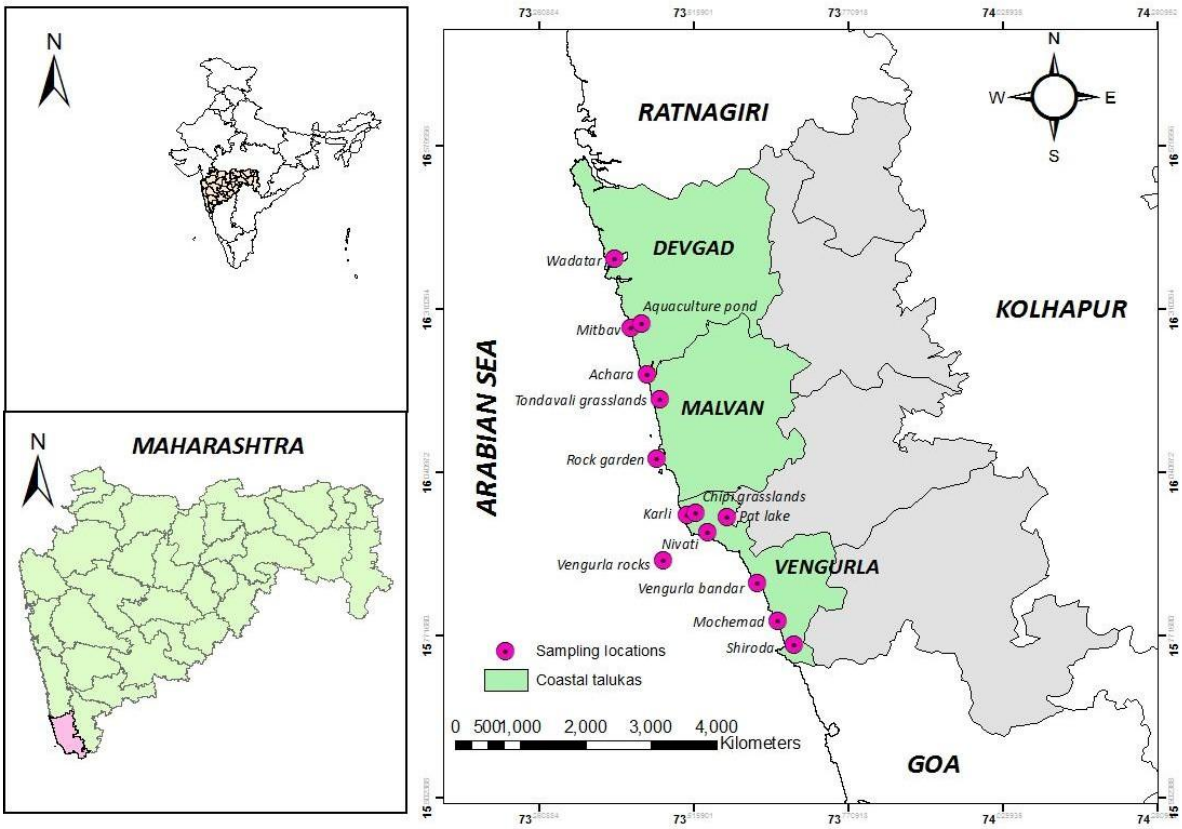



**Figure 3.1.** Bird sampling locations in Sindhudurg coast

All observations on terrestrial birds were opportunistic. Quantitative data was collected only for wetland birds, which were the focus of the study but also recorded other birds as well to make a comprehensive list of birds. Bird surveys were carried out from December 2014 to December 2016. Observations were made between 05.30 hr and 18.00 hr and conducted occasional night surveys for owls Strigiformes. Besides, this conducted four offshore surveys to Vengurla rocks (located nearly 6 km from the coast) to record pelagic birds. In addition to the coastal areas, I also did a survey at pat lake (freshwater lake), laterite grasslands (Chipi, Tondavali, Vengurla and other small grasslands), woodland areas within this buffer (moist deciduous forests and plantations), and man-modified sites (agriculture fields, saltpan and aquaculture ponds) (Fig. 3.2 & 3.3). Nikon spotting scope 20–60x used for bird observation and sufficient photographs were taken to confirm species identities. During the study I did not collect abundance data for the terrestrial birds; thus, all the birds were categorized into three broad categories based on the percentage of sighting such as >3% (Common), 1–3 % (uncommon) and <1% (rare). The percentages of sightings were expressed by dividing frequency of sightings of particular species by total visits. On the basis of observation in the district, the distribution status of each bird species was categorized into five groups.

**Resident-**Occurs in the district throughout the year

**Winter Migrant-**Species occurs only during winter (September to May)

**Passage Migrant-**Species occurs in the study area for refueling their energy during onward and return migration

**Vagrant-**Species is either not resident/not regular breeding or wintering migrant but has a few stray records

**Monsoon Migrant-**Species occurs only during the monsoon


**Figure 3.2.** Natural habitats surveyed in Sindhudurg coast: a) Mudflats b) Mangroves c) Rocky shore d) Vengurla rocks e) Pat lake f) Laterite grasslands g) Sandy beach

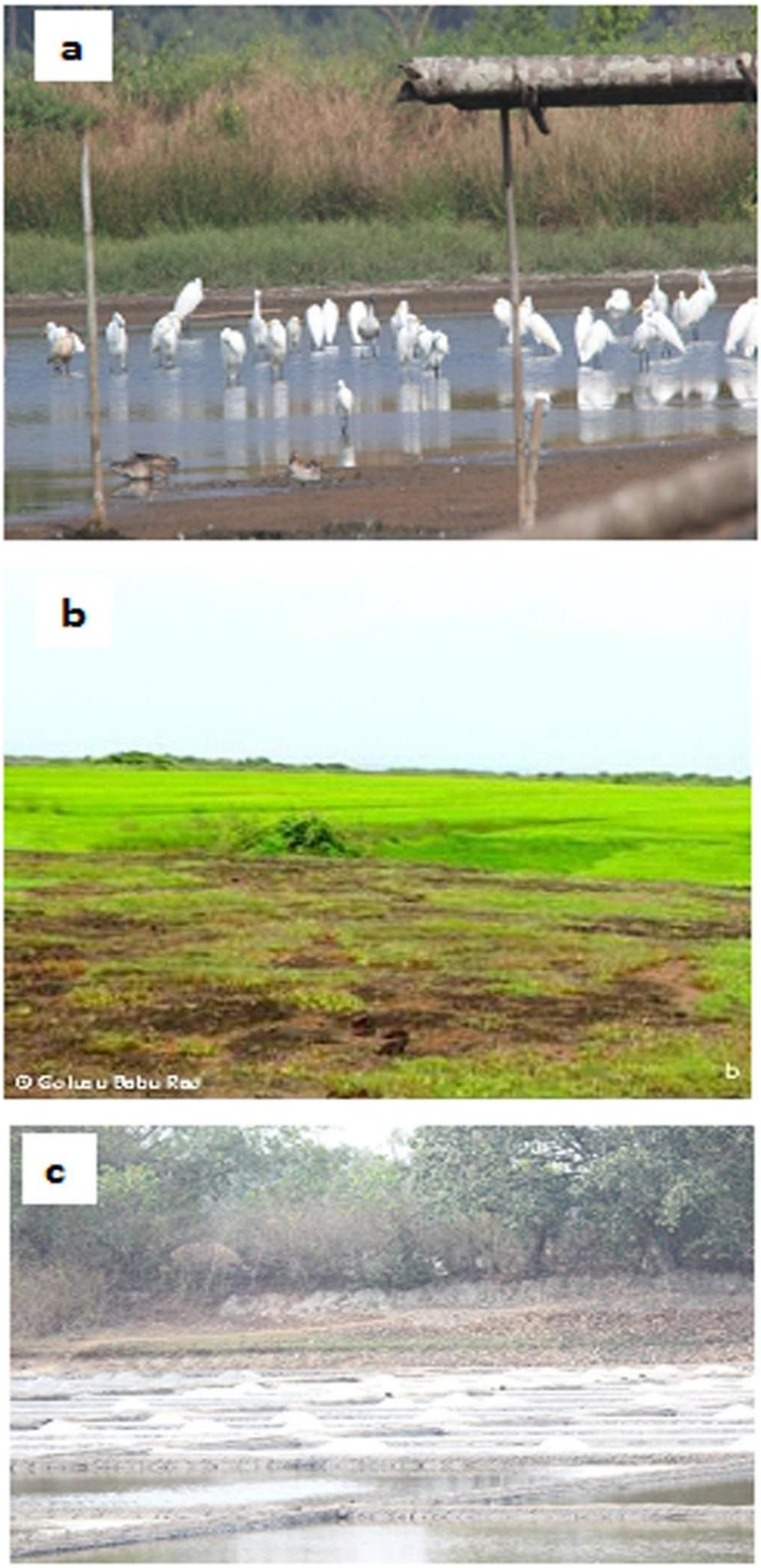



**Figure 3.3.** Man-modifed habitats in Sindhudurg coast: a) Aquaculture pond, b) Agriculture lands c) Saltpan

### 3.3. RESULTS

This study, collated 307 species belonging to 78 families, and 22 orders for the coastal areas of Sindhudurg district (Appendix 1). In total, 283 species recorded during the survey, and 24 more species compiled from the published literature. Species richness was highest in Vengurla taluka (256 species) followed by Malvan taluka (247), and Devgad taluka (213). Order Passeriformes (111 species) had the highest species representation followed by Charadriiformes (63), Accipitriformes (20) and Pelecaniformes (15) and one species each represented in Procellariiformes and Gaviiformes (Fig. 3.4). Out of 283 species, 175 (~62%) and 108 (~38%) were resident and migratory birds respectively. Among 108 migrants, 93 winter migrants, 13 passage migrants, one monsoon migrant and one vagrant were recorded.

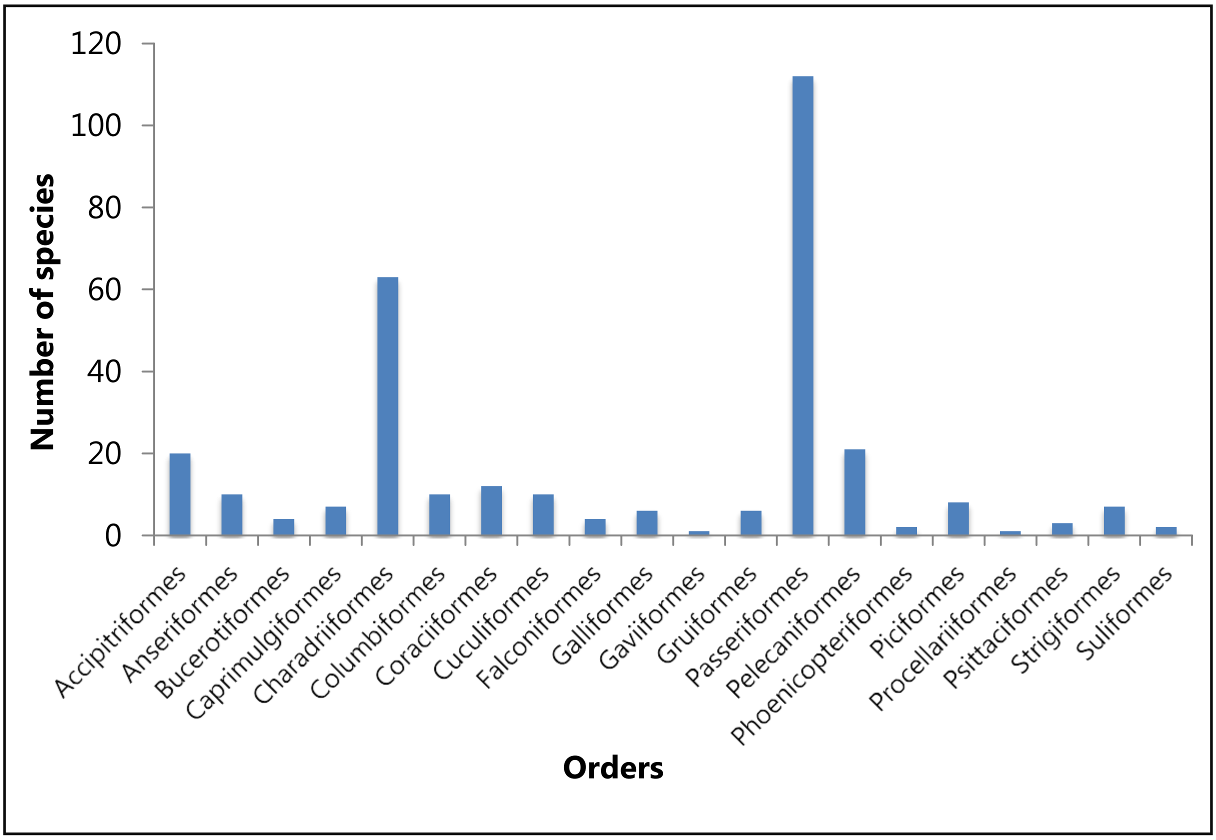



**Figure 3.4.** Species richness of birds in different orders in the Sindhudurg district

Sindhudurg coast used to support three Critically Endangered species namely Red-headed Vulture (*Sarcogyps calvus*), White-rumped Vulture (*Gyps bengalensis*), and Indian Vulture (*G. Indicus*), one Endangered Great Knot (*Calidris tenuirostris*), and Vulnerable Woolly-necked Stork (*Ciconia episcopus*) but this study did not record any vultures. Besides, 14 more species fall under the Near Threatened category of IUCN. Grey-headed Bulbul (*Pycnonotus priocephalus*), Malabar Grey Hornbill (*Ocyceros griseus*), Crimson-backed Sunbird (*Leptocoma minima*), and Vigor's Sunbird (*Aethopyga vigorsii*) are the birds recorded from the Sindhudurg coast that are considered to be endemic to the Western Ghats. Based on the sighting percentage, 151, 114 and 18 species were common, uncommon and rare, respectively. Location and date of observation of species sighted less than <1% of total visits are given below.

**Interesting sight records**

**Northern Shoveler** (*Anas clypeata*): It was recorded twice: once in an aquaculture pond of Mitbav on 6 November 2016, and another on 8 November 2016 at Shiroda saltpans of Vengurla. On both occasions, the flock size was >10.

**Ruddy Shelduck** (*Tadorna ferruginea*): One bird was seen in an aquaculture pond at Mitbav on 6 November 2016.

**Painted Stork** (*Mycteria leucocephala*): A sub-adult bird was seen in a saltpan at Shiroda on 22 January 2015.

**Amur Falcon** (*Falco amurensis*): One bird was seen in grassland at Vengurla on 20 November 2015.

**Common Buzzard** (*Buteo buteo*): Recorded it three times: one individual each at Vijayadurg and Kochara beach on 22 October 2015, and three individuals at Kochara beach on 10 October 2016.

**Masked Booby** (*Sula dactylatra*): Three sub-adults were seen resting on rocky islets close to Vengurla rocks on 7 October 2015.

**Eurasian Oystercatcher** (*Haematopus ostralegus*): Recorded twice: two birds on 8 October 2016 at Tambaldeg beach.

**Crab-plover** (*Dromas ardeola*): A bird was observed in mixed flocks of gulls at Mochemad beach on 7 November 2016.

**Great Knot** (*Calidris tenuirostris*): Two birds were seen on mudflats of Mochemad estuary on 6 November 2016.

**Great Thick-knee** (*Esacus recurvirostris*): The solitary bird was observed in the intertidal mudflat of Vengurla Bandar on 26 December 2016.

**Wilson's Storm-petrel** (*Oceanites oceanicus*): A single bird was seen foraging actively in the open sea on 23 October 2015 between Nivati beach and Vengurla rocks

**Common Tern** (*Sterna hirundo*): During the offshore surveys between Nivati beach and Vengurla rocks on 23 October 2015 four individuals were observed at Burnt Island.

**Little Tern** (*Sternula albifrons*): The solitary bird was seen in Shiroda saltpans on 12 March 2015.

**Brown-breasted Flycatcher** (*Muscicapa muttui*): Observed one individual in wooded areas of Karli village on 19 October 2016.

Although birds such as Steppe Eagle (*Aquila nipalensis*), Grey-headed Fish Eagle (*Ichthyophaga ichthyaetus*), Indian Spotted Eagle (*Clanga hastata*), Red-necked Falcon (*Falco chicquera*), Eurasian Sparrowhawk (*Accipiter nisus*) and Common Ringed Plover (*Charadrius hiaticula*) were observed during the study, due to a lack of good quality photographs they were excluded them from the list. The foraging guild of birds species in the district was dominated by insectivores (~49%) followed by piscivores (~18%), and omnivores and nectarivores showed least contribution (1% to 3%) (Fig. 3.5).

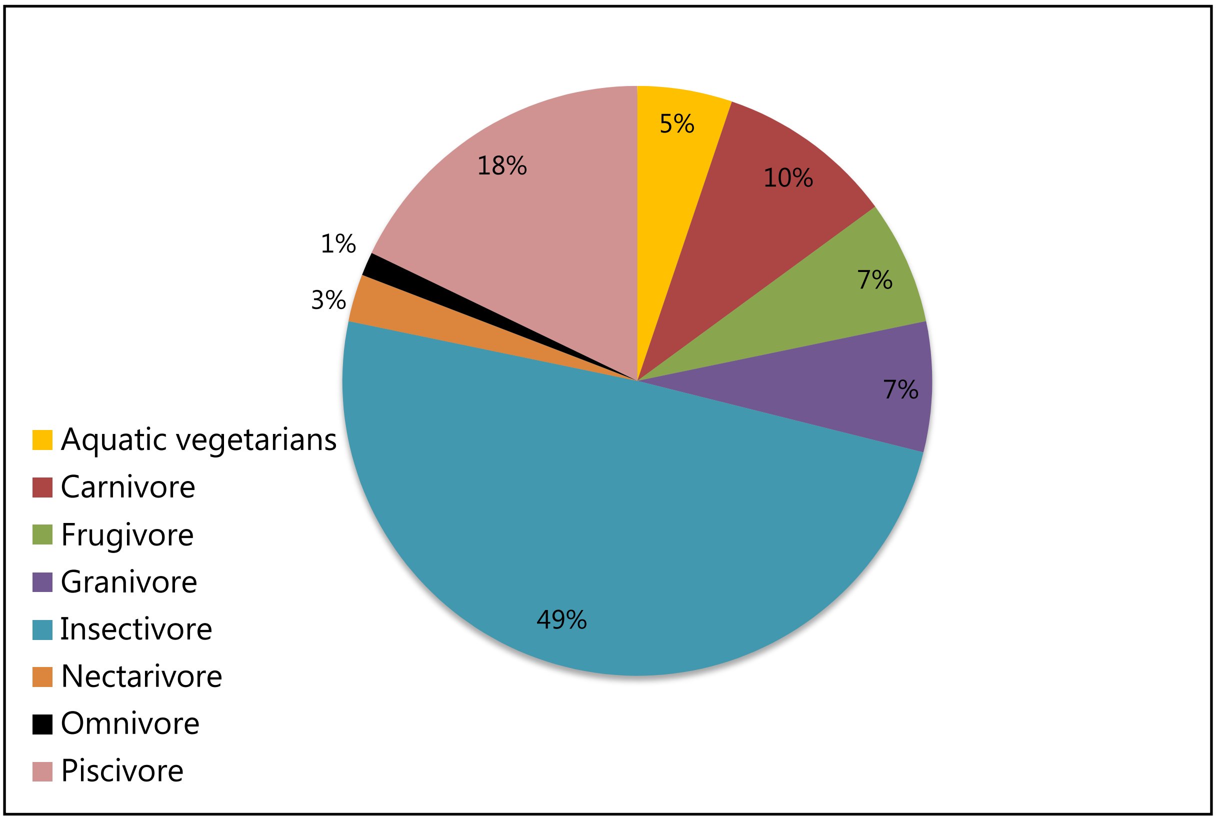



**Figure 3.5.** Species composition of birds in different foraging guilds in the Sindhudurg district

### 3.4. DISCUSSION

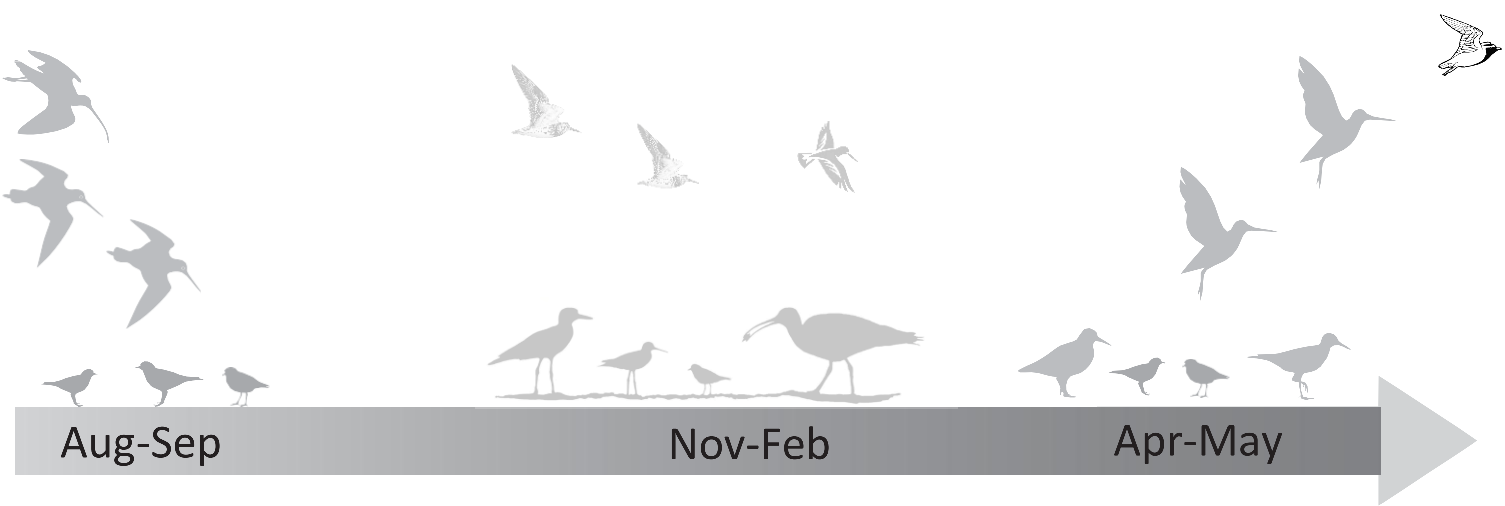
Altogether, collated 307 species from Sindhudurg coast, which represents nearly 84% of birds recorded from the Sindhudurg district as a whole (eBird, 2019). Out of these 307 species, four are endemic to the Western Ghats. A multi-observer effort of 997 and 838 eBird lists yielded 364 and 340 bird species in Sindhudurg and Ratnagiri districts respectively while the present study recorded 283 bird species from 329 field days in the coastal areas indicating the high diversity of birds in these talukas. Despite inadequate sampling effort in the Western Ghats, year-round monitoring along the Sindhudurg coast raised the total species pool. A few stretches of natural forests (for example moist deciduous forests) in the district were surveyed, but intensive sampling was not conducted. Accordingly, the total species pool compiled here is only for the coastal regions of the district and more species might be added if one samples the forest areas of the district. Among the talukas surveyed, from Vengurla taluka, a maximum richness of birds was recorded, and availability of mosaic of habitats within the coastal areas might be attributed for this pattern. The lower diversity of birds in Devgad taluka can be associated with the presence of laterite grasslands along the coasts and an absence of a large extent of woody vegetation in the coastal areas.

This study observed a few rare and under-recorded species of western Maharashtra, as mentioned in Prasad (2006), such as Amur Falcon, Common Buzzard, Montagu's Harrier (*Circus pygargus*), Wilson's Storm- petrel, Masked Booby, Eurasian Oystercatcher, Great Knot, Crab-plover, Orange-breasted Green Pigeon, and Brown breasted Flycatcher during the study along the Sindhudurg coast. In comparison with Vidal's (1880) observation, present study did not record few species such as the Red-headed Vulture, Indian Vulture, White-rumped Vulture, Sirkeer Malkoha (*Taccocua leschenaultii*), Indian Blackbird (*Turdus merula simillimus*), Brown Hawk Owl (*Ninox scutulata*), Brown Wood Owl (Strix leptogrammica), Verditer Flycatcher (*Eumyias thalassinus*), Forest Wagtail (*Dendronanthus indicus*), Blue-capped Rock Thrush (*Monticola cinclorhynchus*), Indian Thick-knee (*Burhinus indicus*), Grey-bellied Cuckoo (*Cacomantis passerines*), White-naped Woodpecker (*Chrysocolaptes festivus*), Bridled Tern ( *Onychoprion anaethetus*), and the White-cheeked Tern (*Sterna repressa*), during the sampling. In addition, Greater Flamingo *Phoenicopterus roseus* (Abdulali, 1942), Brown Skua (*Stercorarius antarcticus*, Editors, 1958), Pomarine Skua (*Stercorarius pomarinus*, Pande, 2002a), Arctic Skua (*Stercorarius parasiticus*), and Brown Noody (*Anous stolidus*, Lainer, 2003), Brown Booby (*Sula leucogaster*, Jamalabad, 2013), Blue-bearded Bee-eater (*Nyctyornis athertoni*, Khot, 2016), Red-throated Diver (*Gavia stellata*, Avalaskar, 2016), and Crimson-backed Sunbird (*Leptocoma minima*, Shrikrishna Ramachandra Magdum pers. obs. 7.xii.2017) were reported from the Sindhudurg coast but not observed during the study. The vulture species had been distributed all over India but due to a recent population decline, their distribution range has shrunk to a few pockets, and this might be the reason for not encountering these species in all historical occurrence localities. Furthermore, as discussed earlier, less sampling in the northern Western Ghats might be the reason for missing a few forests dwelling species. Although present study conducted coastal and offshore surveys, but did not carry out any surveys during the monsoon months because Bridled Tern is anticipated to occur in Vengurla rocks during the monsoon (Lainer, 2003). In brief, less sampling in the Western Ghats and offshore and rare nature of some species (e.g., Red-throated Diver) might be the reason for missing these birds.

Grey-headed Bulbul has been stated to occur in the Western Ghats, i.e., from Kanyakumari to Goa (Grimmett et al. 2011), however, this bird observed along the Sindhudurg coast. Prasad (2006) listed the Grey-headed Bulbul in Maharashtra's bird list, but comprehensive information about their distribution and occurrences within Maharashtra is not available. During the survey it was seen repeatedly (5 times in two locations: Hadi and Karli villages) in the forested areas along the Malvan and Vengurla coasts, and hence I speculate that the distribution range of this species in Maharashtra might be much more widespread than predicted. A survey of the Grey-headed Bulbul's population in abutting districts may be attempted to define the distribution range of this near-threatened and endemic species of the Western Ghats. Vidal (1880) also had observed a few forest dwelling species, viz., Indian Scimitar Babbler, Blue-capped Rock Thrush, and Malabar Whistling Thrush in wooded habitats close to the coast. Out of 283 species, 38% of them were migratory. Sindhudurg coast attracts migratory species especially transcontinental migratory birds like waders. Almost 68% of resident birds occur throughout the year in the district. The high richness of resident birds in Sindhudurg is attributed to the availability of the mosaic of habitats. It has also been observed in other studies that variation in bird populations among sites in different seasons and the same has been attributed to environmentally dependent factors such as the change in local and regional habitat conditions (Ericia et al. 2005). Unregulated tourism and associated developments, sand mining, stray dogs and conversion of laterite grasslands are the major threats to the coastal avifauna in the district.

# Chapter 4

# Spatial and Temporal Patterns of Shorebird Assemblage



## 4.1. INTRODUCTION

Shorebirds mainly feed on benthic invertebrates and play an vital role in balancing the invertebrate community and sediment reworking (Orvain et al. 2014; Mathot et al. 2018). Migratory shorebirds halt at several sites, using these as either stopover or staging sites, to complete their annual migration to tropical coasts during winter and to temperate regions during summer (breeding). The conservation of these species is thus a challenging task due to their vast range of distributuion that spreads across several habitats and countries.

Understanding habitat use by migratory shorebirds and their duration of stay in wintering sites is a prerequisite for the conservation of these birds (Farmer & Durbian, 2006; Ewert et al. 2012). Although migratory shorebirds use a wide array of habitats during migration (Myers et al. 1987), they select certain habitats more frequently over others, considering various intrinsic and extrinsic factors (Morrison et al. 2007; Kober & Bairlein, 2009). Identifying habitats that have high conservation value for shorebirds is important to implement management actions to secure wintering shorebird populations (Helmers, 1992; Placyk & Harrington, 2004; Albanese & Davis, 2015). Furthermore, defining the duration of stay at a site for each species is also important as it indicates the habitat quality required for the species (e.g., food resource) (Ma et al. 2005). Generally, migratory shorebirds visit southern latitudes during their migration, but they prefer to use some sites for a longer duration compared with other sites; such preferences vary across species. In this context, understanding spatial and temporal patterns of habitat use by migratory shorebirds in any given landscape is important for the conservation and management of these sites.

India has a coastline of 7,516.6 km that comprises both natural (e.g., mudflats, mangroves, sandy shores, lagoons, marshy areas, and grasslands) and man-made habitats (e.g., saltpans, aquaculture ponds, agriculture fields, Sivakumar, 2013). During winter, these habitats attract millions of migratory shorebirds that use three flyways: CAF, EAAF and WAEAF Flyway. A large portion of the Indian coast falls under CAF, which is one of the shortest flyways. Nearly 182 bird species, including 29 globally threatened species, use this flyway annually (CMS, 2019). However, the trends of most of the shorebird population in this flyway are largely unkown (Balachandran, 2006; Convention on Migratory Species, 2005). Many parts of India's coastline are not legally protected despite their high conservation significance. As a result, many of these sites face severe anthropogenic perturbations. Nearly 40% of mangrove forests and large stretches of mudflats have been converted due to various developmental activities over the last few decades (Krishnamurthy et al. 1987). These increased threats influence the population of several species of shorebirds that winter in Indian waters (Balachandran, 2006). Therefore, such anthropogenic activities along the Indian coast warrant prioritization of key coastal habitats/sites, that host large congregations of migratory shorebirds during the wintering season.

To prioritize important coastal habitats, data on the temporal pattern of habitat use by migratory shorebirds is required. Studies pertaining to habitat use by shorebirds and temporal patterns of their diversity in India are meagre (Urfi, 2015 and see Table 1). Existing studies are mainly focused on the east coast of India (Sampath & Krishnamurthy, 1990, 1993; Balachandran, 1990; Nagarajan, 1990; Nagarajan & Thiyagesan, 1996; Sandilyan, 2009; Kannan & Pandiyan, 2012; Pandiyan & Asokan, 2016) rather than the west coast (Kurup, 1991; Sivaperuman, 2004; Vijayan et al. 2008; Aarif et al. 2014, 2021). Most of these studies are also confined to specific wetlands (e.g., Aarif et al. 2021) and do not cover on larger spatial scales (Table 1). Owing to this limited information on shorebirds, as well as the high level of coastal tourism along the west coast, the current chapter was aimed to address the following questions: 1) elucidate the spatial and temporal patterns of shorebird assemblages, 2) provide information on shorebird migration phases on the basis of species distribution and abundance, and 3) identify important wintering sites of shorebirds, especially where their key wintering and stopover sites are largely unknown.

**Table 4.1.** Summary of comparison table showing shorebird studies conducted with details of richness, density and diversity and importance of present study

| Site | Area covered | Species richness | Diversity | Density No/Ha | Small waders species richness | Preferred habitat | Source | Study period (months) |
|---|---|---|---|---|---|---|---|---|
| | | | | **East coast** | | | | |
| Sundarbans | 47 $km^2$ & 488 km | 32 | NA | NA | 32 | Na | Zöckler et al. (2005) | 2 |
| Bhitarkanika | NA | 37 | NA | NA | 37 | NA | Nayak (2006) | 12 |
| Bhitarkanika | 357.69 $km^2$ | (263) [a] | NA | NA | 45 | OW, TF | Gopi & Pandav (2007) | 41 |
| Chilika/Nalabana Island | 15.53 $km^2$ | (47) [a] | NA | NA | 34 | MD | Acharya & Kar (1996), Acharya et al. (1999) | 36 |
| Chilika Lake | NA | 44 | NA | NA | 44 | NA | Nayak (2006) | 3 |
| Coringa WLS | 235.70 $km^2$ | (236) [a] | NA | NA | 45 | MD | Rao et al. (1996) | 60 |
| Pulicat Lake | 720 $km^2$ | 28 | 0.05-0.98 | 1.43 | 28 | MD, TF | Kannan & Pandiyan (2012) | 27 |
| Pichavaram | 11000 ha | (200) [a] | NA | NA | 36 | MD, SF | Sampath & Krishnamurthy (1990) | 12 |
| Pichavaram | 11000 ha | 6.6±0.65 (27)[a] | 1.418±0.08 | 95.8±17.30 | 13 | CL | Nagarajan & Thiyagesan (1996) | 6 |
| Pichavaram | 28.33 ha | (42) [a] | NA | NA | 20 | MD | Sandilyan & Kathiresan (2015) | 42 |
| Coromandel coast | 462 ha | 3.9±0.24 | 0.3±0.01 | 21.5 ± 2.19 | 21 | MD | Pandiyan (2002), Pandiyan & Asokan (2016) | 19 |
| Vedaranyam | 2400 ha | 39 | NA | NA | 39 | SA | Sampath & | 29 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Krishnamurthy (1989) | |
| Point Calimere WLS | NA | (233) [a] | NA | NA | 46 | NA | Sugathan (1983) | 24 |
| Point Calimere WLS | NA | (49) [a] | 2.01 | 516km$^2$ | 21 | SA | Natarajan (1993) | 12 |
| Gulf of Mannar | 1265 ha | (187) [a] | NA | NA | 37 | TF | Balachandran (1995) | 36 |
| | | | **West coast** | | | | | |
| Kadalundi-Vallikkunnu Community Reserve | 1.5 km$^2$ | 16–27 (31) | 0.77–1. 29 | NA | 31 | MD | Aarif et al. (2014) | 96 |
| Thane Creek | 26 km | (95) [a] | NA | NA | 13 | M, SA, C | Chaudhari-Pachpande & Pejaver (2016) | 18 |
| Mahul creek | 10 km$^2$ | (149) [a] | NA | NA | 27 | M, SA, C | Verma et al. (2004) | 17 |
| Gulf of Kutch/Byet Dwaraka | 25 km$^2$ | (103) [a] | NA | NA | 31 | CL, MD, SF | Urfi (2002) | 10 |
| Sindhudurg | 121 km | (283) [a] | NA | NA | 36 | Mudflats | Present study | |

**NA-**Not available, **OW-**Open wetlands, **TF-**Tidal flats, **MD-**Mudflats, **SF-**Sandflats, **CL-**Crop lands, **SA-**Saltpans, **M-**Marsh, **C-**Creek, **CL-**Coral

## 4.2. METHODS

### 4.2.1. Sampling design

Reconnaissance surveys were conducted in all the estuaries and coastal habitats within the coastal zones of Sindhudurg district between October and December 2014, the peak wintering time for shorebirds. Three natural habitats: mangroves (mudflat associated with mangroves), mudflats, and sandy beaches were observed to be potential habitats for shorebirds in the study area (habitat descriptions are provided in the study area section). Therefore, I selected seven estuaries for sampling. Intensive sampling was conducted in each of the selected estuaries (Fig. 4.1).

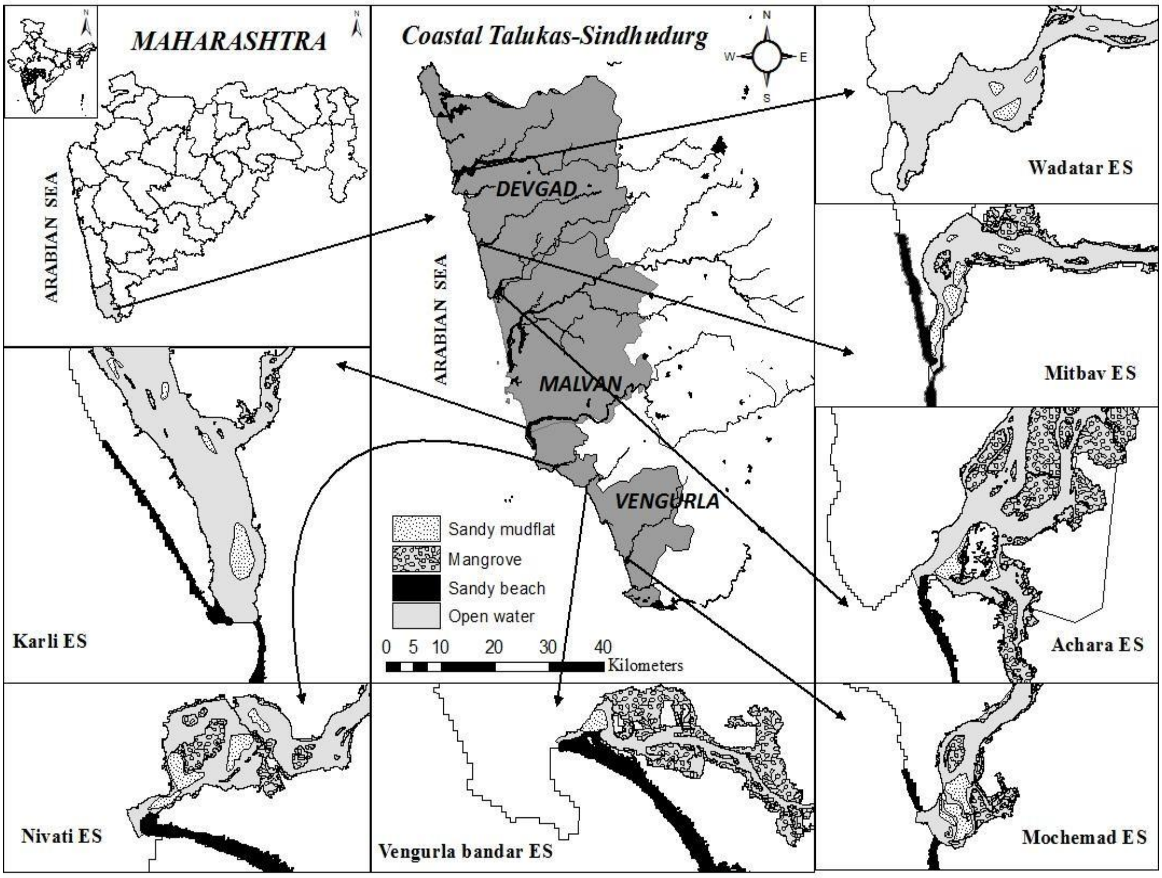



**Figure 4.1.** Map of the study area showing the seven estuaries studied along the Sindhudurg coastal district, India

### 4.2.2. Shorebird sampling

In each estuary established three vantage points, one each in mangrove, mudflat and sandy beach habitats, to count birds during the low tide. Total count method (Nagarajan & Thiyagesan, 1996) was followed to count birds and occasional photograph-based counts were also made when the flock size was big or when the flocks kept moving (Javed & Kaul, 2000; Urfi et al. 2005). For the photograph-based method, a series of pictures were taken first and later, birds counted and identified using image viewing software (Picasa photo viewer). NIKON PROSTAF 7s 8X42 binocular and Nikon spotting scope 20-60X were used to identify and count the birds. Field guides of Message and Taylor (2005) and Grimmett et al. (2011) were used for species identification.

### 4.2.3. Statistical analysis

Count data of shorebirds were pooled across habitats and months for further analysis. Shannon diversity index (H'), total species richness (S) and mean abundance of shorebirds (ratio of number of individuals' counted and total replicates in a habitat or month) were calculated using PAST version 3.17. Individual-based rarefaction analysis was performed to compare the species richness among habitats using iNEXT package in R v.1.1.383 (R Core Development Team, 2009). One-way ANOVA with Tukey post-hoc multiple comparisons tests was performed (significance level 0.05) to determine differences in species richness and abundance of shorebirds across habitats and months. The difference in diversity indices across habitats and months was assessed using bootstrapping methods following Hammer et al. (2001). The count data were log-transformed (normal log) before treating the data for community analysis. Non-metric multidimensional scaling (nMDS) was performed to extract patterns of species composition across the habitats and months, using species abundance data of three habitats and 24 months. Bray-Curtis similarity measures were applied to perform nMDS. nMDS generates an ordination based on the order of dissimilarity between sampling sites. One-way ANOSIM was employed to determine differences in the spatial and temporal species composition of shorebirds. Hierarchical cluster analysis was used to explain the different phases of shorebirds occurrences (wintering, arrival, early departure and late arrival, departure and breeding phases) based on the distribution and abundance of shorebirds in the study area. Among the recorded shorebirds few species used this area as stopover and wintering sites. Stopover and wintering species were categorized based on their duration of stay in the coastal district, species that occurred continuously from October to April were considered as wintering shorebirds and species observed irregularly in the coasts (August-April) were treated as stopover species.

## 4.3. RESULTS

In total 36 species of shorebirds were recorded, of which 26 were migrants, 5 residents and 5 resident winter migrants (i.e., breed within political boundary of India but occur in the study area only during winter, Table 4.2). Seven species over-summer, a few individuals (5-10) of these species found here throughout the year. Five Near-Threatened species Eurasian Oystercatcher, Eurasian Curlew (*Numenius arquata*), Curlew Sandpiper (*Calidris ferruginea*), Black tailed Godwit, and Bar-tailed Godwit, and one endangered species the Great Knot were recorded. Excluding resident shorebirds, 21 and 10 species used Sindhudurg coast as their wintering and stopover sites respectively (Fig. 4.2). The Common Sandpiper (*Actitis hypoleucos,* 82%), Common Redshank (*Tringa totanus*, 65%), Lesser Sand Plover (*Charadrius mongolus,* 55%), Common Greenshank (*Tringa nebularia,* 43%), Kentish Plover (*Charadrius alexandrinus,* 39%) and Greater Sand Plover (*Charadrius leschenaultii,* 35%) were the most frequently seen species in the study area their percentage of occurrence is given in the parenthesis. Lesser Sand Plover (38%), Common Sandpiper (19%) and Kentish Plover (15%) accounted for 72% of Sindhudurg's shorebird population.

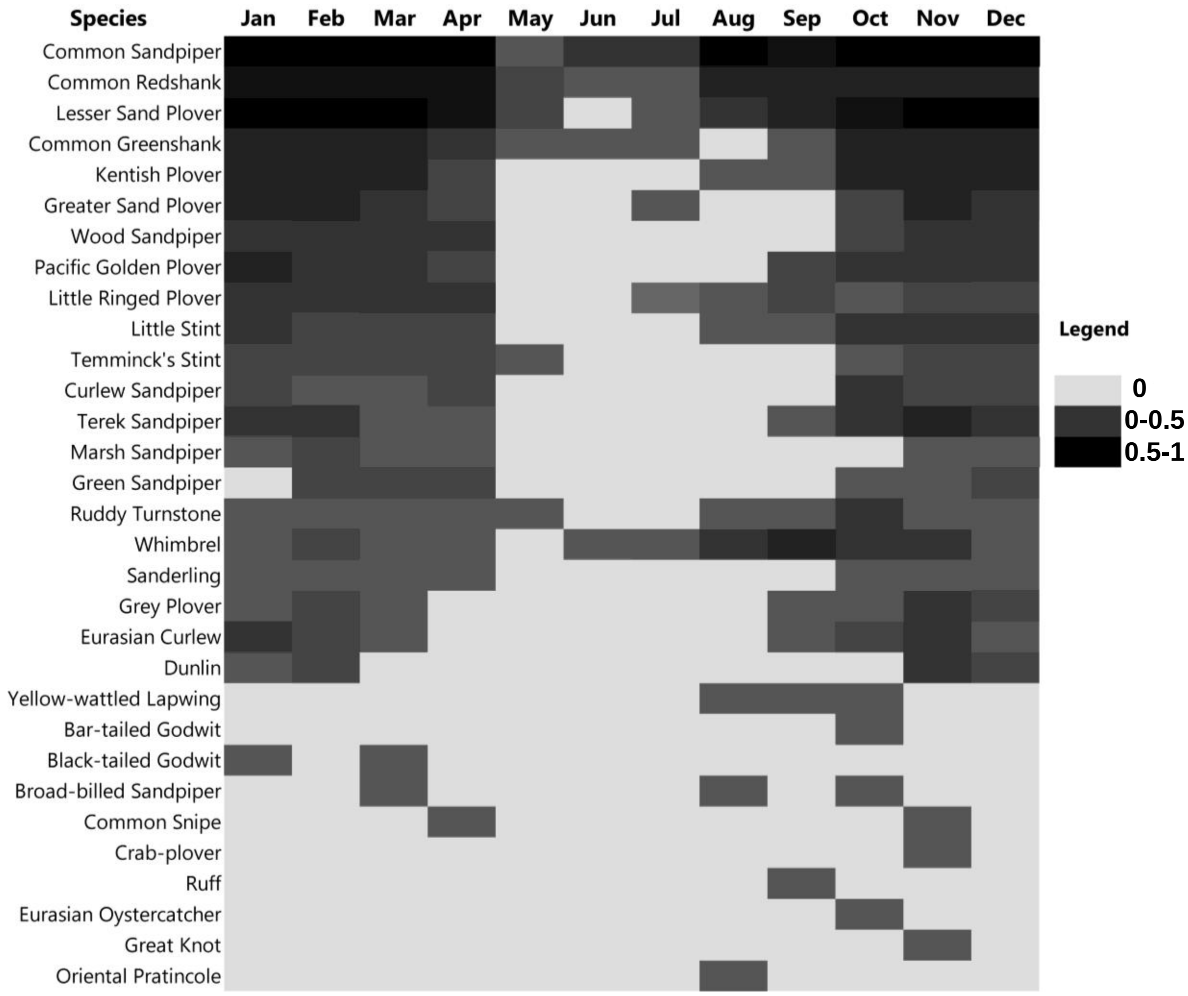



**Figure 4.2.** Proportion of study sites used by the shorebirds across months in Sindhudurg district, Maharashtra, India

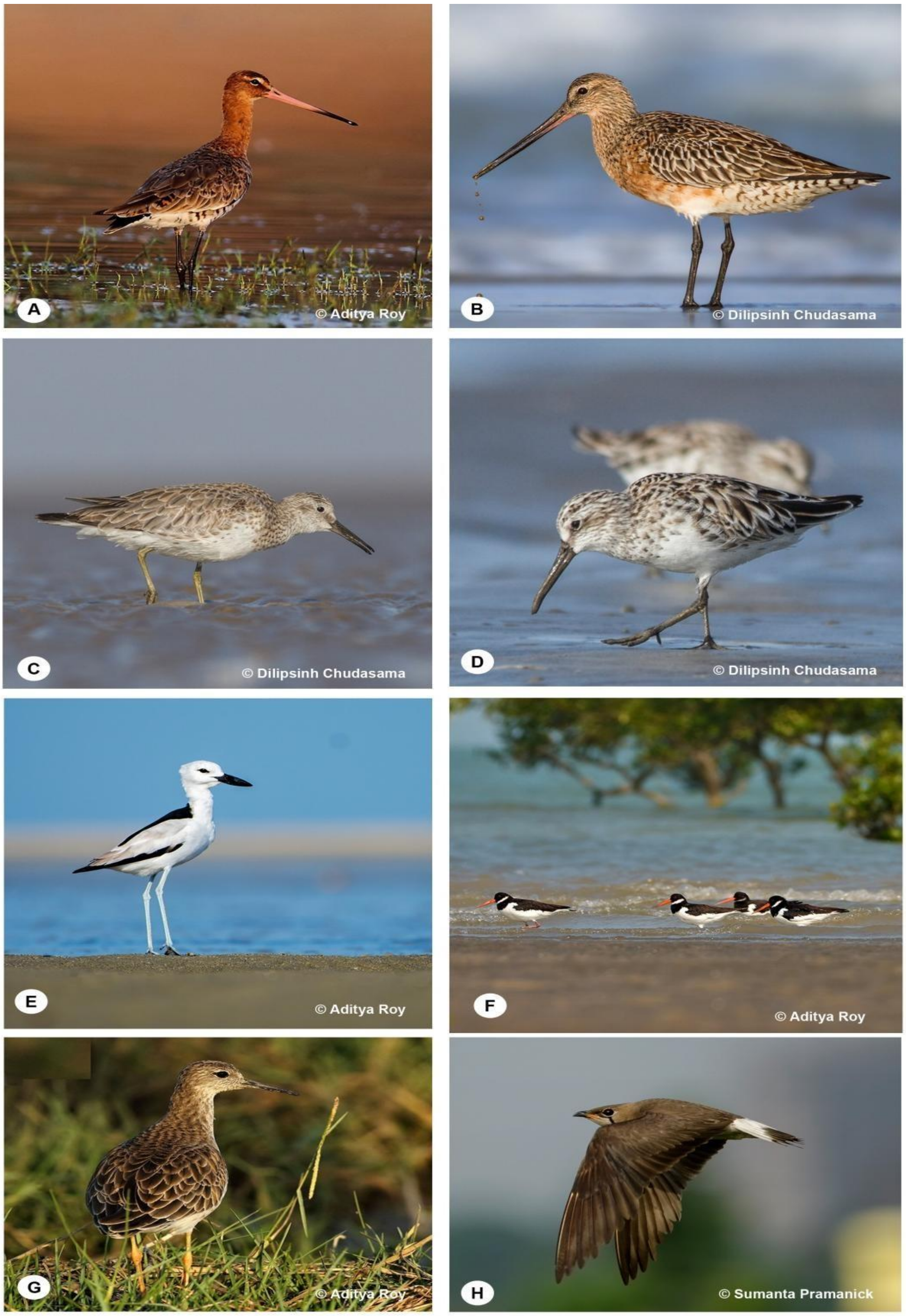



**Plate I**. Species used Sindhudurg coast as stopover site A) Black-tailed Godwit, B) Bar-tailed Godwit, C) Great Knot, D) Broad-billed Sandpiper, E) Crab-plover, F) Eurasian Oystercatcher, G) Ruff, H) Oriental Pratincole

**Table 4.2.** Mean abundance (range in brackets) of shorebirds recorded in Sindhudurg district. "+" indicates species recorded opportunistically, SD- Standared deviation, (**M**=Migrant, **R/WM**=Resident winter migrant, **R**=Resident).

| Species | Species acronyms | Status | Beach | Mangrove | Mudflat |
|---|---|---|---|---|---|
| **Charadriidae** | | | | | |
| Pacific Golden Plover (*Pluvialis fulva*) | PCP | M | 0 | 0.85 (2 - 52) | 0.09 (2 - 10) |
| Grey Plover (*Pluvialis squatarola*) | GPR | M | 0.33 (1- 31) | 0 | 0.16 (1 - 14) |
| Greater Sand Plover (*Charadrius leschenaultii*) | GSP | M | 0.51(2 -15) | 0.17 (6 - 24) | 7.75 (1 - 125) |
| Lesser Sand Plover (*Charadrius mongolus*) | LSP | M | 4.43 (1 - 125) | 2.51 (2 - 115) | 28.49 (1 - 206) |
| Kentish Plover (*Charadrius alexandrinus*) | KP | R/WM | 2.78 (1 - 36) | 0.07 (1 - 13) | 10.87 (2 - 139) |
| Little Ringed Plover (*Charadrius dubius*) | LRP | R/WM | 0.005 (1 - 1) | 0 | 0 |
| Red-wattled Lapwing (*Vanellus indicus*) | RW | R | 0 | 2.02 (2 - 35) | 0.03 (7 - 7) |
| Yellow-wattled Lapwing (*Vanellus malabaricus*) + | YWLW | R/WM | -- | -- | -- |
| **Scolopacidae** | | | | | |
| Broad-billed Sandpiper (*Limicola falcinellus*) | BBS | M | 0.02 (1 - 3) | 0 | 0 |
| Common Greenshank (*Tringa nebularia*) | CGS | M | 0.31 (1 -11) | 0.59 (1 - 11) | 1.28 (1 - 21) |
| Common Redshank (*Tringa totanus*) | CRS | M | 0.26 (2 - 7) | 2.72 (1 - 30) | 3.82 (1 - 33) |
| Common Sandpiper (*Actitis hypoleucos*) | CS | M | 1.75 (1 - 15) | 4.11 (1 - 27) | 11.38 (1 - 72) |
| Curlew Sandpiper (*Calidris ferruginea*) | CSP | M | 0.04 (1 - 3) | 0.01 (1 - 2) | 0.22 (1 - 20) |
| Dunlin (*Calidris alpina*) | DN | M | 0.24 (1 - 32) | 0 | 0.20 (2 - 26) |
| Eurasian Curlew (*Numenius arquata*) | EC | M | 0.05 (1 - 6) | 0 | 0.73 (1 - 30) |
| Great Knot (*Calidris tenuirostris*) | GN | M | 0 | 0 | 0.01 (2 - 2) |
| Green Sandpiper (*Tringa ochropus*) | GRS | M | 0 | 0.005 (1 - 1) | 0 |
| Little Stint (*Calidris minuta*) | LS | M | 0.51 (5 - 69) | 0.03 (0 - 7) | 0.35 (2 - 18) |
| Ruddy Turnstone (*Arenaria interpres*) | RT | M | 0.10 (1 - 10) | 0.01 (2 - 2) | 0.005 (1 - 1) |
| Sanderling (*Calidris alba*) | SD | M | 0.05 (1 - 5) | 0 | 0.06 (1 - 4) |
| Terek Sandpiper (*Xenus cinereus*) | TSP | M | 0.18 (1 - 12) | 0.03 (6 - 6) | 0.36 (1 - 10) |
| Whimbrel (*Numenius phaeopus*) | WH | M | 0.05 (1 - 5) | 0.02 (1 - 3) | 0.68 (1 -30) |
| Wood Sandpiper (*Tringa glareola*) | WSP | M | 0 | 0 | 0.02 (2 - 3) |
| Temminck's Stint (*Calidris temminckii*) + | TS | M | -- | -- | -- |

| | | | | | |
|---|---|---|---|---|---|
| Marsh Sandpiper (*Tringa stagnatilis*) + | MSP | M | -- | -- | -- |
| Ruff (*Philomachus pugnax*) + | RF | M | -- | -- | -- |
| Common Snipe (*Gallinago gallinago*) + | CSNP | R/WM | -- | -- | -- |
| Black-tailed Godwit (*Limosa limosa*) + | BTGW | M | -- | -- | -- |
| Bar-tailed Godwit (*Limosa lapponica*) + | BRGW | M | -- | -- | -- |
| **Rostratulidae** | | | | | |
| Greater Painted-snipe (*Rostratula benghalensis*) + | GPS | R | -- | -- | -- |
| **Haematopodidae** | | | | | |
| Eurasian Oystercatcher (*Haematopus ostralegus*) | EO | M | 0.01 (1 - 2) | 0 | 0 |
| **Burhinidae** | | | | | |
| Great Thick-knee (*Esacus recurvirostris*) | GTN | R | 0 | 0 | 0.005 (1 - 1) |
| **Dromadidae** | | | | | |
| Crab-plover (*Dromas ardeola)* | CP | M | 0.005 (1 - 1) | 0 | 0 |
| **Glareolidae** | | | | | |
| Small Pratincole (*Glareola lactea*) | SP | R | 0.36 (65 - 65) | 0 | 0.40 (1 - 71) |
| Oriental Pratincole (*Glareola maldivarum*) + | OP | R/WM | -- | -- | -- |
| **Recurvirostridae** | | | | | |
| Black-Winged Stilt (*Himantopus himantopus*) + | BWS | R | -- | -- | -- |
| Mean diversity (H)/(±SD) | | | 0.52 ± 0.53 | 0.62 ± 0.44 | 0.89 ± 0.51 |
| Mean species richness (±SD) | | | 1.51 ± 1.94 | 1.86± 1.44 | 3.70 ± 2.50 |
| Overall species richness | | | **20** | **14** | **21** |

The Broad-billed Sandpiper *Limicola falcinellus* and Eurasian Oystercatcher were observed only from beach habitats, while Great Knot was recorded only in mudflats. The pooled species richness across habitats was 21 20, and 14 in mudflats beach, and mangroves respectively. The rarefaction curve clearly indicated that the species richness in mudflat and beach was higher compared to mangrove (Fig. 4.3).

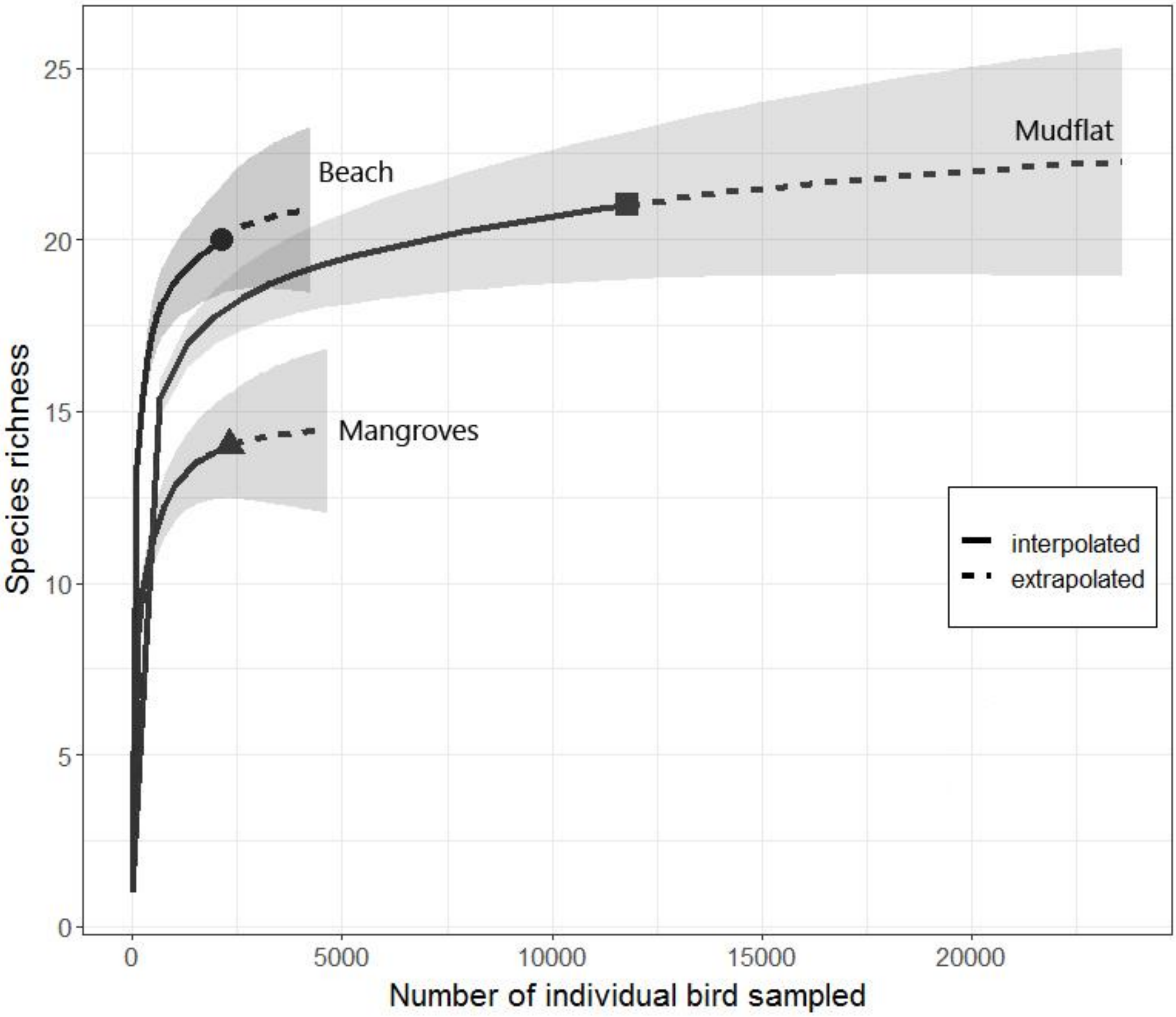



**Figure 4.3.** Individual-based rarefaction curve of species richness for three habitats in Sindhudurg district with 95% confidence intervals (shaded areas). Solid and dashed lines are indicating interpolated and extrapolated curves

Species diversity (Shannon 'H') across the habitats fluctuated greatly, with higher diversity values recorded in mudflats followed by mangroves and sandy beaches (Table 4.2). Mean species richness ($F_{(2, 367)}$ = 43.55, P < 0.001) and abundance ($F_{(2, 367)}$ = 28.37, P <0.001) of shorebirds were significantly higher in mudflats. The tukey post-hoc comparison test showed that mean scores of species richness (M=3.70, SD=2.50) and abundance (M=1.41, SD=0.74) in mudflats significantly different from that in beaches (M=1.51, SD=1.94, M=0.56, SD=0.65) and mangroves (M=1.86, SD=1.44, M=0.84, SD=0.57). The relative abundance of shorebirds was higher for 14, two, and six species in mudflats, mangroves and beaches respectively (Fig. 4.4). Around 73% of birds counted in Sindhudurg district were encountered in mudflats. Mean species richness and diversity of shorebirds was relatively higher in the winter phase (Table 4.3). Abundance of bird species were slowly decreased from February to May.

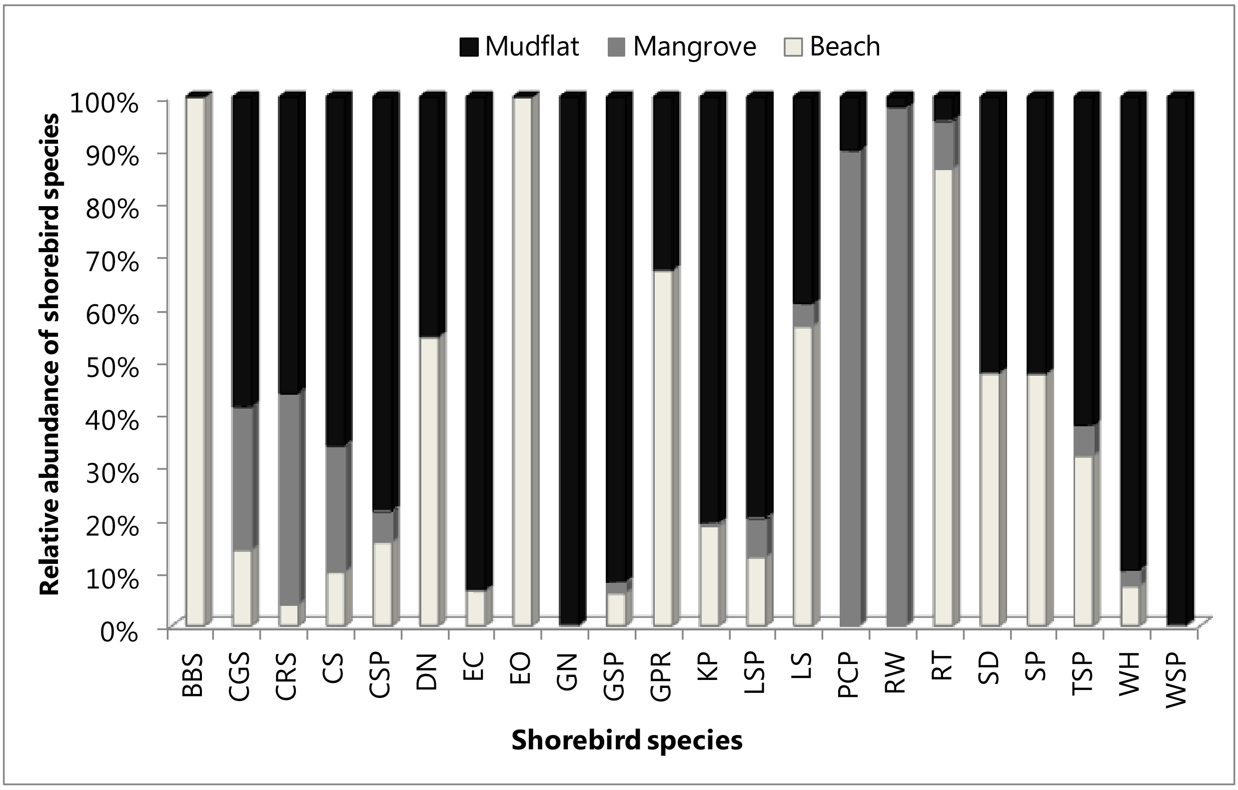



**Figure 4.4.** Relative abundance of shorebirds in three habitats along the Sindhudurg coast, India

**Table 4.3.** Mean abundance and range (wintering group) of shorebirds in different phases along the Sindhudurg coast, SD- Standared deviation

| Species | Breeding phase (Jun-Jul) | Arrival phase (Aug-Sep) | Wintering phase (Nov-Feb) | Early depature & late arrival phase (Mar-Apr, Oct) | Departure phase (May) |
|---|---|---|---|---|---|
| **Charadriidae** | | | | | |
| Pacific Golden Plover | 0 | 2.73 (52 - 52) | 1.21 (2 - 26) | 0.54 (2 - 25) | 0 |
| Grey Plover | 0 | 0.10 (2 - 2) | 1.18 (1 - 31) | 0.03 (0 - 2) | 0 |
| Greater Sand Plover | 0.05 (1 - 1) | 0 | 17.28 (3 - 125) | 5.03 (2 - 52) | 0 |
| Lesser Sand Plover | 0 | 16.43 (4 - 100) | 52.62 (2 - 332) | 36.73 (1 - 192) | 14.14 (43 -56) |
| Kentish Plover | 0 | 0.38 (4 - 4) | 27.90 (6 - 175) | 7.68 (1 - 73) | 0 |
| Little Ringed Plover | 0 | 0.05 (1 - 1) | 0 | 0 | 0 |
| Red-wattled Lapwing | 0.67 (2 - 7) | 1.84 (2 - 21) | 3.13 (4 - 35) | 1.50 (6 - 15) | 1.14 (8 -8) |
| **Scolopacidae** | | | | | |
| Broad-billed Sandpiper | 0 | 0.14 (3 – 3) | 0 | 0.04 (2 - 2) | 0 |
| Common Greenshank | 0.10 (1 - 1) | 0.05 (1 - 1) | 3.37 (1 - 21) | 2.46 (1 - 28) | 1 (7 - 7) |
| Common Redshank | 0.10 (1 - 1) | 4.67 (1 - 16) | 9.90 (1 - 48) | 6.95 (1 - 32) | 1 (7 - 7) |
| Common Sandpiper | 0.81 (1 - 4) | 12.76 (1- 44) | 22.70 (4 - 73) | 20.09 (4 - 81) | 2 (14 - 14) |
| Curlew Sandpiper | 0 | 0 | 0.28 (1 - 11) | 0.57 (1 - 20) | 0 |
| Dunlin | 0 | 0 | 1.11 (1 - 32) | 0 | 0 |
| Eurasian Curlew | 0 | 0.10 (0 - 1) | 1.56 (1 - 30) | 0.45 (1 - 12) | 0 |
| Great Knot | 0 | 0 | 0.03 (2 - 2) | 0 | 0 |
| Green Sandpiper | 0 | 0 | 0 | 0.01 (0 - 1) | 0 |
| Little Stint | 0 | 0 | 1.97 (4 - 71) | 0.38 (2 - 16) | 0 |
| Ruddy Turnstone | 0 | 0 | 0.04 (1 - 1) | 0.34 (1 - 10) | 0 |

| | | | | | |
|---|---|---|---|---|---|
| Sanderling | 0 | 0 | 0.24 (1 - 6) | 0.07 (1 - 2) | 0 |
| Terek Sandpiper | 0 | 0.26 (5 - 5) | 0.89 (1 - 13) | 0.68 (1 - 12) | 0 |
| Whimbrel | 0.67 (6 - 8) | 3.89 (1 - 30) | 0.38 (1 - 10) | 0.36 (1 - 9) | 0 |
| Wood Sandpiper | 0 | 0 | 0.07 (2 - 3) | 0 | 0 |
| **Haematopodidae** | | | | | |
| Eurasian Oystercatcher | 0 | 0 | 0 | 0.04 (2 - 2) | 0 |
| **Burhinidae** | | | | | |
| Great Thick-knee | 0 | 0 | 0.01(1 - 1) | 0 | 0 |
| **Dromadidae** | | | | | |
| Crab-plover | 0 | 0 | 0.01 (1 - 1) | 0 | 0 |
| **Glareolidae** | | | | | |
| Small Pratincole | 0 | 0 | 1.93 (1 - 71) | 0 | 0 |
| Mean diversity (H)/(±SD) | 0.40 ± 0.39 | 0.79 ± 0.39 | 1.38 ± 0.31 | 1.40 ± 0.40 | 0.36 ± 0.62 |
| Mean species richness (±SD) | 1.88 ± 0.78 | 3.36 ± 1.57 | 6.31 ± 2.48 | 4.78 ± 2.41 | 2.00 ± 1.73 |

The overall species richness ($F_{(11, 138)}$ = 12.15, P<0.001) and abundance ($F_{(11, 138)}$ = 14.81, P<0.001) showed significant variation between months. The first and second axis of nMDS explained 63% and 17% of variation for habitats respectively whereas it was 69% and 28% for seasons. This study observed a strong gradient of species composition across habitats and months (Figs. 4.5 & 4.6). The nMDS plot explained five different phases of species composition with respect to months: 1) arrival phase 2) wintering phase c) early departure and late arrival phase d) departure phase and e) breeding phase. This pattern was further explained with a cluster diagram (Fig 4.7). The composition of shorebirds during the wintering phase did not fluctuate across the estuaries whereas it fluctuated highly in other phases (Figs. 4.6 &4.7).

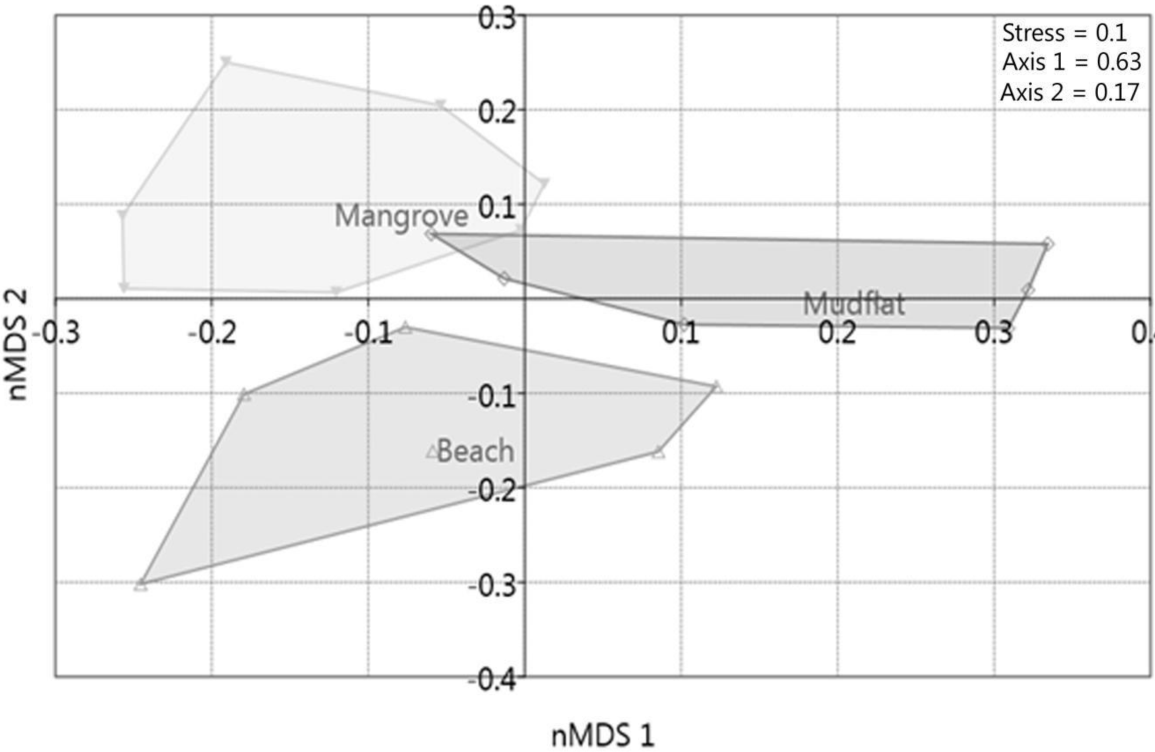



**Figure 4.5.** nMDS plot showing the species composition of shorebirds in different coastal habitats of Sindhudurg district, India

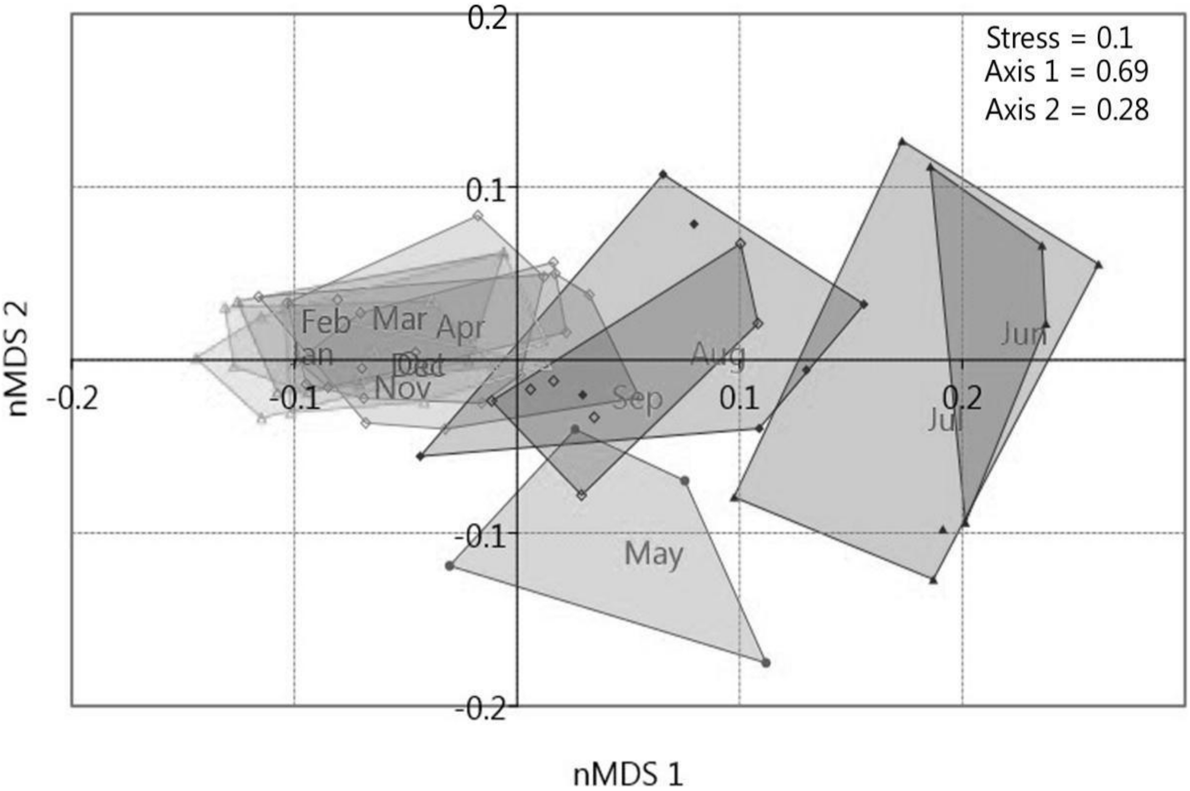



**Figure 4.6.** nMDS plot showing the species composition of shorebirds in different months in Sindhudurg district, India

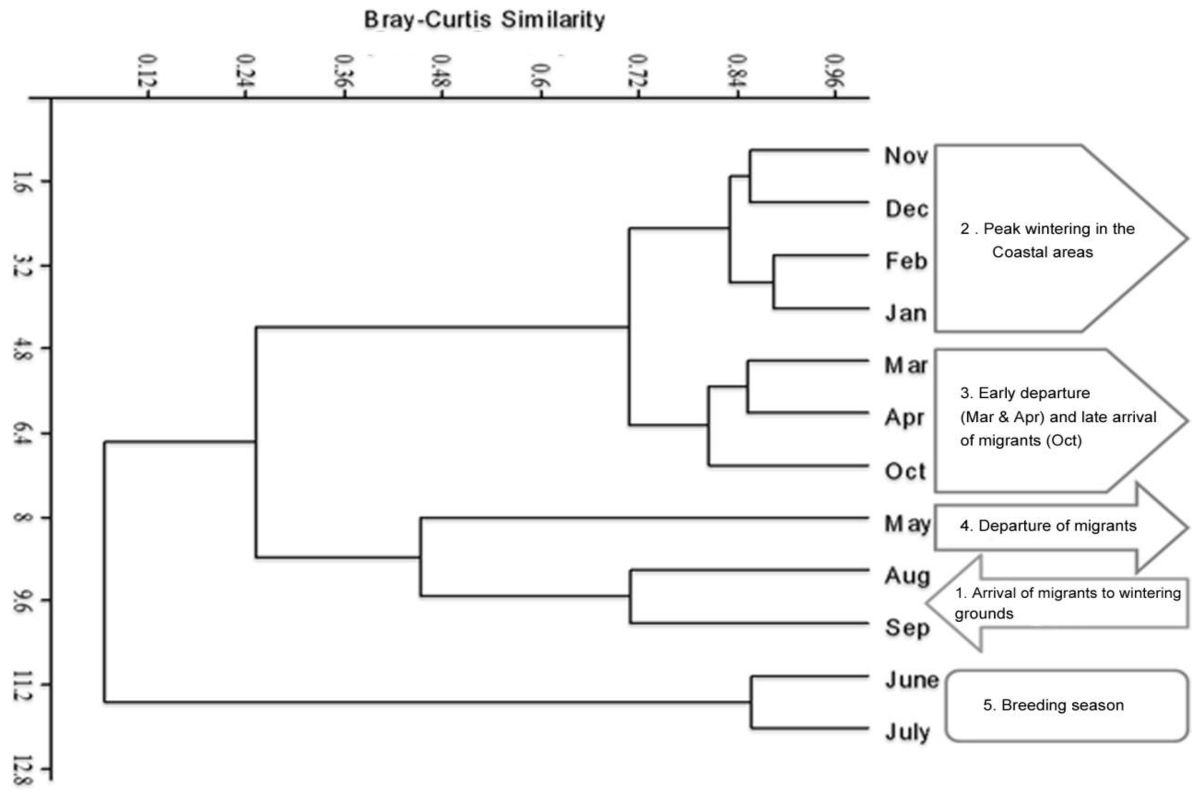



**Figure 4.7.** Cluster diagram showing different phases of species composition of wintering shorebirds in Sindhudurg coast

One-way ANOSIM showed that overall species composition across habitats (R=0.46, P<0.001) and months (R=0.34, P<0.001) varied widely. The species composition of shorebirds across habitats was significantly different, excluding a slight overlap between mudflats and mangroves. A significance difference in pairwise species composition was recorded between beach and mangrove (R=0.46, P<0.001), beach and mudflat (R = 0.40, P < 0.001) and mudflat and mangrove (R=0.51, P<0.001).

## 4.4. DISCUSSION

This study is the first attempt in India to assess the spatial and temporal patterns of shorebird presence across a large coastal stretch. This study recorded 36 species of shorebirds along the Sindhudurg coast, a comparative list of shorebird species recorded from a few important sites along the Indian coast is provided in (Table 1). Nearly 32% migratory shorebirds used the Sindhudurg coast as a stopover site. Plovers dominated the species composition followed by Greenshanks and Redshanks. Mudflats supported the highest species richness, abundance, and diversity of shorebirds compared with other habitats. Richness and abundance were highest during the peak wintering months (i.e., November to February). Five different patterns of species composition were identified on the basis of shorebird movement along the Sindhudurg coast.

### 4.4.1. Spatial patterns of shorebird distribution

Plovers, Common Sandpiper, and shanks were the most abundant and commonly observed species during the study. Similarly, a study from the southwest coast of India also observed that the dominant shorebird group was plovers, followed by shanks (Aarif et al. 2014). However, studies conducted in the east coast of India, recorded Little Stint and other tactile foraging shorebirds (e.g., Blact-tailed Godwit, Bar-tailed Godwit, and Curlew Sandpiper) as abundant shorebirds (Sampath & Krishnamurthy, 1990; Balachandran, 2006; Nayak, 2006; Kannan & Pandiyan, 2012). The dominance of plovers in the study area could be due to the narrow intertidal mudflats dominated by sand as compared to the east coast. East coast of India has a large extent of mudflats characterized by muddy substrates (Kathiresan, 2018).

Muddy substrates enable probing shorebirds to capture prey easily thus, their numbers may be more on the east coast. Detailed comparative studies from both the coasts (east and west) can help to understand this pattern better.

Among the recorded species, the Great Knot, Crab-plover, Broad-billed Sandpiper, Black-tailed Godwit, Ruff, and Bar-tailed Godwit used the Sindhudurg coast as a stopover site. However, in many coastal sites in India, these species have been documented as regular wintering species (Sampath & Krishnamurthy, 1990; Balachandran, 1995, 2006; Kannan & Pandiyan, 2012). This observed pattern indicates that the duration of stay varies for species with location thus, wintering and stopover habitat assessment can support effective management actions. In the future, indicator shorebirds need to be tagged and tracked for their movement to obtain a fine-scale pattern of shorebird movement along flyways.

High species richness, diversity, and abundance of shorebirds was recorded from mudflats, which highlights the significance of mudflats in the conservation of shorebirds. This observed pattern corroborates the findings of other shorebird studies along the west and east coast of India (Sandilyan & Kathiresan, 2012; Aarif et al. 2014; Sandilyan & Kathiresan, 2015; Pandiyan & Asokan, 2016) and in different parts of Central Asian Flyway and the East Asian-Australasian Flyways (Zou et al. 2008; Mathot et al. 2018) The soil structure of mudflats is dominated by clay components, which allows the tactile foragers to feed more efficiently on macroinvertebrates and bioflims over the mudflat without too much impact on their beaks (Quammen, 1982; Kelsey & Hassall, 1989; Yates et al. 1993). Mudflats are one of the most productive intertidal habitats and support a wide diversity of benthic organisms (Kathiresan, 2000; van de Kam et al. 2004; Spruzen et al. 2008), which are an important prey base for wintering shorebirds (Sandilyan & Kathiresan, 2012; Aarif et al. 2021). This could be one of the possible reasons for the greater shorebird abundance and richness in mudflats.

In contrast to this study Nagarajan (1990), Sampath and Krishnamurthy (1993) and Nagarajan and Thiyagesan (1996) reported that microhabitats (muddy patches) in and around mangrove habitats act as potential habitats for waterbird populations in Pichavaram. Minimum use of mangrove habitats by shorebirds was observed in the study because large parts of the mangrove habitats were dominated by oyster beds (*C. madrasensis* and *C. cuttackensis*) and provided limited foraging space for shorebirds. Shorebirds might have found it difficult to capture the prey buried under the outer hard surface of oyster beds, preventing them from using this habitat. This observation corroborates the findings of Myers et al. (1980) and Finn et al. (2007), which reported substrate penetrability influences the occurrence of select shorebirds.

With regard to the species composition of shorebirds, observed a unique pattern of species composition in mangroves but a slight overlap between mangrove and mudflats. Owing to a lack of information on these aspects in India, this study could not make any comparisons with other studies. As reported in other countires, this pattern of composition might largely be influenced by the physical and chemical properties of the substrate (van Dusen et al. 2012; Russell et al. 2014), extent of area (Zou, 2008), prey availability and accessibility ( Aarif et al. 2021), density of predators (Roger et al. 2006b; Pomeroy, 2006), anthropogenic disturbances (Pfister et al. 1992; Yasue, 2006) and structure and composition of the landscape (Guadagnin et al. 2005; Albanese & Davis, 2015).

### 4.4.2. Temporal pattern of shorebird distribution

Current study identified five distinct phases, with respect to the shorebird composition along the west coast in Sindhudurg district: 1. arrival phase: shorebirds start arriving along the coast in August and this continues till October (Plovers, Sandpipers, Stints, and Shanks), 2. wintering phase: the population of shorebirds increases and peaks during this phase (Plovers, Sandpipers, and Shanks), and some passage migrants stopover in the region before proceeding to their destinations (Great Knot, Broad-billed Sandpiper, and Crab-plover, and Ruff). 3. early departure phase: by end of March and in April, few species of waders, Grey Plover (*Pluvialis squatarola*) and the Eurasian Curlew return to their breeding ground, and the population of shorebirds starts to decline. 4. departure phase: except a few individuals of over-summering shorebirds, all waders leave the wintering ground to breeding ground. 5. non-wintering or breeding phase: a few over-summering species (e.g., the Greater Sand Plover-*Charadrius leschenaultii*, Common Redshank, Lesser Sand Plover, Common Greenshank, Common Sandpiper, and Whimbrel) and resident waders like Red-wattled Lapwing were recorded from the coastal areas during this phase, and these species were also seen over-summering in the Kadalundi estuary (Aarif et al. 2020). This observed pattern indicates the importance of habitat protection and conservation, because several species use these areas at different spatial and temporal scales. Prey and threat assessment in different phases can throw more light on this pattern.

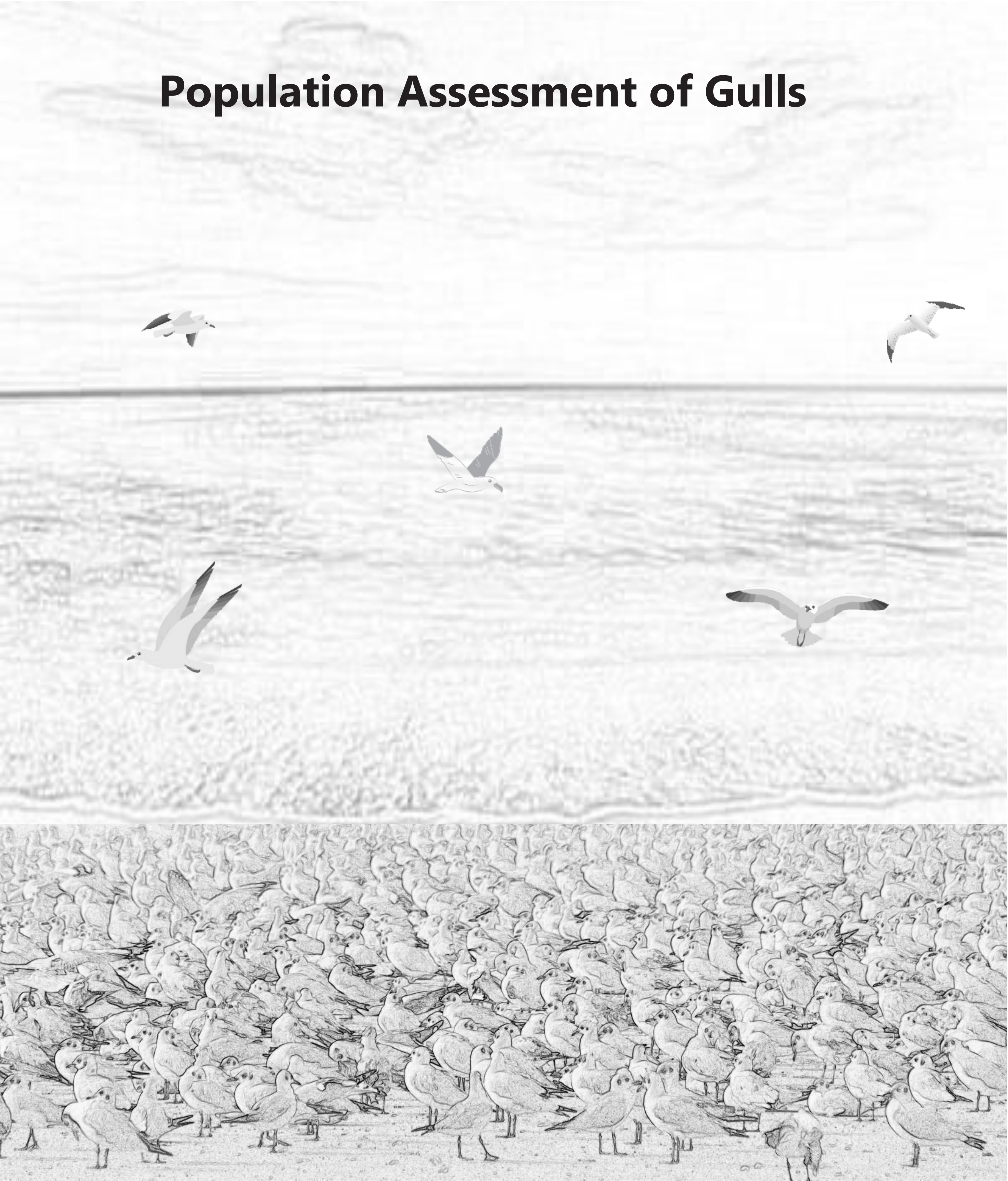
#### 4.4.3. Conservation implications

Shorebirds use mudflats extensively for foraging, but no special attempts have been made to conserve this habitat in India. Furthermore, such areas have been traditionally used for mangrove nursery and plantation grounds. The current study recommends that the mangrove plantation can be done in areas other than mudflats where bird use is minimal. Further estuarine mudflats are potential sites for shorebirds in the region, and beach sand dunes are used for roosting during high tide. Increasing beach tourism is threatening these roost sites. In addition, sand mining is one of the major issues along the coast which alters the river flow and affects the sediment composition of mudflats. Therefore immediate mitigation measures should be undertaken for the conservation of these habitats. A few estuaries viz., Mitbav, Karli, and Mochemad support many numbes of shorebirds, and these sites can be recognized as important bird areas for the protection and conservation of migratory shorebirds.

**Plate II.** Threats to the coastal habitats in the Sindhudurg district

# Chapter 5

# Population Assessment of Gulls



## 5.1. INTRODUCTION

In peninsular India, wintering gulls are found mostly in coastal areas and less frequently at freshwater reservoirs and rivers (Pandiyan et al. 2006; Lainer & Alvares, 2013; Aarif et al. 2015; Kushwaha et al. 2017). The coastal zone along India's west coast has come under severe pressure from a range of threats that include the conversion of natural coastal habitats, sand mining in estuaries, and the use of tetrapods for erosion control, and uncontrolled recreational activities (Sivakumar, 2013; Ministry of Tourism, 2019). The human activities have been deemed to alter the structure and composition of coastal bird communities, and especially impact migratory birds (CAF National Action Plan, 2018).

Among migratory bird taxa, gulls are often ignored because of their abundance and scavenging tendencies (Li & Mundkur, 2007). Other than a few sporadic observations and some site-specific information (Table 5.1), knowledge on gull population trends is lacking in India. Thus, it is important to assess the regional population sizes of gulls to develop conservation measures and manage anthropogenic threats along the highly dynamic stretches of India's west coast. Hence, this chapter assessed gull numbers at selected sites along the coast of Sindhudurg district.

**Table 5.1.** A comparison of gull studies carried out on the Indian subcontinent (**BKHG-**Black-headed Gull, **BHG-**Brown-headed Gull, **LBBG-**Lesser Black-backed Gull, **PG-**Pallas's Gull, **SBG-**Slender billed Gull, **M-** Mean**, D-**Density)

| Area | BKHG | BHG | LBBG | PG | SBG | Source |
|---|---|---|---|---|---|---|
| | | | **West coast** | | | |
| **Sindhudurg** | **877** | **11,572** | **3,595** | **2,800** | **2,381** | **Present study** |
| Purathur Estuary | — | 5,000 | — | — | — | Nameer et al. (2014) |
| Puduvyppu Mangroves | — | 1,500 | — | — | — | Nameer et al. (2014) |
| Katapuram | — | 2,000 | — | 1,000 | | Nameer et al. (2014) |
| Kumbla-Shiriya Estuary | — | — | — | 3000 | — | Nameer et al. (2014) |
| Muzhappilangad Estuary | — | 5,000 | — | — | — | Nameer et al. (2014) |
| Thaikadapuram | — | 3,000 | — | — | — | Nameer et al. (2014) |
| Mogral Estuary | — | — | — | 4,500 | — | Nameer et al. (2014) |
| Kadalundi-Vallikkunnu CMR | 15,000 | 10,000 | 500 | 1,000 | 3 | Aarif et al. (2015) |
| Kadalundi-Vallikkunnu CMR$^{(M)}$ | 66 – 66 | 79 – 330 | 26 – 597 | 2–57 | — | Ansari (2018) |
| Goa | 177 – 40,000 | 2,500 – 60,000 | >3,600 | 245 | >1,800 | Lainer & Alvares (2013) |
| Chhaya Rann Wetland Complex | 848 – 1,100 | 140 – 1,100 | — | — | — | Vargiya & Chakraborty (2019) |
| Khijadiya wetland | 15 | 6 | 1 | 1 | — | Jethva et al. (2017) |
| | | | **East coast** | | | |
| Chilika | 172 | 20,000 | 520 | 300 | — | Balachandran et al. (2005) |
| Chilika | — | 160 | — | — | — | Ram et al. (1994) |
| Coringa WLS | 6 – 100 | 2,068 – 4,000 | — | 38 – 150 | — | Sathiyaselvam & Sreedhar (2014) |
| Pulicat Bird Sanctuary | 475 – 1,603 | 6–48 | — | — | — | Raghavaiah (2007) |
| Pulicat Bird Sanctuary | 2,408 | 1,890 | — | — | | Kalle et al. (2018) |
| Pichavaram Mangroves | 93 – 152 | 215 – 382 | — | 2–14 | — | Nagarajan & Thiyegesan (2014) |
| Point Calimere WLS | 1–13 | 4 – 163 | 1–5 | 1–4 | — | Manikannan (2011) |
| Point Calimere WLS | 37 | 56 | — | | 5 | TFD (2020) |
| Pazhaiyar (**D**) | 312.48 | 372.11 | — | — | — | Pandiyan (2002) |
| Thirumullaivasal (**D**) | 203.46 | 305.81 | — | — | — | Pandiyan (2002) |
| Chinnangudi (**D**) | 99.03 | 103.56 | — | — | — | Pandiyan (2002) |
| Tharangambadi (**D**) | 22.36 | 24.85 | — | — | — | Pandiyan (2002) |
| Karaikal (**D**) | 4.25 | 0.10 | — | — | — | Pandiyan (2002) |
| Niravi (**D**) | 196.31 | 196.00 | — | — | — | Pandiyan (2002) |
| Nandupallam (**D**) | — | 3.2 ± 0.64 | — | — | — | Pandiyan et al. (2013) |
| Nedunthittu (**D**) | — | — | 5.9 ± 1.71 | — | — | Pandiyan et al. (2013) |
| Camplast (**D**) | — | — | 2.5 ± 0.62 | — | — | Pandiyan et al. (2013) |
| Pushkarani (**D**) | — | — | 18.1 ± 17.57 | — | — | Pandiyan et al. (2013) |
| Gulf of Mannar | 85 | 600 | 87 | 85 | — | Balachandran (1995) |
| | | | **Other Indian states** | | | |
| Okhla Bird Sanctuary | 61 – 1,200 | — | — | — | — | Manral et al. (2014) |
| Jhansi district UP | 113 – 139 | 73 – 89 | — | 32 – 52 | — | Kushwaha et al. (2017) |

## 5.2. METHODS

### 5.2.1. Study area

The population parameters of gulls were assessed along a 121 km coastal swathe (Fig. 5.1) of Sindhdurg district. For that seven sites were selected viz., Wadatar, Mitbav, Achara, Karli, Nivati, Vengurla Bandar, and Mochemad to monitor gull populations (Fig. 5.1).

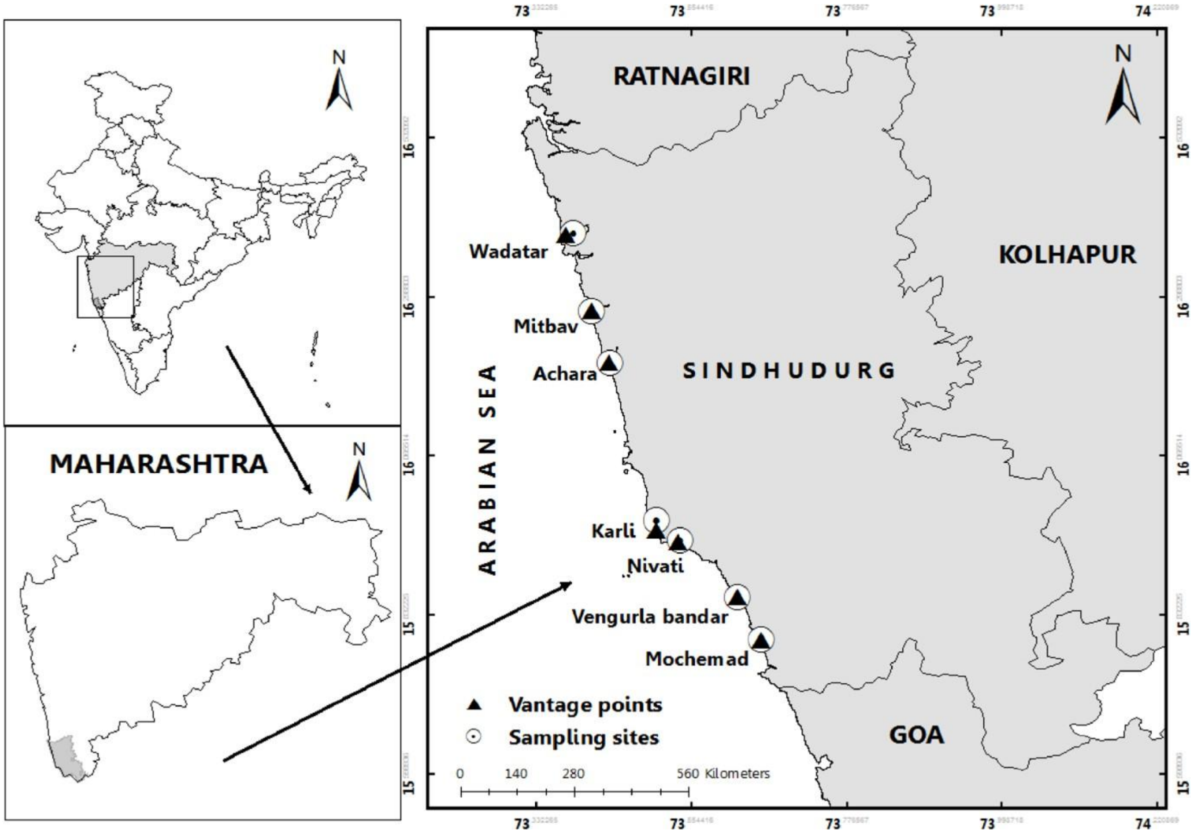



**Figure 5.1.** Map showing sampling locations in the Sindhudurg district

### 5.2.2. Population count and effect of sampling covariates

In order to count the gull numbers, I conducted daytime near-shore surveys from January 2015 to April 2017 in seven estuaries in the study area. At each selected estuary, established a single, slightly elevated vantage point, generally on the embankments of the estuary (Fig. 5.1), it's allowed to count all of the gulls roosting on the estuary and beach. All counts were made during low tide as during this period there is more space available for roosting gulls. As gull flock sizes were large (1,000s) and constantly change, therefore counts were made based on photographs taken of the gull flocks (Verner, 1985; Howes & Bakewell, 1989; Javed & Kaul, 2000; Urfi et al. 2005). Whenever a roosting flock of gulls was located, took a sequence of images later these images were used to identify and count the birds using a field guide (Olsen, 2010) and image-viewing software (Picasa photo viewer).

During each session at the intensively studied sites, sampling covariates also quantified that might influence gull sightings at the estuaries, such as the level of anthropogenic disturbance, including variables such as sand mining, the number of tourists, the number of people fishing, and biotic disturbance such as the presence of cattle, dogs, and raptors. The number of people present within a 500 m radius of roosting gull flocks, and the numbers of cattle and stray dogs were counted at the time of sampling. In addition, the species, and abundance, of raptors were also recorded during counts from vantage points.

### 5.2.3. Statistical analysis

Gull count data from seven study sites were tabulated (see Table 5.2) along with the population range (min-max) and the figure for the one percent bio-geographic population (BGP) was obtained from Wetland International 2019. The presence of one percent BGP of a species is an indication of the international significance of a site. The maximum number of individuals of a species counted in a day was taken to calculate the 1% BGP of gulls. The mean number of gulls per visit was calculated for each species. Non-parametric Krushkal-Wallis test was performed to test the difference in gull species abundance across sites and months. Zeroinflated Negative Binomial (ZINB) analysis was applied to test the effect of sampling covariates on gulls at intensively studied locations. ZINB used as the count data contained many zero values. ZINB fitted with the 'zeroinf' function using the pscl package in R software (Zeileis et al. 2008).

## 5.3. RESULTS

At the seven intensive sites, total of 125,874 gulls of five species: Black-head Gull *Chroicocephalus ridibundus* (BKHG), Brown-headed Gull *Chroicocephalus brunnicephalus* (BHG), Lesser Black-backed Gull *Larus fuscus* (LBBG), Pallas's Gull *Ichthyaetus ichthyaetus* (PG) and Slender-billed Gull *Chroicocephalus genei* (SBG) with a mean count of 642.21 gulls/site/visit were recorded. Brown-headed Gull (41%), Lesser Black-backed Gull (32%), and Pallas's Gull (23%) accounted for 96% of all gulls counted. In total, a maximum of 8.2 % (BHG), 3 % (PG) and 1.5 % (SBG) BGP were recorded. Amongst sampling sites, 10.3 %, 8.2 %, and 5.6 % BGP (when pooling all species together) were recorded from three sites respectively: Mochemad, Karli, and Mitbav (Table 5.2). The maximum number of individuals was recorded in the wintering months December-February (Table 5.3). Mean counts of gulls differed significantly between sites ($\chi2=58.03$, df=6, P=0.00) and months ($\chi2=46.19$, df=11, P=0.00). Furthermore, observed a decline in gull numbers over the three years of the study (Fig. 5.2). The effect of sampling covariates, on species richness and abundance of gulls during the temporal replicates, was tested and found that none of the measured covariates influenced the richness and abundance of gulls (Table 5.4).

**Table 5.2.** Minimum and maximum numbers of gulls at study sites; estimated for 1% biogeographic population (BGP)

| | **Flyway population estimate (CAF) in thousand** | **Arrival** | **Departure** | **Sites-Total count in range (min-max)** | | | | | | | | **1% BGP** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | **ACH** | **KL** | **MT** | **MC** | **NT** | **VB** | **WD** | **Overall** | |
| Black-headed Gull | 25 - 1000 | Nov | Apr | 2 | 18-154 | 10-60 | 3 - 877 | - | 5 - 31 | 133 | 2 - 877 | 10,000 |
| Brown-headed Gull | 100 - 200 | Oct | Apr | 1 - 9 | **11 -11572 (8.2%)** | **1 – 4981 (4%)** | **12 – 8500 (6%)** | 583 | 4 - 893 | | 1 - 11572 **(4 – 8.2%)** | 1400 |
| Lesser Black-backed Gull | 25 - 1000 | Oct | Apr | 9 | 7 - 1920 | 4 - 1743 | 1 - 3595 | - | 1 - 117 | 2 - 4 | 1 - 3595 | 10000 |
| Pallas's Gull | 25 -100 | Oct | Apr | 4 | 2 - 840 | **3 – 1662 (2%)** | **4 - 2800 (3%)** | - | - | - | 2 - 2800 **(2 – 3%)** | 1000 |
| Slender-billed Gull | 150 -150 | Oct | Apr | - | 15 - 184 | 3 | **1 - 2381 (1.5%)** | - | 2 - 84 | - | 2 - 2381 **(1.5%)** | 1500 |
| **Total 1% BGP** | | | | **-** | **~8.2%** | **~5.6%** | **~10.3%** | **-** | **-** | **-** | | **-** |

**Flyway population and 1% BGP estimated from** Wetlands International (2019) "Waterbird Population Estimates". Availabe at wpe.wetlands. org (accessed on 23 December 2019), **ACH-**Achara, **KL**-Karli, **MT-**Mitbav, **MC-**Mochemad, **NT-**Nivati, **VB-**Vengurla bandar, **WD-**Wadatar, **BGP-** Biogeographic population

**Table 5.3.** Minimum and maximum numbers of gulls recorded across the months in the study area from 2015-2017.

| Month | BKHG | BHG | LBBG | PG | SBG |
|---|---|---|---|---|---|
| JAN | 10- 21 | 42 - 10334 | 21 - 3925 | 28 - 2800 | 28 - 532 |
| FEB | 10 - 154 | 1 - 4600 | 1 - 2310 | 17 - 2374 | 3 - 184 |
| MAR | 2 - 25 | 1 - 1272 | 2 - 244 | 2 - 234 | 1 - 84 |
| APR | 5 - 5 | 4 - 612 | 1 - 15 | 4 - 6 | 2 - 12 |
| MAY | - | - | - | - | - |
| JUN | - | - | - | - | - |
| JUL | - | - | - | - | - |
| AUG | - | - | - | - | - |
| SEP | - | - | - | - | - |
| OCT | 0 - 0 | 14 - 840 | 20 - 395 | 2 - 486 | 298 - 298 |
| NOV | 206 - 206 | 162 - 4475 | 66 - 420 | 20 - 472 | 1317 - 1317 |
| DEC | 877 - 877 | 5 - 11572 | 4 - 1639 | 3 - 596 | 3 - 2381 |

**BKHG-**Black-heade Gull, **BHG-**Brown-headed Gull**, LBBG-**Lesser Black-backed Gull**, PG-** Pallas's Gull**, SBG-**Slender-billed Gull

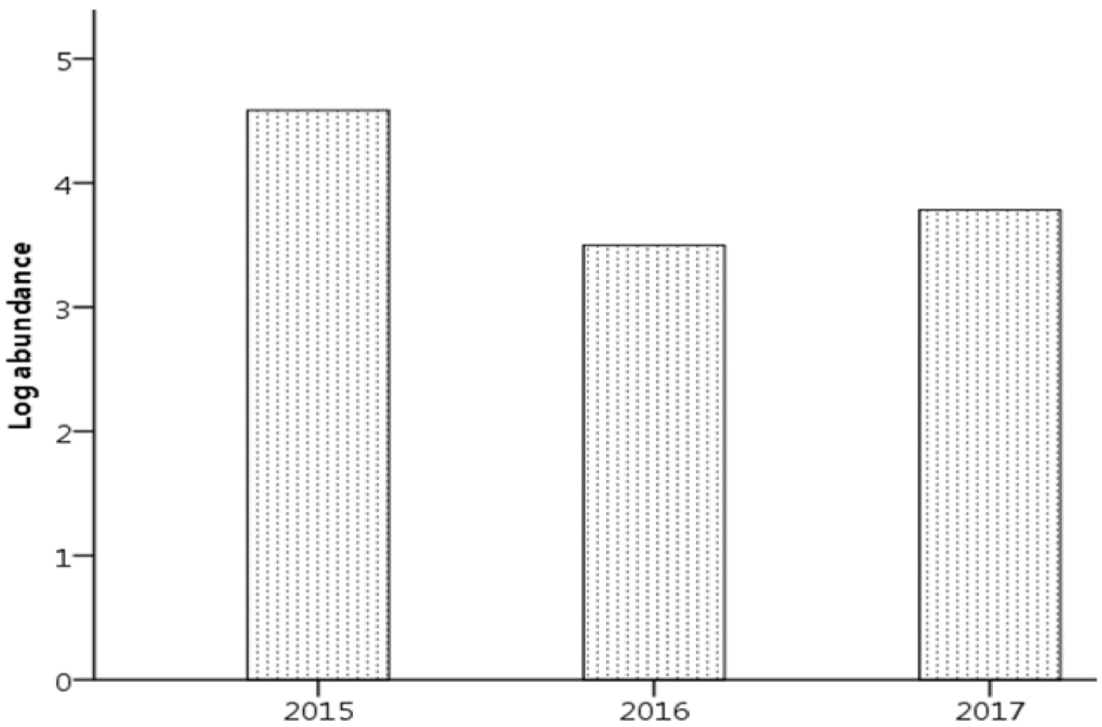



**Figure 5.2.** Gull numbers at select locations of the Sindhudurg coast for three consecutive years (2015 – 2017)

**Table 5.4.** The effect of various sampling covariates on gull richness and abundance in select locations of Sindhudurg district

| Model factor | Estimate | SE | p-value | Estimate | SE | p-value |
|---|---|---|---|---|---|---|
| | Count model | | | | Zero model | |
| **Gull richness** | | | | | | |
| Intercept | −0.01 | 0.47 | 0.98 | −1.37 | 1.47 | 0.34 |
| Raptor richness | 0.18 | 0.13 | 0.19 | 0.30 | 0.35 | 0.39 |
| Raptor abundance | −0.001 | 0.006 | 0.74 | −0.01 | 0.03 | 0.65 |
| No. of Dogs | 0.03 | 0.02 | 0.25 | 0.04 | 0.06 | 0.44 |
| No. of Tourists | 0.001 | 0.001 | 0.15 | −0.007 | 0.006 | 0.22 |
| **Gull abundance** | | | | | | |
| Intercept | 6.63 | 1.59 | 0.00 | -0.56 | 1.12 | 0.61 |
| Raptor richness | 0.15 | 0.47 | 0.73 | 0.24 | 0.38 | 0.51 |
| Raptor abundance | 0.004 | 0.01 | 0.69 | −0.001 | 0.01 | 0.90 |
| No. of Dogs | −0.03 | 0.05 | 0.50 | −0.01 | 0.08 | 0.82 |
| No. of Tourists | 0.004 | 0.003 | 0.21 | −0.03 | 0.01 | 0.07 |

## 5.4. DISCUSSION

This study recorded important numbers of Brown-headed Gull (8.2 % of 1% BGP), Pallas's Gull (3 % of 1% BGP), and Slender-billed Gull (1.5 % of 1% BGP) in the study area. None of the sampling covariates that were quantified appeared to influence the presence of gulls, indicating that roost site fidelity is very high among wintering gulls. This study generated systematic data on wintering gull populations from a coastal swathe of Peninsular India and the findings provide useful insights for the management of the coastal habitats of peninsular India and wintering sites along the Central Asian Flyway.

Gulls are highly neglected group of birds in the CAF and along Indian coasts, despite the fact that India's coasts attract the largest proportion of wintering gull populations (Li & Mundkur, 2007). The present study results, and gull studies elsewhere in India, demonstrate that a greater number of gulls occur along the west coast than on the east coast (Table 5.1). The reasons for this pattern are not clearly known but I suspect that the availability of food resources and suitable roost sites is crucial. The Slender-billed Gull is considered uncommon on India's east coast but this species recorded regularly in the study area. With reference to the available literature

(Table 5.1), it seems that few sites in the study area support a 1% BGP of Slender-billed Gull, which is high for the species in India. Aarif et al. (2015) observed one percent threshold populations of Brown-headed Gull and Pallas's Gull (but not Slender-billed Gull) from the southwest coast of India. In current study, the wintering Black-headed Gull numbers were lower than found by Aarif et al. (2015), perhaps because of the geographical location of the sampling sites and different counting techniques followed. The present study recorded more than one percent biogeographic populations of gulls mainly from three sites: Mochemad, Karli, and Mitbav. These sites require protection for the conservation of migratory birds and their habitats along India's west coast.

The distribution and abundance of gulls in winter is largely shaped by the availability of natural food resources, discarded offal, and fishery waste (Cramp et al. 1974; Camphuysen et al. 1995; Stone et al. 1995; Garthe et al. 1999; Furness et al. 2007). During the survey it was observed that gulls chose roost sites close to fish landing centers. These were deemed very likely to provide important foraging grounds for gulls. These observations corroborate the results from a study on the Severn Estuary, UK, where gulls used sandbanks for roosting and foraged close to their roost sites (Vernon & Walsh, 1966), and from several other studies on birds (Furness, 1973; Rogers et al. 2006b; Peters & Otis, 2007; Zharikov & Milton, 2009; Végvári & Barta, 2015; Clark et al. 2016a; Pearse et al. 2017; Yu et al. 2019). Larger roosts, which are far away from important foraging sites, are less likely to be used by species and *vice-versa* (Clark et al. 2016a); this may be attributed to saving energy expedited while traveling. Flying between roosting and foraging sites is energetically expensive and hence, roost sites close to foraging sites minimize energy expenditure (Dias et al. 2006; Chudzinska et al. 2015).

Among the observed gulls, mainly Black-headed and Brown-headed gulls, scavenging on discarded fish at fish landing centers; they are also known to follow fishing vessels. This behavior is species-specific but other species might perhaps be specialists at sea. Stone et al. (1995), and Vernon and Walsh (1966), explained that Black-headed Gulls rarely occur far away from the coast and mostly rely on near-shore food resources, which were able to corroborate in this study.

None of the sampling covariates (such as sand mining activity, the numbers of tourists, dogs, and raptors) influenced the detection of gulls at study sites. Species used the same sites for roosting every year. Many avian species roost in precisely the same locations year after year, indicating that such locations are traditional. Several factors during winter may limit a species' population; however using the same traditional sites can facilitate finding local food resources, alternate local roost sites, and potential predators (Somershoe et al. 2009). Individual gulls joining winter roosts may benefit from the presence of experienced birds in the flock participate either from the same or different species (Webster et al. 2002). Since this study did not conduct telemetry studies, thus cannot comment on this behavior. However, radio-collared gulls (Clark et al. 2016b) and shorebirds (Warnock & Takekawa, 1996) have shown high site fidelity, returning to the same sites in subsequent winters. Because of high site fidelity, sampling covariates, although relevant, may not influence the detection of gulls at roosting sites. It seems that the gulls observed did not change their roost sites much during winter; even when disturbed, they simply avoided the disturbance for a short period before returning to the same sites after a while. This was evident from another site on the west coast where gulls shifted their roosting sites while a bridge across an estuary was being constructed, but returned to their original roost site once the construction was completed (Aarif et al. 2015). Similarly, at Farmoor Reservoir, UK, when deterrence calls were broadcast to chase away roosting gulls the birds avoided the roost site for a while but then reappeared when alternative roost sites became frozen (Gosler et al. 1995).

Gulls roost on large sandbanks close to fish landing centres; therefore, the conservation of estuarine sandbanks is important for managing wintering gull populations in India's coastal areas. Currently, along beaches and at estuaries, the construction of seawalls, the use of tetrapods, sand mining, and uncontrolled recreational activities pose serious threats to gull roost sites. Though the presence of tourists does not itself affect gull numbers negatively, throwing stones and chasing roosting flocks to take photographs disturb the birds forcing them sometimes to leave the site temporarily. This aspect of gull movement, however, requires further study. Curbing sand mining and implementing the sustainable use of coastal areas for recreational activities is warranted along the Indian coast. Gull roosts have not prevented any developmental projects along the Indian coasts hitherto; however, the airport constructed near Malvan in Maharashtra State may face aviation hazards as very large congregations of gulls, sometimes more than 10,000 individuals, occur nearby. This study recommends that the Karli, Mochemad, and Mithbav sites be brought under the protected area category of community reserves as these sites hold significant regional populations of Brown-headed, Pallas's, and Slender-billed gulls.

# Chapter 6

# Factors influencing Habitat use of Shorebirds

## 6.1. INTRODUCTION

During migration, shorebirds mostly depend on estuarine intertidal mudflats for energy resources (Morrison, 1984; Myers et al. 1987). Prey availability and accessibility largely determine the shorebird distribution and abundance on the intertidal mudflats (Goss-Custard et al. 1977; Evans & Dugan, 1984; Ribeiro et al. 2004). In several studies, a positive relationship between shorebirds with their preferred prey items has been noticed (Placyk & Harrington, 2004). In addition to prey, factors such as vegetation cover (Pomeroy, 2008), predatory pressure (Lima & Dill, 1990; Barbosa, 1997) and sediment structure (Grant, 1984; Kelsey & Hassall, 1989; Finn et al. 2007) also influence shorebird's habitat use. Predatory pressure is one of the less studied habitat features, which is also expected to influence shorebird habitat choice at wintering and stopover sites (Lank et al. 2003; Lima, 1998). Therefore, shorebird habitat assessment should include multiple factors like inter and intra-specific competition, disturbances from natural and anthropogenic sources.

Prey distribution varies on intertidal mudflat in space and time and largely governed by physico-chemical parameters of water (Angermeier & Winston, 1998, Liang et al. 2002) and sediment particle size (Colwell & Landrum, 1993, Quadros et al. 2009). Any change in physico-chemical parameters of water greatly affects the surface and bottom-dwelling invertebrates, eventually influencing habitat use of shorebirds (Zabbey & Hart, 2006). In a direct way, water depth is a key limiting factor that influences waterbird access to prey (Nagarajan & Thiyagesan, 1996; Collanzo et al. 2002; Sumathi et al. 2008). Temperature, salinity, soil moisture content, pH and DO indirectly influence the abundance, and distribution of macro benthic community (Kalejta & Hockey, 1991; Nagarajan & Thiyagesan, 1996; Zabbey & Hart, 2006; Quadros et al. 2009; Sandiliyan et al. 2010; Dissanayake & Chandrasekara, 2014; Aarif et al. 2021). Therefore, understanding the role of abiotic variables on benthic invertebrate communities is curial in shorebird studies.

The distribution and feeding ecology of shorebirds on coastal mudflats have been well documented in temperate countries (Goss-Custard, 1970; Evans, 1976; Duijns et al. 2009; Lunardi et al. 2012). There are very few studies that looked at the functional relationship between shorebirds and prey in India (Sampath & Krishnamurthy, 1989; Nagarajan & Thiyagesan, 1996; Aarif et al. 2021). Despite the long coastline and its importance, studies pertaining to the effects of biotic and abiotic factors on habitat use of shorebirds are scarce in India (Sampath & Krishnamurthy, 1989; Nagarajan & Thiyagesan, 1996; Aarif et al. 2021). Therefore, this chapter particularly examined the following questions 1) to understand the spatio-temporal pattern of benthic invertebrate communities and environmental parameters 2) how environmental parameters and prey variations influence habitat use of wintering shorebirds.

## 6.2. METHODS

### 6.2.1. Collection of water and sediment samples

Sediment and water samples were collected during the five phases (A detailed description is given about all these phases in chapter 4) at predefined sampling stations during low tide. Collected water samples were carried to the laboratory in an insulated icebox. Salinity (ppt) was estimated using Mohr's Argentometry method (Strickland & Parsons, 1972). Dissolved oxygen (mg/L) levels were estimated by Winkler's method. A pH meter was used to measure the water pH. Water and soil temperature ($^{o}$C) was measured by the alcohol thermometer. Total suspended solids (TSS, mg/L) were estimated using the Gravimetric method.

Sediment samples were collected from 10cm depth from each habitat viz., beach, mangrove and mudflat, covering three tidal zones viz., high tide, mid tide, and low tide water level mark (Quadros et al. 2009). Collected soil samples were sieved using 1mm and 0.5mm mesh sieves. Organisms trapped on the sieves were preserved in 10 % formalin by adding rose bengal stain (Quadros et al. 2009). Rose Bengal stain turns animal protein into red, allowing for easy identification of organisms while sorting and counting benthos in the laboratory. Sorted samples were first segregated and identified up to major taxonomic groups viz., polychaetes, crustaceans (amphipods, isopods, crabs, etc.), insects, bivalves, and gastropods. Prey densities were estimated as the number of individuals/$m^2$. Soil moisture content (%) was measured by ignition at 70 $^{o}$C for 24 hrs. Organic matter (%) was calculated using the standard method. Variables measured and their method of quantification is given in (Table 6.1).

**Table 6.1.** Parameters investigated during the study and method of analysis

| Variable | Acronym | Units | Method |
|---|---|---|---|
| Water temperature | WAT | $^{o}$C | Alcohol thermometer |
| Sediment temperature | SEDT | $^{o}$C | Alcohol thermometer |
| Salinity | SAL | ppt | Mohr's argentometric method Strickland & Parsons (1972) |
| Dissolved oxygen | DO | Mg/L | Winkler's method |
| pH | pH | - | pH meter |
| Total suspended solids | TSS | Mg/L | Gravimetric |
| Soil moisture content | MC | % | Oven drying |
| Organic matter | OM | % | Walkley-Black method (1934) |

**Plate III.** Photographs showing the collection of water and sediment samples

### 6.2.2. Shorebird counts

Bird surveys were carried out in five season's viz., arrival phase (Aug-Sep), wintering phase (Nov-Feb), early departure phase (Mar-Apr), departure phase (May), and breeding phase (Jun-Jul) from January 2015 to December 2016. Birds were counted during low tide when intertidal mudflats were exposed and these exposed areas provide foraging space for the shorebirds. To count birds the total count method (Howes & Bakewell, 1989) was followed.

### 6.2.3. Mangrove cover

Previous studies reported that presence of forest cover would influence shorebird habitat use (Lima & Dill, 1990; Zharikov & Skilleter, 2002; Pomeroy, 2008). Mangroves were the dominant vegetation types in the study area. Raptors like, Oriental Honey-buzzard (*Pernis ptilorhynchus*), White-bellied Sea Eagle (*Haliaeetus leucogaster*), Black kite (*Milvus migrans*), and Brahminy Kite (*Haliastur Indus*) were seen using the mangroves. In several occasions it was noticed that, these species were disturbing foraging shorebirds. Therefore, this study tried to understand the influence of mangrove cover on shorebird habitat use. For that the extent of mangrove vegetation and its nearest distance from the centre of the intertidal mudflat was calculated using GIS tools.

### 6.2.4. Data analysis

To test the difference in physiochemical properties, macrobenthos density, and shorebirds abundance between sampled habitats and seasons one-way ANOVA and Tukey-HSD posthoc was applied. BIO-ENV analysis was performed to calculate the best subset of environmental variables which explain the distribution of prey using the bioenv function from the 'Vegan' package. BIO-ENV is a dissimilarity-based exploratory method that selects the best subset of environmental variables from a set of variables, whose Euclidean distance matrix correlates highly with the Bray-Curtis dissimilarity matrix of species (Clarke & Ainsworth, 1993). This procedure calculates Spearman correlation coefficients. To examine the association between physicochemical parameters and benthic invertebrates abundance, Canonical correspondence analysis (CCA) was used. This analysis produces results on the ordination axis with a set of highly correlated predictors. The scores of species and environmental variables indicate together on the space provided by the axes to summarize the relationship between them (Palmer, 1993). Prior to CCA analysis, variables were tested for the autocorrelation, and highly correlated variables (i.e., Pearson's $r$ < 0.70), were excluded from the analysis (Fig. 6.1). Finally, CCA was run on square-root transformed data to minimize the variation between very high abundance and rare species. The significance of the global model and CCA axes was evaluated using the ANOVA test. A permutation test was conducted to examine the correlations between macrobenthos and physico chemical parameters.


**Figure 6.1.** Predictor variables used in CCA analysis and their correlation coefficient values

A generalized linear model (negative binomial) was applied to examine the relationship between biotic and abiotic factors with shorebird abundance and richness using the 'MASS' package. Poisson models were overdispersed thus this study used GLM negative binomial (Venables & Ripley, 1999). To address the collinearity issue among the predictor variables, Pearson correlation analysis was performed, variables with correlation value $r < 0.40$ were used in the model for robustness (Fig. 6.2). The global model was ran using glm.nb function; performed step AIC to achieve the best model. Model selection was done, model combinations with the lowest AIC and BIC values. The influence of vegetation cover on shorebirds was analyzed individually. Overall model fit was assessed using the Wald chi-square test. SPSS and R statistical software, version 1.1.383 (R Development Core Team, 2009) was used for statistical analysis.

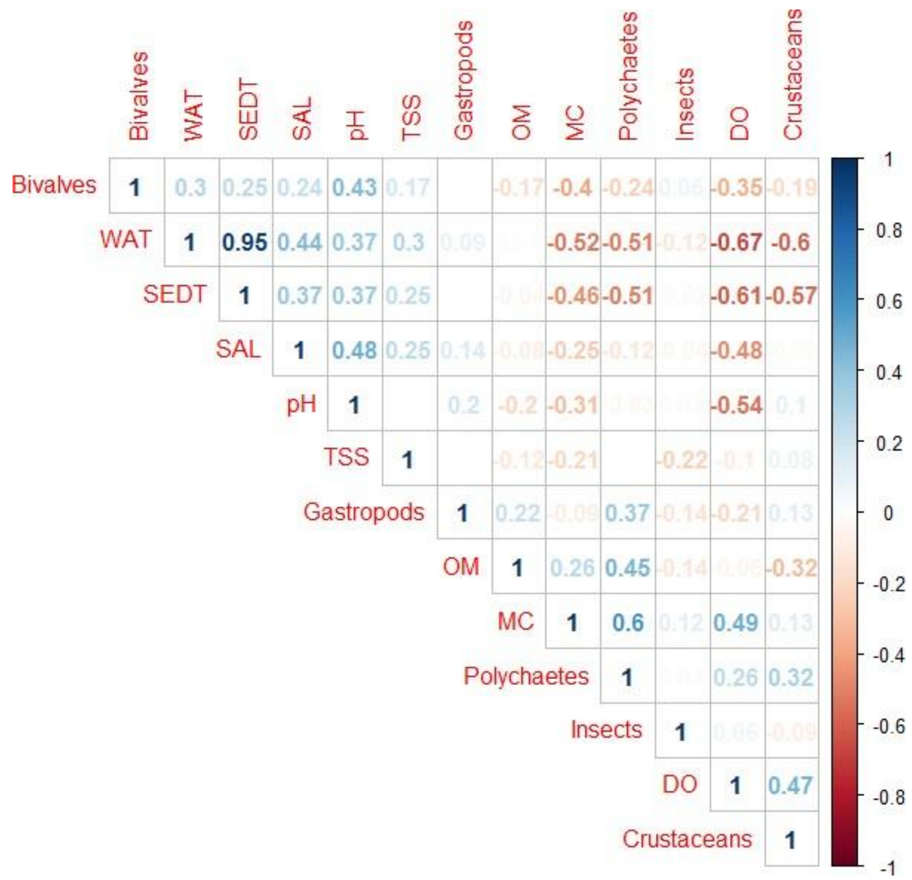



**Figure 6.2.** Predictor variables used in GLM (negative binomial) and their correlation coefficient values

## 6.3. RESULTS

### 6.3.1. Environmental parameters

Among the measured variables salinity, soil moisture content, and organic matter were significantly different between habitats (Table 6.2 and Fig. 6.3). The salinity showed a decreasing trend from sandy beach towards the mangroves. Organic matter and soil moisture content were higher in mudflats and mangroves compared with the beach (Table 6.2). Other parameters did not show much variation (Fig. 6.3). The Tukey posthoc test showed that salinity was significantly different between beach and mangrove but not between mudflat and mangrove and beach and mudflat. Soil organic matter and soil moisture content explained a significant difference between beach and mangrove but not between other habitats.

**Table 6.2.** Environmental parameters and invertebrate densities (Mean ± SD) across the study sites in the Sindhudurg district

| Physiochemical and biological variables | Beach | Mudflat | Mangrove | Overall | ANOVA |
|---|---|---|---|---|---|
| **Physiochemical parameters** | | | | | |
| Water temperature °C | 28.17±2.25 | 28.63±2.49 | 28.28±2.94 | 28.37±2.51 | $F_{2,92,}$ F=0.31, $P$<0.73 |
| Sediment temperature °C | 28.74±2.64 | 28.72±2.52 | 28.20±2.69 | 28.59±2.59 | $F_{2,92,}$ F=0.38, $P$<0.68 |
| Salinity (ppt) | 34.67±5.94 | 31.16±6.49 | 28.07±7.66 | 31.64±7.06 | $F_{2,92,}$ F=7.02, $P$<0.00 |
| DO (mg/L) | 2.00±0.97 | 1.79±0.78 | 1.83±0.91 | 1.88±0.88 | $F_{2,92,}$ F=0.43, $P$<0.65 |
| pH | 7.85±0.48 | 7.68±0.58 | 7.65±0.56 | 7.74±0.54 | $F_{2,92,}$ F=1.22, $P$<0.30 |
| TSS (mg/L) | 0.70±0.30 | 0.77±0.45 | 0.59±0.33 | 0.70±0.39 | $F_{2,92,}$ F=1.44, $P$<0.24 |
| Organic matter (%) | 0.29±0.31 | 1.12±1.50 | 2.03±2.76 | 1.06±1.80 | $F_{2,92,}$ F=8.81, $P$<0.00 |
| Moisture content (%) | 17.40±6.96 | 21.39±8.37 | 25.87±14.04 | 21.11±10.22 | $F_{2,92,}$ F=4.34, $P$<0.02 |
| **Macro benthos (no.ind/m$^2$)** | | | | | |
| Bivalves | 110.04±126.22 | 124.63±88.14 | 53.72±65.04 | 100.60±102.39 | $F_{2,92,}$ F=6.19, $P$<0.00 |
| Crustaceans | 95.77±120.00 | 162.69±198.99 | 51.50±63.27 | 108.78±150.24 | $F_{2,92,}$ F=4.52, $P$<0.02 |
| Insects | 2.85±7.77 | 1.90±5.70 | 0.44±2.22 | 1.86±5.98 | $F_{2,92,}$ F=1.05, $P$<0.36 |
| Gastropods | 12.05±28.28 | 81.50±90.41 | 238.42±218.69 | 97.21±153.47 | $F_{2,92,}$ F=37.22,$P$<0.00 |
| Polychaetes | 21.88±21.61 | 39.32±56.81 | 65.26±86.11 | 39.37±59.34 | $F_{2,92,}$ F=4.16, $P$<0.02 |
| Overall | 242.61±153.24 | 410.06±237.32 | 409.36±268.40 | 348.18±232.01 | $F_{2,92,}$ F=5.20, $P$<0.00 |

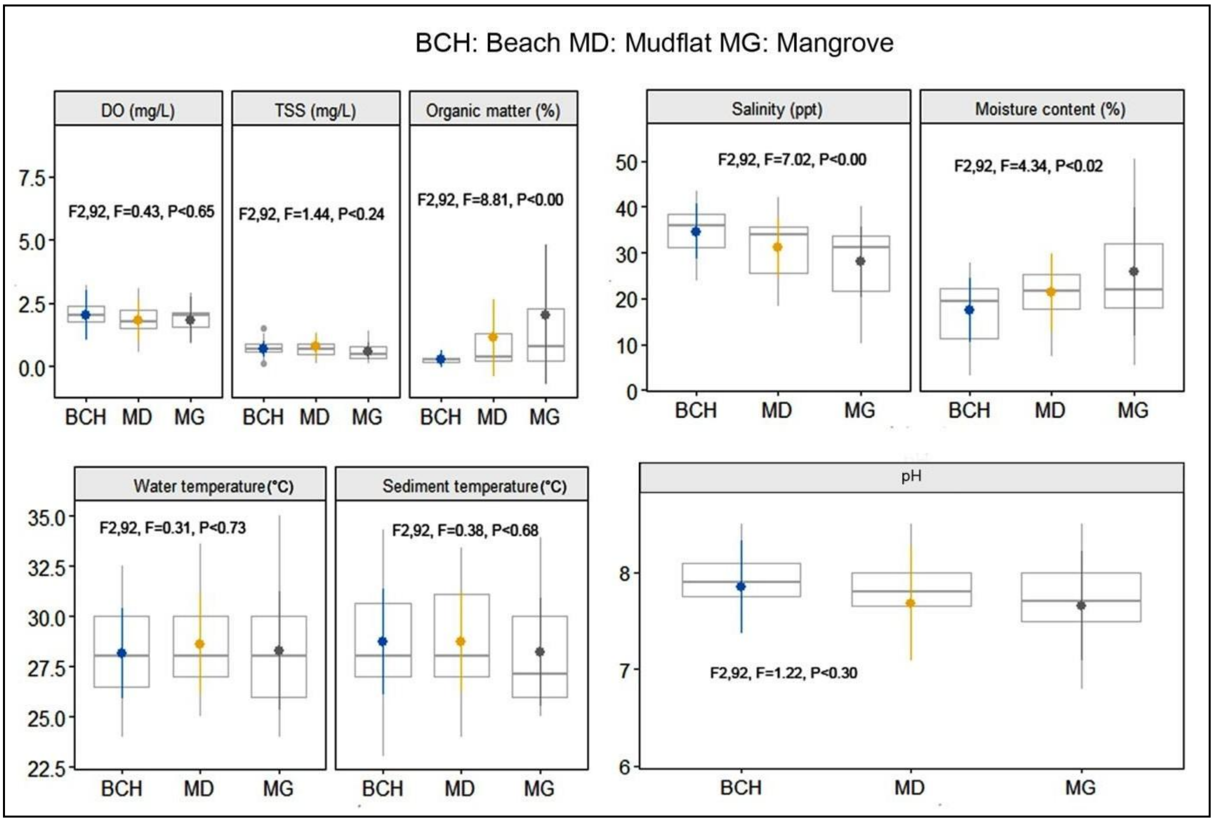



**Figure 6.3**. Variations in environmental parameters across habitats in the study area

Measured soil and water parameters were relatively stable in the winter phase (Fig. 6.4). Excluding TSS and organic matter, all other parameters differed between seasons (Table 6.3). Salinity, pH, sediment, and water temperatures fluctuated highly and were low during the breeding phase (Table 6.3). Many water parameters showed marked differences with departure (pre-monsoon) and breeding phase (monsoon).

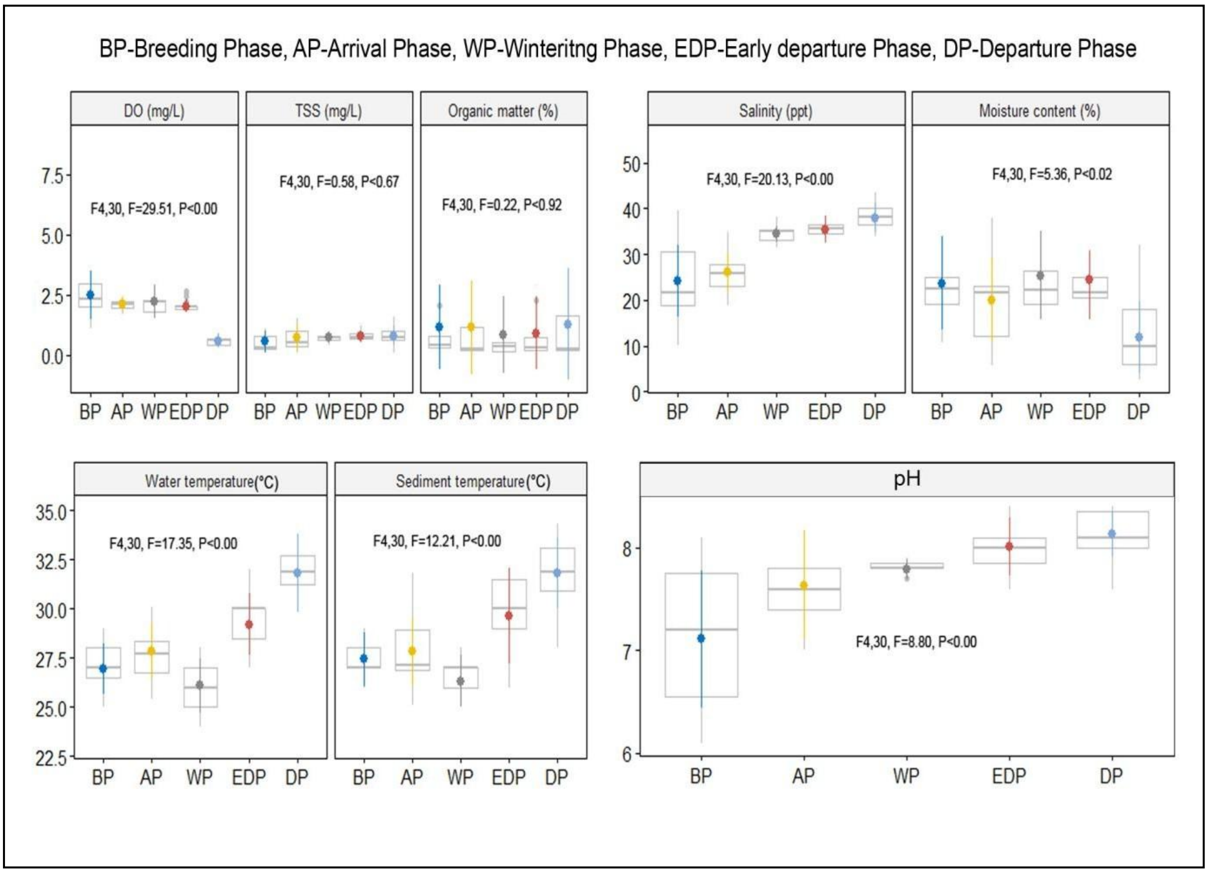



**Figure 6.4**. Variations in environmental parameters in different seasons in the study area **BP**-Breeding phase (Jun-Jul), **AP**-Arrival phase (Aug-Sep), **WP**-Winter phase (Nov-Feb), **EDP**-Early departure phase (Mar-Apr), and **DP**-Departure phase (May)

**Table 6.3.** Environmental parameters and invertebrate densities (Mean ± SD) in different phases in Sindhudurg district

| Physiochemical and biological variables | AP | WP | EDP | DP | BP | ANOVA |
|---|---|---|---|---|---|---|
| **Physiochemical parameters** | | | | | | |
| Water temperature $^{o}$C | 27.83±1.42 | 26.97±1.39 | 29.21±1.58 | 31.78 ±1.98 | 26.94±1.26 | $F_{4,30}$, F=17.35, *P*<0.00 |
| Sediment temperature $^{o}$C | 27.80 ±1.71 | 26.31±1.33 | 29.63±2.40 | 31.80 ±1.78 | 27.42±1.38 | $F_{4,30}$, F=12.21, *P*<0.00 |
| Salinity (ppt) | 26.10±4.35 | 34.45±1.83 | 35.47±2.86 | 38.00±3.18 | 24.18±7.89 | $F_{4,30}$, F=20.13, *P*<0.00 |
| DO (mg/L) | 2.13 ± 0.33 | 2.21±0.71 | 2.01±0.29 | 0.58±0.28 | 2.46±1.00 | $F_{4,30}$, F=29.51, *P*<0.00 |
| pH | 7.63 ± 0.53 | 7.79±0.09 | 8.01±0.28 | 8.13±0.22 | 7.11±0.66 | $F_{4,30}$, F=8.80, *P*<0.00 |
| TSS (mg/L) | 0.70 ±0.54 | 0.70±0.13 | 0.76±0.23 | 0.79±0.39 | 0.54±0.44 | $F_{4,30}$, F=0.58, *P*<0.67 |
| Organic matter (%) | 1.12 ±1.94 | 0.84±1.57 | 0.90±1.49 | 1.26±2.31 | 1.16±1.75 | $F_{4,30}$, F=0.22, *P*<0.92 |
| Moisture content (%) | 20.05±9.30 | 25.41±9.60 | 24.41±8.48 | 11.94±7.88 | 23.69±10.21 | $F_{4,30}$, F=5.36, *P*<0.02 |
| **Macro benthos (no.ind/m$^{2}$)** | | | | | | |
| Bivalves | 361.54±184.27 | 277.50 ±128.17 | 274.32±197.91 | 382.15±186.93 | 69.77±42.37 | $F_{4,30}$, F=6.50, *P*<0.00 |
| Crustaceans | 266.40±189.13 | 532.80±254.73 | 380.57±163.35 | 22.20±27.93 | 274.32±251.95 | $F_{4,30}$, F=9.78, *P*<0.00 |
| Gastropods | 312.38 ±191.87 | 344.10±245.37 | 225.17±216.25 | 318.72±340.18 | 118.92±125.33 | $F_{4,30}$, F=1.46, *P*<0.23 |
| Insects | 4.75±8.73 | 9.51±13.48 | 4.75±8.73 | 3.17±8.39 | 3.17±8.39 | $F_{4,30}$, F=0.47, *P*<0.75 |
| Polychaetes | 118.92±96.06 | 207.72 ±150.52 | 118.92±134.68 | 22.20±21.25 | 71.35±87.36 | $F_{4,30}$, F=2.91, *P*<0.04 |
| Overall | 1064.01±197.57 | 1371.64±514.08 | 1003.75±309.66 | 748.45±320.93 | 537.55±342.29 | $F_{4,30}$, F=5.74, *P*<0.00 |

**AP**-Arrival phase (Aug-Sep), **WP**-Winter phase (Nov-Feb), **EDP**-Early departure phase (Mar-Apr), **DP**-Departure phase (May) and **BP**-Breeding phase (Jun-Jul)

### 6.3.2. Invertebrate community

During the study, five invertebrate groups such as crustaceans, polychaetes, bivalves, gastropods, and insects were recorded under the macrobenthic community. There was large spatial and temporal variation occurred in macrobenthic densities. Spatially, the macrobenthic densities varied among sampling sites (Table 6.2). Higher prey abundance was observed in mudflats compared with other habitats (Fig. 6.5). Among the prey group, crustaceans were higher in mudflats whereas bivalves and gastropods in beach and mangrove habitats respectively (Table 6.2). The densities of crustaceans differed between mudflats and mangroves but not between other habitats. Polychaete density was low in beach habitat and showed a significant difference with mangroves.

Prey densities significantly differed between seasons and their densities were higher in the winter phase (post-monsoon, Table 6.3). The overall prey density declined in the departure and breeding phase (Table 6.3 & Fig. 6.5). The population of major prey species like crustaceans and polychaetes showed a significant difference between wintering and departure phases.

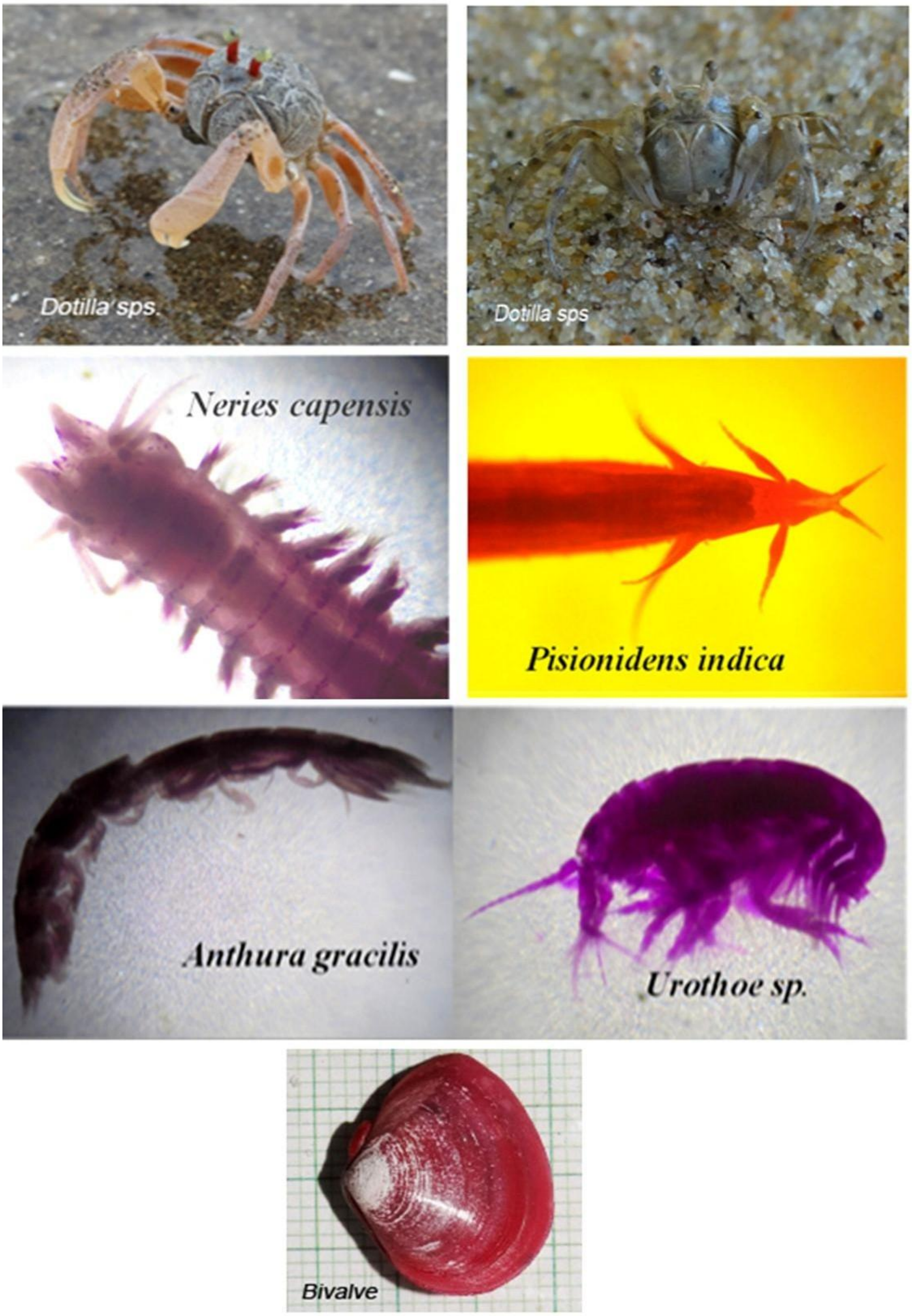



**Plate IV.** Major prey species of shorebirds in the study area

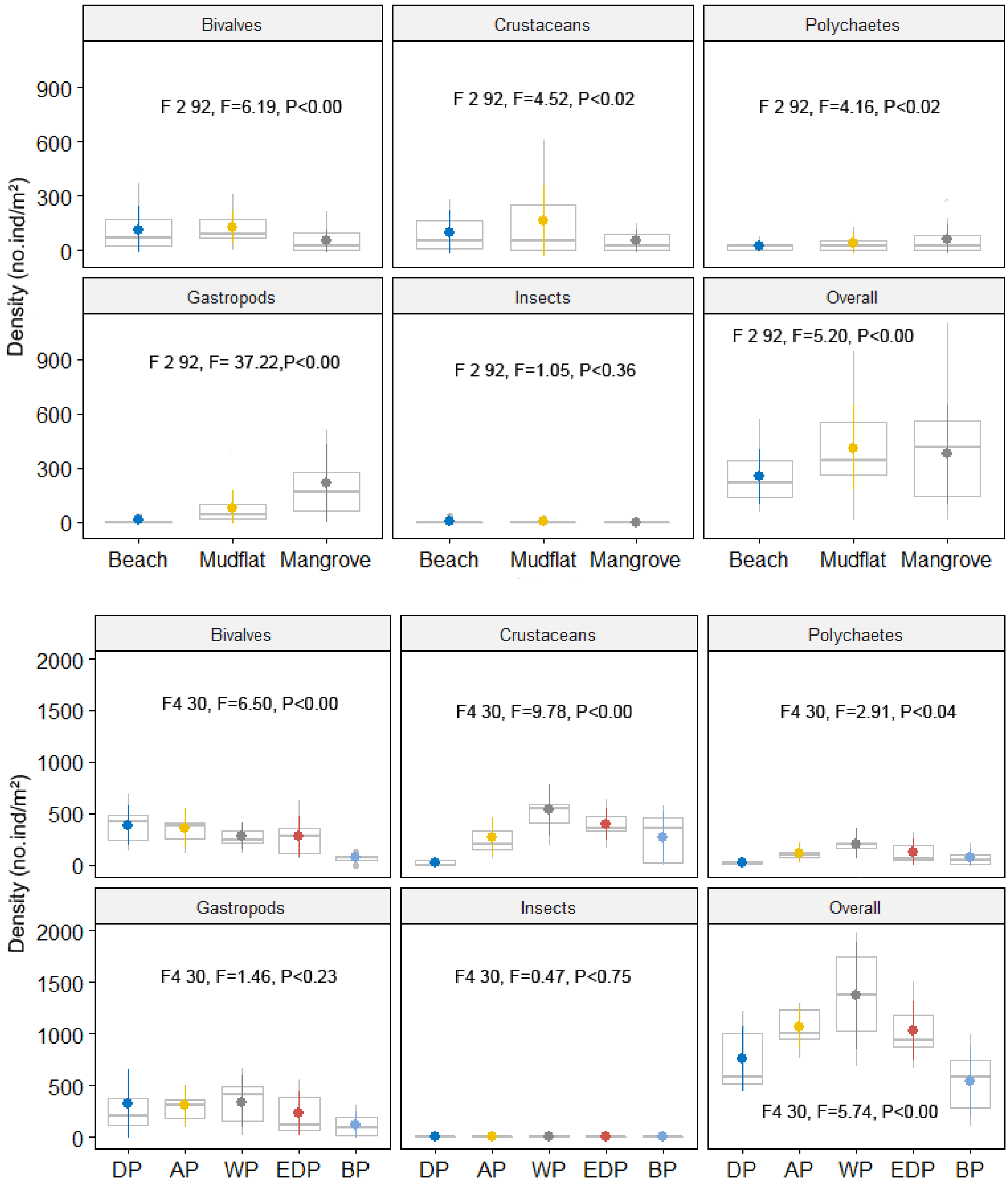



**Figure 6.5.** Invertebrate densities across the sites and seasons in Sindhudurg district **DP**-Departure phase (May), **AP**-Arrival phase (Aug-Sep), **WP**-Winter phase (Nov-Feb), **EDP**-Early departure phase (Mar-Apr), and **BP**-Breeding phase (Jun-Jul)

### 6.3.3. Shorebird distribution and abundance

The shorebird abundance differed between habitats and seasons (Fig 6.6). Lesser Sand Plover, Kentish Plover, Common Sandpiper, and Common Redshank were the most dominant species during the study. Shorebird abundance was higher in mudflats and in the winter phase. The shorebird numbers were gradually decreased from wintering phase to the breeding phase (Fig 6.6).

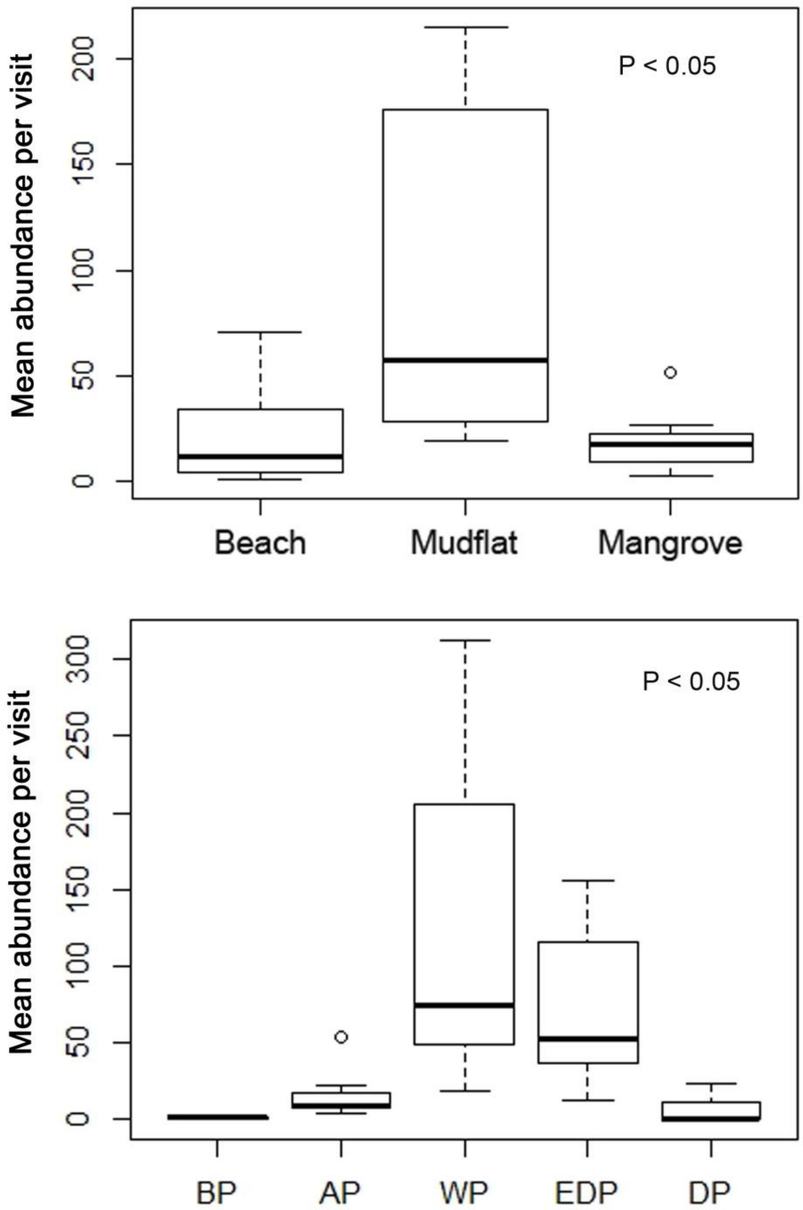



**Figure 6.6.** Mean shorebird abundance across habitats and seasons during the study in Sindhudurg district

### 6.3.4. Effect of environmental parameters on macrobenthos

BIO-ENV results indicated that single environmental parameter salinity had the highest correlation (ρ=0.51) that explained the distribution of the macrobenthic community. Salinity and soil moisture content were the next best set of environmental variables influencing prey (Table 6.4).

**Table 6.4.** The BIO-ENV analysis of macrobenthos compared with environmental parameters

| No of variables | Parameters | Spearman correlation |
|---|---|---|
| 1 | **SAL** | **0.51** |
| 2 | **SAL, MC** | **0.50** |
| 3 | SAL, DO, MC | 0.49 |
| 4 | SAL, DO, TSS, MC | 0.43 |
| 5 | SAL, DO, TSS, OM, MC | 0.40 |
| 6 | SAL, DO, pH, TSS, OM, MC | 0.36 |
| 7 | SEDT, SAL, DO, pH, TSS, OM ,MC | 0.31 |
| 8 | WAT, SEDT, SAL, DO, pH, TSS, OM, MC | 0.25 |

**SAL-**Salinity, **MC-**Moisture content, **DO-**Dissolved oxygen, **TSS-**Total suspended solids
**OM-**Organic matter, **WAT-**Water temperature, **SEDT-**Sediment temperature

The association of individual prey groups with environmental variables was examined using CCA. Five environmental variables were used in CCA; the first two canonical axes explained 97% variance of macrobenthos and environmental relationship (67 and 30 of axis 1 and axis 2 respectively). Organic matter and soil moisture content were positively correlated with axis 1 and axis 2. Salinity positively correlated with axis 2 (Table 6.5). Polychaetes were positively associated with soil moisture content and gastropods with organic matter, whereas crustaceans showed a negative relationship with water temperature. Bivalves mainly occurred in sites with modest concentrations of salinity (Fig. 6.7).

**Table 6.5.** Results of canonical correspondence analysis with axis scores

| Environmental variables | Axis | | | |
|---|---|---|---|---|
| | **CCA1** | **CCA2** | **CCA3** | **CCA4** |
| Water temperature | 0.21 | 0.78* | -0.10 | -0.52 |
| Salinity | -0.29 | 0.53 | -0.70* | 0.26 |
| Soil moisture content | 0.26 | -0.90* | -0.30 | 0.01 |
| TSS | -0.13 | 0.53 | -0.58 | 0.15 |
| Organic matter | 0.98** | -0.12 | 0.10 | -0.09 |
| Eigen values | 0.09 | 0.04 | 0.002 | 0.001 |
| Proportion of variance explained | 0.67 | 0.30 | 0.03 | 0.001 |
| Cumulative proportion | 0.67 | 0.97 | 0.99 | 1.00 |

*Denotes significance at ***p<0.001, **p<0.01, p<0.05

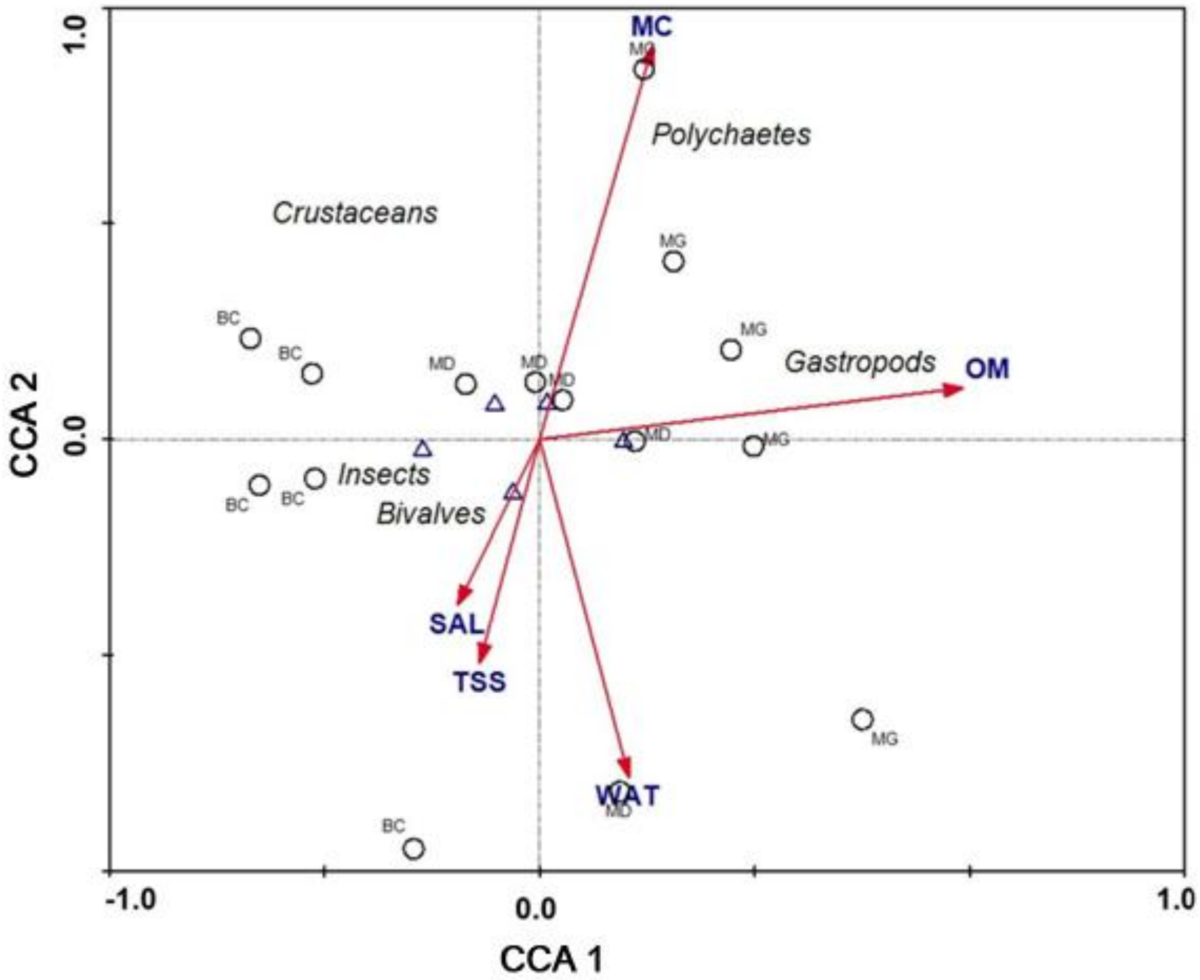



**Figure 6.7.** CCA ordination diagram indicates the relationship between benthic invertebrates and environmental parameters in the Sindhudurg district (**MC-**Moisture content, **OM**-Organic matter, **SAL-**Salinity, **TSS-**Total suspended solids, **WAT-**Water temperature)

### 6.3.5. Shorebird's response to macrobenthic community and environmental variables

A positive relationship was observed between shorebird abundance and its prey (Fig. 6.8). Crustacean density and salinity were the only predictors that influenced shorebird abundance, this top model had the lowest AIC value 168.06 (Table 6.6 and Fig 6.9). Whereas shorebird richness influenced by the crustaceans, polychaetes, bivalves, and salinity (Table 6.7 & Fig. 6.10). The abundance of shorebirds increased as the distance from vegetation cover increased (Fig. 6.11).

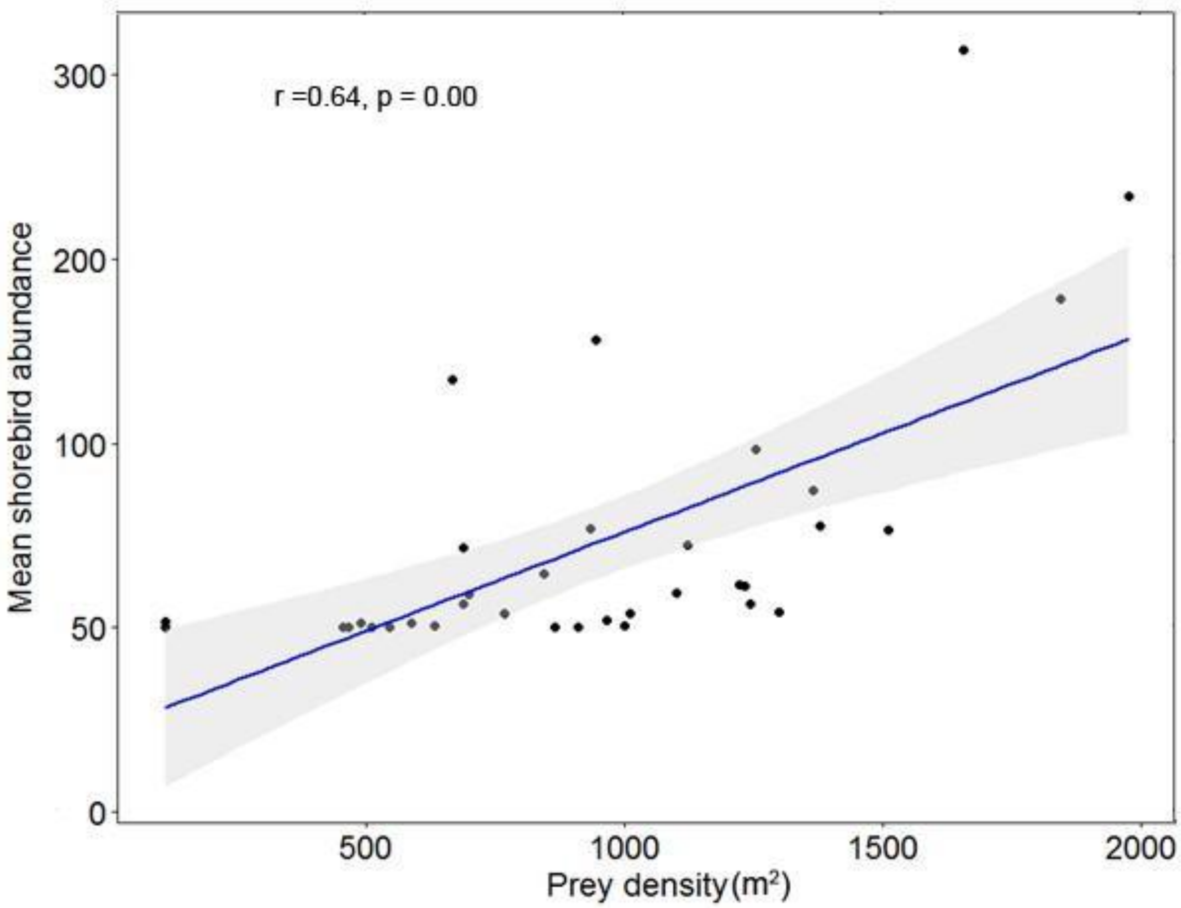



**Figure 6.8.** Relationship between abundance of shorebirds and invertebrate prey

**Table 6.6.** Results of all-subsets from GLM negative binomial regression comparing shorebird abundance and richness with prey and environmental variables in the Sindhudurg district

| Dependent variable | Model | AIC | BIC | $r^2$ |
|---|---|---|---|---|
| Shorebird abundance | CS+SAL+BV | 168.06 | 175.83 | 0.55 |
| | CS+PC+SAL+BV | 168.86 | 178.19 | 0.57 |
| | CS+PC+SAL+BV+INS | 170.15 | 181.04 | 0.58 |
| | CS+PC+SAL +BV+TSS+ INS | 171.98 | 184.43 | 0.58 |
| Shorebird richness | CS+PC+SAL+BV | 156.69 | 166.02 | 0.56 |
| | CS+PC+SAL+BV+TSS | 157.49 | 168.38 | 0.57 |
| | CS+PC+SAL+BV+pH+TSS | 159.46 | 171.90 | 0.57 |

**CS-**Crustaceans, **SAL**-Salinity, **BV-**Bivalves, **PC**-Polychaetes, **TSS-**Total suspended solids, **INS-**Insects, $\mathbf{r^2}$-Adjusted (Adj $r^2$ ), **AIC**- Akaike Information Criterion, **BIC**- Bayesian Information Criterion

**Table 6.7.** GLM negative binomial results of shorebirds abundance and richness in relation to biotic and abiotic variables

| Response variable | Coefficients (β) | Std. Error | P | AIC | BIC |
|---|---|---|---|---|---|
| **Shorebirds abundance** | | | | | |
| (Intercept) | -4.46 | 1.36 | 0.01* | 168.06 | 175.83 |
| Crustaceans | 0.09 | 0.01 | 0.00*** | | |
| Salinity | 0.68 | 0.22 | 0.00** | | |
| Bivalves | 0.04 | 0.01 | 0.02* | | |
| | $\mathbf{X^2}$=32.6, P =0.00 | | | | |
| **Shorebird richness** | | | | | |
| (Intercept) | -4.33 | 1.24 | 0.00*** | 156.69 | 166.02 |
| Crustaceans | 0.06 | 0.01 | 0.00*** | | |
| Polychaetes | 0.03 | 0.02 | 0.09 | | |
| Salinity | 0.67 | 0.20 | 0.00** | | |
| Bivalves | 0.03 | 0.02 | 0.04* | | |
| | $\mathbf{X^2}$=56.5, P =0.00 | | | | |

*Denotes significance at ***p<0.001, **p<0.01, p<0.05

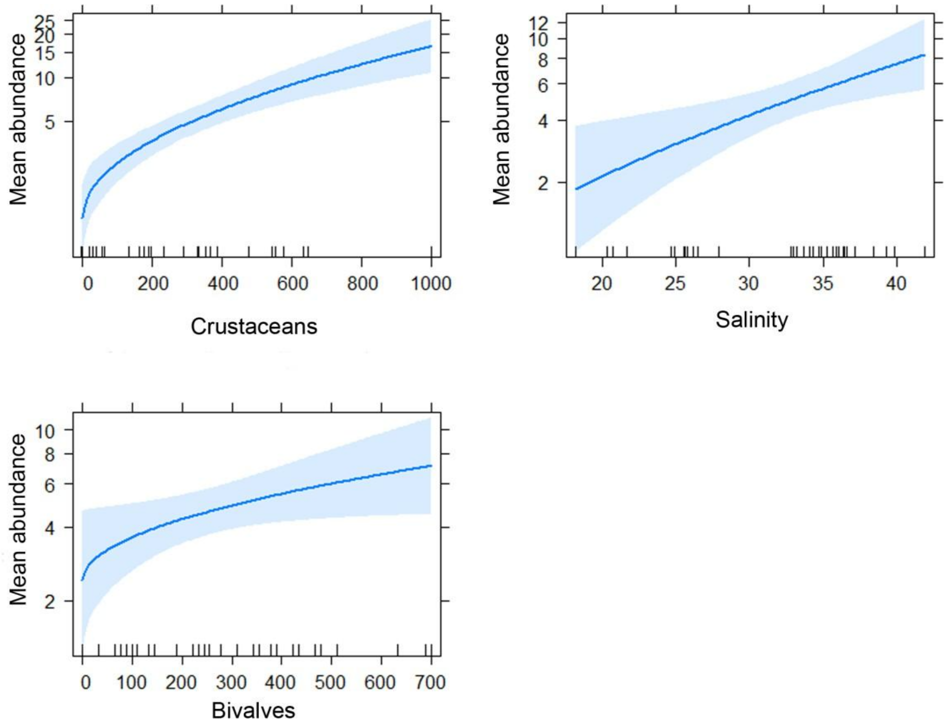



**Figure 6.9.** Response of shorebirds in relation to biotic and abiotic variables in Sindhudurg district

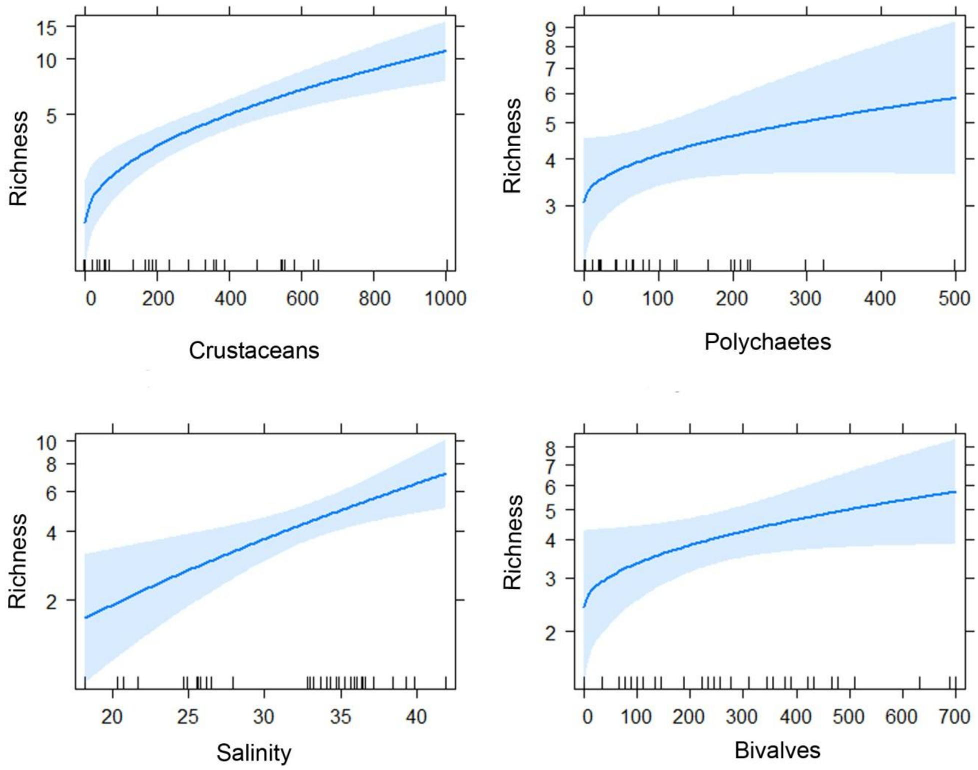



**Figure 6.10.** Response of shorebirds richness in response to the biotic and abiotic variables in Sindhudurg district

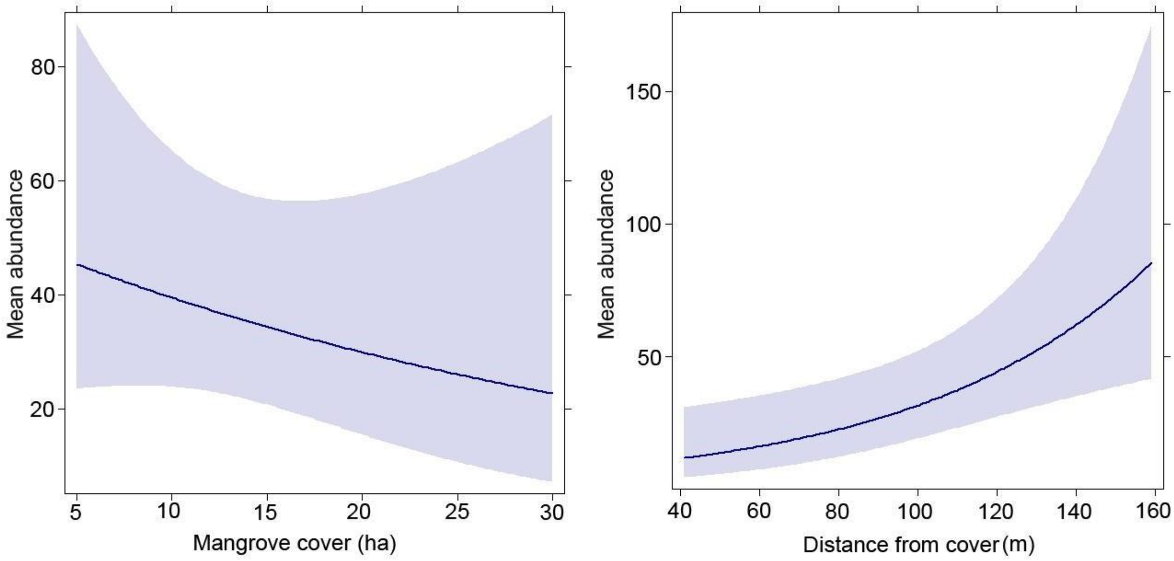



**Figure 6.11.** Influence of vegetation cover on shorebird habitat use in Sindhudurg district

## 6.4. DISCUSSION

Results from the present study indicate that shorebird habitat use was mainly determined by prey density, physical parameters of water and vegetation cover. Prey distribution varied between space and time and was largely governed by environmental parameters. With this, it's clear that non-breeding shorebirds use foraging habitats with the highest invertebrate density among the range of habitats.

### 6.4.1. Influence of environmental parameter on the distribution and abundance of macrobenthic community

Salinity concentrations varied across habitats, showed a decreasing trend towards the mangroves. This difference mainly occurred owing to the dilution of seawater by mixing with fresh water. Due to this complex nature, estuaries have different salinity gradients from upstream to down streams and provide different environmental conditions for organisms, therefore, the distribution and abundance of benthic invertebrates differ (Carriker, 1967; Parulekar & Dwivedi, 1974; Wolff, 1983; Velasquez, 1992; Liang et al. 2002; Sandilyan et al. 2010). High soil moisture content in mudflats and mangroves is a characterization of sandy-silt/clay and silt-clay substrates in these habitats. Beaches were dominated by sand due to the higher drainage capacity of sandy soils, so this habitat had lower water holding capacity. Pore space and organic matter also control water holding capacity (Mosier, 1905). Higher organic matter in the mudflats and mangroves was also one of the possible reasons for their higher water retention capacity. Soil wetness is an important variable that directly influences prey activity (Rosa et al. 2007). The increased soil moisture content in the mudflats and mangroves may be the reason for higher prey abundance in these habitats.

Water and sediment temperatures were high during the departure phase; this was generally influenced by solar radiation and evaporation. Higher salinity values in the departure phase (pre-monsoon) owning to increased atmospheric temperature and decreased freshwater runoff and the shallow nature of the estuaries. Flooding of rainwater into the estuaries from the southwest monsoon was the possible reason for decreased salinity concentrations in the breeding phase (monsoon). Similar observations were made in other coastal sites in India and recorded the highest salinity values in post-monsoon and lowest in monsoon season (Nair et al. 1993; Saravanakumar et al. 2007).

The spatial variation in the benthic invertebrate community is commonly observed in many estuaries due to the physico-chemical properties of water and soil (Parulekar & Dwivedi 1974; Ansari et al. 1986; Kalejta & Hockey, 1991; Murgan & Ayyakkannu, 1991; Kumar, 1995; Wang et al. 2021). Among the several water parameters, salinity acts as a key environmental factor, influencing the distribution and abundance of benthic invertebrates (Carriker, 1967; Parulekar & Dwivedi, 1974; Liang et al. 2002). This was evident in the current study where prey distribution was largely governed by differences in salinity gradient between habitats and seasons. The higher prey abundance in mudflats may be due to slight variations in salinity. Mudflats are intermediate zones in terms of salinity gradient and experience moderate salinity fluctuations therefore accounted higher prey abundance. Similarly, in Nueces estuary Texas, observed high prey abundances in mid to high salinity regions (Mannio & Montango 1997). The macrofaunal study of Mandovi River in Goa by Parulekar and Dwivedi (1974) observed the highest prey densities towards the sea and the lowest in the upstream regions. Correspondingly the benthic community composition studied by Ansari et al. (1986) on the west coast of India, noticed a decreasing prey species from increasing distance from the mouth region. With this, it's clear that during the study prey distribution was strongly influenced by salinity. Salinity is one among the several factors which through their interplay influence the distribution of benthic invertebrates. Therefore, it is important to understand the effect of other environmental factors e.g., soil types and soil moisture content may also influence prey distribution and abundance (Kalejta & Hockey, 1991; Dissanayake & Chandrasekara, 2014). The degree of tolerance levels by species is also a fundamental factor for variation in prey abundance. The lower prey abundance in beach region was possibly due to continuous wave action. These results are corroborated with McLachlan (1996) he found that decreasing prey species richness due to continuous wave action in the beach areas of the Namibia coast

The positive association of polychaetes with soil moisture content indicates that their surface activity would be more in wet soils. Thus polychaete abundances were more in mudflats and mangroves due to their higher water retention capacity. Leaf litter in the mangroves increases organic matter which is considered the main source of food for gastropods. Thus gastropods showed a positive association with organic matter. Salinity is a key variable that influences shell development in bivalves (Nagarajan et al. 2006) this could be the possible reason for bivalves having a positive relationship with salinity in this study. The negative association of crustaceans with water temperature may be due to stressed environmental conditions. The increased temperature fluctuations create stressed environmental conditions in the aquatic ecosystems that influence prey behavior. Furthermore, physiological conditions in crustaceans are adversely affected by temperature variations (Le Moullac & Haffner, 2000).

The differences in prey densities between seasons were mainly attributed to seasonal changes in the hydrological parameters. The maximum prey densities in the winter phase owing to stable environmental conditions and nutrient enrichment. Similarly, a number of studies from the west coast of India reported the highest invertebrate densities during the post-monsoon season (Ansari et al. 1986; Kumar, 1995). The monsoon rains bring a considerable amount of nutrients to the water bodies. As the season progresses nutrient levels decrease (Chandran & Ramamoorthi, 1984) and are concentrated into small areas (Gopal & Chauhan, 2001). Thus these nutrient-enriched water bodies support a numerical abundance of benthic invertebrates. The decreased invertebrate abundance in the breeding phase may be due to increased freshwater runoff, sediment instability, and decreasing salinity in the area. Alongi (1990) stated that during the monsoon most of the benthic invertebrates suffer and die as a result of increased sedimentation. Similarly, Murgan and Ayyakkannu (1991) reported that a significant decline of macrobenthic density during the monsoon season was caused by the flushing of soft-bottom sediments and lowered salinity conditions in the southeast coast of India.

### 6.4.2. Shorebird's relationship with benthic invertebrates and other environmental parameters

Shorebird's habitat use was not random at the Sindhudurg coast; shorebirds abundance and richness were positively correlated with the invertebrate abundance during the winter phase. These results are corroborated with several other studies in India (Sampath & Krishnamurthy, 1989; Nagarajan & Thiyagesan, 1996; Aarif et al. 2021). The decreasing shorebird abundance in the breeding and departure phases corresponds with unfavorable environmental conditions and prey depletion. The increased salinity and reduced freshwater inflow during the departure phase and heavy runoff in the breeding phase are mostly reflected the prey availability. Similarly, at Robert bank in Canada, noticed lower shorebird abundance owing to reduced prey availability, which was influenced by heavy runoff from the Fraser River (Canham et al. 2021).

Shorebirds feed on a wide range of food items but their preferred prey items are polychaetes and crustaceans (Bryant, 1979; Colwell & Landrum, 1993; Finn et al. 2007). In the study, the most preferred prey species of shorebirds were crustaceans (including amphipods, isopods, and crabs) followed by polychaetes and bivalves. A study from the southwest coast of India also reported that polychaetes and crustaceans were the major food species in the shorebird diet (Aarif, 2014). However, a study from the east coast of India noticed that the Chironomidae larve was the most preferred prey item for shorebirds at saltpans (Sampath & Krishnamurthy, 1989). These results indicate that prey choices vary in species with different habitats. Therefore assessing prey availability in a range of habitats and understanding diet selection by migratory shorebirds is an important aspect of shorebird study.

Positive association of salinity with shorebird abundance was an indirect relationship through influencing their prey distribution. Similarly, Aarif et al. (2021) observed a positive relationship between salinity and shorebirds and increased salinity showed a negative impact on the macrobenthic community. In the same way, the highest Greater Flamingo (*Phoenicopterus ruber*) densities were observed in ponds with low salinity concentrations at Great Vedaranyam Swamp, assuming that prey distribution was influenced by salinity to use such ponds (Sumathi et al. 2008). The abundance of shorebirds decreased with increasing vegetation cover and increased distance from the cover positively influenced their habitat use. These observations show that shorebirds avoid danger by using areas with higher visibility and minimum vegetation cover in the immediate surroundings of their foraging grounds.

Chapter 7

# Habitat Selection of Shorebirds

## 7.1. INTRODUCTION

Shorebirds use a range of habitats during breeding and wintering season (Lunardi et al. 2012). But, understanding how animals select their habitat is the primary concern for species and habitat conservation (Jonzén, 2008). On the wintering grounds, their main concern is to refuel the energy reserves for long-distance migration (Piersma, 1997; Kvist & Lindstrom, 2003). In recent years, global shorebird populations have steadily decreased due to hunting and loss of suitable habitats in their wintering grounds (Stroud et al. 2004; Delaney et al. 2009). The non-breeding season is the most crucial period for shorebirds where the mortality rate might be higher (Evans & Pienkowski, 1984; Sandercock, 2003). Therefore, the selection of suitable wintering sites is crucial for species population survival and reproductive success (Evans & Pienkowski, 1984).

The choice of intertidal feeding sites by migratory shorebirds is largely influenced by prey density (Bryant, 1979; Zwarts & Blomert, 1992; Piersma et al. 1993b) sediment characteristics (Grant, 1984; Kelsey & Hassall, 1989; Yates et al. 1993; Nagarajan & Thiyagesan, 1996; Finn et al. 2008), prey accessibility (Backwell et al. 1998) anthropogenic disturbances (Pfister et al. 1992, Kirby et al. 1993; Yasue, 2006), predatory pressure (Pomeroy, 2006), tidal immersion (Burger et al. 1977), morphology (Baker, 1979), and water edge (Granadeiro et al. 2004). However, this information is available only from a small portion of the Indian coast (Nagarajan & Thiyagesan, 1996; Aarif et al. 2021). Thus, understanding the habitat requirements of migratory shorebirds will help to identify suitable management actions.

It is reported that shorebirds use different substrate types (sand, mud, algae, oyster beds, cobble, etc.) for foraging (Colwell & Landrum, 1993; Finn et al. 2007). However, they use few substrates more often as compared to others (Kelsey & Hassall 1989; Yates et al. 1993; van Dusen et al. 2012). Such preferences are not studied in many shorebird species. The factors influencing habitat selection by shorebirds vary on a spatial scale. Factors that influence shorebird distribution on a large spatial scale might be different from those determines on a small spatial scale (Morris, 1987; Kotliar & Wiens, 1990; Schlacher et al. 2014). Further, resource availability and accessibility may change over space and time. Therefore shorebirds need to select suitable habitats to track the changing resources (Railsback & Harvey, 2002) and also select the sites in such a way to acquire maximum energy resources by spending less time. Unfortunately, such information is not available in India. Hence this chapter assessed fine-scale habitat selection of different shorebird species with a wide range of environmental parameters which is expected to influence the spatial pattern of fine scale habitat selection by shorebirds.

## 7.2. METHODS

### 7.2.1. Reconnaissance survey and sampling design

To assess fine-scale habitat selection of select shorebird species, sampling was carried out in their peak wintering period between November 2018 and February 2019. The intertidal habitats in the study area are dominated by sandy mudflats and lower intertidal zones characterized by gravel and oyster beds. Therefore, grid plots were laid in such a way to cover an extensive range of intertidal areas and their physical characteristics (substrate types, particle size composition). For this study estuarine intertidal mudflats of Mitbav and Mochemad estuary were selected, based on bird abundance, area availability, and accessibility. In selected areas, a total of 65 grid plots (25 X 25 m = 625 SQM, 625 X 65= 4.0625 ha) were laid manually using the compass, nylon rope, and hand-held GPS during peak low tide (Fig. 7.1). These grid plots were the basic unit for sampling birds and other grid parameters. Each grid corner was marked with wooden stakes (Fig. 7.2). These wooden stakes were deployed in the sediment one month before the beginning of the study to settle and acclimatize the birds to these sticks. Meantime, regular field visits were made in these areas to see whether birds were using these grid plots or not. Shorebirds used these plots regularly; the presence of stakes did not alter the foraging behavior of shorebirds.


**Figure 7.1.** The map showing grid plots on the intertidal mudflats of the study area in the Sindhudurg district


**Figure 7.2.** Imaging showing experimental plots with wooden stakes in the study area

### 7.2.2. Bird Count

Shorebirds were observed from an elevated bund (about 5 meters) using NIKON PROSTAFF 7s 8X42 binocular. Counting was done in the day during low tide (low tide height 1-0.3 m) when all grid plots become available for foraging. Counts began in low tide and ended when plots were filled with the rising tide. Birds were counted at every 30 minutes interval using the total count method (Nagarajan & Thiyagesan, 1996). At every 30 minutes of observations, number of birds of each species was noted. In addition to that, the presence of humans, the number of raptors, and other terrestrial predators (dogs) were also recorded. Whenever the bird was sighted, variables such as foraging microhabitat, foraging activity, distance from the nearest water source (pool, running tide) were recorded.

Immediately after bird count, the foraging behavior of shorebirds was also observed in the grids. Each species was observed for three minutes and following information such as substrate used (sand or oyster bed), foraging behavior (pecking and probing) was recorded. For analysis, observations of species that remained in the same substrate or grid plot for three minutes were used.

### 7.2.3. Sediment Sampling

In each grid, sediment samples of 10 $cm^2$ (area covered 10X10=100 $cm^2$) were collected with the help of a handheld grab. Care was taken while collecting the sediment samples to avoid disturbance to the prey by walking along with the grid corners. The collected soil samples were sieved using 0.5 mm mesh sieves and organisms trapped in the sieves were stored in 10% formalin for further identification. In the laboratory, sieved samples were sorted and macrobenthos was identified and counted up to major taxonomic groups (Amphipods, Bivalves, Gastropods, Crustaceans, Polychaetes, etc.). Benthic density was expressed as the number of individuals per $m^2$ (Ind. $m^2$). To analyze soil grain size composition three sediment core samples (5 cm diameter) were collected from each grid plot. The sediment grain size was analyzed using dry sieving with nested series of sieves, grain size decreasing from 2000-63 µm. The sediment grain size was categorized on the basis of Udden-Wentworth scale (Udden, 1914, Wentworth, 1922) sediment category: gravel (>2000 μm), very coarse sand (<2000 μm), coarse sand (<1000 μm), medium sand (<500 μm), fine sand (<250 μm), very fine sand (<125 μm), and silt/clay (<63 μm). Apart from this, the percentage of area occupied by oyster beds in each grid plot was visually estimated during sampling. The details of collected variables in grids are provided in (Table 7.1).

**Table 7.1.** Biological and physical characteristics of grid plots in the study area

| Variable | Min. | Max. | Mean ± SD | Dominant species |
|---|---|---|---|---|
| Prey density ($m^2$) | 278 | 3330 | 947.59 ± 482.56 | - |
| Crab density ($m^2$) | 33 | 921 | 317.63 ± 203.06 | *Dotilla* sp. |
| Polychaete density ($m^2$) | 11 | 921 | 245.23 ± 200.58 | *Orbinia* sp, *Orbiniidae* sp, *Sphionidae* sp, *Nereis* sp and *capitella* sp |
| Bivalve density ($m^2$) | 11 | 488 | 143.78 ± 122.29 | *Donax* sp, *Meretrix* sp and *Tellina* sp. |
| Gastropod density ($m^2$) | 11 | 389 | 114.07 ± 78.40 | *Cerithidea cingulata*, and *Umbonium* sp. |
| Isopod density ($m^2$) | 11 | 544 | 66.77 ± 118.91 | *Anthura gracilis* |
| Amphipod density ($m^2$) | 11 | 666 | 61.82 ± 116.95 | *Ampithoe* sp. |
| Oyster bed (%) | 2 | 85 | 35.45 ± 31.37 | - |
| Gravel sand (%) | 0.01 | 3.52 | 0.23 ± 0.56 | - |
| Coarse sand (%) | 0.07 | 9.90 | 2.80 ± 3.05 | - |
| Medium sand (%) | 0.05 | 5.85 | 1.33 ± 1. 12 | - |
| Very fine sand (%) | 32.41 | 95.22 | 60.35 ± 15.38 | - |
| Silt/Clay (%) | 0.3 | 16.19 | 2.85 ± 2.08 | - |

### 7.2.4. Statistical analysis

Though the study recorded the number of shorebirds in each grid plot, here I modelled only factors influcing the presence and absence of select shorebird species. This procedure is followed because count data often produces aggregative distributions therefore it is difficult to model precisely (Granadeiro et al. 2004). Out of nine species observed, only seven species were used in the model (i.e., percentage of occurrence >20) and the remaining species were excluded from the analysis (Table

7.2). Each species was modeled separately. Multicollinearity is a major issue in regression models therefore predictor variables were screened first for autocorrelation. Predictor variables that had low collinearity (VIF <10) with other variables were used in the model. GLM was used to predict fine-scale habitat selection by select shorebirds. The response variable was coded as 0 (plot unoccupied) and 1 (occupied). Thus, the GLM fitted with binomial family using logit link function. The model selection and model averaging were performed using dredge and model.avg functions in the MuMIn package in R (Barton, 2020). The most parsimonious model had a model weight <0.90, so model averaging was performed using model ΔAICc <2 to estimate regression coefficients (Burnham & Anderson, 2002). Akaike's Information Criterion with a small sample bias correction (AICc) was used to select the most parsimonious model (Burnham & Anderson, 2002). Finally, Hosmer and Lemeshow goodness of test was applied to check the model fit (Hosmer & Lemeshow, 2000).

**Table 7.2.** Body size, bill length, density, occurance percentage and foraging techniques used by shorebirds in the study area

| **Species** | **Abbreviation** | **Body size (cm)/ bill length (mm)** | **Density (Mean±SD, individuals/ha)** | **Occupancy (%)** | **Foraging technique** |
|---|---|---|---|---|---|
| Kentish Plover (*Charadrius alexandrinus*) | KP | (17, 14-15) | 9.58 ± 6.99 | 84.62 | Visual |
| Lesser Sand Plover (*Charadrius mongolus*) | LSP | (19, 16-19) | 8.02 ± 10.29 | 67.69 | Visual |
| Common Sandpiper (*Actitis hypoleucos*) | CS | (21, 23-26) | 2.47 ± 3.65 | 67.69 | Visual |
| Common Redshank (*Tringa totanus*) | CRS | (28, 45-54) | 1.02 ± 1.72 | 50.77 | Mixed |
| Eurasian Curlew (*Numenius arquata)** | EC | (58, 136-182) | 0.29 ± 0.48 | 46.15 | Tactile |
| Grey Plover (*Pluvialis squatarola*) | GP | (31, 27-32) | 0.19 ± 0.40 | 27.69 | Visual |
| Common Greenshank (*Tringa nebularia*) | CGS | (36, 50-59) | 0.17 ± 0.27 | 36.92 | Mixed |
| Greater Sand Plover (*Charadrius leschenaultii*) | GSP | (22, 24-27) | 0.05 ± 0.16 | 10.76 | Visual |
| Terek Sandpiper (*Xenus cinereus*) | TRK | (24, 43-52) | 0.01 ± 0.08 | 4.61 | Visual |

* Near-threatened, Morphometric information collected from Ali and Ripley (1980).

Various studies have shown that foraging site selection by migratory shorebirds is influenced by substrate types (Kelsey & Hassall, 1989; Colwell & Landrum, 1992). Hard materials in the sediment restrict shorebird foraging activity (Finn et al. 2007). Hence, to test this pattern, sampled grids were divided into two major substrate types' viz., sand and oyster beds. Oyster beds have hard surface areas, which spread across the study sites (Fig. 7.3). Thus the mean shorebird density and invertebrate abundance in these two substrate types were compared with independent sample t-test. The mean time spent in different foraging activities by shorebirds in various grid plots was regressed against the overall prey density of those plots using regression techniques. R and SPSS statistical softwares were used for data analysis.

**Figure 7.3.** Major substrate types in the study area

## 7.3. RESULTS

### 7.3.1. Distribution of invertebrates

Macrobenthic assemblage in the grid plots was dominated by crustaceans mainly crabs (33%), polychaetes (26%), bivalves (15%), gastropods (12%) followed by amphipods (7%) and isopods (7%). Sand babbler crab *Dotilla sp.* was the most frequently occurring species in the grid plots. Polychaetes were dominated by *Orbinia sp.* and *Nereis sp.* Bivalves and gastropods mainly consisted of *Donax sp. and Cerithidea cingulata* (Table 7.1). The total macrobenthic density ranged from 278 to 3330 ind. $m^2$ (average: 947 ind. $m^2$ Table 7.1). Invertebrate density between the grid plots was significantly different (t (64)=34.59, P=0.00). The overall prey density between major substrate types i.e., sand and oyster beds did not show much variation (t(18)=1.36, P=0.19). However, the density of individual prey species varied between substrate types. The dominant prey group (crabs) was two times higher in sandy substrate than the oysterbeds (t(16)=2.34, P=0.03). Polychaete density was relatively higher in oyster beds but it did not show any significant difference (t(15)=-1.35, P=0.19, Fig. 7.4).

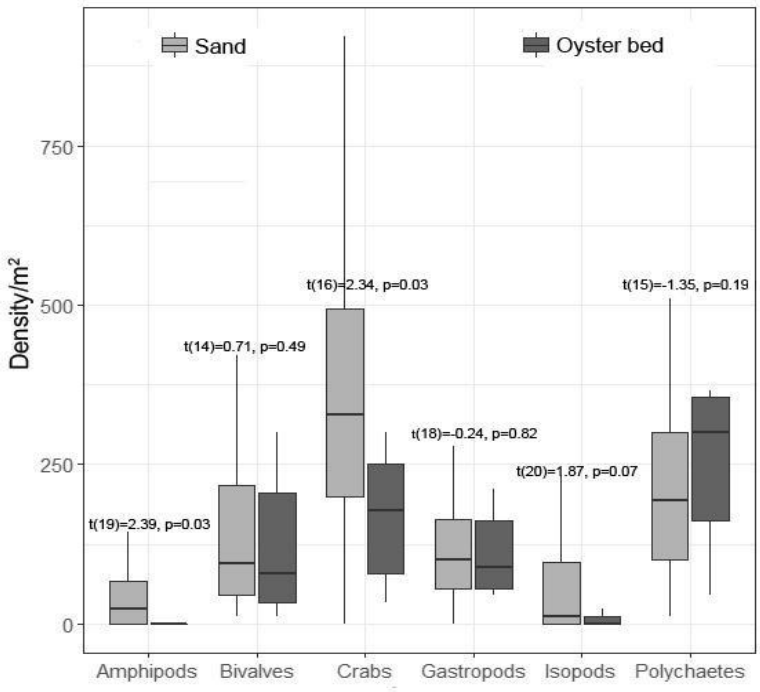



**Figure 7.4.** Prey density in the two major substrate types (sand and oyster bed) in the study area

### 7.3.2. Distribution of birds and behaviour

In total, nine species of shorebirds were recorded from the grid plots (Table 7.2). Kentish Plover and Lesser Sand Plover were the most abundant species in the grid plots. Other species occurred frequently but their densities were less than one individual per hectare. Shorebird densities between the two substrate types were significantly different (t (12)=2.37, P=0.04). Densities of different shorebird species were higher in sandy substrate except for Common Redshank, which was recorded most commonly in plots with oyster beds (Fig. 7.5). Shorebirds predominantly used visual and tactile foraging methods. Common Redshank and Common Greenshank used both foraging techniques, whereas Eurasian Curlew followed the tactile method. Plovers mainly used visual search for prey (Table 7.2 & Fig. 7.6).

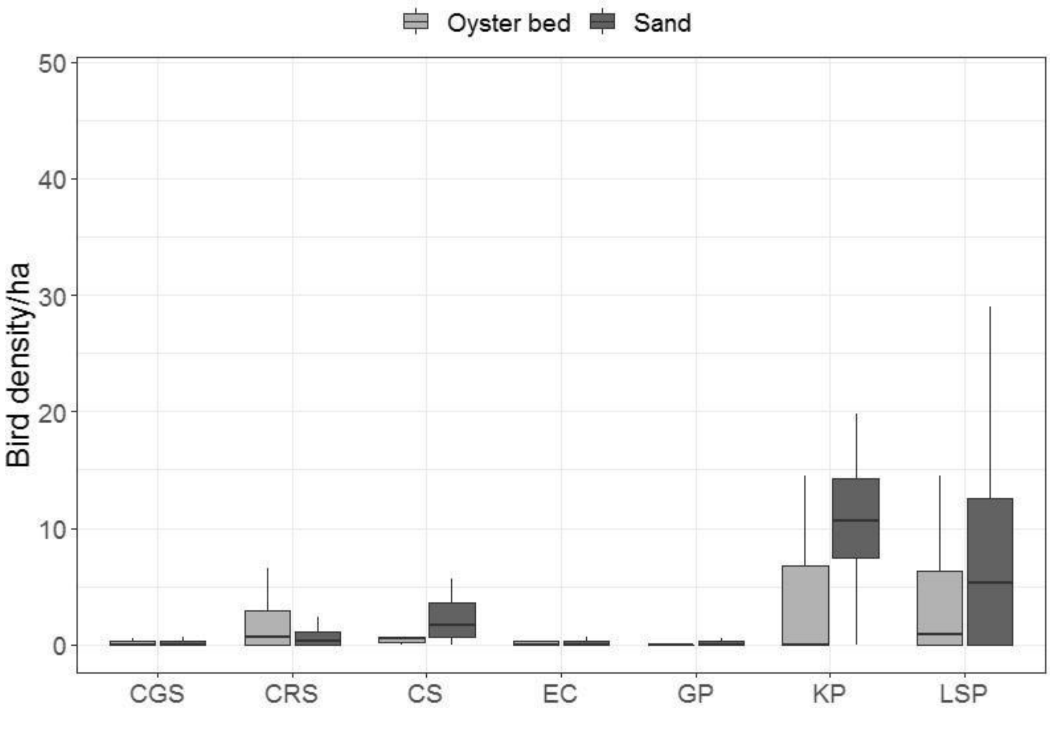



**Figure 7.5.** Density of different bird species in the two substrate types (**CGS**-Common Greenshank, **CRS**-Common Redshank, **CS**-Common Sandpiper, **EC**-Eurasian Curlew, **GP**-Grey Plover, **KP**-Kentish Plover and **LSP**-Lesser Sand Plover)

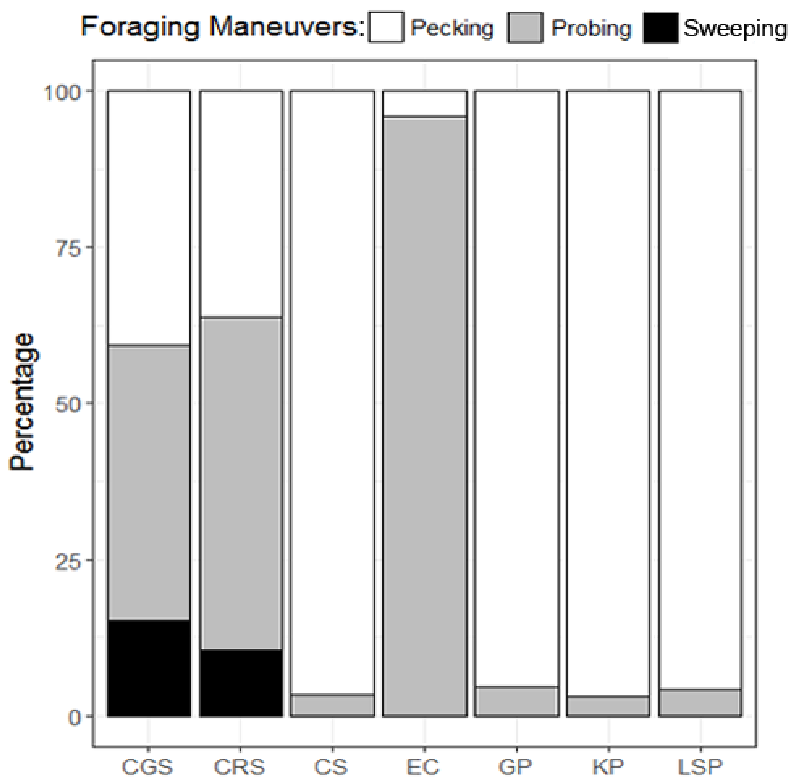



**Figure 7.6.** Different foraging techniques used by shorebirds in the study area

**Plate V.** Pecking and probing behavior in Lesser Sand Plover and Eurasian Curlew

Waterline is an important factor for shorebirds. All studied species foraged between 0-40m distances from the waterline. When the distance increased from the waterline (>40m) their abundances were gradually decreased. Interestingly the tactile foraging shorebirds (e.g. shanks) used areas close to the waterline as compared to visual foragers such as Lesser Sand Plover and Kentish Plover (Fig. 7.7).

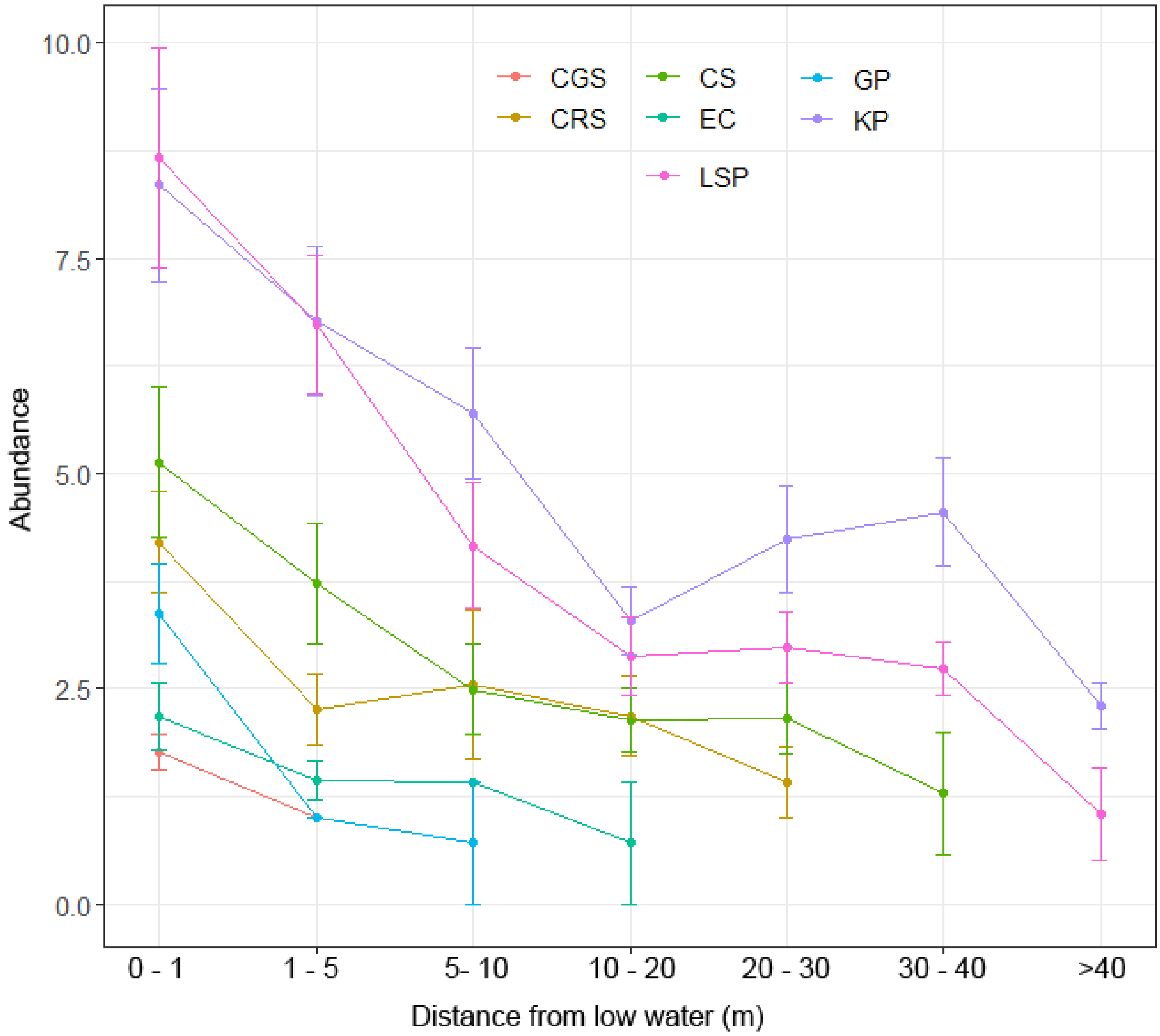



**Figure 7.7.** Foraging distance of different shorebird species from the waterline in the study area (**CGS**-Common Greenshank, **CS**-Common Sandpiper, **GP**-Grey Plover, **CRS**-Common Redshank, **EC**-Eurasian Curlew, **KP**-Kentish Plover and **LSP**-Lesser Sand Plover)

Foraging activity of individual shorebird species was positively influenced by prey density in the grid plots (Fig. 7.8). The mean pecking and probing rate of shorebirds were strongly influenced with prey abundance (Fig. 7.9 & 7.10). The mean pecking rate of Lesser Sand Plover, Kentish Plover and Common Sandpiper increased with prey density. Grey Plover also had positive association with prey abundance but it was not significant. Eurasian Curlew had no significant effect in peck rate (Fig. 7.9). However, their mean probing rate showed positive influence. Similar pattern was seen in Common Redshank and Greenshank (Fig. 7.10).

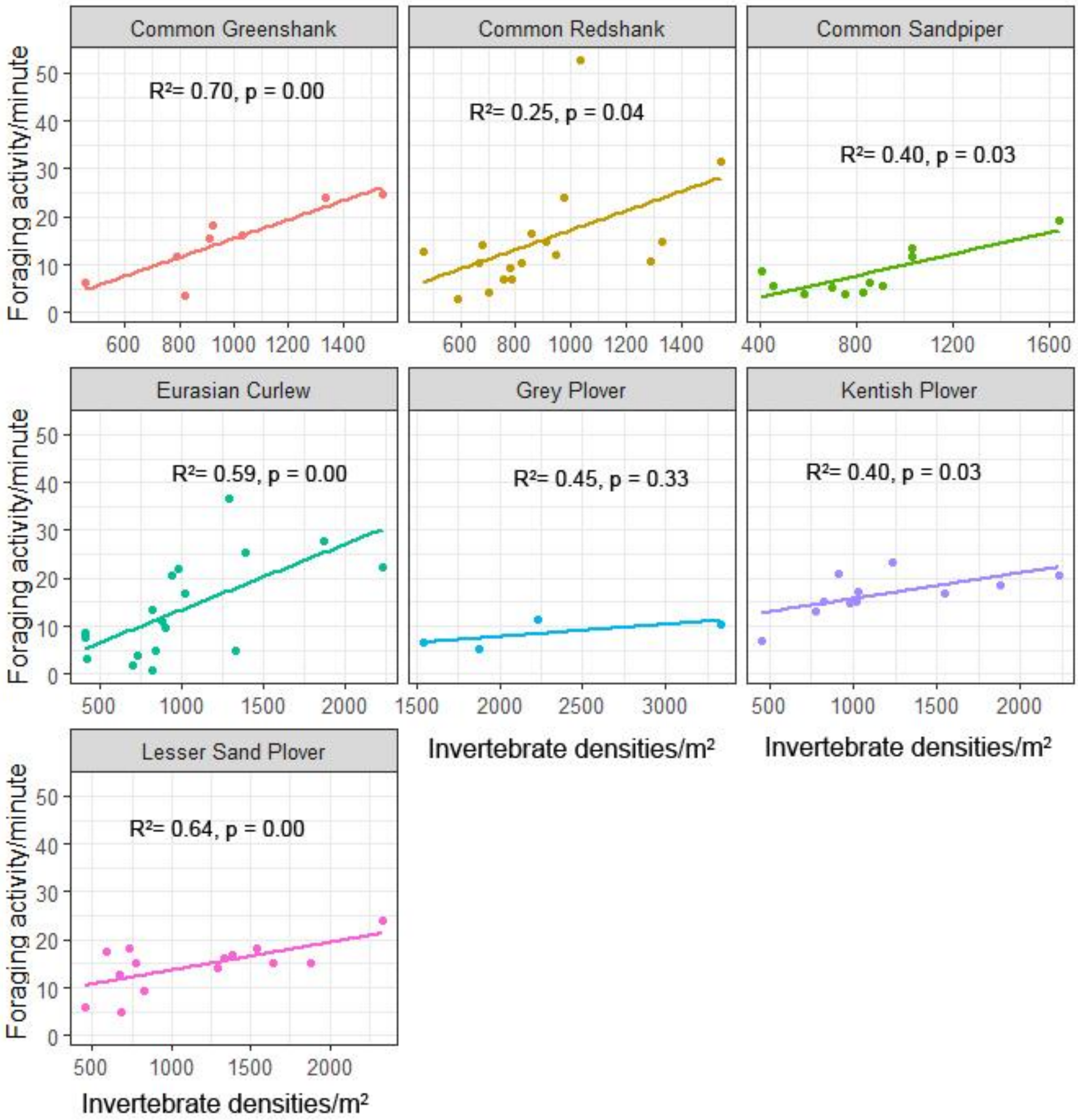



**Figure 7.8.** Regression results of shorebird foraging activity with invertebrate density in the study area

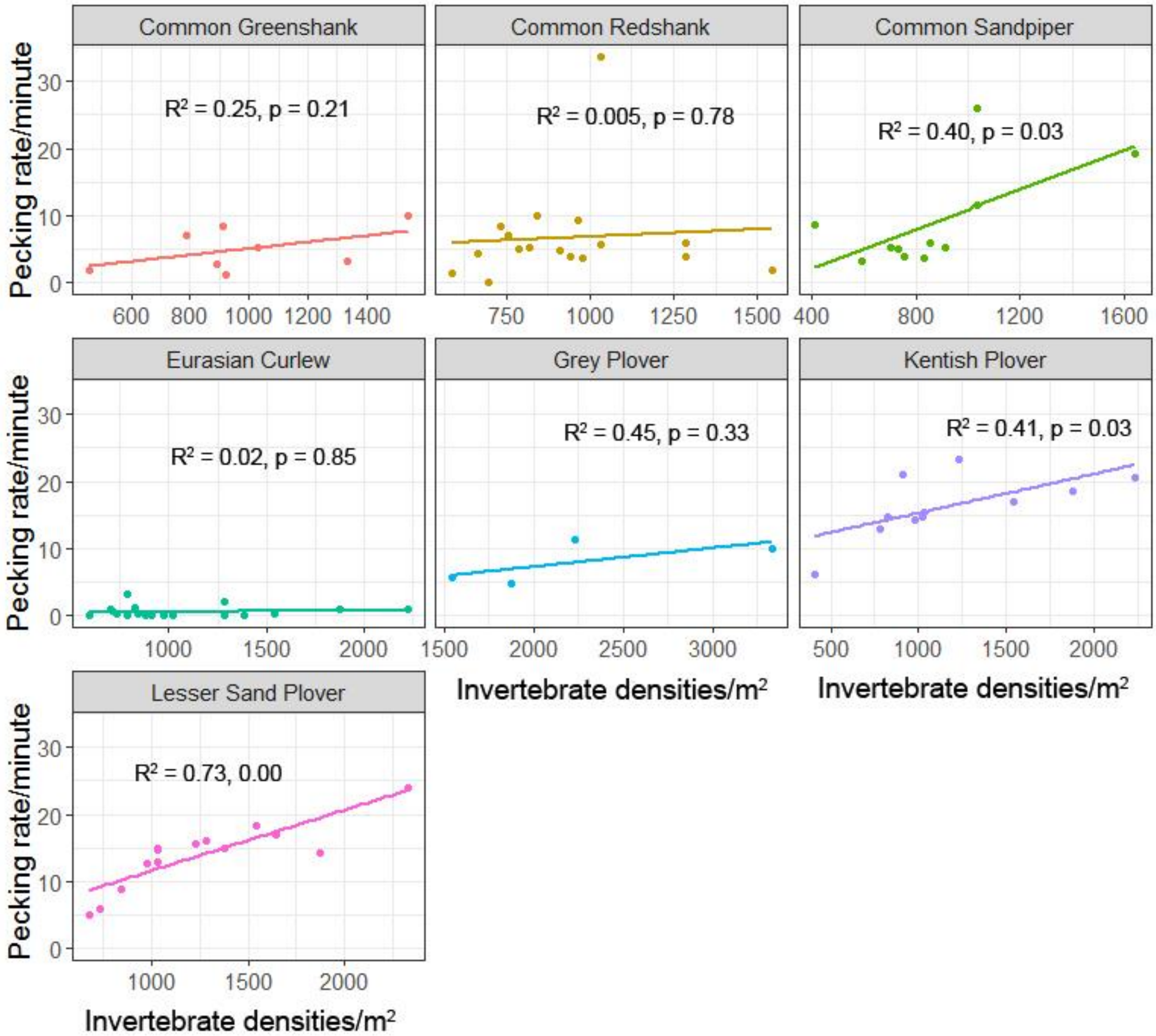



**Figure 7.9.** Regression results of shorebird pecking rate with invertebrate density in the study area

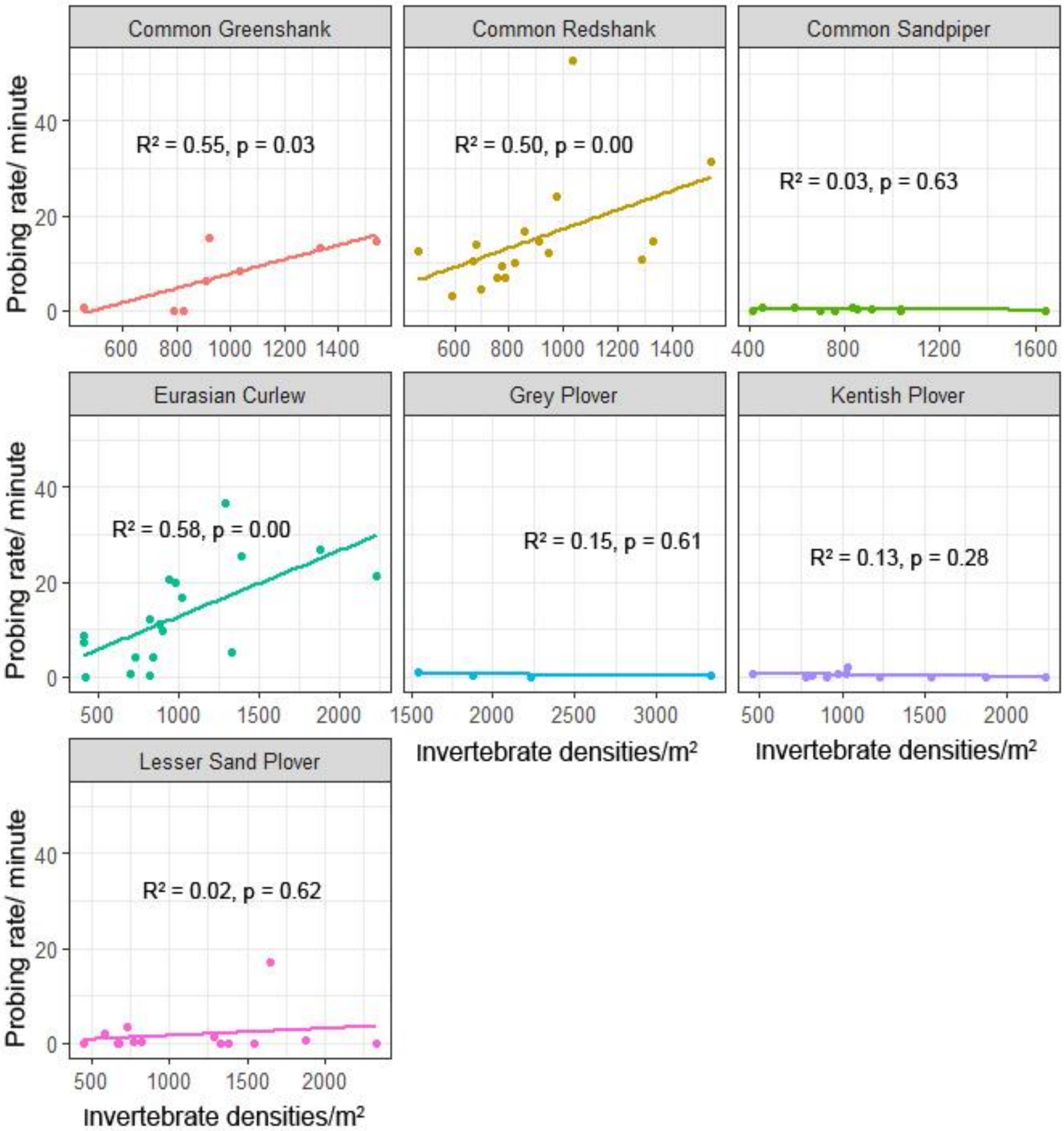



**Figure 7.10.** Regression results of shorebird probing rate with invertebrate density in the study area

The overall foraging activity of different shorebird species showed marked differences between the two substrate types (Fig. 7.11). Their pecking and probing activities were drastically decreased in oyster beds compared with the sandy substrate. The probing rate of Eurasian Curlew, Common Greenshank, and Common Redshank greatly decreased in oyster beds and they mainly used the pecking method in this substrate (Fig. 7.11).

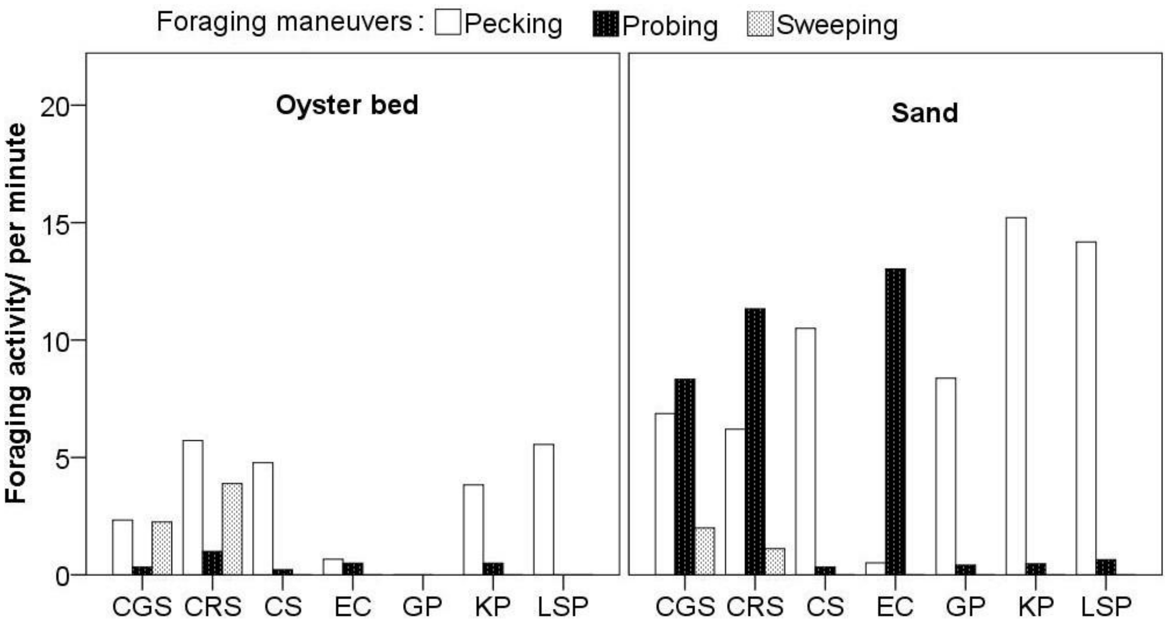



**Figure 7.11.** Foraging activity of studied species between two substrate types (oyster bed and sand) in the study area

### 7.3.3. Fine-scale habitat selection of shorebirds in relation to invertebrate density and sediment characteristics

Fine-scale habitat selection by selectshorebirds was largely governed by invertebrate density, sediment types, and soil grain size composition (Table 7.3 & 7.4). Even though species were at the same habitat patch, they showed non-random distribution. The major prey group that influenced their grid occupancy of shorebirds was the density of crustaceans and polychaetes. Species like Lesser Sand Plover, Eurasian Curlew, and Kentish Plover selected fine sandy substrates. The increasing coarse sand percentage showed a negative impact on these species. Further, oyster beds also negatively influenced Kentish Plover and Lesser Sand Plover foraging site selection. Common Redshank used mixed foraging techniques selected areas with fine sand as well as silt/clay substrates. Grey Plover used areas with fine sandy substrates and with low silt/clay content. Common Greenshank fed in areas with higher prey density and with fine sandy substrates.

**Table 7.3.** Results of Generalized Linear Model testing the effects of substrate and invertebrate density on fine-scale habitat selection by select shorebirds in the Sindhudurg district (**LSP**-Lesser Sand Plover, **KP**-Kentish Plover, **CS**-Common Sandpiper, **EC**-Eurasian Curlew, **GP**-Grey Plover, **CRS**-Common Redshank, and **CGS**-Common Greenshank)

| Species | Model | df | LogLink | AICc | ΔAICc | *wi* |
|---|---|---|---|---|---|---|
| LSP | Cd+Fsp+Isd+Pd | 5 | -15.94 | 42.90 | 0.00 | 0.36 |
| | Cd+Fsp+Isd+Pd+Oys | 6 | -14.89 | 43.23 | 0.33 | 0.31 |
| | Cd+Fsp+Gd+Isd+Pd | 6 | -15.32 | 44.10 | 1.20 | 0.20 |
| | Cd+Fsp+Pd | 4 | -18.11 | 44.88 | 1.99 | 0.13 |
| KP | Cd+Isd | 3 | -20.314 | 47.00 | 0.00 | 0.21 |
| | Amd+Cd+Isd | 4 | -19.64 | 47.90 | 0.92 | 0.13 |
| | Cd+Gp+Isd | 4 | -19.813 | 48.30 | 1.27 | 0.11 |
| | Cd+Isd+Oys | 4 | -19.935 | 48.50 | 1.51 | 0.09 |
| | Cd+Isd+Sc | 4 | -19.949 | 48.60 | 1.54 | 0.09 |
| | Cd+Fsp+Isd | 4 | -19.997 | 48.70 | 1.64 | 0.09 |
| | Fsp+Grp+Isd | 4 | -20.067 | 48.80 | 1.78 | 0.08 |
| | Amd+Fsp+Grp | 4 | -20.078 | 48.80 | 1.80 | 0.08 |
| | Cds++Isd+Cs | 4 | -20.144 | 49.00 | 1.93 | 0.08 |
| CS | Amd+Cd+Fsp+Pd | 5 | -21.12 | 53.26 | 0.00 | 0.69 |
| | Amd+Cd+Fsp+Isd+Pd | 6 | -20.70 | 54.86 | 1.60 | 0.31 |
| EC | Cs+Cd+Pd | 4 | -21.92 | 52.50 | 0.00 | 0.43 |
| | Cs+Cd+Fsp+Pd | 5 | -21.47 | 53.96 | 1.46 | 0.21 |
| | Cs+Cd+Pd+Oys | 5 | -21.53 | 54.07 | 1.57 | 0.18 |
| | Bd+Cs+Cd+Pd | 5 | -21.65 | 54.32 | 1.82 | 0.18 |
| GP | Amd+Bd+Fsp+Sc | 5 | -19.63 | 50.28 | 0.00 | 0.22 |
| | Amd+Bd+Fsp | 4 | -21.06 | 50.79 | 0.50 | 0.17 |
| | Amd+Bd | 3 | -22.21 | 50.81 | 0.53 | 0.17 |
| | Bd+Fsp+Sc | 4 | -21.42 | 51.51 | 1.22 | 0.12 |
| | Bd+Fsp | 3 | -22.60 | 51.59 | 1.31 | 0.12 |
| | Amd+Bd+Sc | 4 | -21.65 | 51.97 | 1.68 | 0.10 |
| | Amd+Bd+Isd | 4 | -21.67 | 52.00 | 1.72 | 0.09 |
| CRS | Cd+Fsp+Sc | 4 | -31.41 | 71.48 | 0.00 | 0.16 |
| | Cd+Fsp+Gd+Sc | 5 | -30.30 | 71.61 | 0.13 | 0.15 |
| | Cd+Pd+Sc | 4 | -31.87 | 72.40 | 0.93 | 0.10 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Cd+Isd+Sc | 4 | -31.95 | 72.57 | 1.09 | 0.09 |
| | Cd+Fsp+Pd+Sc | 5 | -30.85 | 72.72 | 1.24 | 0.08 |
| | Cd+Fsp+Gd+Pd+Sc | 6 | -29.71 | 72.88 | 1.40 | 0.08 |
| | Cd+Isd+Pd+Sc | 5 | -30.93 | 72.89 | 1.41 | 0.08 |
| | Cd+Fsp+Isd+Sc | 5 | -31.00 | 73.02 | 1.54 | 0.07 |
| | Cd+Gd+Pd+Sc | 5 | -31.04 | 73.10 | 1.63 | 0.07 |
| | Cd+Pd | 3 | -33.38 | 73.15 | 1.68 | 0.07 |
| | Cd+Sc | 3 | -33.52 | 73.43 | 1.96 | 0.06 |
| CGS | Amd+Fsp+Gd | 4 | -25.43 | 59.53 | 0.00 | 0.20 |
| | Fsp+Gd | 3 | -27.02 | 60.43 | 0.90 | 0.13 |
| | Amd+Fsp | 3 | -27.22 | 60.83 | 1.29 | 0.11 |
| | Amd+Fsp+Gd+Pd | 5 | -25.02 | 61.05 | 1.51 | 0.09 |
| | Fsp | 2 | -28.57 | 61.33 | 1.80 | 0.08 |
| | Amd+Cd+Fsp+Gd | 5 | -25.16 | 61.34 | 1.81 | 0.08 |
| | Amd+Fsp+Gd+Cs | 5 | -25.17 | 61.36 | 1.82 | 0.08 |
| | Amd+Fsp+Gd+Isd | 5 | -25.23 | 61.48 | 1.94 | 0.08 |
| | Amd+Fsp+Gd+Sc | 5 | -25.25 | 61.53 | 1.99 | 0.07 |
| | Amd+Fsp+Gd | 5 | -25.25 | 61.53 | 1.99 | 0.07 |

**Cd-**Crab density, **Fsp-**Fine sand, **Pd-**Polychaete density, **Oys-**Oyster bed, **Amd-**Amphipod density, **Sc-**Silt/Clay, **Cs-**Coarse sand, **Gd-**Gastropod density, **Bd-**Bivalve density, **Gs-**Gravel sand

**Table 7.4.** Estimated beta coefficients of top ranked models explaining shorebird fine-scale habitat selection in the Sindhudurg district (**LSP**-Lesser Sand Plover, **KP**-Kentish Plover, **CS**-Common Sandpiper, **EC**-Eurasian Curlew, **GP**-Grey Plover, **CRS**-Common Redshank, and **CGS**-Common Greenshank)

| Species | Parameters | Estimates | SE | Z-score | Hosmer and Lemeshow (GOF) test |
|---|---|---|---|---|---|
| LSP | Intercept | 3.54 | 1.31 | 2.65 | |
| | Crabs | 1.64 | 0.70 | 2.31 | |
| | Fine sand | 2.37 | 1.06 | 2.19 | $\mathbf{X^2}$ = 4.68, |
| | Isopods | 2.04 | 1.41 | 1.43 | df = 8, p = 0.79 |
| | Polychaetes | 2.53 | 1.11 | 2.23 | |
| | Oyster beds | -0.73 | 1.63 | 0.45 | |
| | Gastropods | -0.12 | 0.33 | 0.35 | |
| KP | Intercept | 3.52 | 1.26 | 2.73 | |
| | Crabs | 0.96 | 0.67 | 1.40 | |
| | Isopods | 3.12 | 2.43 | 1.26 | $\mathbf{X^2}$ = 7.58, |
| | Amphipods | 0.32 | 0.94 | 0.34 | df = 8, p = 0.48 |
| | Gravel sand | -0.11 | 0.24 | 0.47 | |
| | Oyster beds | -0.08 | 0.40 | 0.20 | |

| | | | | | |
|---|---|---|---|---|---|
| | Silt/Clay | -0.03 | 0.13 | 0.20 | |
| | Fine sand | 0.31 | 0.66 | 0.47 | |
| | Coarse sand | -0.01 | 0.10 | 0.14 | |
| CS | Intercept | 2.41 | 0.81 | 2.93 | |
| | Amphipods | 2.63 | 1.53 | 1.68 | |
| | Crabs | 1.34 | 0.58 | 2.27 | $\mathbf{X^2}$ = 7.04, |
| | Fine sand | 1.40 | 0.68 | 2.03 | df = 8, p = 0.53 |
| | Polychaetes | 0.98 | 0.51 | 1.89 | |
| | Isopods | 0.24 | 0.64 | 0.38 | |
| EC | Intercept | -0.34 | 0.41 | 0.82 | |
| | Crabs | 2.23 | 0.65 | 3.39 | |
| | Coarse sand | -1.74 | 0.80 | 2.12 | $\mathbf{X^2}$ = 10.79, |
| | Polychaetes | 2.10 | 0.78 | 2.63 | df = 8, p = 0.21 |
| | Fine sand | 0.09 | 0.28 | 0.31 | |
| | Oyster beds | -0.21 | 0.78 | 0.27 | |
| | Bivalves | 0.06 | 0.21 | 0.26 | |
| GP | Intercept | -1.50 | 0.46 | 3.18 | |
| | Amphipods | 0.72 | 0.60 | 1.19 | |
| | Bivalves | 1.67 | 0.50 | 3.25 | $\mathbf{X^2}$ = 6.63, |
| | Fine sand | 0.59 | 0.60 | 0.97 | df = 8, p = 0.58 |
| | Silt/Clay | -0.40 | 0.63 | 0.62 | |
| | Isopods | 0.04 | 0.19 | 0.22 | |
| CRS | Intercept | 0.10 | 0.32 | 0.30 | |
| | Crabs | 1.24 | 0.45 | 2.72 | |
| | Fine sand | 0.37 | 0.46 | 0.81 | $\mathbf{X^2}$ = 9.13, |
| | Silt/Clay | 0.78 | 0.43 | 1.76 | df = 8, p = 0.33 |
| | Gastropods | 0.16 | 0.32 | 0.48 | |
| | Polychaetes | 0.31 | 0.45 | 0.68 | |
| | Isopods | 0.13 | 0.32 | 0.41 | |
| CGS | Intercept | -0.57 | 0.36 | 1.54 | |
| | Amphipods | 0.67 | 0.57 | 1.17 | |
| | Fine sand | 1.96 | 0.53 | 3.62 | |
| | Gastropods | 0.64 | 0.53 | 1.19 | |
| | Polychaetes | 0.04 | 0.17 | 0.21 | $\mathbf{X^2}$ = 7.08, |
| | Crabs | 0.02 | 0.14 | 0.17 | df = 8, p = 0.53 |
| | Coarse sand | -0.02 | 0.15 | 0.16 | |
| | Isopods | 0.02 | 0.16 | 0.14 | |
| | Silt/Clay | 0.02 | 0.13 | 0.14 | |
| | Gravel sand | -0.02 | 0.17 | 0.12 | |

## 7.4. DISCUSSION

Fine-scale habitat selections by select shorebirds are influenced by the variation in invertebrate density, substrate type, and sediment particle size composition. Prey distribution varied between two substrate types. Shorebird foraging activity increased in sandy substrates as compared to oyster beds.

In numerous studies, salinity was reported to have a major effect on benthic organisms (Parulekar & Dwivedi, 1974; Smyth & Elliott, 2016). In addition, the sediment particle size has also been reported as a key variable that could influence benthic community composition (Yates et al. 1993). In this study, distribution of benthos was strongly influenced by the sediment types. These results are corroborating with Goss-Custard & Yates (1992) and van Dusen et al. (2012) where the sediment particle size determined the benthic invertebrate distribution in the intertidal mudflats. The dominant prey species in the study area were crustaceans; their densities were higher in the sand as compared to substrate type owing to enhanced burrowing opportunities in sandy substrates. High polychaete abundance in oyster beds was due to less predatory pressure and the presence of muddy soil (silt/clay).

During the study, shorebirds frequently used sandy substrates and their preferred prey species was crustaceans. A large congregation of multiple species using similar habitats and foraging on similar prey would increase inter and intra-specific competition and reduce foraging efficiency among individuals. Additionally, a group of birds at a particular place rapidly remove all available prey (Goss-Custard, 1970) and influences prey activity consequently prey remains deeper inside the burrow (Goss-Custard, 1970; Reading & McGrorty, 1978). However, shorebirds overcome these issues by spatial segregation, foraging at different tidal levels or water depths (Recher, 1966; Dias et al. 2006) using different foraging techniques (van Dusen et al. 2012) micro-habitats (Burger et al. 1977), and through morphological adaptations (Baker, 1979). This pattern is obvious in the study; species spread across the study area used different foraging techniques and micro-habitats.

Shorebird foraging activity was higher in sandy substrates as compared to oyster beds. Their probing activity drastically decreased in oyster beds (especially in tactile and mixed foragers) and they mainly fed by pecking in those sites. This observation indicates presence of hard surfaces in oyster beds restricted their bill movements. Similar observations were made at Moreton Bay where the presence of resistance materials in the substrates (shells, woody debris, and rocks) influenced the foraging activity of Eastern Curlews (*Numenius madagascariensis*) thereon its broad and fine-scale habitat selection.

The physical properties of the sediment largely determine the prey availability and accessibility to the shorebirds (Myers et al. 1980; Kelsey & Hassall, 1989). Sediment texture is an important factor that affects the types and abundance of benthic invertebrates at the site (Quammen, 1982). Coarse particles in the sediment interfere in the prey detection and surface penetrability to the tactile foraging shorebirds (van Dusen et al. 2012). Sediment with the increased amount of coarse material acts as a refuge for benthic invertebrates (Peterson et al. 2006). Maybe, for this reason, the tactile foraging Eurasian Curlew avoided areas with increasing amounts of coarse sand. The coarse sand did not have much effect on visual foraging shorebirds i.e., Lesser Sand Plover and Common Sandpiper; however, it had a negative impact on the Kentish Plover. This could be due to its shorter bill; the prey buried in the coarse sand perhaps not in its accessible bill range. Kentish Plover mainly harvests food by pecking; the prey capture rate increases if the prey is within its accessible bill range.

The selection of oyster beds is a relevant variable in the study because Kentish Plover and Lesser Sand Plover avoided areas with large extent of oyster beds. The possible reason for this is that these two species use the run and paused mode of foraging technique (Jing et al. 2007). The presence of oyster beds might restrict their foraging movements therefore these two species might have shown less preference to those areas. Similar behavior was observed in other shorebird species Bar-tailed Godwit, Dunlin, and Redshank in the Tagus estuary Portugal (Granadeiro et al. 2004).

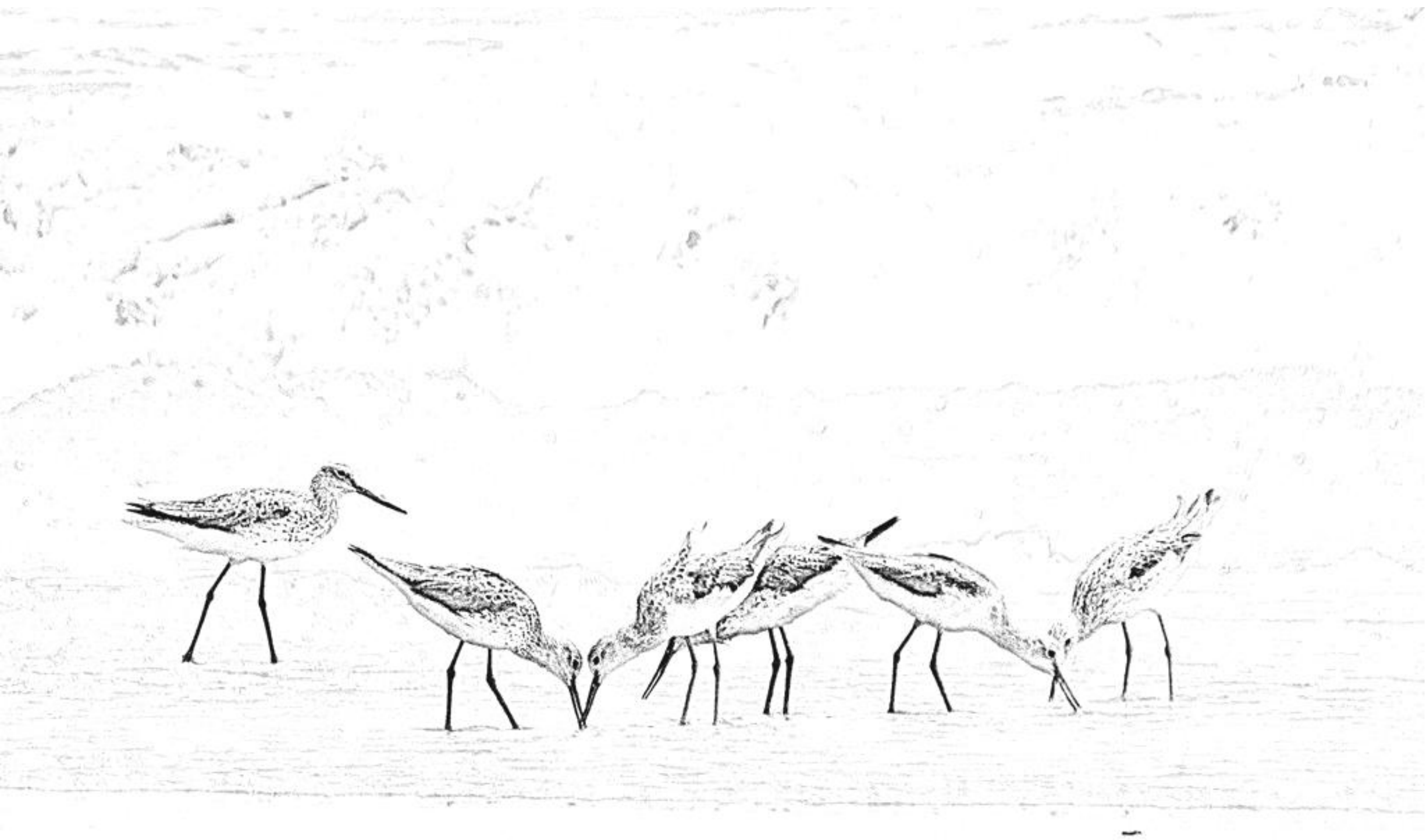
The mixed foraging species Common Redshank and Greenshank fed on amphipods, crabs and polychaetes. During low tide these were the species that appeared first on the exposed grid plots and foraged most of the time in shallow waters. The presence of silt and clay content in oyster beds holds some water even during low tide. Therefore Shanks took advantage of it by foraging in shallow water pools for searching shrimps and fishes by using sweeping method.

To optimize feeding opportunities the individual shorebirds have to move to different habitats. However, when they are in the same habitat they would encounter a range of opportunities with respect to substrate and sediment wetness. It is evident in this study, shorebirds foraged varying distances from the waterline. Wet substrates close to the waterline enhance prey availability and sediment penetrability for tactile foraging shorebirds. The density and surface activity of some invertebrate species would be higher in wet substrates close to the waterline (Rosa et al. 2007). It was observed in a few probing shorebirds their foraging activity was higher in wet substrates where sediment penetrability is greater (Myers et al. 1980; Finn et al. 2007; van Dusen et al. 2012). In this study, the tactile foraging Eurasian Curlew foraged close to the waterline indicating a preference to the wet substrates that would increase its bill penetrability. This observation corroborated with Finn et al. (2007). The mixed and visual foraging shorebirds foraged in damp areas away from the waterline shows that species even if they are at the same habitat patch share the resources equally by exploring different micro-habitats.

From this study, it is concluded that multiple factors influence shorebird habitat selection on the different spatial scales therefore assessing habitat requirements of shorebirds at both scales viz., fine-scale (within the estuary) and large scale (between the estuaries) may be equally important.

# Chapter 8

# Summary



## Chapter 8
## Summary

Coastal habitats are one of the most productive and vulnerable habitats in the world. Approximately 60% of global human populations exist in coastal ecosystems. Increasing population growth, unsustainable resource use, and growing urbanization/tourism in Asia are presently threatening the coastal ecosystem and the shorebirds, which are depend on it. India, holds 7516.6 km coastal line, supports large number of migratory waterbirds, which are reported to be declining worldwide. Despite having long coastal line, the reasons for the population decline of many waterbirds species remains unclear owe to little understanding about their ecology in the wintering grounds. Therefore, present study assessed the population status, wintering phenology, and habitat use pattern and habitat selection of migratory shorebirds in the Sindhudurg district.

Sindhudurg district consists of eight talukas among them three are coastal talukas viz., Vengurla, Malvan, and Devgad. Coastal talukas are characterized by diverse coastal and inland habitats that support rich biodiversity. The coastal habitats in the districts are dominated by three habitat types such as beach, sandy mudflats, and mudflats associated with mangroves (hereafter mangroves). Many coastal bird studies in India are site-specific; hence this study was attempted to sample 121 km coastal stretch of Sindhudurg district.

Considering the ecological and conservation importance of this coastal stretch, I compiled bird records using primary and secondary information to prepare a comprehensive checklist of birds of Sindhudurg district. The spatial and temporal patterns of shorebird assemblage were assessed in seven estuaries using total count method. To assess the population characteristics of gulls, daytime near-shore surveys were carried out monthly once along the 121 km coastal stretch. The factors influencing habitat use of shorebirds were studied in seven estuaries and for this prey, sediment, and water samples were collected across habitats (beach, mudflat, and mangrove) and seasons (arrival, wintering and departure phases). To study the fine-scale habitat selection of most commonly occurring shorebird species in the study area, two sites were selected i.e., Mochemad and Mitbav. Intertidal mudflats of these two sites were divided into 25X25 m grids. Birds were counted in the grids using the total count method during low tide. To assess the prey availability and accessibility to the shorebirds grid parameter like prey density and sediment types were examined.

This study recorded 283 species of birds from the coastal talukas of Sindhudurg district, and 24 more species were added from the secondary information, which was not observed during the study. In total 307 species of birds were recorded for the Sindhudhrg coast belonging to 78 families and 22 orders. Passeriformes was the most dominant order observed with 111 species. Out of 307 bird species, 4 were endemic to the Western Ghats. Maximum species richness was reported from Vengurla taluka (256) followed by Malvan (247) taluka.

**Spatial and temporal patterns of shorebirds:** A total of 36 species of shorebirds were observed, of which 26 were migrants, 5 residents, and 5 resident winter migrants. Five Near-Threatened and one endangered shorebird were recorded. The Common Sandpiper (82%), Common Redshank, (65%), Lesser Sand Plover (55%), Common Greenshank (43%), Kentish Plover (39%), and Greater Sand Plover (35%) were the most frequently seen species in the study. Lesser Sand Plover (38%), Common Sandpiper (19%), and Kentish Plover (15%) accounted for 72% of Sindhudurg's shorebird population. Excluding resident shorebirds, 21 and 10 species used the Sindhudurg coast as their wintering and stopover sites respectively. Shorebird species richness, diversity, and abundances were higher in mudflats as compared to beach, and mangroves. The species richness and abundance of shorebird was significantly different between habitats and months. The nMDS plot explained five different phases of migration phenology viz., arrival phase, wintering phase, early departure, and late arrival phase, departure phase, and breeding phase. Shorebirds started arriving Sindhudurg coast during August-September and increased their numbers in wintering phase. A gradual decrease in shorebird numbers was observed from March-May.

**Population assessment of gulls:** Among the five species of gulls, three species viz., Brown-headed Gull (BHG - 41%), Lesser black-backed Gull (32%), and Palla's Gull (23%) accounted for 96% of gulls counted in the study area. About 10.3, 8.2, and 5.6% biogeographic population (BGP) of gulls was recorded from three sites viz., Mitbav, Mochemad, and Karli. Almost 4 to 8% of 1% BGP of BHG was recorded in Karli (8%), Mochemad (6%), and Mitbav (4%) of Sindhudurg coast which signifies international importance of these sites. The overall abundance of gull species increased between December-February. A clear difference was observed in the arrival and departure dates of gulls and small waders. Small waders started arriving in coastal areas from Aug–Sep, however, gulls arrived later in October and left the wintering grounds earlier (Apr) than the small waders. Slender-billed Gull is considered as most uncommon species along the Indian coast. However, it was reported regularly in the study area and counted 1% biogeographical population of this species from the Mochemad site.

**Factors influencing habitat use of shorebirds:** Factors that influence shorebird habitat use were assessed with environmental parameters and invertebrate densities using GLM negative binomial. The environmental parameters like salinity, soil moisture content, and organic matter were significantly different between habitats. However other parameters i.e., water temperature, sediment temperature, dissolved oxygen, and TSS did not show much variation between habitats but showed significant seasonal variations. Among the measured environmental parameters salinity was the key variable that influenced benthic invertebrate distribution. Salinity was reported to be high during the departure phase (summer) and showed clear differences between habitats indicated decreasing trend towards the mangroves. Invertebrate densities have widely fluctuated showed high abundance in the wintering phase in mudflats. The dominant prey species in the study area were crustaceans and polychaetes. The combined effect of biotic and abiotic variables on shorebird abundance and richness was investigated with generalized linear models. The results showed that crustaceans, polychaetes, bivalves, and salinity influenced shorebird abundance and richness.

**Fine-scale habitat selection:** The results showed that variation in the invertebrate density, substrate types, and soil wetness influenced shorebird habitat selection. The tactile foraging shorebird like Eurasian Curlew selected foraging sites close to the waterline that increased its surface penetrability. Lesser Sand Plover and Kentish Plover selected areas with high density of crustacean and the absence of oyster beds. Common Redshank and Greenshank selected sandy and shallow water oyster beds. These observations indicate that though a number of species using similar habitats for foraging, species avoid competition by exploring a variety of microhabitats.

Intertidal mudflats are major foraging grounds for shorebirds, during the study higher shorebird and prey abundances were observed in the mudflats. Mudflats are considered as mangrove nursery grounds, increasing mangrove plantation in mudflat areas decreases foraging space for the shorebirds. Hence this study suggests that mangrove plantations can be done in areas where birds use is minimal. Secondly, few species are very common in other coastal sites in India but they used the Sindhudurg coast as a stopover site which indicates that regular monitoring of coastal bird population along the Indian coast is important. Tracking and tagging of birds from the unprotected coastal sites in India may throw light on their migration movements.

Increasing sand mining and tourism activities are the major threat to the coastal bird population in the district it needs to be curtailed. During the initial data collection, it was observed that the tourism activities were minimal in the district but now it has increased almost all along the coast. Karli is the traditional tourism site in the district therefore tourism activities can be continued at this location by prohibiting in other sites. Due to high bird abundance in Mochemad and Mitbav sites this study recommends that these areas can be declared as community conservation reserves for the protection of wintering shorebird populations. Shorebird behavioral studies in India are scarce, understanding how species select particular habitat or patch and time spent in each habitat will provide a better understanding of shorebird wintering ecology. Future studies should concentrate on this regard.

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**Appendix 1.** Birds from three coastal talukas of Sindhudurg district, Maharashtra

| SNO | Common name | Scientific name | Observers | Status | Occurrence | Talukas | | | Habitats used |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Vengurla | Malvan | Devgad | |
| | **Galliformes/ Phasianidae** | | | | | | | | |
| 1 | Indian Peafowl | *Pavo cristatus* | P, K | R | C | + | + | + | GS |
| 2 | Grey Junglefowl | *Gallus sonneratii* | P | R | U | + | + | - | WD |
| 3 | Red Spurfowl | *Galloperdix spadicea* | P, V | R | U | + | + | - | WD |
| 4 | Grey Francolin | *Francolinus pondicerianus* | P | R | C | + | + | + | GS,WD |
| 5 | Common Quail | *Coturnix coturnix* | P | W | U | + | - | - | GS,WD |
| 6 | Jungle Bush Quail | *Perdicula asiatica* | P, V, K | R | U | + | - | + | GS,WD |
| | **Charadriiformes/ Turnicidae** | | | | | | | | |
| 7 | Barred Buttonquail | *Turnix suscitator* | P, V, K | R | U | - | + | - | GS |
| | Anseriformes/ Anatidae | | | | | | | | |
| 8 | Lesser Whistling-duck | *Dendrocygna javanica* | P, K | R/LM | C | + | + | + | FW, AQ, SAL |
| 9 | Cotton Pygmy-goose | *Nettapus coromandelianus* | P | R/LM | C | + | - | - | FW |
| 10 | Indian Spot-billed Duck | *Anas poecilorhyncha* | P | R/LM | C | + | - | - | FW |
| 11 | Northern Pintail | *Anas acuta* | P | W | U | + | - | - | FW |
| 12 | Garganey | *Spatula querquedula* | P | W | U | + | - | - | FW, AQ, SAL |
| 13 | Common Teal | *Anas crecca* | P | W | U | + | - | + | FW, AQ, SAL, MG |
| 14 | Gadwall | *Anas strepera* | P | W | U | + | - | + | FW, AQ, SAL, MG |
| 15 | Northern Shoveler | *Anas clypeata* | P | W | R | + | + | + | FW, AQ, SAL |
| 16 | Ruddy Shelduck | *Tadorna ferruginea* | P | W | R | - | - | + | FW, AQ |
| | **Podicipediformes/ Podicipedidae** | | | | | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 17 | Little Grebe | *Tachybaptus ruficollis* | P, V, K | R/LM | C | + | + | + | FW, SAL |
| | Phoenicopteriformes/ Phoenicopteridae | | | | | | | | |
| 18 | Greater Flamingo | *Phoenicopterus roseus*** | A | UN | UN | - | + | - | INMDF |
| | **Ciconiiformes/ Ciconiidae** | | | | | | | | |
| 19 | Painted Stork | *Mycteria leucocephala* | P | W | R | + | - | - | AQ |
| 20 | Asian Openbill | *Anastomus oscitans* | P | W | C | + | + | + | FW, MG, AG |
| 21 | Woolly-necked Stork | *Ciconia episcopus* | P | R/LM | C | + | - | - | SBH, AQ, SAL |
| | **Pelecaniformes/ Threskiornithidae** | | | | | | | | |
| 22 | Black-headed Ibis | *Threskiornis melanocephalus* | P | R/LM | C | + | + | + | FW, AG, MG, AQ, SAL |
| 23 | Glossy Ibis | *Plegadis falcinellus* | P | W | U | + | - | - | FW, AG, AQ |
| 24 | Red-naped Ibis | *Pseudibis papillosa* | P | R/LM | U | + | - | - | FW, AG, AQ |
| | **Pelecaniformes/ Ardeidae** | | | | | | | | |
| 25 | Cinnamon Bittern | *Ixobrychus cinnamomeus* | P, V | R/LM | U | - | + | - | GS, MG |
| 26 | Yellow Bittern | *Ixobrychus sinensis* | P | R/LM | U | + | - | - | MG, VGR |
| 27 | Cattle Egret | *Bubulcus ibis* | P, K | R/LM | C | + | + | + | FW, MG, AQ, SAL, RSH, SBH, GS, AG |
| 28 | Little Egret | *Egretta garzetta* | P, K | R/LM | C | + | + | + | FW, MG, AQ, SAL, AG, RSH |
| 29 | Intermediate Egret | *Mesophoyx intermedia* | P, K | R/LM | C | + | + | + | FW, MG, AQ, SAL, AG |
| 30 | Great Egret | *Casmerodius albus* | P, K | R/LM | C | + | + | + | FW, MG, AQ, SAL, AG, RSH |
| 31 | Western Reef Egret | *Egretta gularis* | P, A, K, L | W | C | + | + | + | FW, MG, AQ, SAL, RSH, SBH |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 32 | Grey Heron | *Ardea cinerea* | P, A, K | W | C | + | + | + | FW, MG, AQ, SAL, INMDF |
| 33 | Purple Heron | *Ardea purpurea* | P, K | R/LM | C | + | + | + | FW, MG, AQ, SAL |
| 34 | Indian Pond Heron | *Ardeola grayii* | P, K, L | R/LM | C | + | + | + | FW, MG, AQ, SAL, AG, RSH, INMDF |
| 35 | Striated Heron | *Butorides striata* | P, V, K | R | C | + | + | + | FW, MG, RSH, SAL, AQ |
| 36 | Black-crowned Night Heron | *Nycticorax nycticorax* | P, V, K | R | U | + | + | - | FW |
| | **Suliformes/ Anhingidae** | | | | | | | | |
| 37 | Darter | *Anhinga melanogaster* | P | W | U | + | + | - | MG, AQ |
| | **Suliformes/ Phalacrocoracidae** | | | | | | | | |
| 38 | Little Cormorant | *Phalacrocorax niger* | P, K | R/LM | C | + | + | + | FW, MG, AQ, SAL |
| 39 | Indian Cormorant | *Phalacrocorax fuscicollis* | P | W | U | + | + | + | FW, MG, AQ, SAL |
| | **Suliformes/ Sulidae** | | | | | | | | |
| 40 | Masked Booby | *Sula dactylatra* | P | V | R | + | + | - | VGR |
| 41 | Brown Booby | *Sula leucogaster*** | J | UN | UN | + | - | - | OFSH |
| | **Falconiformes/ Falconidae** | | | | | | | | |
| 42 | Common Kestrel | *Falco tinnunculus* | P, H, V, L, PKT, K | W | C | + | + | + | GS, VGR |
| 43 | Peregrine Falcon | *Falco peregrinus calidus* | P, V, A, L | W | C | + | + | + | SBH, PL |
| 44 | Amur Falcon | *Falco amurensis* | P | PM | R | + | - | - | GS |
| 45 | Eurasian Hobby | *Falco subbuteo* | P | W | U | + | - | - | GS |
| | **Accipitriformes/ Pandionidae** | | | | | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 46 | Osprey | *Pandion haliaetus* | P, V, A, L | W | C | + | + | + | GS, SBH,MG, INMDF, AQ, SAL, VGR |
| | **Accipitriformes/ Accipitridae** | | | | | | | | |
| 47 | Red-headed Vulture | *Sarcogyps calvus*** | V | UN | UN | - | + | - | WD |
| 48 | White-rumped Vulture | *Gyps bengalensis*** | V, KM | UN | UN | + | + | + | WD |
| 49 | Indian Vulture | *Gyps indicus*** | V | UN | UN | + | + | + | WD |
| 50 | Black Kite | *Milvus migrans* | P, K | R/LM | C | + | + | + | GS, SBH, RSH, MG, INMDF, AQ, SAL, WD |
| 51 | Brahminy Kite | *Haliastur Indus* | P, L, K | R | C | + | + | + | GS, SBH, RSH, MG, INMDF, AQ, SAL, WD |
| 52 | Black-winged Kite | *Elanus caeruleus* | P | R | C | + | + | + | GS, AQ, WD, AG |
| 53 | White-bellied Sea Eagle | *Haliaeetus leucogaster* | P, H, A, PKT, PA, KMP, L, KT | R | C | + | + | + | GS, SBH, RSH, INMDF, AQ, SAL, MG, WD, VGR |
| 54 | Crested Serpent Eagle | *Spilornis cheela* | P, V, K | R | C | + | + | + | GS, AQ, MG, WD |
| 55 | Eurasian Marsh Harrier | *Circus aeruginosus* | P, V, L | W | C | + | + | + | FW, GS, MG |
| 56 | Pallid Harrier | *Circus macrourus* | P | W | U | + | + | + | GS |
| 57 | Montagu's Harrier | *Circus pygargus* | P | W | U | + | + | + | GS |
| 58 | Shikra | *Accipiter badius* | P, V, K | R | C | + | + | + | GS, PL, AG, WD |
| 59 | Besra | *Accipiter virgatus* | P | R | U | + | + | - | GS, WD |
| 60 | Oriental Honey-buzzard | *Pernis ptilorhynchus* | P | R | C | + | + | + | GS, PL, MG, VGR, WD |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 61 | White-eyed Buzzard | *Butastur teesa* | P, K | R | U | + | + | + | GS, WD |
| 62 | Common Buzzard | *Buteo buteo* | P | PM | R | + | - | + | GS, WD |
| 63 | Bonelli's Eagle | *Aquila fasciata* | P | R | U | - | + | + | GS, WD |
| 64 | Booted Eagle | *Hieraaetus pennatus* | P | W | C | + | + | + | GS, SBH, MG |
| 65 | Crested Hawk Eagle | *Nisaetus cirrhatus* | P, K | R | C | + | + | + | GS, SBH, MG ,PL, WD |
| | **Strigiformes/ Tytonidae** | | | | | | | | |
| 66 | Barn Owl | *Tyto alba* | P | R | C | + | + | + | GS, WD |
| | **Strigiformes/ Strigidae** | | | | | | | | |
| 67 | Indian Scops Owl | *Otus bakkamoena* | P, V, K | R | U | + | + | - | GS, WD |
| 68 | Brown Hawk Owl | *Ninox scutulata*** | V | UN | UN | - | + | - | GS, WD |
| 69 | Brown Wood Owl | *Strix leptogrammica*** | V | UN | UN | - | - | + | WD |
| 70 | Jungle Owlet | *Glaucidium radiatum* | P, V, K | R | C | + | + | + | GS, WD |
| 71 | Spotted Owlet | *Athene brama* | P, V | R | C | + | + | + | GS, WD |
| 72 | Brown Fish Owl | *Ketupa zeylonensis* | P | R | U | - | + | - | FW, GS |
| | **Caprimulgiformes/ Caprimulgidae** | | | | | | | | |
| 73 | Jungle Nightjar | *Caprimulgus indicus* | P, V | R | C | + | + | + | WD, GS |
| 74 | Indian Nightjar | *Caprimulgus asiaticus* | P, V | R | U | + | + | + | WD, GS |
| 75 | Savanna Nightjar | *Caprimulgus affinis* | P, V | R | U | - | + | - | WD, GS |
| | **Gruiformes/ Rallidae** | | | | | | | | |
| 76 | Slaty-legged Crake | *Rallina eurizonoides* | P | W | U | - | + | - | FW |
| 77 | Slaty-breasted Rail | *Gallirallus striatus* | P, V | R | U | + | + | - | MG |
| 78 | White-breasted Waterhen | *Amaurornis phoenicurus* | P, K | R | C | + | + | + | FW, MG, AQ, AG |
| 79 | Common Moorhen | *Gallinula chloropus* | P | R/LM | U | + | - | - | FW, SAL |
| 80 | Eurasian Coot | *Fulica atra* | P | R/LM | U | + | - | - | FW, SAL |
| 81 | Purple Swamphen | *Porphyrio porphyrio* | P, V | R/LM | C | + | + | - | FW |
| | **Charadriiformes/ Jacanidae** | | | | | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 82 | Pheasant-tailed Jacana | *Hydrophasianus chirurgus* | P, K | R/LM | C | + | + | - | FW |
| 83 | Bronze-winged Jacana | *Metopidius indicus* | P | R/LM | C | + | - | - | FW |
| | **Charadriiformes/ Haematopodidae** | | | | | | | | |
| 84 | Eurasian Oystercatcher | *Haematopus ostralegus* | P | PM | R | - | + | + | SBH |
| | **Charadriiformes/ Recurvirostridae** | | | | | | | | |
| 85 | Black-Winged Stilt | *Himantopus himantopus* | P, V | R | C | + | + | + | AQ, SAL |
| | **Charadriiformes/ Dromadidae** | | | | | | | | |
| 86 | Crab-plover | *Dromas ardeola* | P | PM | R | + | - | - | SBH |
| | **Charadriiformes/ Charadriidae** | | | | | | | | |
| 87 | Little Ringed Plover | *Charadrius dubius* | P, V, K | W | C | + | + | + | AQ, SAL, SBH, GS |
| 88 | Kentish Plover | *Charadrius alexandrinus* | P, V | W | C | + | + | + | SBH,INMDF, MG, AQ |
| 89 | Lesser Sand Plover | *Charadrius mongolus* | P, V | W | C | + | + | + | SBH, INMDF, MG, AQ, SAL, GS, RSH |
| 90 | Greater Sand Plover | *Charadrius leschenaultii* | P | W | C | + | + | + | SBH, INMDF, MG, AQ |
| 91 | Pacific Golden Plover | *Pluvialis fulva* | P | W | C | + | + | + | SBH, INMDF, MG, AQ, SAL, GS, AG, RSH |
| 92 | Grey Plover | *Pluvialis squatarola* | P, V | W | U | + | + | + | SBH, AQ, SAL, INMDF |
| 93 | Yellow-wattled Lapwing | *Vanellus malabaricus* | P, V | R/LM | C | + | + | + | GS, AG |

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|---|---|---|---|---|---|---|---|---|---|
| 94 | Red-wattled Lapwing | *Vanellus indicus* | P, K | R | C | + | + | + | MG, AQ, SAL, GS, AG,FW |
| | **Charadriiformes/ Rostratulidae** | | | | | | | | |
| 95 | Greater Painted-snipe | *Rostratula benghalensis* | P | R | U | + | - | - | GS, AQ |
| | **Charadriiformes/ Scolopacidae** | | | | | | | | |
| 96 | Ruff | *Philomachus pugnax* | P | PM | R | - | + | - | GS |
| 97 | Common Snipe | *Gallinago gallinago* | P, K | W | C | + | + | + | GS, AG, AQ |
| 98 | Black-tailed Godwit | *Limosa limosa* | P | PM | R | + | - | | SAL |
| 99 | Bar-tailed Godwit | *Limosa lapponica* | P | PM | R | - | - | + | AQ, INMDF |
| 100 | Whimbrel | *Numenius phaeopus* | P, V | W | C | + | + | + | SBH, INMDF, MG, AQ, SAL, GS |
| 101 | Eurasian Curlew | *Numenius arquata* | P | W | C | + | + | + | SBH, INMDF, MG, AQ, GS |
| 102 | Common Redshank | *Tringa totanus* | P, K | W | C | + | + | + | SBH, INMDF, MG, AQ, SAL |
| 103 | Common Greenshank | *Tringa nebularia* | P | W | C | + | + | + | SBH, INMDF, MG, AQ, SAL, AG |
| 104 | Marsh Sandpiper | *Tringa stagnatilis* | P | W | U | + | + | + | AQ, SAL |
| 105 | Green Sandpiper | *Tringa ochropus* | P | W | U | + | + | + | AQ, SAL, GS, AG |
| 106 | Wood Sandpiper | *Tringa glareola* | P, K | W | C | + | + | + | AQ, SAL, GS, FW, AG |
| 107 | Terek Sandpiper | *Xenus cinereus* | P | W | C | + | + | + | SAT, SBH, INMDF, MG |
| 108 | Common Sandpiper | *Actitis hypoleucos* | P, A, PA, L, K | W | C | + | + | + | AQ, SAL, SBH, INMDF, MG, RSH, FW, GS, AG |
| 109 | Ruddy Turnstone | *Arenaria interpres* | P, V, A, G, KMP, PA, L | W | C | + | + | + | SBH, RSH, GS |

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|---|---|---|---|---|---|---|---|---|---|
| 110 | Little Stint | *Calidris minuta* | P | W | C | + | + | + | AQ, SAL, SBH, INMDF, RSH, GS |
| 111 | Temminck's Stint | *Calidris temminckii* | P | W | C | + | + | + | AQ, SAL |
| 112 | Sanderling | *Calidris alba* | P, V | W | U | + | + | + | SBH, INMDF |
| 113 | Curlew Sandpiper | *Calidris ferruginea* | P, V | W | U | + | + | + | SBH, INMDF, AQ, SAL, RSH |
| 114 | Great Knot | *Calidris tenuirostris* | P | PM | R | + | - | - | INMDF, SBH |
| 115 | Broad-billed Sandpiper | *Limicola falcinellus* | P | PM | U | + | + | + | SAT, SBH, INMDF |
| 116 | Dunlin | *Calidris alpina* | P | W | U | + | + | + | AQ, SAL, INMDF, SBH |
| | **Charadriiformes/ Glareolidae** | | | | | | | | |
| 117 | Small Pratincole | *Glareola lacteal* | P | R/LM | U | + | - | - | ASL, SBH |
| 118 | Oriental Pratincole | *Glareola maldivarum* | P | W | R | - | + | - | GS |
| 119 | Great Thick-knee | *Esacus recurvirostris* | P | R/LM | R | + | - | - | FW, INMDF |
| 120 | Indian Thick-knee | *Burhinus indicus*** | V | UN | UN | - | + | - | FW, GS |
| | **Charadriiformes/ Laridae** | | | | | | | | |
| 121 | Pallas's Gull | *Ichthyaetus ichthyaetus* | P | W | C | + | + | + | SBH, OFSH, INMDF |
| 122 | Heuglin's Gull | *Larus heuglini* | P, V, L | W | C | + | + | + | SBH, OFSH, RSH, INMDF |
| 123 | Steppe Gull | *Larus barabensis* | P | W | U | + | + | + | SBH, OFSH, INMDF |
| 124 | Slender-billed Gull | *Chroicocephalus genei* | P | W | C | + | + | + | SBH, OFSH, INMDF |
| 125 | Brown-headed Gull | *Chroicocephalus brunnicephalus* | P, V, A, L | W | C | + | + | + | SBH, OFSH, INMDF, RSH |
| 126 | Black-headed Gull | *Chroicocephalus ridibundus* | P, G, L | W | C | + | + | + | SBH, OFSH, INMDF, RSH |
| 127 | Gull-billed Tern | *Gelochelidon nilotica* | P | W | C | + | + | + | SBH, INMDF |
| 128 | Lesser Crested Tern | *Thalasseus bengalensis* | P, V, A, L,VK, KMP, KD | W | C | + | + | + | SBH, INMDF, VGR |

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| 129 | Greater Crested Tern | *Thalasseus bergii* | P, V, A, M, VK, PA, KMP, L | R | C | + | + | + | SBH, INMDF, VGR |
| 130 | Caspian Tern | *Hydroprogne caspia* | P, A, L | W | U | + | + | + | SBH, INMDF |
| 131 | Sandwich Tern | *Thalasseus sandvicensis* | P, G, L | W | U | + | + | + | SBH, INMDF |
| 132 | River Tern | *Sterna aurantia* | P, PA | R/LM | U | + | - | - | FW |
| 133 | Little Tern | *Sternula albifrons* | P, A, G | R/LM | R | + | + | - | FW, SAL |
| 134 | Roseate Tern | *Sterna dougallii* | P, H, A, VK, PA, KMP, L | R/LM | U | + | - | - | VGR |
| 135 | Common Tern | *Sterna hirundo* | P, PA, L | W | R | - | + | - | OFSH |
| 136 | Whiskered Tern | *Chlidonias hybrida* | P | W | U | + | + | + | AQ, SAL, INMDF, SBH |
| 137 | White-cheeked Tern | *Sterna repressa*** | V, M, PA, L | UN | UN | + | + | - | OFSH |
| 138 | Sooty Tern | *Onychoprion fuscatus* | P, A, M, PA, L | PM | U | + | - | + | OFSH |
| 139 | Bridled Tern | *Onychoprion anaethetus*** | V, A, M, VK, PA, KMP, L | UN | UN | + | - | - | VGR, OFSH |
| 140 | Brown Noddy | *Anous stolidus*** | L | UN | UN | + | - | - | OFSH |
| | **Charadriiformes/ Stercorariidae** | | | | | | | | |
| 141 | Brown Skua | *Stercorarius antarcticus*** | ED | UN | UN | - | + | - | OFSH |
| 142 | Arctic Skua | *Stercorarius parasiticus*** | L | UN | UN | + | - | - | OFSH |
| 143 | Pomarine Skua | *Stercorarius pomarinus*** | PA | UN | UN | + | - | - | OFSH |
| | **Procellariiformes/ Oceanitidae** | | | | | | | | |
| 144 | Wilson's Storm-petrel | *Oceanites oceanicus* | P | PM | R | + | - | - | OFSH |
| | **Gaviiformes/ Gaviidae** | | | | | | | | |
| 145 | Red-throated Diver | *Gavia stellata*** | AV | UN | UN | - | - | + | OFSH |
| | **Columbiformes/ Columbidae** | | | | | | | | |

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| 146 | Common Pigeon | *Columba livia* | P, H, V, A, PKT, PA, KMP, L MP, K | R | C | + | + | + | WD, GS, VGR |
| 147 | Laughing Dove | *Stigmatopelia senegalensis* | P | R | C | + | + | + | WD, GS |
| 148 | Spotted Dove | *Stigmatopelia chinensis* | P, K | R | C | + | + | + | WD, GS |
| 149 | Red Collared Dove | *Streptopelia tranquebarica* | P, K | R/LM | U | + | + | + | WD, GS |
| 150 | Emerald Dove | *Chalcophaps indica* | P | R | C | + | + | + | WD |
| 151 | Oriental Turtle Dove | *Streptopelia orientalis* | P, L | R | U | + | + | + | WD, GS |
| 152 | Eurasian Collared Dove | *Streptopelia decaocto* | P | R | C | + | + | + | WD, GS |
| 153 | Grey-fronted Green Pigeon | *Treron affinis* | P | R/LM | U | + | + | - | WD |
| 154 | Yellow-footed Green Pigeon | *Treron phoenicopterus* | P, K | R/LM | C | + | + | + | WD |
| 155 | Orange-breasted Green Pigeon | *Treron bicinctus* | P | PM | U | + | + | - | WD |
| | **Psittaciformes/ Psittaculidae** | | | | | | | | |
| 156 | Vernal Hanging Parrot | *Loriculus vernalis* | P, K | R | C | + | + | + | WD |
| 157 | Rose-ringed Parakeet | *Psittacula krameri* | P, K | R | C | + | + | + | WD, PL |
| 158 | Plum-headed Parakeet | *Psittacula cyanocephala* | P, K | R/LM | C | + | + | + | WD, PL |
| | **Cuculiformes/ Cuculidae** | | | | | | | | |
| 159 | Grey-bellied Cuckoo | *Cacomantis passerinus*** | V | UN | UN | + | + | - | WD, GS |
| 160 | Jacobin Cuckoo | *Clamator jacobinus* | P | W | U | + | + | + | WD |
| 161 | Common Hawk Cuckoo | *Hierococcyx varius* | P, K | R/LM | C | + | + | + | WD |
| 162 | Banded Bay Cuckoo | *Cacomantis sonneratii* | P, V | R/LM | C | + | + | - | WD |
| 163 | Eurasian Cuckoo | *Cuculus canorus* | P | PM | U | - | + | + | WD |
| 164 | Lesser Cuckoo | *Cuculus poliocephalus* | P | PM | U | - | + | - | WD, GS |

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| 165 | Asian Koel | *Eudynamys scolopaceus* | P, V, K | R | C | + | + | + | WD, MG, GS |
| 166 | Southern Coucal | *Centropus sinensis parroti* | P, K | R | C | + | + | + | WD, MG, GS |
| 167 | Blue-faced Malkoha | *Rhopodytes viridirostris* | P, V | R | U | + | + | + | WD, MG |
| 168 | Sirkeer Malkoha | *Taccocua leschenaultii*** | V | UN | UN | - | + | - | WD |
| | **Caprimulgiformes/ Hemiprocnidae** | | | | | | | | |
| 169 | Crested Treeswift | *Hemiprocne coronate* | P, V | R | C | - | - | + | GS |
| | **Caprimulgiformes/ Apodidae** | | | | | | | | |
| 170 | Asian Palm Swift | *Cypsiurus balasiensis* | P, V, A | R | C | + | + | + | WD, FW |
| 171 | Indian Swiftlet | *Collocalia unicolor* | P, V, A, L, MB, PKT | R | U | + | - | - | VGR |
| 172 | Little Swift | *Apus affinis* | P, L | R | C | + | + | + | WD, FW, VGR |
| | **Coraciiformes/ Coraciidae** | | | | | | | | |
| 173 | Indian Roller | *Coracias benghalensis* | P, V, K | R/LM | C | + | + | + | GS, WD, AG, FW |
| 174 | Eurasian Roller | *Coracias garrulus* | P | W | U | + | + | + | GS, WD |
| | **Coraciiformes/ Alcedinidae** | | | | | | | | |
| 175 | Common Kingfisher | *Alcedo atthis* | P | R | C | + | + | + | FW, INMDF, MG, AQ, SAL |
| 176 | Stork-billed Kingfisher | *Pelargopsis capensis* | P, V, K | R/LM | U | + | + | + | FW, MG |
| 177 | White-throated Kingfisher | *Halcyon smyrnensis* | P, V, K | R | C | + | + | + | MG, FW, INMDF, SBH, AQ, SAL, GS |

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| 178 | Black-capped Kingfisher | *Halcyon pileata* | P, V | W | U | + | + | + | MG, INMDF |
| 179 | Oriental Dwarf Kingfisher | *Ceyx erithaca* | P | MM | U | - | + | - | MG |
| 180 | Pied Kingfisher | *Ceryle rudis* | P, K | R/LM | U | + | + | + | FW, MG, AQ, SAL |
| | **Coraciiformes/ Meropidae** | | | | | | | | |
| 181 | Green Bee-eater | *Merops orientalis* | P, K | R | C | + | + | + | FW, WD, GS, AQ, SAL |
| 182 | Chestnut-headed Bee- eater | *Merops leschenaultia* | P | W | C | + | + | + | FW, WD, GS |
| 183 | Blue-tailed Bee-eater | *Merops philippinus* | P, V | W | U | - | + | - | GS, WD |
| 184 | Blue-bearded Bee-eater | *Nyctyornis athertoni*** | K | UN | UN | - | + | - | WD |
| | **Bucerotiformes/ Upupidae** | | | | | | | | |
| 185 | Common Hoopoe | *Upupa epops* | P, V, L, K | R | C | + | + | + | WD, GS |
| | **Bucerotiformes/ Bucerotidae** | | | | | | | | |
| 186 | Malabar Grey Hornbill | *Ocyceros griseus* | P | R | U | - | + | - | WD |
| 187 | Malabar Pied Hornbill | *Anthracoceros coronatus* | P, V, K | R | C | + | + | + | WD, PL, GS, MG |
| 188 | Indian Grey Hornbill | *Ocyceros birostris* | P, K | R/LM | U | + | + | + | WD |
| | **Piciformes/ Megalaimidae** | | | | | | | | |
| 189 | Brown-headed Barbet | *Megalaima zeylanica* | P, K | R | C | + | + | + | WD |
| 190 | Coppersmith Barbet | *Megalaima haemacephala* | P, K | R | C | + | + | + | WD |
| 191 | White-cheeked Barbet | *Megalaima viridis* | P | R | U | + | + | - | WD |

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| | **Piciformes/ Picidae** | | | | | | | | |
| 192 | Rufous Woodpecker | *Micropternus brachyurus* | P | R | U | - | - | + | WD, PL |
| 193 | Lesser Goldenback | *Dinopium benghalense* | P, V, K | R | C | + | + | + | WD, PL |
| 194 | Greater Goldenback | *Chrysocolaptes lucidus* | P | R | U | + | - | - | WD, PL |
| 195 | Yellow-crowned Woodpecker | *Dendrocopos mahrattensis* | P, V, K | R | U | - | + | - | WD |
| 196 | White-naped Woodpecker | *Chrysocolaptes festivus*** | V | UN | UN | - | - | + | WD |
| | **Passeriformes/ Pittidae** | | | | | | | | |
| 197 | Indian Pitta | *Pitta brachyura* | P, V | W | U | - | + | + | WD |
| | **Passeriformes/ Artamidae** | | | | | | | | |
| 198 | Ashy Woodswallow | *Artamus fuscus* | P | R | C | + | + | + | WD |
| | **Passeriformes/ Vangidae** | | | | | | | | |
| 199 | Common Woodshrike | *Tephrodornis pondicerianus* | P, V | R | C | + | + | + | PL, WD |
| 200 | Bar-winged Flycatcher- shrike | *Hemipus picatus* | P | R | U | + | - | - | WD |
| | **Passeriformes/ Aegithinidae** | | | | | | | | |
| 201 | Common Iora | *Aegithina tiphia* | P, K | R | C | + | + | + | PL, WD |
| | **Passeriformes/ Campephagidae** | | | | | | | | |
| 202 | Black-headed Cuckooshrike | *Coracina melanoptera* | P, V, L | R/LM | C | + | + | + | WD |
| 203 | Small Minivet | *Pericrocotus cinnamomeus* | P, V, K | R | C | + | + | + | PL, WD |
| 204 | Orange Minivet | *Pericrocotus flammeus* | P, K | R | U | - | + | - | WD |
| 205 | Large Cuckooshrike | *Coracina macei* | P | R | U | - | + | - | WD |
| | **Passeriformes/ Laniidae** | | | | | | | | |
| 206 | Brown Shrike | *Lanius cristatus* | P | W | U | + | - | - | WD, GS |
| 207 | Long-tailed Shrike | *Lanius schach* | P, K | R | C | + | + | + | WD, GS |
| 208 | Bay-backed Shrike | *Lanius vittatus* | P, K | R | U | + | + | + | WD, GS |
| | **Passeriformes/ Dicruridae** | | | | | | | | |

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| 209 | Black Drongo | *Dicrurus macrocercus* | P, L, K | R | C | + | + | + | FW, WD, GS, MG |
| 210 | Ashy Drongo | *Dicrurus leucophaeus* | P | W | C | + | + | + | WD |
| 211 | White-bellied Drongo | *Dicrurus caerulescens* | P | R/LM | U | + | + | + | WD |
| 212 | Greater Racket-tailed Drongo | *Dicrurus paradiseus* | P, V, K | R | C | + | + | + | WD |
| 213 | Bronzed Drongo | *Dicrurus aeneus* | P | R | U | + | - | - | WD |
| | **Passeriformes/ Oriolidae** | | | | | | | | |
| 214 | Indian Golden Oriole | *Oriolus kundoo* | P, K | W | C | + | + | + | WD, GS |
| 215 | Black-hooded Oriole | *Oriolus xanthornus* | P, V, K | R | C | + | + | + | WD, GS |
| | **Passeriformes/ Rhipiduridae** | | | | | | | | |
| 216 | White-browed Fantail | *Rhipidura aureola* | P | R | C | + | + | + | WD, PL, MG |
| 217 | White-spotted Fantail | *Rhipidura albicollis albogularis* | P, V, K | R | U | - | + | + | WD, PL, MG |
| | **Passeriformes/ Monarchidae** | | | | | | | | |
| 218 | Black-naped Monarch | *Hypothymis azurea* | P | R | U | + | + | - | WD |
| 219 | Asian Paradise-flycatcher | *Terpsiphone paradisi* | P, V, K | R/LM | U | + | + | + | WD |
| | **Passeriformes/ Corvidae** | | | | | | | | |
| 220 | Rufous Treepie | *Dendrocitta vagabunda* | P, K | R | C | + | + | + | WD, GS |
| 221 | House Crow | *Corvus splendens* | P, L, K | R | C | + | + | + | WD, SBH, RSH, MG |
| 222 | Indian Jungle Crow | *Corvus culminatus* | P, PKT, K | R | C | + | + | + | WD, SBH, RSH, MG |
| | **Passeriformes/ Paridae** | | | | | | | | |
| 223 | Great Tit | *Parus major* | P | R | U | + | + | + | WD |
| 224 | Indian Yellow Tit | *Parus aplonotus* | P | R | C | + | + | - | WD |

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| | **Passeriformes/ Hirundinidae** | | | | | | | | |
| 225 | Dusky Crag Martin | *Ptyonoprogne concolor* | P | R | C | - | + | + | WD |
| 226 | Eurasian Crag Martin | *Ptyonoprogne rupestris* | P | W | U | + | + | + | WD |
| 227 | Wire-tailed Swallow | *Hirundo smithii* | P, V, K | R | C | + | + | + | WD, GS, AQ, SAL, FW |
| 228 | Red-rumped Swallow | *Cecropis daurica* | P, K | R | C | + | + | + | WD, GS, AQ, SAL, FW |
| 229 | Barn Swallow | *Hirundo rustica* | P | W | U | + | - | - | FW |
| 230 | Streak-throated Swallow | *Petrochelidon fluvicola* | P, V | R/LM | U | + | - | - | FW |
| | **Passeriformes/ Alaudidae** | | | | | | | | |
| 231 | Rufous-tailed Lark | *Ammomanes phoenicura* | P | R | U | + | + | + | GS |
| 232 | Oriental Skylark | *Alauda gulgula* | P | R | C | + | + | + | GS |
| 233 | Greater Short-toed Lark | *Calandrella brachydactyla* | P, L | W | U | + | + | - | GS |
| 234 | Malabar Lark | *Galerida malabarica* | P, K | R | C | + | + | + | GS |
| | **Passeriformes/ Pycnonotidae** | | | | | | | | |
| 235 | Red-vented Bulbul | *Pycnonotus cafer* | P, K | R | C | + | + | + | WD, GS, MG, PL |
| 236 | White-browed Bulbul | *Pycnonotus luteolus* | P, V | R | U | + | + | + | WD, GS, MG |
| 237 | Red-whiskered Bulbul | *Pycnonotus jocosus* | P, K | R | C | + | + | + | WD, GS, MG, PL |
| 238 | Grey-headed Bulbul | *Pycnonotus priocephalus* | P | R | U | + | + | - | WD |
| | **Passeriformes/ Cisticolidae** | | | | | | | | |
| 239 | Grey-breasted Prinia | *Prinia hodgsonii* | P, K | R | C | + | + | + | WD, GS |
| 240 | Ashy Prinia | *Prinia socialis* | P, K | R | C | + | + | + | WD, GS |
| 241 | Plain Prinia | *Prinia inornata* | P, K | R | C | + | + | + | WD, GS |
| 242 | Jungle Prinia | *Prinia sylvatica* | P | R | C | + | + | + | WD, GS |
| 243 | Zitting Cisticola | *Cisticola juncidis* | P, K | R | U | + | + | - | GS, AG |

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| 244 | Common Tailorbird | *Orthotomus sutorius* | P, K | R | C | + | + | + | WD, GS, FW, MG |
| | **Passeriformes/ Acrocephalidae** | | | | | | | | |
| 245 | Blyth's Reed Warbler | *Acrocephalus dumetorum* | P | W | U | + | + | + | FW |
| 246 | Booted Warbler | *Iduna caligata* | P | W | U | - | + | - | WD |
| 247 | Clamorous Reed Warbler | *Acrocephalus stentoreus* | P, V | W | U | + | + | + | WD |
| | **Passeriformes/ Phylloscopidae** | | | | | | | | |
| 248 | Greenish Warbler | *Phylloscopus trochiloides* | P, V | W | U | + | + | + | MG, WD |
| | **Passeriformes/ Timaliidae** | | | | | | | | |
| 249 | Indian Scimitar Babbler | *Pomatorhinus horsfieldii* | P, V | R | U | + | + | - | WD |
| 250 | Tawny-bellied Babbler | *Dumetia hyperythra* | P | R | U | - | + | - | WD |
| | **Passeriformes/ Leiothrichidae** | | | | | | | | |
| 251 | Jungle Babbler | *Turdoides striata* | P, V, K | R | C | + | + | + | WD, GS, PL |
| 252 | Large Grey Babbler | *Turdoides malcolmi* | P | R | U | + | + | + | WD |
| 253 | Brown-cheeked Fulvetta | *Alcippe poioicephala* | P, V | R | U | - | + | - | WD |
| | **Passeriformes/ Pellorneidae** | | | | | | | | |
| 254 | Puff-throated Babbler | *Pellorneum ruficeps* | P | R | U | + | + | + | WD |
| | **Passeriformes/ Sylviidae** | | | | | | | | |
| 255 | Yellow-eyed Babbler | *Chrysomma sinense* | P, V | R | U | - | + | + | WD |
| | **Passeriformes/ Zosteropidae** | | | | | | | | |
| 256 | Oriental White-eye | *Zosterops palpebrosus* | P | R | U | - | - | + | WD |
| | **Passeriformes/ Sturnidae** | | | | | | | | |
| 257 | Brahminy Starling | *Sturnia pagodarum* | P, V | R/LM | C | + | + | + | WD, GS |
| 258 | Chestnut-tailed Starling | *Sturnia malabarica* | P | W | C | + | + | + | WD, MG, GS, PL |
| 259 | Rosy Starling | *Pastor roseus* | P | W | C | + | + | + | GS |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 260 | Common Myna | *Acridotheres tristis* | P, K | R | C | + | + | + | WD,GS, MG |
| 261 | Jungle Myna | *Acridotheres fuscus* | P, K | R | C | + | + | + | WD,GS, MG |
| | **Passeriformes/ Turdidae** | | | | | | | | |
| 262 | Orange-headed Thrush | *Zoothera citrina* | P, V, K | R | C | + | + | + | WD |
| 263 | Indian Blackbird | *Turdus merula simillimus*** | V | UN | UN | - | + | + | WD |
| | **Passeriformes/ Muscicapidae** | | | | | | | | |
| 264 | Oriental Magpie Robin | *Copsychus saularis* | P, K | R | C | + | + | + | WD, GS, FW, MG |
| 265 | Indian Robin | *Saxicoloides fulicatus* | P, PKT, K | R | C | + | + | + | WD, GS, FW, MG |
| 266 | Blue Throat | *Luscinia svecica* | P | W | U | - | - | + | WD |
| 267 | White-rumped Shama | *Copsychus malabarica* | P | R | U | + | - | - | WD |
| 268 | Black Redstart | *Phoenicurus ochruros* | P | W | U | - | - | + | WD |
| 269 | Common Stonechat | *Saxicola torquatus* | P | W | C | + | + | + | GS |
| 270 | Pied Bushchat | *Saxicola caprata* | P, V, K | R | C | + | + | + | AG, GS, SAL |
| 271 | Blue Rock Thrush | *Monticola solitarius* | P, H, A, L | W | C | + | + | + | RSH |
| 272 | Blue-capped Rock Thrush | *Monticola cinclorhynchus*** | V | UN | UN | + | - | - | WD |
| 273 | Malabar Whistling Thrush | *Myophonus horsfieldii* | P, V | R | U | - | - | + | WD |
| 274 | Asian Brown Flycatcher | *Muscicapa dauurica* | P, V, L | W | U | + | - | + | WD |
| 275 | Brown-breasted Flycatcher | *Muscicapa muttui* | P | W | R | + | - | - | WD |
| 276 | Tickell's Blue Flycatcher | *Cyornis tickelliae* | P, K | R | C | + | + | + | WD, MG |
| 277 | Verditer Flycatcher | *Eumyias thalassinus*** | V | UN | UN | - | - | + | WD |
| | **Passeriformes/ Stenostiridae** | | | | | | | | |
| 278 | Grey-headed Canary Flycatcher | *Culicicapa ceylonensis* | P | W | U | + | - | - | WD |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Passeriformes/ Chloropseidae** | | | | | | | | |
| 279 | Golden-fronted Leafbird | *Chloropsis aurifrons* | P | R | C | + | + | + | WD |
| 280 | Jerdon's Leafbird | *Chloropsis jerdoni* | P, V, K | R | C | + | + | + | WD |
| | **Passeriformes/ Dicaeidae** | | | | | | | | |
| 281 | Pale-billed Flowerpeckar | *Dicaeum erythrorhynchos* | P, K | R | C | + | + | + | WD |
| 282 | Thick-billed Flowerpecker | *Dicaeum agile* | P, V, K | R | C | + | + | + | WD |
| 283 | Nilgiri Flowerpecker | *Dicaeum concolor* | P, K | R | U | - | + | - | WD |
| | **Passeriformes/ Nectariniidae** | | | | | | | | |
| 284 | Purple-rumped Sunbird | *Leptocoma zeylonica* | P, V, K | R | C | + | + | + | WD, PL, MG |
| 285 | Purple Sunbird | *Cinnyris asiaticus* | P | R | C | + | + | + | WD, PL, MG |
| 286 | Loten's Sunbird | *Cinnyris lotenia* | P | R | U | + | + | + | WD, PL |
| 287 | Vigor's Sunbird | *Aethopyga vigorsii* | P, K | R | U | - | + | - | WD |
| 288 | Crimson-backed Sunbird | *Leptocoma minima*** | MU | UN | UN | - | + | - | WD |
| | **Passeriformes/ Passeridae** | | | | | | | | |
| 289 | House Sparrow | *Passer domesticus* | P, K | R | C | + | + | + | WD |
| 290 | Chestnut-shouldered Petronia | *Gymnoris xanthocollis* | P, K | R | C | + | + | + | WD, GS |
| | **Passeriformes/ Ploceidae** | | | | | | | | |
| 291 | Baya Weaver | *Ploceus philippinus* | P, K | R | C | + | + | + | FW, AG, GS |
| | **Passeriformes/ Estrildidae** | | | | | | | | |
| 292 | Indian Silverbill | *Euodice malabarica* | P | R | C | + | + | + | AG, GS |
| 293 | Scaly-breasted Munia | *Lonchura punctulata* | P | R | C | + | + | + | AG, MG, GS |
| 294 | Black-headed Munia | *Lonchura malacca* | P | R | C | + | + | + | AG, MG, GS |
| 295 | White-rumped Munia | *Lonchura striata* | P, V, K | R | C | + | + | + | AG, MG, GS |

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|---|---|---|---|---|---|---|---|---|---|
| | **Passeriformes/ Motacillidae** | | | | | | | | |
| 296 | Forest Wagtail | *Dendronanthus indicus*** | V | UN | UN | - | + | - | WD, GS |
| 297 | White Wagtail | *Motacilla alba* | P, V | W | C | + | + | + | FW, AQ, SAL |
| 298 | White-browed Wagtail | *Motacilla maderaspatensis* | P, K | R | C | + | + | + | AG, FW, AQ, SAL |
| 299 | Citrine Wagtail | *Motacilla citreola* | P | W | U | - | + | - | AG |
| 300 | Yellow Wagtail | *Motacilla flava* | P, K | W | U | + | + | + | AG |
| 301 | Grey Wagtail | *Motacilla cinerea* | P, L | W | C | + | + | + | AG, FW, AQ, SAL |
| 302 | Paddyfield Pipit | *Anthus rufulus* | P, K | R | C | + | + | + | AG, GS, AQ, SAL |
| 303 | Tawny Pipit | *Anthus campestris* | P | W | U | + | - | - | AG, GS, AQ, SAL |
| 304 | Blyth's Pipit | *Anthus godlewskii* | P | W | U | + | - | + | AQ, SAL |
| 305 | Tree Pipit | *Anthus trivialis* | P, V | W | U | + | + | + | GS |
| 306 | Richard's Pipit | *Anthus richardi* | P | W | U | + | + | + | GS |
| | **Passeriformes/ Emberizidae** | | | | | | | | |
| 307 | Black-headed Bunting | *Emberiza melanocephala* | P | W | U | - | + | + | GS |

Observers: **Species compiled from published literature, **P**—Present study, **H**—Hume 1876, **V**—Vidal 1880, 1883, **A**—Adbulali 1940, 1942, 1983, **ED**—Editors 1958, **M**—Madsen 1988, **G**—Gole 1994, **VK**—Katdare 2001, **PKT**—Pande et al. 2001, **PA**—Pande 2002a,b, **L**—Lainer 2003, **KMP**—Katdare et al. 2004a, **MP**—Mahabal & Pande 2006, **KD**—Kasambe & Deshmukh 2011, **KM**—Kamble et al. 2011, **J**—Jamalabad 2013, **K**—Khot 2016, **AV**—Avalaskar 2016, **MU**—Shrikrishna Ramachandra Magdum pers. obs. 2017. Status: **R**—Resident, **W**—winter migrant, **PM**—Passage migrant, **MM**—Monsoon migrant, **V**—Vagrant. **Occurrence**: **Common**—percentage of sightng >3%, **Uncommon**—percentage of sightng 1–3 %, **Rare**—percentage of sightng <1%, **UN**—Unknown, species compiled from literature. Habitats: **GS**—Grasslands, **WD**—Woodlands, **FW**—Fresh water habitat, **AQ**—Aquaculture Pond, **SAL**—Saltpan, **INMDF**—Intertdal sandy mudfats, **MG**—Mangroves, **SBH**—Sandy beach, **RSH**—Rocky shore, **VGR**—Vengurla Rocks, **OFSH**—Offshore waters, **AG**—Agriculture lands.

**Appendix 2.** Arrival and departure dates of wintering birds in the Sindhudurg

| S.NO | Species | Departure time 2015-2016 | Arrival time 2015-2016 | Departure time 2016-2017 | Arrival time 2016-2017 | Departure time 2017-2018 |
|---|---|---|---|---|---|---|
| 1 | Lesser Sand Plover | 16-Apr | 01-Sep | Jun-16 | 19-Aug | 27-Apr |
| 2 | Greater Sand Plover | 16-Apr | 24-Oct | 13-Apr | 06-Oct | 27-Apr |
| 3 | Kentish Plover | 12-Apr | 05-Sep | 17-Apr | 17-Aug | 27-Apr |
| 4 | Pacific Golden Plover | 16-Apr | 06-Sep | 15-Apr | 04-Oct | 28-Apr |
| 5 | Grey Plover | 12-Mar | 02-Sep | 28-Mar | 04-Oct | 18-Mar |
| 6 | Little Ringed Plover | 16-Apr | 02-Oct | 19-Apr | 04-Oct | 28-Apr |
| 7 | Common Sandpiper | 16-Apr | 08-Aug | 15-Apr | 17-Aug | 28-Apr |
| 8 | Wood Sandpiper | 16-Apr | 18-Sep | 15-Apr | 07-Oct | 28-Apr |
| 9 | Marsh Sandpiper | 12-Apr | 05-Jan | 15-Apr | 06-Nov | 28-Apr |
| 10 | Green Sandpiper | 16-Apr | 18-Sep | 16-Apr | 08-Oct | 18-Apr |
| 11 | Terek Sandpiper | 12-Apr | 06-Sep | 04-Mar | 04-Oct | 30-Apr |
| 12 | Curlew Sandpiper | 16-Apr | 02-Oct | 13-Apr | 04-Oct | 30-Apr |
| 13 | Broad-billed Sandpiper | 25-Mar | 02-Oct | Unpredicted | 19-Aug | Unpredicted |
| 14 | Dunlin | 14-Feb | 16-Nov | 13-Apr | 08-Oct | Unpredicted |
| 15 | Sanderling | 25-Mar | 04-Oct | 13-Apr | 04-Oct | 18-Apr |
| 16 | Little Stint | 16-Apr | 02-Sep | 15-Apr | 19-Aug | 30-Apr |
| 17 | Temminck's Stint | 16-Apr | 28-Oct | 15-Apr | 08-Oct | 30-Apr |
| 18 | Ruddy Turnstone | 14-Apr | 07-Aug | 19-Apr | 20-Aug | 28-Apr |
| 19 | Common Redshank | 16-Apr | 01-Sep | 23-Apr | 19-Aug | 30-Apr |
| 20 | Common Greenshank | 16-Apr | 02-Sep | 05-May | 06-Oct | 30-Apr |
| 21 | Whimbrel | 15-Apr | 04-Aug | 02-Mar | 11-Jul | 18-Mar |
| 22 | Eurasian Curlew | 29-Mar | 02-Sep | 28-Mar | 19-Aug | 19-Mar |
| 23 | Black-tailed Godwit | 05-Jan | - | 04-Mar | - | Unpredicted |
| 24 | Bar-tailed Godwit | - | 28-Oct | Unpredicted | - | Unpredicted |

| | | | | | | |
|---|---|---|---|---|---|---|
| 25 | Ruff | - | 18-Sep | Unpredicted | - | Unpredicted |
| 26 | Crab-Plover | - | - | - | 07-Nov | Unpredicted |
| 27 | Great Knot | - | - | - | 07-Nov | Unpredicted |
| 28 | Eurasian Oystercatcher | - | - | - | 07-Oct | Unpredicted |
| 29 | Common Snipe | - | 06-Nov | 28-Apr | - | - |
| 30 | Oriental Pratincole | | | 26-Aug | Unpredicted | - |
| 31 | Pallas's Gull | 16-Apr | 04-Oct | 05-Mar | 11-Oct | 22-Mar |
| 32 | Slender-billed Gull | 13-Apr | 25-Oct | 18-Mar | 07-Oct | 30-Apr |
| 33 | Black-headed Gull | - | 05-Jan | 16-Apr | 06-Nov | 22-Mar |
| 34 | Brown-headed Gull | 13-Apr | 20-Oct | 17-Apr | 11-Oct | 30-Apr |
| 35 | Lesser Black-backed Gull | 13-Apr | 04-Oct | 19-Apr | 11-Oct | 30-Apr |
| 37 | Gull-billed Tern | 12-Apr | 02-Oct | 15-Apr | 18-Oct | 21-Mar |
| 38 | Lesser Crested Tern | 27-Jun | 10-Aug | 15-Apr | 08-Oct | - |
| 39 | Caspian Tern | 09-Apr | 04-Dec | 15-Apr | 08-Oct | 21-Mar |
| 40 | Sandwich Tern | 12-Apr | 02-Oct | 17-Apr | 11-Oct | 21-Mar |
| 41 | Little Tern | 12-Mar | - | - | - | - |
| 42 | Whiskered Tern | - | 19-Oct | Unpredicted | 07-Oct | 21-Mar |

**Appendix 3.** Results of Tukey Post-hoc test comparing environmental parameters and invertebrate densities between habitats in Sindhudurg district

| Physical and biological variables | Beach x Mudflat | Beach x Mangrove | Mudflat x Mangrove |
|---|---|---|---|
| **Physical parameters** | | | |
| Water temperature °C | .73 | .99 | .84 |
| Sediment temperature °C | 1.0 | .70 | .73 |
| Salinity (ppt) | .10 | .00* | .16 |
| DO (mg/L) | .66 | .77 | .99 |
| pH | .40 | .36 | .98 |
| TSS (mg/L) | .89 | .43 | .22 |
| Organic matter (%) | .03* | .00* | .21 |
| Moisture content (%) | .19 | .01* | .39 |
| **Macrobenthos (no.ind/$m^2$)** | | | |
| Bivalves | .24 | .10* | .00* |
| Crustaceans | .13 | .47 | .01* |
| Gastropods | .00* | .00* | .00* |
| Polychaetes | .41 | .01* | .20 |
| Insects | .85 | .32 | .60 |
| Overall | .01* | .03* | .97 |

*Indicates significance levels at the 0.05

**Appendix 4.** Results of Tukey Post-hoc test comparing environmental parameters between seasons (**AP-**Arrival phase, **WP-**Winter phase, **EDP-**Early departure phase, **DP-**Departure phase, and **BP-**Breeding phase)

| **Physical parameters** | **Season** | **AP** | **WP** | **EDP** | **DP** | **BP** |
|---|---|---|---|---|---|---|
| Water temperature | AP | | .22 | .25 | .00* | .85 |
| | WP | .22 | | .00* | .00* | .77 |
| | EDP | .25 | .00* | | .02* | .03* |
| | DP | .00* | .00* | .02* | | .00* |
| | BP | .85 | .76 | .03* | .00* | |
| Sediment temperature | AP | | .54 | .15* | .00* | .99 |
| | WP | .54 | | .00* | .00* | .73 |
| | EDP | .15 | .00* | | .18 | .08 |
| | DP | .00* | .00* | .18 | | .00* |
| | BP | .99 | .77 | .08 | .00* | |
| Salinity | AP | | .00* | .00* | .00* | .90 |
| | WP | .00* | | .98 | .41 | .00* |
| | EDP | .00* | .98 | | .73 | .00* |
| | DP | .00* | .41 | .73 | | .00* |
| | BP | .91 | .00* | .00* | .00* | |
| DO | AP | | .99 | .99 | .00* | .57 |
| | WP | .99 | | .97 | .00* | .74 |
| | EDP | .99 | .97 | | .00* | .38 |
| | DP | .00* | .00* | .00* | | .00* |
| | BP | .57 | .74 | .38 | .00* | |
| pH | AP | | .94 | .38 | .13 | .04* |
| | WP | .94 | | .83 | .46 | .00* |
| | EDP | .38 | .83 | | .97 | .00* |
| | DP | .13 | .46 | .97 | | .00* |
| | BP | .04* | .00* | .00* | .00* | |
| TSS | AP | | .98 | .94 | .94 | .99 |
| | WP | .99 | | .99 | .99 | .89 |
| | EDP | .94 | .99 | | 1.0 | .73 |
| | DP | .94 | .99 | 1.00 | | .71 |
| | BP | .99 | .86 | .73 | .71 | |
| Organic matter | AP | | .98 | .99 | 1.0 | 1.0 |
| | WP | .98 | | 1.0 | .95 | .95 |
| | EDP | .99 | 1.0 | | .99 | .99 |
| | DP | 1.0 | .95 | .98 | | 1.0 |
| | BP | 1.0 | .95 | .98 | 1.0 | |
| Moisture content | AP | | .71 | .81 | .08 | .87 |
| | WP | .71 | | 1.0 | .00* | .99 |
| | EDP | .81 | 1.0 | | .00* | 1.0 |
| | DP | .08 | .00* | .00* | | .00* |
| | BP | .87 | .99 | 1.0 | .00* | |

*Indicates significance levels at the 0.05,

**Appendix 5.** Results of Tukey Post-hoc test comparing macro benthic densities between seasons (**AP-**Arrival phase, **WP-**Winter phase, **EDP**-Early departure phase, **DP-**Departure phase and **BP-**Breeding phase)

| **Macrobenthos** | **Season** | **AP** | **WP** | **EDP** | **DP** | **BP** |
|---|---|---|---|---|---|---|
| Bivalves | AP | | .91 | .79 | .99 | .02* |
| | WP | .91 | | .99 | .81 | .15 |
| | EDP | .79 | .99 | | .68 | .03 |
| | DP | .99 | .81 | .66 | | .00* |
| | BP | .00* | .02* | .03* | .00* | |
| Crustaceans | AP | | .24 | .81 | .00* | .99 |
| | WP | .24 | | .85 | .00* | .09 |
| | EDP | .81 | .84 | | .00* | .50 |
| | DP | .00* | .00* | .00* | | .02 |
| | BP | .99 | .09 | .50 | .02* | |
| Gastropods | AP | | 1.0 | .87 | .99 | .28 |
| | WP | 1.0 | | .89 | .99 | .28 |
| | EDP | .87 | .87 | | .96 | .82 |
| | DP | .99 | .99 | .96 | | .43 |
| | BP | .28 | .28 | .82 | .43 | |
| Insects | AP | | .94 | 1.0 | .99 | .99 |
| | WP | .94 | | .94 | .75 | .75 |
| | EDP | 1.0 | .94 | | .99 | .99 |
| | DP | .99 | .75 | .99 | | 1.0 |
| | BP | .99 | .75 | .99 | 1.0 | |
| Polychaetes | AP | | .87 | .99 | .20 | .70 |
| | WP | .87 | | .63 | .02* | .19 |
| | EDP | .99 | .63 | | .41 | .91 |
| | DP | .20 | .02* | .41 | | .88 |
| | BP | .70 | .19 | .91 | .88 | |

*Indicates significance levels at the 0.05,