Seasonal and interannual variability of NDVI and waterbird abundance and diversity in Fuente de Piedra Lagoon, Spain

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by

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UNIVERSITY OF TWENTE.

ITC FACULTY OF GEO-INFORMATION SCIENCE AND EARTH OBSERVATION

Dedicated to

My Chachan and Amma

Abstract

Waterbird abundance and diversity is highly influenced by the productivity of its habitat. Remote sensing technique can be used to estimate productivity using NDVI as the surrogate. The present study examine the seasonal and interannual relationships between NDVI and waterbird abundance & diversity at two spatial scales in the Fuente de Piedra lagoon, Spain from 2000 to 2009 using time-series MODIS 250 m NDVI data. The NDVI has extracted at lagoon and 500 m buffer of the lagoon. The waterbird abundance has analysed based on body size, forage type and foraging habitat at individual species level and major waterbird guilds. The seasonal abundance of individual waterbird species is strongly correlated with forage type, body size and forage habitat while the interannual NDVI is moderately correlated with forage type and foraging habitat. The correlation of individual waterbird at the NDVI of the 500 m buffer of the lagoon was higher than the NDVI of the lagoon. The abundance of major waterbird guild is moderately correlated with the seasonal and interannual NDVI of the lagoon and the NDVI of 500 m buffer of the lagoon. The diversity of Anatidae family is strongly correlated with the NDVI of the lagoon and the NDVI of the 500 m buffer lagoon seasonally. The present study reveals that MODIS NDVI can be used as an efficient tool for monitoring seasonal and interannual waterbird abundance and diversity.

Key words: Waterbird, Abundance, Diversity, MODIS NDVI, body size, forage type, foraging habitat, Anatidae.

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1. Introduction

1.1. Background

Wetlands are the important habitat for variety of waterfowls and wetland dependent birds. It serves as feeding, breeding, resting and roosting areas for different species of resident and migratory birds during different seasons of the year (Broyer and Calenge 2010). Presence of various microhabitats in the wetland such as open water, shallow water, mudflats, submerged vegetation, emergent vegetation increases the available foraging area and subsequently the abundance and richness and diversity of avifauna (Murphy *et al*. 1984, Wiens 1989, Safran *et al.* 2000). The waterbird population tends to be high in the wetlands possess variety of microhabitat (Moreno-Mateos *et al*. 2009). The most interesting fact is that birds rely mainly on wetlands free from pollution, rich in food availability and the lack of anthropogenic pressure (Nudds *et al.* 1994, Schreer and Kovacs 1997, Paracuellos 2006). Hence waterbird are widely used as the indicator species of wetland ecosystem monitoring and management activities (Paillisson *et al.* 2002, Gabriel *et al.* 2010).

Food web in the wetland ecosystem acts as the key factor attracting the birds of various foraging requirements and it is controlled by the hydrological conditions of the wetland (Weller 1999, Osiejuk *et al.* 1999). The changes in water regime produce varying microhabitats necessary for diving ducks, dabbling ducks, grazers, waders, shoreliners and divers (Laubhan and Gammonley 2000, Elmberg *et al*. 2010). In addition to microhabitats, productivity increases the carrying capacity of the wetland which is directly influenced by nutrient dynamics (Riffell *et al.* 2001). The positive correlation between physico-chemical characteristics of the water body and waterbird community has been established by various researches in different parts of the world (Parker *et al.* 1992, Townsend *et al.* 1983, Eilers *et al.* 1984). This correlation is due to the high primary productivity of the wetland ecosystem which increases food availability at higher trophic levels (Wen *et al.* 2011).

Considering the role of primary productivity on determining the population size of waterbird, remote sensing technique can be used for waterbird studies. Most ecological studies agree that there is an increasing relationship between species richness and primary productivity of the dependent habitat (Tilman 1996, Jørgensen and Nøhr 1996, Ritchie and Olff 1999). The commonly used index for the primary productivity is Normalized Difference Vegetation Index (NDVI). The relationship between NDVI and vegetation productivity is well studied, indicating that NDVI could be a fairly good surrogate for primary productivity (Pettorelli *et al*. 2005).

Recently, studies have coupled the NDVI with biodiversity (Nagendra 2000, Oindo and Skidmore 2002, Hurlbert and Haskell 2003) animal species distribution (Osborne *et al.* 2001, Zinner *et al.* 2002) the movement patterns of animals (Seto *et al.* 2004, Wilson *et al.* 2007, Tøttrup 2008, Stralberg *et al.* 2010) and the performance of animal populations (Saino *et al.* 2004, Sanz *et al*. 2003). The correlation between NDVI and ornithological studies has carried out in different parts of the world. NDVI has used to analyse avian biodiversity (Jørgensen and Nøhr 1996, Hawkins *et al.* 2003), avian species richness and habitat heterogeneity in America (Hurlbert and Haskell 2003). NDVI showed positive association with foraging guilds of neotropical migrants and negative association with species richness and foraging guilds of resident birds in Taiwan (Lee *et al.* 2004).

1.2. Problem statement

Fuente de Piedra lagoon is the largest natural playa lake in the Iberian Peninsula. It is a haven for birds with over 170 different species recorded here. Apart from its abundant aquatic avifauna, it is the second largest breeding colony of flamingos in Europe after the French Camargue region and the only inland site on the continent where they breed. The lake is an important stopover site for migratory birds. The lake is shallow, highly seasonal and usually dries up by the end of June.

The aquatic avifaunal abundance and species richness in this lagoon showed a fluctuating trend in the last 19 years (Figure 1-1). The environmental factor causing this population fluctuation is unknown. This could be the effect of interaction of lake environmental and hydrological condition or the changes in the climatic factors controlling the bird migration pathway towards the Fuente de Piedra lagoon. Although multiple factors are involved in this phenomenon, the external factors outside the lake are difficult to quantify as it entirely depend on the climatic changes, possible predation on migratory routes and anthropogenic threats. But the variability in environmental and hydrological factors of the lagoon such as water level, water depth, and physico-chemical characteristics of the lake is already available from the Fuente de Piedra Natural Reserve. The other important factor attracting the waterbird could be the productivity of the lagoon. Although, the primary productivity data of the lagoon is not available, remote sensing technique can be used to estimate the productivity as assessed by NDVI from the historical satellite imageries.

A few remote sensing studies has undertaken in the lagoon explaining the interaction of waterbird population on hydrology, landscape and land use level. The hydrological study was to derive various microhabitats using DEM created using contour lines of the lakebed and the preferred water depth was calculated for selected species (Wang 2008). At the landscape level, the lagoon is classified into four distinct class namely deep water, shallow water, wet muddy flat and land using DEM and historical water level data. The waterfowl community was subdivided into swimmers, waders, shoreliners and others and the correlation with landscape classes was investigated (Maviza 2010). In the third study author (Wambugu 2010) point out the influence of olive plantation in decreasing the water level of the lagoon and the subsequent decline in the abundance of breeding flamingos.

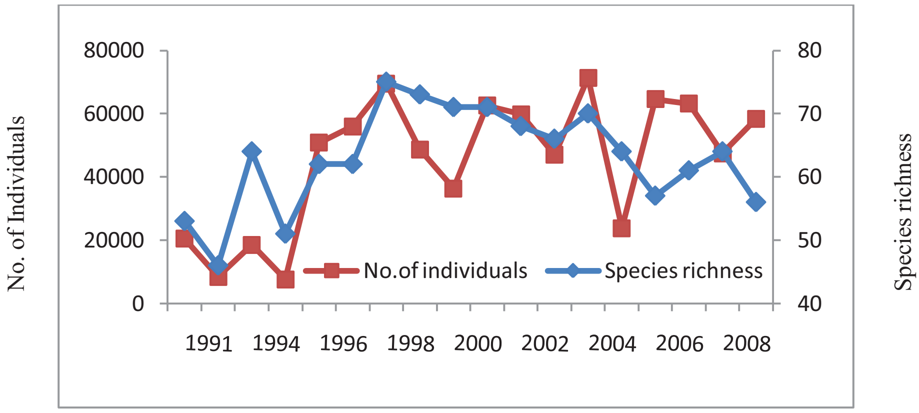

Figure 1-1: Waterbird abundance and species richness from 1991-2009 in the Fuente de Piedra lagoon

In the present study an attempt has taken to estimate productivity using NDVI as a surrogate from MODIS NDVI imageries, waterbird and water level data of the lagoon.

1.3. Overall objective

To examine the seasonal and interannual relationships between NDVI and waterbird abundance & diversity at two spatial scales in the Fuente de Piedra lagoon from 2000 to 2009 using time-series MODIS 250 m NDVI data.

1.3.1. Specific objective

- To investigate if the abundance of selected waterbird according to their body size, forage type and habitat type are correlated to the seasonal variation of NDVI in the lagoon.
- To investigate if the abundance of selected waterbird according to their body size, forage type and habitat type are correlated to the interannual variation of NDVI in the lagoon.
- To investigate if the waterbird diversity based on dominant families are correlated to the seasonal variation of NDVI in the lagoon.
- To investigate if the waterbird diversity based on dominant families are correlated to the interannual variation of NDVI in the lagoon.
- To investigate if the waterbird abundance & diversity are correlated to the seasonal and interannual variation of NDVI within 500 m buffer of the lagoon.

1.4. Research questions

1. What is the correlation between water level and NDVI of the lagoon at two spatial scales?
2. What is the correlation between seasonal changes of waterbird abundance & diversity and NDVI in the lagoon?
3. What is the correlation between interannual changes of waterbird abundance & diversity and NDVI in the lagoon?
4. What is the correlation between seasonal changes of waterbird abundance & diversity and NDVI within 500 m buffer of lagoon?
5. What is the correlation between interannual changes of waterbird abundance & diversity and NDVI within 500 m buffer of lagoon?

1.5. Research hypotheses

H_0^1: The abundance of small body size waterbird is not significantly correlated to the seasonal variation of NDVI in the lagoon *

H_1^1: The abundance of small body size waterbird is significantly correlated to the seasonal variation of NDVI in the lagoon *

H_0^2: The abundance of herbivorous waterbird is not significantly correlated to the seasonal variation of NDVI in the lagoon *

H_1^2: The abundance of herbivorous waterbird is significantly correlated to seasonal variation of NDVI in the lagoon *

H_0^3: The diversity of Anatidae family is not significantly correlated to the seasonal variation of NDVI in the lagoon *

H_1^3: The diversity of Anatidae family is significantly correlated to the seasonal variation of NDVI in the lagoon *

1.6. Conceptual framework

The Figure 1-2 illustrates the main study components. There are three factors potentially influencing the change of waterbird abundance and diversity, i.e., NDVI of the lagoon, NDVI of the surrounding habitat and the water level of the lagoon. Water level of the lagoon plays two roles directly by creating various microhabitats and indirectly on the NDVI of the lagoon. The overall abundance and diversity of waterbird could be the result of combined interaction of NDVI of the lagoon, NDVI of the surrounding habitat and the water level of the lagoon.

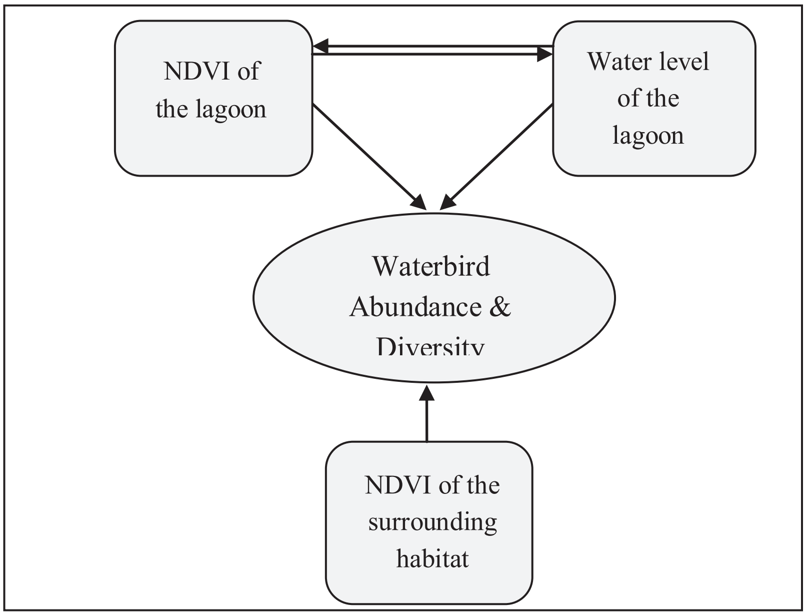

Figure 1-2: Conceptual framework showing main components of the study

2. Materials and Methodology

2.1. Study area

The Fuente de Piedra lagoon is the largest saline inland wetland in the autonomous region of Andalucía (area approximately 1,364 ha) located in the far north of the province of Malaga, Spain with an elevation of 412m (Figure 2-1).

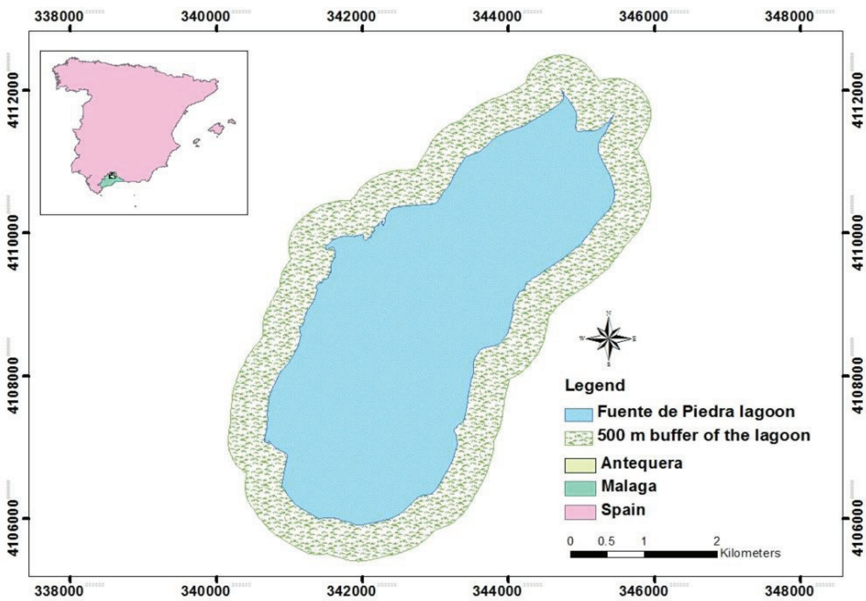

Figure 2-1: Map of the study area

The study site forms part of a protected wetland at regional (natural reserve), European (special bird protection area) and international (Ramsar site) level. It is an ideal nesting area for the pink flamingo (*Phoenicopterus ruber roseus*) because of the shallow water depth that reaches an average value of 70.5 cm (Rodrı´guez-Rodrı´guez, 2002). These wetlands provide habitat for non-migrating and migrating birds as well as a number of endemic and endangered species (Rendo´n 1996).

2.1.1. Climate

The climate in the study area is Mediterranean with a semiarid trend. The mean precipitation is 450 mm and the average annual temperature varies from about 15 - 17 °C. Intense sunshine combined with low humidity caused the playa's potential evapotranspiration to exceed 800 mm per year, of which about half is processed from June to August (ITGE 1998). The present evapotranspiration over the basin was estimated to be 35% of its ETP. Total evaporation in the lagoon was 1600 mm.

2.1.2. Hydrogeology

The catchment of Fuente de Piedra covers an area of 150 km^2. The aquifer is mainly composed of upper Miocene calcareous sands and of quaternary alluvial. Locally, they could be considered as permeable material. The highest piezometric level coincides generally with the basin divide, so the groundwater flows centripetally towards the lagoon. Constituting the base level of the aquifer, the lagoon acts as the main groundwater discharge area (Almecija 1997). The mean water level in the lake is 10 to 40 cm and the lake dries up by the end of July and the flooding season is March.

2.1.3. Flora and fauna

The lagoon is rich in phyto and zooplanktons .The major aquatic vegetation consists of Fennel pond weed (*Potamogeton pectinatus*), Bulrush (*Scirpus maritimus*), Reed (*Phragmites australis*) and Narrow leaf cattail *(Typha angustifolia*). The lake is well known for its abundant avifaunal diversity. Overall 170 species of birds have reported from the lake and supports over 50000 of birds in each year. The other major faunal groups include Spiny-footed lizard (*Acanthodactylus erythrurus*), Ocellated lizard (*Timon lepidus*), Spanish sand lizard (*Psammodromus hispanicus*), Algerian sand lizard (*Psammodromus algirus*), Southern wall lizard (*Podarcis siculus*), Three-toed skink (*Saiphos equalis*), Horseshoe snake (*Hemorrhois hippocrepis*), Ladder snake (*Rhinechis scalaris*), Water snake (*Natrix maura*) and Grass snake *(Natrix natrix*). In the fields surrounding the lake are Rabbits (*Oryctolagus cuniculus*), Hares (*Lepus europaeus*), Garden dormice (*Eliomys quercinus*), Foxes (*Vulpes vulpes*) and Badgers (*Melinae sp.*).

2.1.4. Bird habitats

For the present study Fuente de Piedra lagoon and adjoining 500 m buffer is selected considering the wetland birds exclusively depend on the lagoon and its immediate surrounding for foraging, nesting and roosting. There are various habitats available in the lagoon for the birds of different foraging guilds. Major habitats are deep water, shallow water, reed beds, shorelines, marsh land and bank vegetation (Figure 2-2). Presence of these habitats makes the Fuente de Piedra lagoon a paradise for waterbird and one of the important tourist places for nature lovers in Spain. The 500 m buffer of the lagoon mainly consists of olive plantations of various ages and the remaining parts are cereals and sunflower crops. In order to ensure bird protection, the lagoon is fenced in all sides and the tourists can watch birds only from a distance of 200 m away from the lagoon boundary.

Figure 2-2: Various habitats available for waterbird in the Fuente de Piedra lagoon

2.2. Materials

Three types of datasets from 2000-2009 have been used in this study. They are MODIS NDVI, watebird census data and water level data (Table 2-1). The 16 days composite of MODIS NDVI image was downloaded from ftp://e4ft101u.ecs.nasa.gov/MOLT/MODI13Q1.005. The waterbird census and water level data collected from Natural Reserve of Fuente de Piedra during the field visit in September.

Table 2-1: Materials used for the study

S. No	Data Type	Period	Source
1	MODIS NDVI image	2000-2009	NASA
2	Waterbird Census	2000-2009	Natural Reserve of Fuente de Piedra
3	Water level	2000-2009	Natural Reserve of Fuente de Piedra

2.2.1. Secondary information from local people

During the field visit in September, discussion with local experts has done regarding the arrival of migratory birds, foraging requirements of waterbird, sources of water and food availability, breeding status of Greater flamingo and other birds. Conservation efforts for the waterbird and the various protective measures has discussed with the conservator of the Natural reserve. Field survey of lagoon and the adjoining buffer area was carried out in order to understand the habitat thoroughly.

2.3 Methods

2.2.2. Data processing

2.2.2.1. MODIS NDVI Image

The MODIS NDVI image was processed using the software ENVI 4.7. Sub setting has done on 5 km region of interest of the lagoon. The sub setted image was smoothed using a software package of TIMESAT (Beck *et al.* 2007, Agarwal and Garg 2009, Eklund and Jonnson 2010). From the TIMESAT corrected image, lagoon and 500 m buffer parts were extracted (Figure 2-3 to 2-6). NDVI values for each image was calculated using Compute statistics option in the ENVI. The NDVI values for each month were calculated selecting the images falls within the representative month considering two images for one month except for the month of August. For August only one image was used because of the availability of 23 images in a year and the lagoon is dry during this period and the abundance of birds is very poor. For the seasonal analysis mean NDVI value of each month in 10 years was used. For the interannual analysis average value of NDVI of each year was considered (Oindo and Skidmore 2002, Kerr and Ostrovsky 2003, Pettorelli *et al.* 2005, Levin *et al*. 2007, Fernández *et al.* 2010).

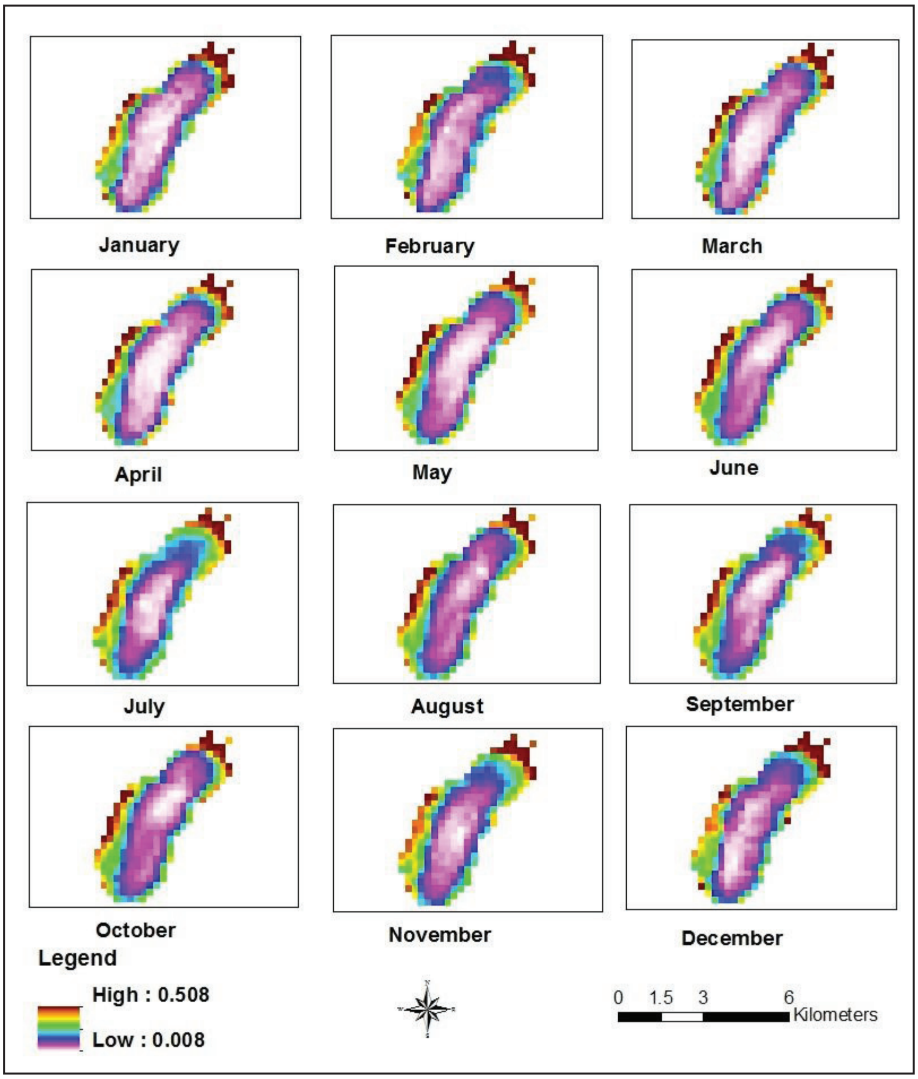

Figure 2-3: Seasonal NDVI of the Fuente de Piedra lagoon

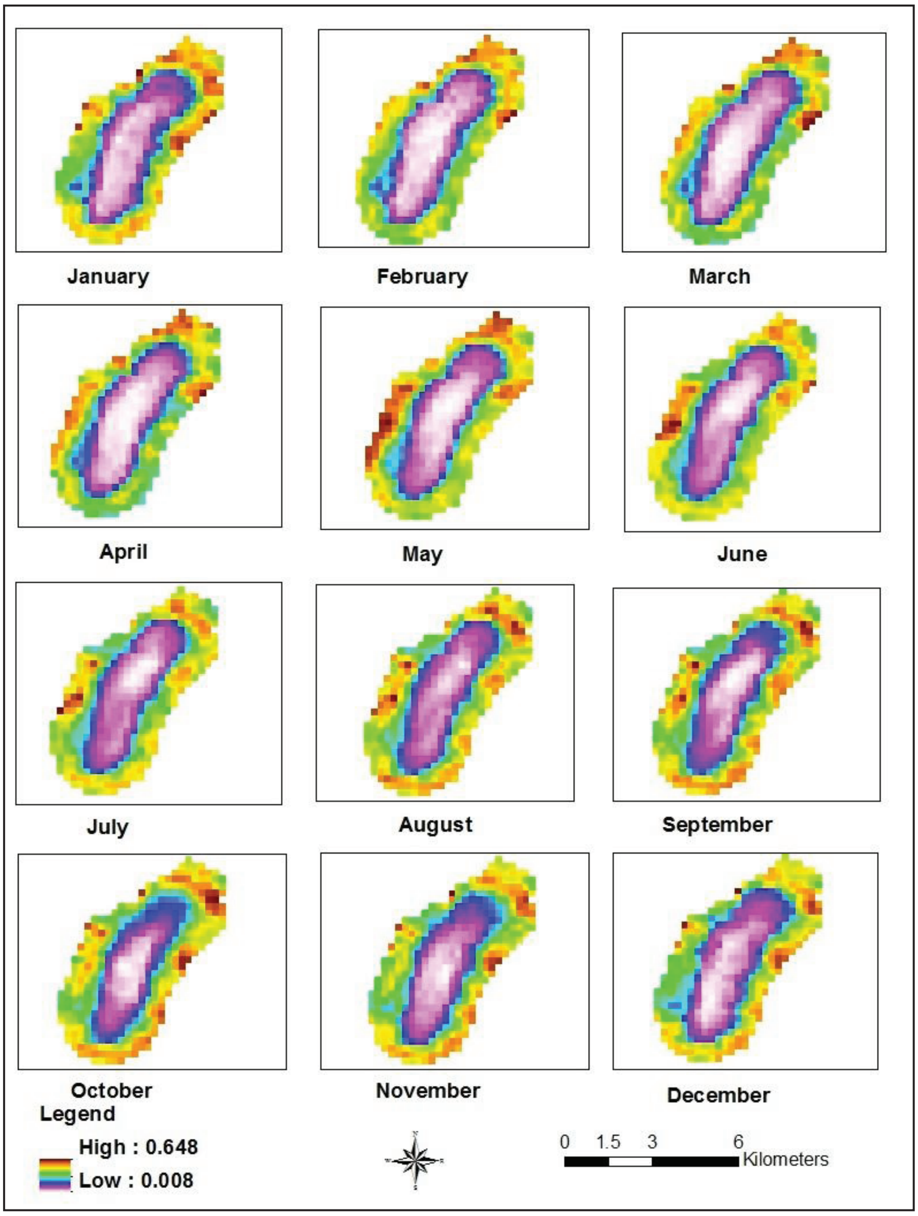

Figure 2-4: Seasonal NDVI of 500 m buffer of the Fuente de Piedra lagoon

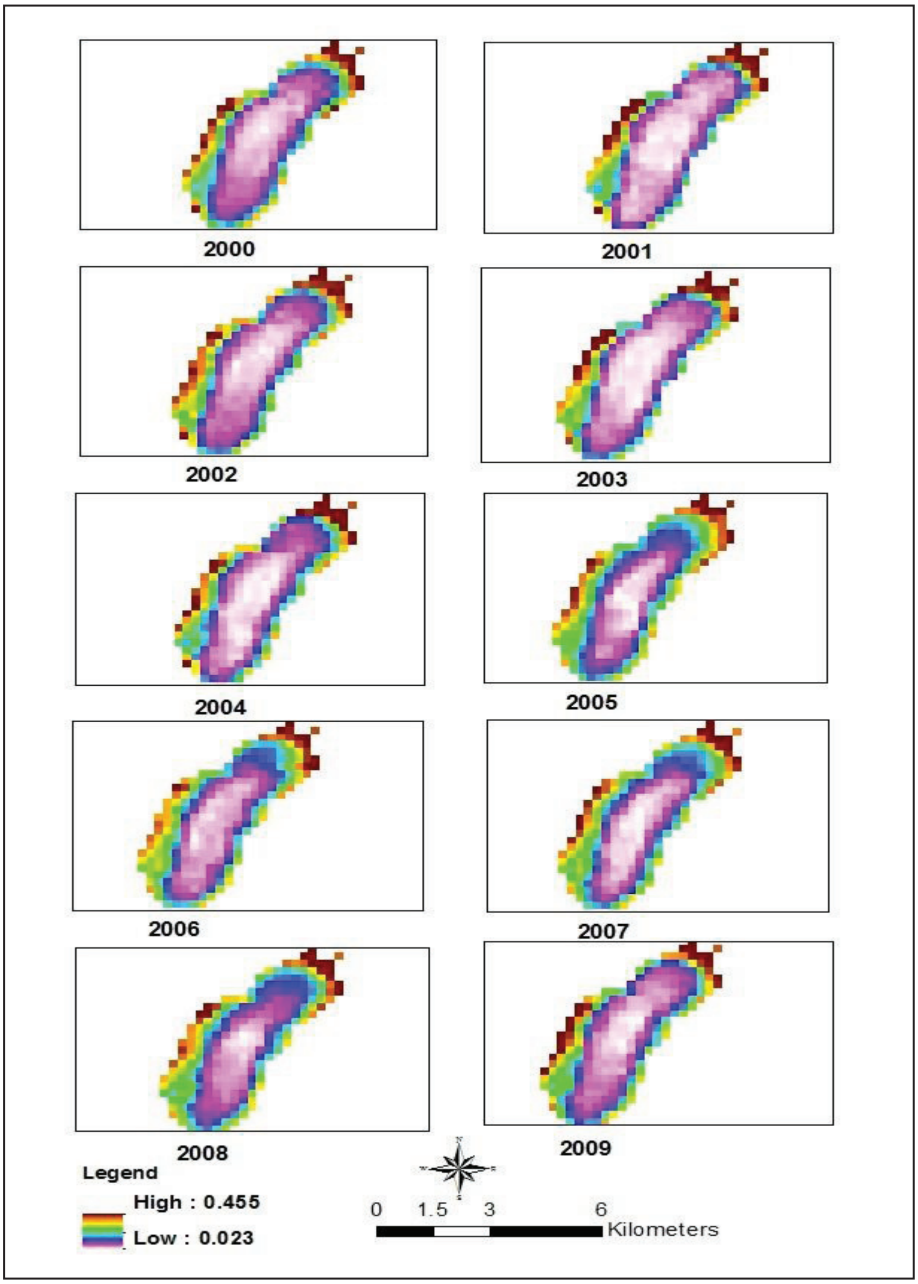

Figure 2-5: Interannual NDVI of the Fuente de Piedra lagoon

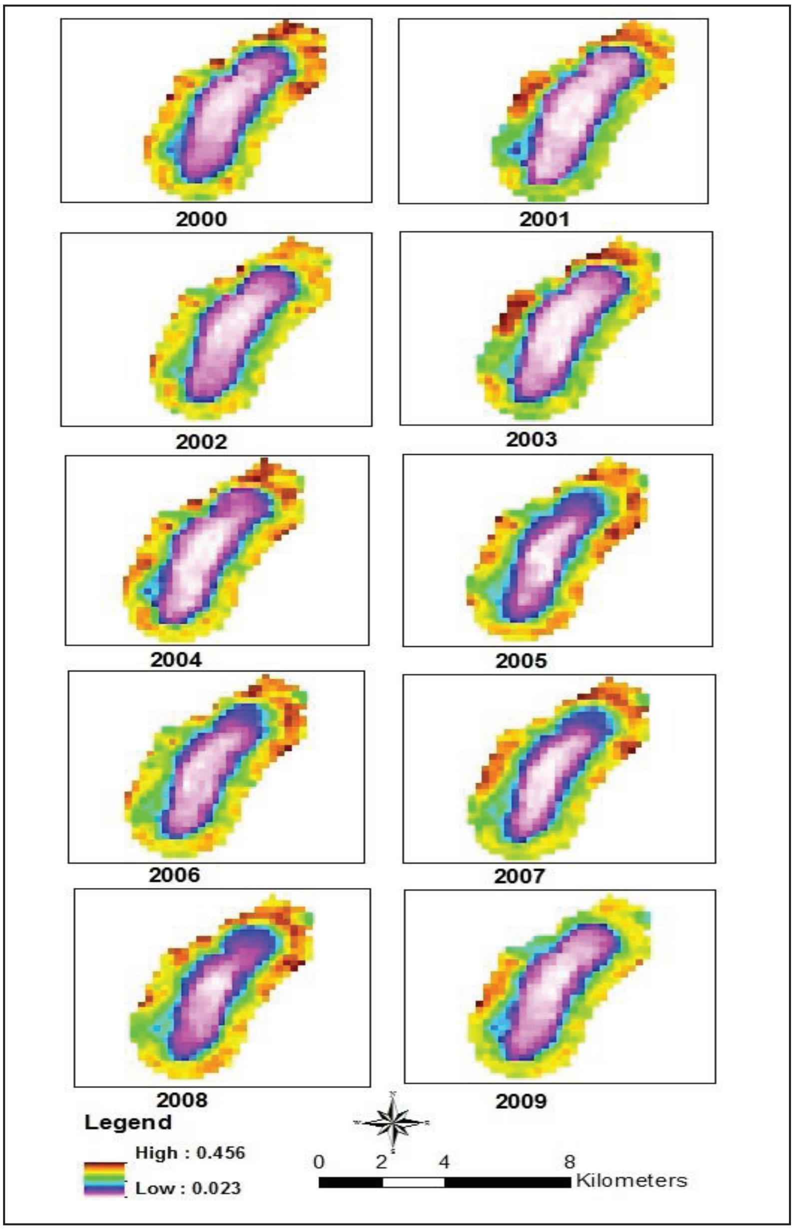

Figure 2-6: Interannual NDVI of 500 m buffer of the Fuente de Piedra lagoon

2.2.2.2. Calculation of waterbird abundance and diversity

The waterbird data collection was weekly census in nature. For the analysis purpose, the data was separated monthly basis and the maximum count was considered as the representative for each month. For the calculation of seasonal waterbird abundance and diversity average value of each month of 10 years was used. For the interannual analysis, average birds of each year were taken (Abrams 1995, Fairbairn and Dinsmore 2001, Webb *et al.* 2010). Diversity (H') was calculated using Shannon-Wiener diversity Index (Shannon and Wiener 1949).

$$H' = -\sum_{i=1}^{S} (pi * \ln pi)$$

2.2.2.3. Selection of indicator species for waterbird abundance and diversity

The waterbird selection for abundance was carried based on three approaches such as body size, forage type and forage habitat to understand the influence of body size (Elmberg *et al.* 1994) , forage type (Maheswaran and Rahmani 2001)and forage habitat (Weller 1999, Castaneda and Herrero *et al.* 2005) at individual species and major guild level. This criterion incorporates species occupying various habitat requirements and energy requirements. According to the water bird census data, the dominant water bird communities present in the Fuente de Piedra is represented in the Figure 2-7.

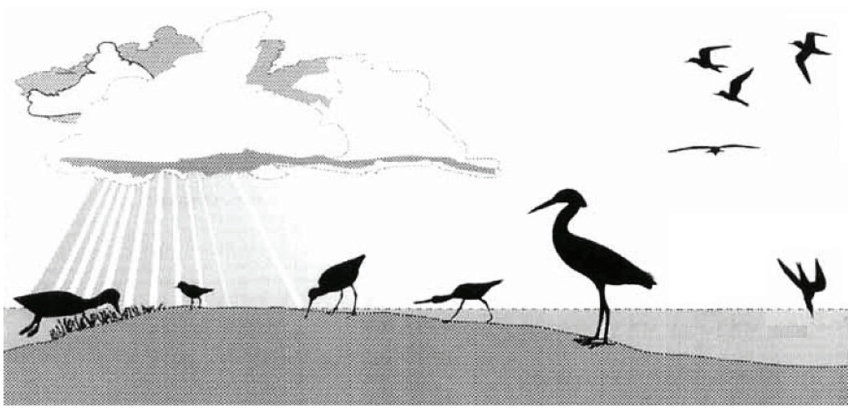

Figure 2-7: Dominant waterbird communities present in the Fuente de Piedra lagoon

(The figure was modified from Ntiamoa-Baidu et al 1997)

2.2.2.4. Selection criteria for the abundance of individual species

In the selection criteria for body size, the species are classified as large (80-132 cm), medium (40-80 cm) and small (14-40 cm). Herbivore, omnivore and carnivore was selected for forage type and the foraging habitat was deep water (> 20cm), shallow water (3 - 20cm), wet muddy flat (0 - 3cm) and meadows/plains/agriculture. The details of selected individual species are given in the Table 2-2 and Figure 2-8.

Table 2-2: Selection criteria for the abundance of individual species

S. No	**Selection Criteria**	**Species**	**Migratory Status**	**Diet**
1	**Body size**			
	Large (80-132 cm)	Greater flamingo (*Phoenicopterus ruber roseus*)	Resident	crustacea
	Medium (40-80 cm)	Common Shelduck (*Tadorna tadorna*)	Winter Visitor	grass/vegetarian
	Small (14-40 cm)	Black-winged stilt (*Himantopus himantopus*)	Resident	shells, crustacea, insects
2	**Forage type**			
	Herbivore	Northern Shoveler (*Anas clypeata*)	Winter Visitor	vegetarian
	Omnivore	Common Coot (*Fulica atra),* Common Moorhen (*Gallinula chloropus*)	Resident	insects, seeds, berries
	Carnivore	Black-headed Gull (*Larus fuscus*)	Summer Visitor	fish, animals, insects, worms
3	**Foraging habitat**			
	Deep water (> 20cm)	Mallard (*Anas platyrhynchos*)	Resident	vegetarian
	Shallow water (3 - 20cm)	Pied Avocet (*Recurvirostra avosetta*)	Resident	shells, crustacea, insects
	Wet-muddy flat (0 - 3cm)	Dunlin (*Calidris alpine*)	Winter Visitor	insects, shells, worms
	Meadows/Plains/ Agriculture	Common Crane (*Grus grus*)	Winter Visitor	insects, seeds, berries

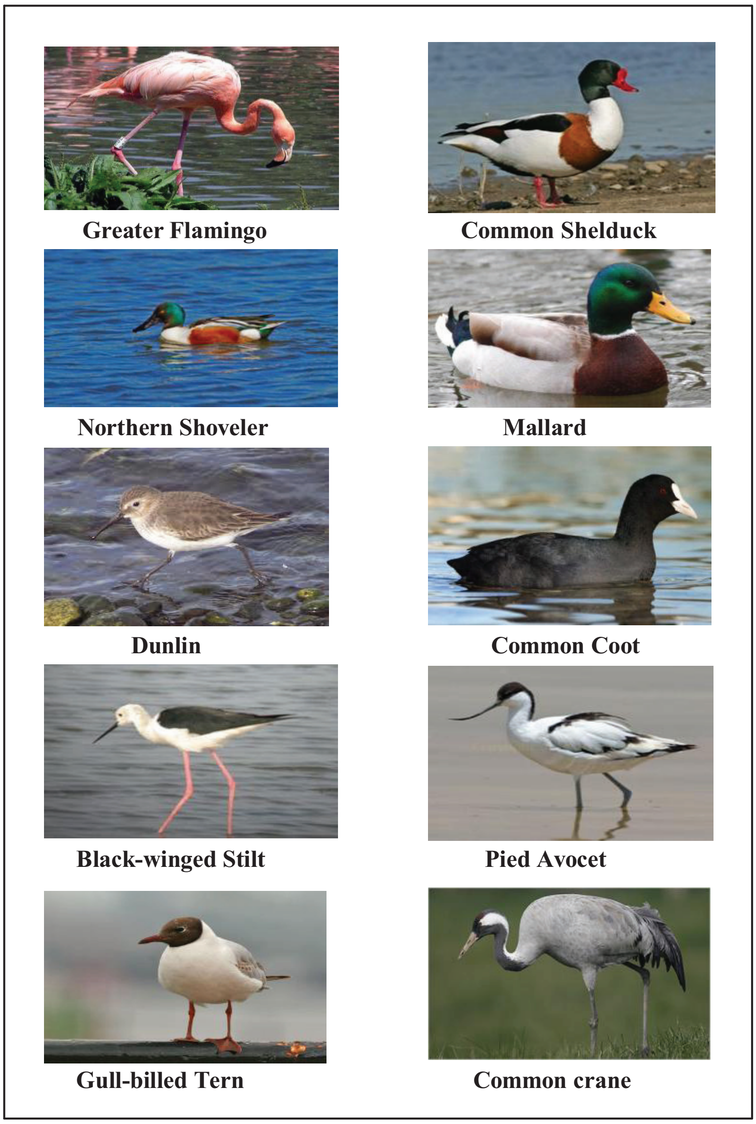

Figure 2-8: Selected species for abundance

2.2.2.5. Selection criteria for the abundance of major waterbird guilds

In the calculation of waterbird guilds, the species falls within each category is added together and considered as a group. The criteria for individual species and guild are similar. Here also the group for body size, the species are classified as large (80-132 cm), medium (40-80 cm) and small (14-40 cm). Herbivore, omnivore and carnivore was selected for forage type and the foraging habitat was deep water (> 20cm), shallow water (3 - 20cm), wet muddy flat (0 - 3cm) and meadows/plains/agriculture. The number of species present in each guild has given in the Table 2-3.

Table 2-3: Selection criteria for the abundance of major guild

S. No	Criteria	No. of Species
1	**Body size**	
	Small (14-40 cm)	33
	Medium (40-80 cm)	36
	Large (80-132 cm)	29
2	**Forage type**	
	Herbivore	19
	Omnivore	12
	Carnivore	67
3	**Foraging habitat**	
	Deep water (> 20cm)	12
	Shallow water (3 - 20cm)	18
	Wet-muddy flat(0 - 3cm)	20
	Meadows/Plains/Agriculture	8

2.2.2.6. Selection criteria for the diversity

The waterbird in the Fuente de Piedra lagoon represent 18 families with 98 species (Table 2-4 & Appendices 7-1).Three diverse and dominant families were selected for diversity study. The selected families are Scolopacidae (23 species), Anatidae (19) and Ardeidae (9). The Scolopacidae family mainly consist of omnivorous medium and small body size waders. Anatidae members are mostly herbivorous in nature. The Ardeidae members are mainly fish eaters and they can be considered as carnivore. The other families did not taken in account as the species present in the family is comparatively and low and it may not give the real picture of food availability and productivity of the lagoon. Moreover, the family Laridae and

Sternidae have 8 species, they are carnivore birds and do not depend the lagoon directly.

Table 2-4: Details of waterbird families present in the lagoon

S. No	Family	No. of Species
1	Scolopacidae	23
2	Anatidae	19
3	Ardeidae	9
4	Sternidae	8
5	Laridae	8
6	Rallidae	6
7	Charadriidae	6
8	Podicipedidae	4
9	Threskiornithidae	3
10	Recurvirostridae	2
11	Phoenicopteridae	2
12	Phalacrocoridae	2
13	Ciconiidae	3
14	Haematopodidae	1
15	Gruidae	1
16	Glareolidae	1
17	Burhinidae	1
18	Alcedinidae	1
	Overall	**98**

2.2.2.7. Water level data

Water level is an important factor determining the abundance of waterbird. The variation in water level creates different microhabitats for the varying functional guilds of waterbird. The effect of water level on the abundance of selected waterbird was studied in the lagoon using the DEM created using the contour lines of the lake bed (Wang 2008). The DEM has successfully helped to derive four microhabitat such as deep water (> 20 cm), shallow water (3-20 cm), wet muddy flat (0-3 cm) and land area (Maviza 2010). The present study tries to understand the influence of water level on the NDVI to establish the indirect effect of productivity on waterbird abundance and diversity. The water level data obtained from the Natural Reserve was recorded daily. The daily water level data from 2000-2009 was streamlined to monthly basis and mean water level was calculated. Analysis was carried at seasonal and interannual level. For the seasonal analysis mean value of each month in the 10 years was calculated while the average value of each year was considered for interannual water (Ma et al 2007, Miwei *et al.* 2009).

2.2.3. Statistical analysis

In the present study only two variables are considered (NDVI and waterbird) for analysis. Therefore simple regression statistics is used for the study (Jørgensen and Nøhr 1996). Regression lines between dependent variable (waterbird abundance and diversity) and independent variable (NDVI) were calculated at 95% confidence interval.

$$Y_i = a + b X_{i+} e$$

The significance of R^2 value is interpreted as strong correlation, moderate and weak correlation. The R^2 value >0.5 is considered as strong correlation, 0.20- 0.50 for moderate correlation and <0.20 is considered as weak correlation (Gaston and Blackburn 1995, Lee *et al.* 2004). The various studies shows that regression can be used to establish the correlation between NDVI and bird diversity (Hawkins *et al.* 2003) and the species richness and NDVI (Hurlbert and Haskell 2003).

3. Results

3.1. Abundance of individual waterbird species and NDVI

3.1.1. Waterbird abundance based on the body size of species

3.1.1.1. Seasonal waterbird abundance based on body size and the NDVI of the lagoon

The large body size species, Greater flamingo is moderately correlated to the NDVI of the lagoon (R^2= 0.22).The abundance of flamingo increased from January and reached maximum in May followed by gradual decline till the end of the year. The NDVI values reached maximum in March and then decreased until July and then gradually increased. (Figure 3-1)

The medium body size Common Shelduck is moderately correlated with the NDVI of the lagoon (R^2= 0.43). The species is winter visitor and reached maximum population in January while NDVI of the lagoon was high in March (Figure 3-1). The Species abundance and NDVI did not match exactly in the beginning of year and the trend was stronger towards the end of the year.

The small body size Black-winged stilt is strongly correlated with the NDVI of the lagoon (R^2=0.89). The abundance of the species and the NDVI of the lagoon followed the same trend (Figure 3-1). The NDVI and the abundance of black-winged stilt were high in March followed by gradual decline. The species abundance was very low from May to September. The population again started increasing from the month of October.

3.1.1.2. Seasonal waterbird abundance based on body size and the NDVI of 500 m buffer of the lagoon

The Greater flamingo with large body size is moderately correlated with the NDVI of the 500 m buffer of the lagoon (R^2= 0.31). The bird population reached in its maximum abundance in May while the NDVI was high in March (Figure 3-2).

The medium body size Common Shelduck is moderately correlated with the NDVI of the 500 m buffer of the lagoon (R^2=0.47). The species abundance was high in January and the NDVI reached its peak in March (Figure 3-2). The species is primarily herbivore and prefer the wetland rich in aquatic macrophytes for plant parts and seeds.

The small body size Black-winged stilt is strongly (R^2=0.87) correlated with the NDVI of the 500 m buffer of the lagoon (Figure 3-2). The abundance of the species and the NDVI of the 500 m of the lagoon followed the same trend.

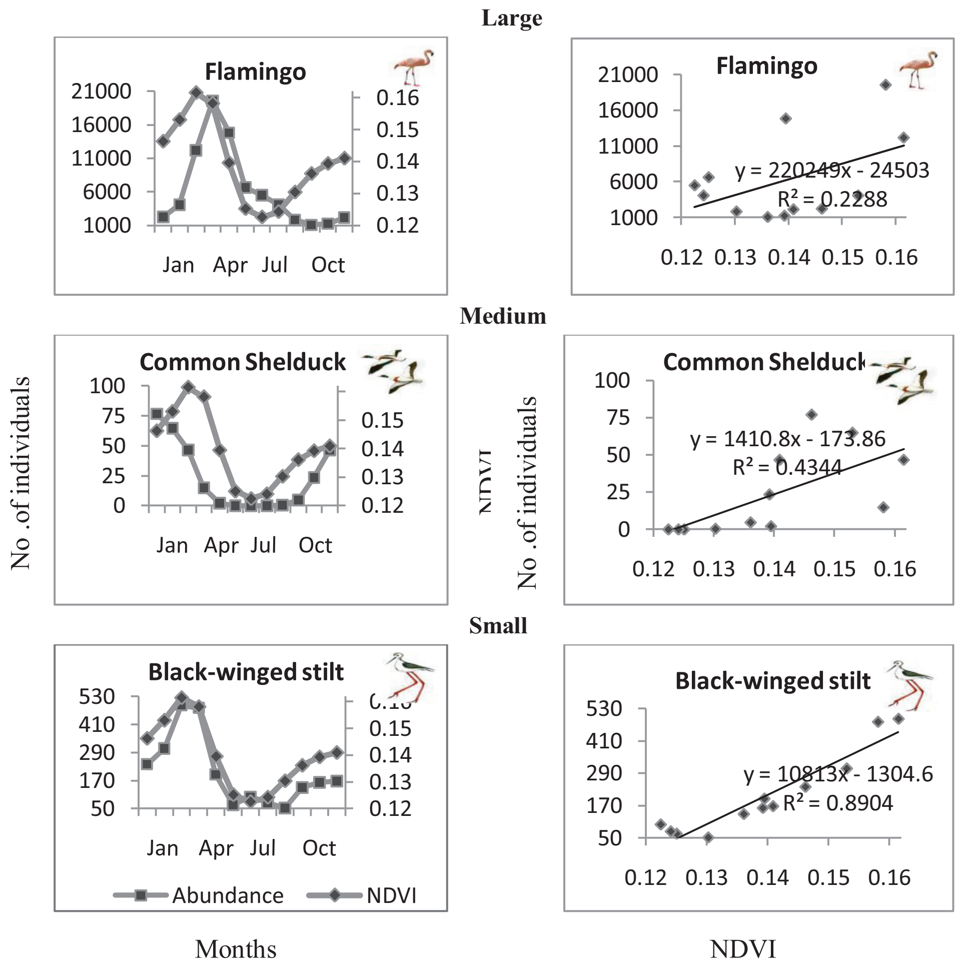

Figure 3-1: Correlation between seasonal waterbird abundance based on body size and the NDVI of the lagoon

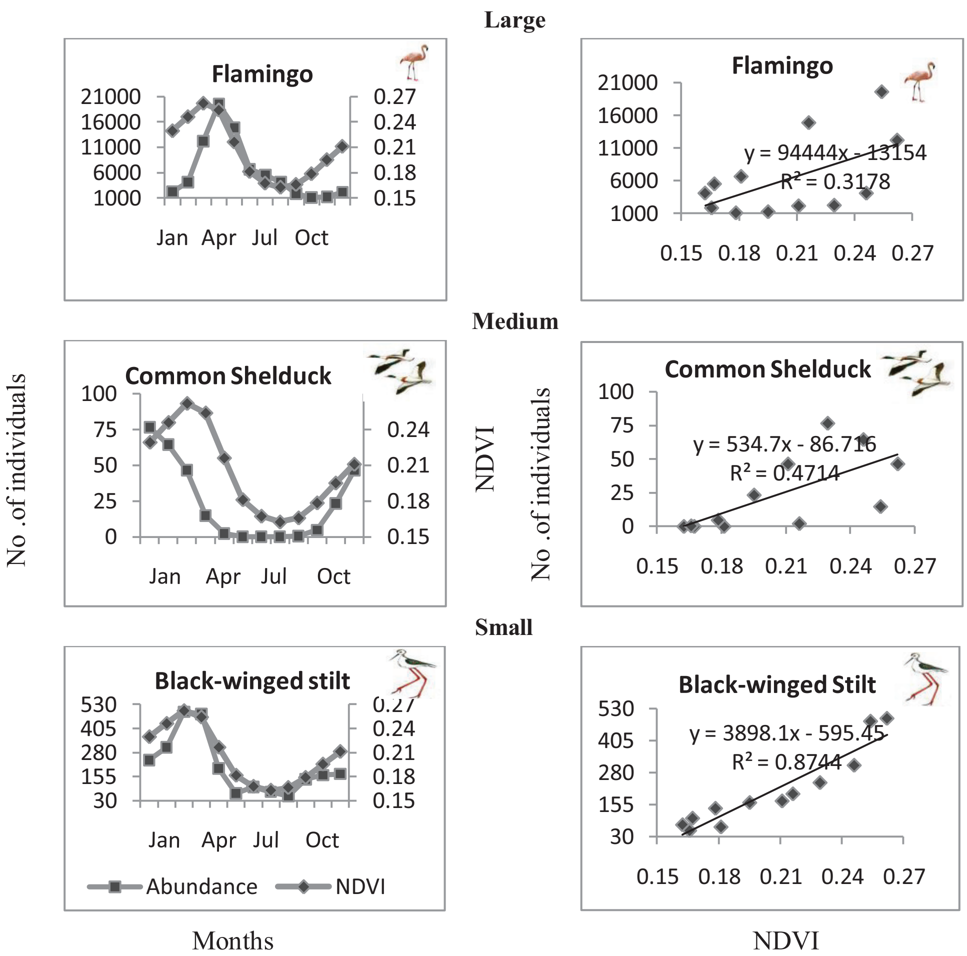

Figure 3-2: Correlation between seasonal waterbird abundance based on body size and the NDVI of 500 m buffer from the lagoon

3.1.1.3. Interannual waterbird abundance based on body size and the NDVI of the lagoon

The interannual abundance based on body size shows that large body size Greater flamingo shows weak correlation (R^2=0.13) with the NDVI of the lagoon (Figure 3-3). The poor correlation indicates that interannual NDVI is not significant for flamingo population. The correlation of medium body size Common Shelduck and Black-winged Stilt was also weak (R^2=0.03 and 0.15).

3.1.1.4. Interannual waterbird abundance based on body size and the NDVI of 500 m buffer of the lagoon

In the correlation of abundance based on body size, only small body size Black-winged Stilt showed a better weak correlation (R^2= 0.14). The correlation in large body size Flamingo and the medium body size Common Shelduck was very weak (Figure 3-3).

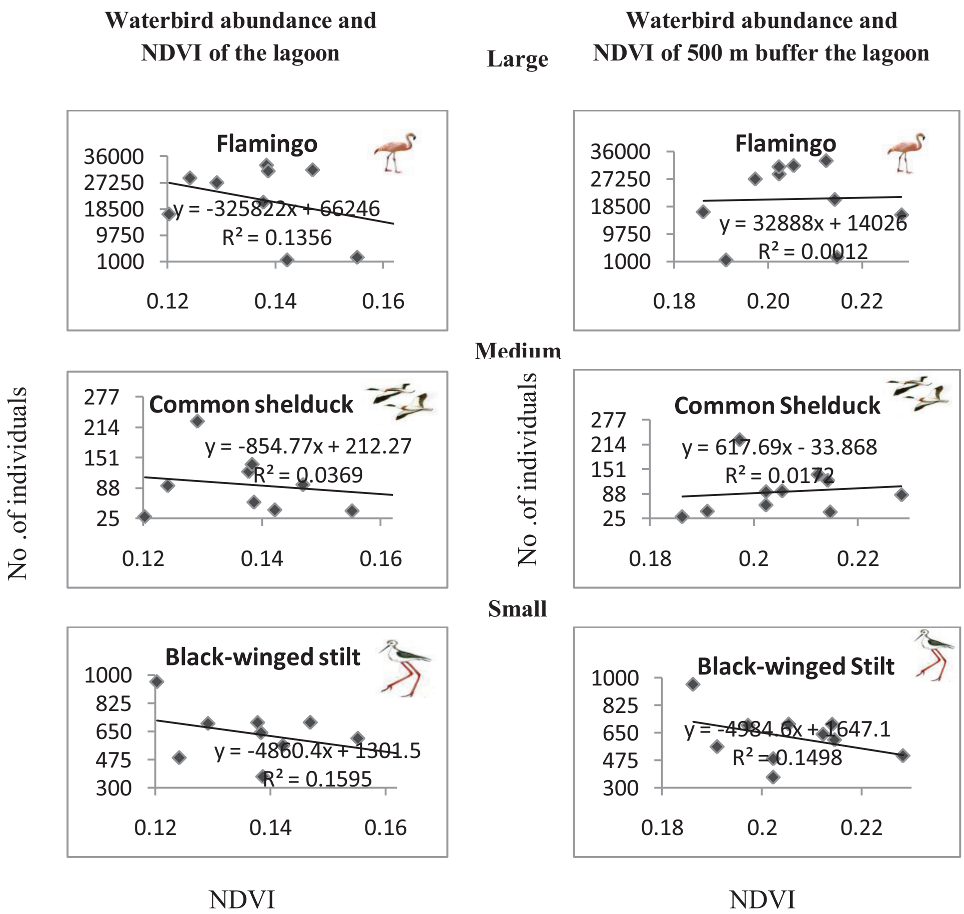

Figure 3-3: Correlation between interannual waterbird abundance based on body size and the NDVI the lagoon and 500 m buffer of the lagoon

3.1.2. Waterbird abundance based on the forage type of species

3.1.2.1. Seasonal waterbird abundance based on forage type and the NDVI of the lagoon

The herbivorous Northern Shoveler was strongly correlated with the NDVI of the lagoon (R^2=0.58). The species was abundant in December followed by January and February. But the NDVI of the lagoon was high from February-March. Both the species abundance and NDVI decreased by the month of May followed by an increase from October onwards (Figure 3-4).

Two omnivorous species was selected to understand the correlation between species abundance and NDVI of the lagoon (Figure 3-4). The Common Moorhen did not show any correlation with NDVI of the lagoon while the Common coot was strongly correlated with the NDVI of the lagoon (R^2=0.69). Although the selected species were omnivorous in nature, the difference in the correlation values indicate that one species prefer to eat more vegetation parts while the other species eats non-vegetable parts more.

The carnivorous Black-headed Gull was strongly correlated with the NDVI of the lagoon (R^2= 0.60). The Black-headed Gull and NDVI of the lagoon was high in March (Figure 3-4). The species abundance and NDVI followed a decreasing trend in the following months till September and again an increase in bird population and the NDVI of the lagoon. It is surprising that the carnivorous Black-headed Gull shows a positive correlation with the NDVI of the lagoon.

3.1.2.2. Seasonal waterbird abundance based on forage type and the NDVI of 500 m buffer of the lagoon

The herbivorous Northern Shoveler is strongly correlated with the NDVI of 500 m buffer of the lagoon as shown in the Figure 3-5 (R^2= 0.62) and it supports that the buffer of the lagoon has enough vegetation for nesting and roosting.

The Omnivorous Common Moorhen did not show any correlation with NDVI of 500 m buffer of the lagoon (Figure 3-5) while the other species of the similar forage type Common coot was strongly correlated with the NDVI of 500 m buffer of the lagoon (R^2= 0.80).

The carnivorous Black-headed gull showed strong correlation with the NDVI of 500 m buffer of the lagoon (R^2= 0.68) as given in the Figure 3-5.

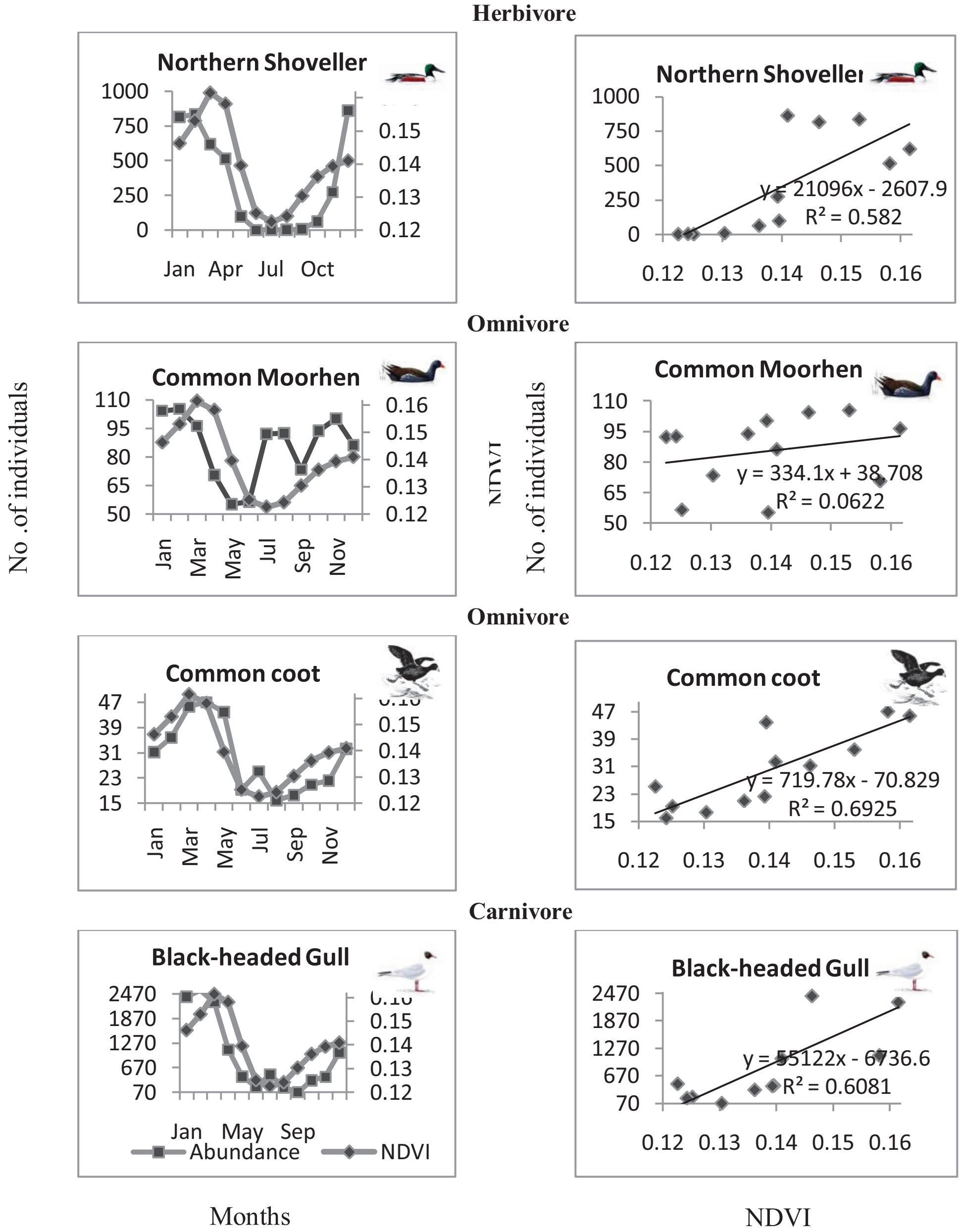

Figure 3-4: Correlation between seasonal waterbird abundance based on forage type and the NDVI of the lagoon

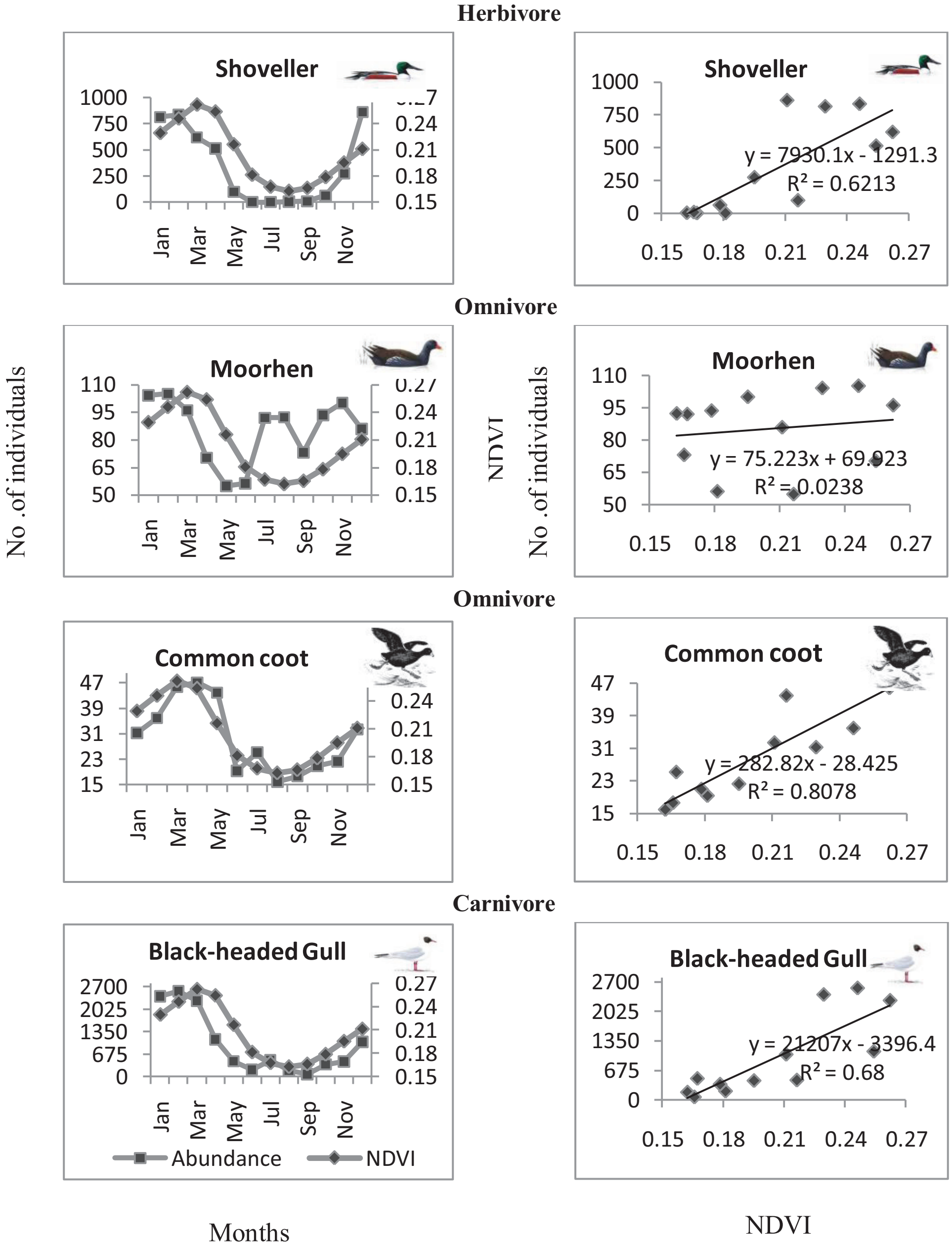

Figure 3-5: Correlation between seasonal waterbird abundance based on forage type and the NDVI of 500 m buffer of the lagoon

3.1.2.3. Interannual waterbird abundance based on forage type and the NDVI of the lagoon

The herbivorous Northern Shoveler is moderately correlated with the NDVI of the lagoon (R^2= 0.27). The correlation is moderately better and indicates that presence of sufficient vegetable matter to attract this migrant species towards the lagoon (Figure 3-6).

The omnivorous Common Moorhen is moderately correlated with the NDVI of the lagoon (R^2= 0.48). The moderate correlation shows that interannual NDVI and plays an important role in the abundance of this resident species (Figure 3-6). The Common Coot did not show any correlation with the interannual NDVI of the lagoon.

The interannual abundance of Carnivorous Black-headed Gull and NDVI of the lagoon was very weak (Figure 3-6). This poor correlation may be due to the carnivorous nature of Black-headed Gull and it depend the lagoon only for breeding and nesting.

3.1.2.4. Interannual waterbird abundance based on forage type and the NDVI of 500 m buffer of the lagoon

The herbivorous species, Northern Shoveler did not show any correlation with the NDVI of 500 m buffer of the lagoon (Figure 3-6). The result indicates that the interannual NDVI of 500 m buffer of the lagoon is not significant for the interannual abundance of Northern Shoveler.

The Common Moorhen is moderately correlated with the NDVI of 500 m buffer of the lagoon (R^2= 0.37). The omnivorous feeding forage nature of the species allows utilising maximum available resources for its survival and thereby increasing correlation with the 500 m buffer of the lagoon. The Common Coot showed only was weakly with the NDVI of 500 m buffer of the lagoon.

The interannual abundance of Carnivorous Black-headed Gull and NDVI of 500 m buffer of the lagoon was weakly correlated (R^2= 0.09) as shown in the (Figure 3-6). The species is winter visitor to the lagoon and the forage type is carnivore and the influence of biomass is comparatively less for this species and this could be the reason for weak correlation with the interannual NDVI of 500 m buffer.

Waterbird abundance and NDVI of the lagoon | **Waterbird abundance and NDVI of 500 m buffer the lagoon**

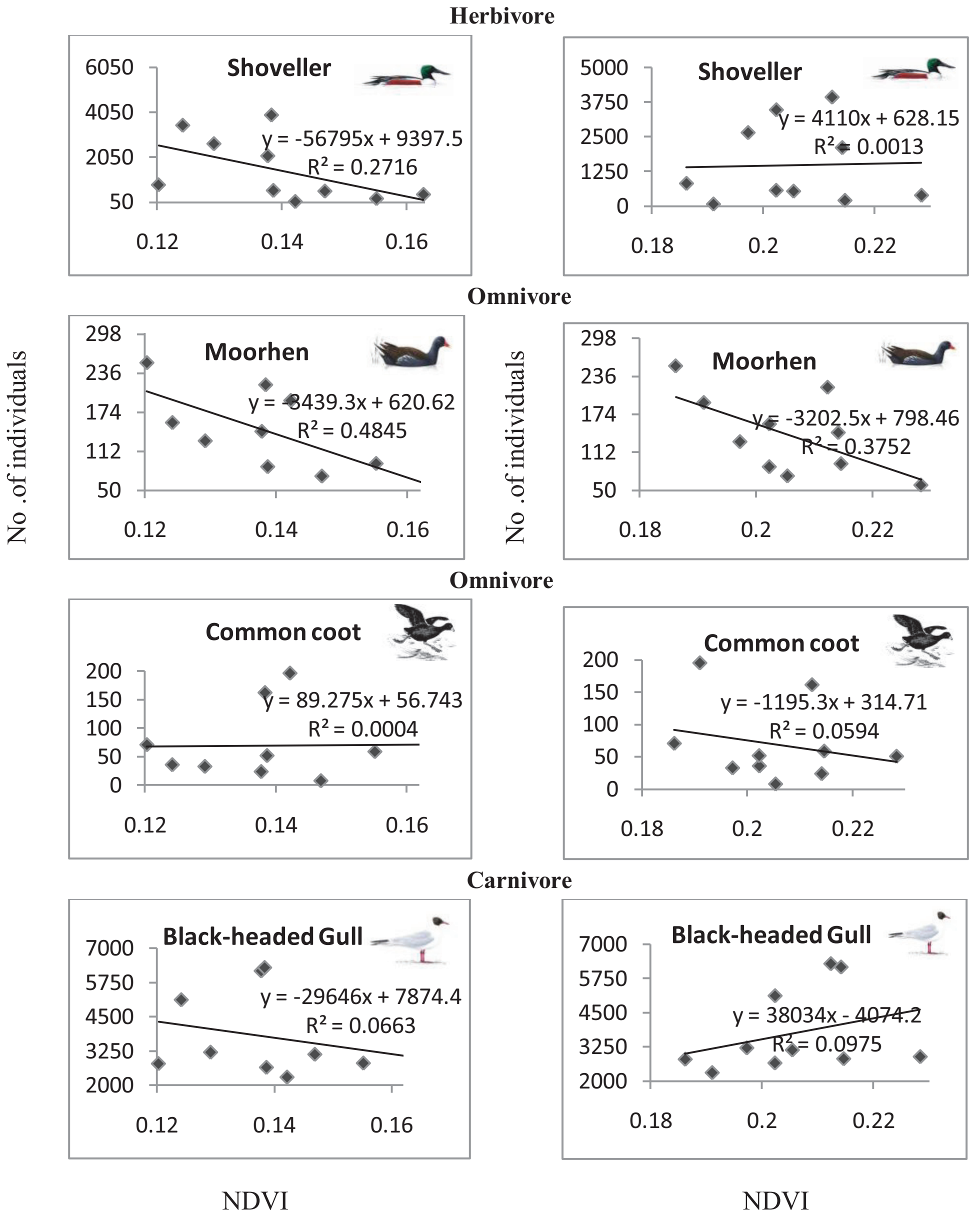

Figure 3-6: Correlation between interannual waterbird abundance based on forage type and the NDVI the lagoon and 500 m buffer of the lagoon

3.1.3. Waterbird abundance based on foraging habitat of species

3.1.3.1. Seasonal waterbird abundance based on foraging habitat and the NDVI of the lagoon

The deep water species Mallard did not show any correlation with the NDVI of the lagoon (R^2= 0.04). The species abundance was high in November while the NDVI reached its peak in March (Figure 3-7). The NDVI of the lagoon and the species was extremely opposite in pattern.

The shallow water species Pied Avocet is moderately correlated with the NDVI of the lagoon (R^2= 0.38). The maximum population of the species recorded in the month of May while the NDVI was high in March (Figure 3-7).

The Dunlin, wet muddy flat species is strongly correlated with NDVI of the lagoon (R^2=0.80). The species abundance and NDVI followed same trend from the beginning of the year to the end of the year (Figure 3-7).

The species belong to meadows/plains /agriculture (Common Crane) was weakly correlated with the NDVI of the lagoon (R^2= 0.04). The species use the lagoon only for roosting purpose and forage on the nearby agriculture areas (Figure 3-7).

3.1.3.2. Seasonal waterbird abundance based on foraging habitat and the NDVI of 500 m buffer of the lagoon

The Mallard preferring deep water habitat was weakly correlated with the NDVI of 500 m buffer of the lagoon (Figure 3-8). The species abundance was high in November while the NDVI was high in March. The poor correlation could due to the extremely opposite pattern of NDVI and abundance.

The shallow water species Pied Avocet is strongly correlated with the NDVI of 500 m buffer of the lagoon (R^2= 0.58). The NDVI and the species were high in winter season (Figure 3-8).

The wet muddy flat species Dunlin was strongly correlated with the NDVI of 500 m buffer of the lagoon (R^2= 0.88) as shown in the Figure 3-8.

The Common Crane prefers to feed to prefer in meadows/plains /agriculture was weakly correlated with the NDVI of 500 m buffer of the lagoon (Figure 3-8).

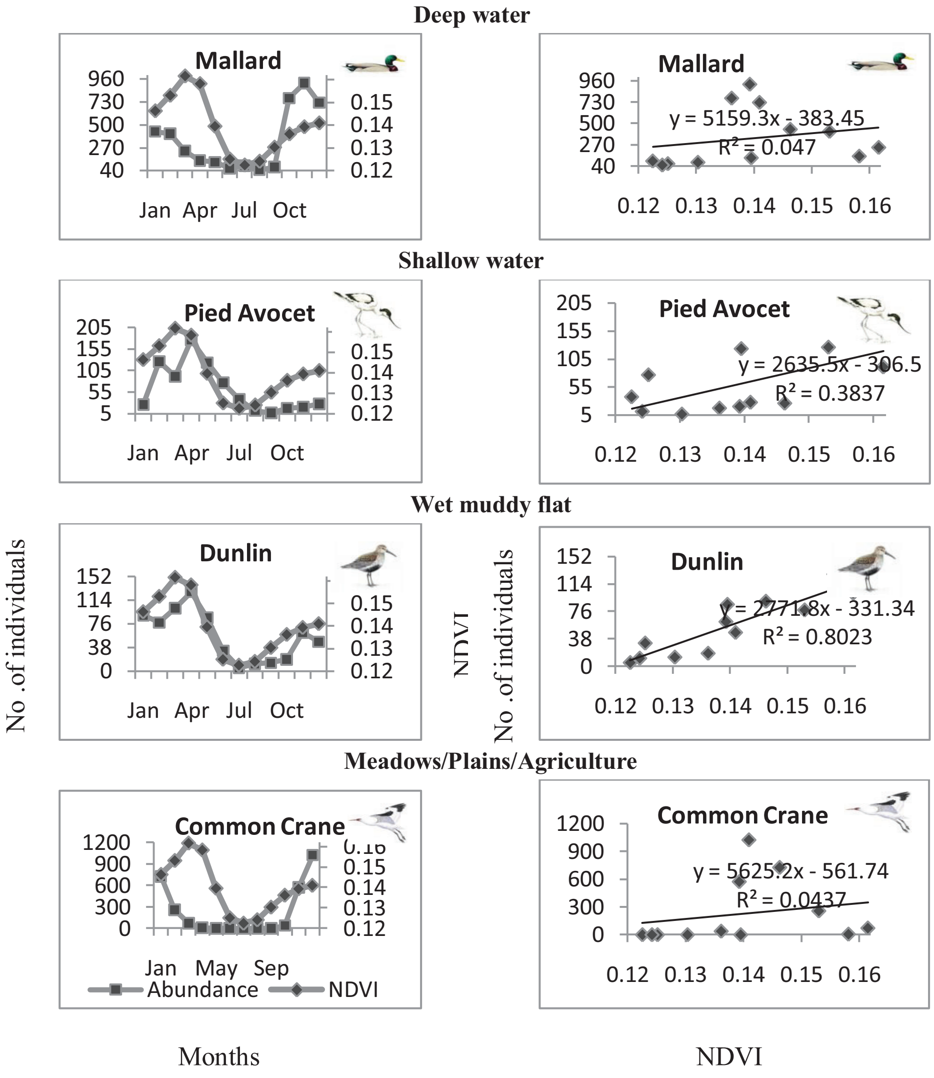

Figure 3-7: Correlation between seasonal waterbird abundance based on foraging habitat and the NDVI of the lagoon

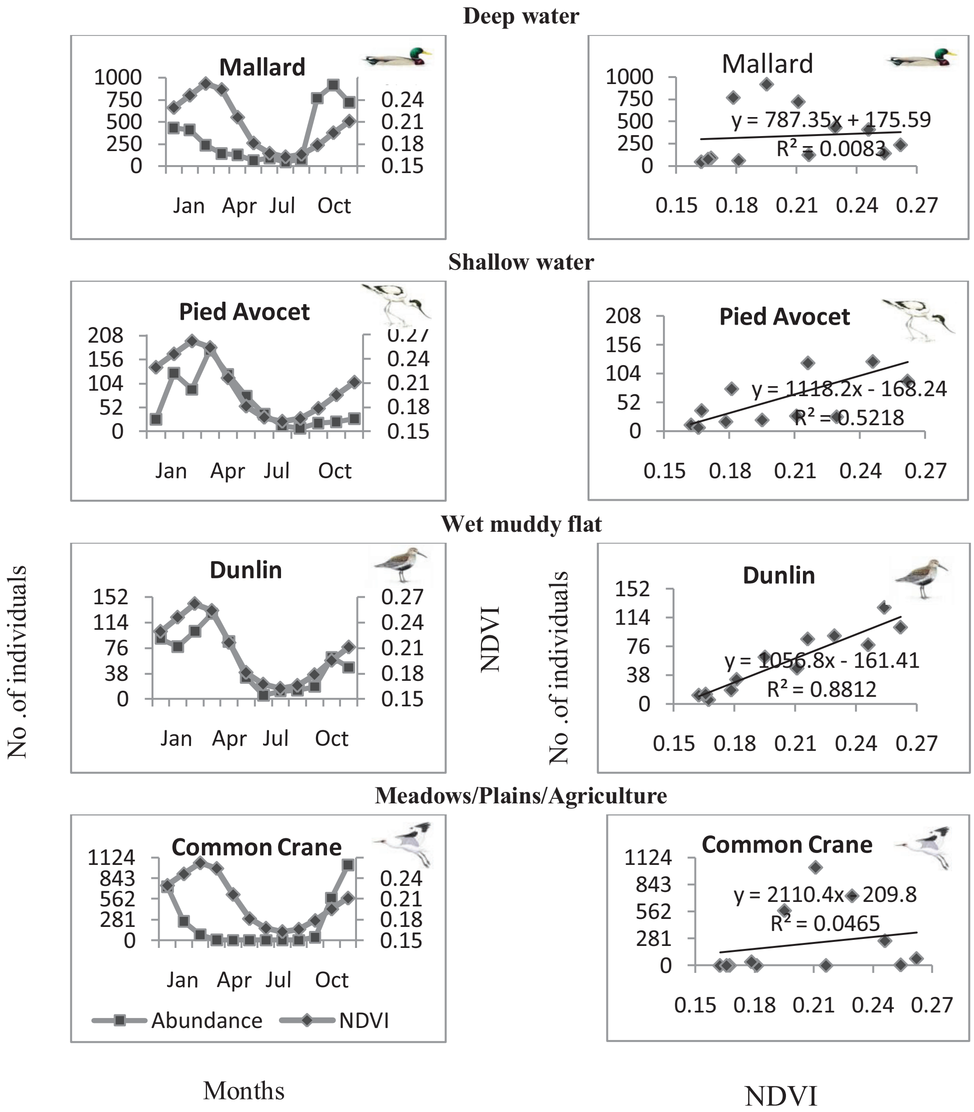

Figure 3-8: Correlation between seasonal waterbird abundance based on foraging habitat and the NDVI of 500 m buffer of the lagoon

3.1.3.3. Interannual waterbird abundance based on foraging habitat and the NDVI of the lagoon

The deep water habitat preferring Mallard is weakly correlated with the NDVI of the lagoon showed (R^2= 0.16). The correlation is very poor as the availability of food is less in deep water (Figure 3-9).

The shallow water species Pied Avocet showed a weak correlation with the NDVI of the lagoon (R^2=0.12). The weak correlation indicates that interannual abundance is not influenced by interannual NDVI of the lagoon (Figure 3-9).

The Dunlin prefers to feed in wet mudflat area is moderately correlated with NDVI of the lagoon (R^2= 0.35). The moderate correlation shows that NDVI determines the interannual abundance of Dunlin (Figure 3-9). The wet muddy flat species is mainly insectivorous and eats invertebrate and the habitat provides sufficient food for the species.

The Common Crane forage in meadows/plains/agriculture habitat is weakly correlated with the NDVI of the lagoon (R^2= 0.08). The correlation is not significant to the use of the lagoon only as a resting ground by the species (Figure 3-9).

3.1.3.4. Interannual waterbird abundance based on foraging habitat and the NDVI of 500 m buffer of the lagoon

The deep water Mallard did not show any correlation with the NDVI of 500 m buffer of the lagoon (Figure 3-9).

The Pied Avocet is not correlated with the NDVI of 500 m buffer of the lagoon (Figure 3-9) and the abundance of the species is not influenced by the NDVI of the 500 m buffer of the lagoon.

The wet muddy flat preferring species Dunlin was moderately correlated with the NDVI of 500 m buffer of the lagoon (R^2= 0.20) as shown in the Figure 3-9.

The Common Crane forage in meadows/plains or agriculture habitat was weakly correlated correlation with the NDVI of 500 m buffer of the lagoon (R^2= 0.08) The weak correlation is due to the less dependence of the species as foraging ground (Figure 3-9).

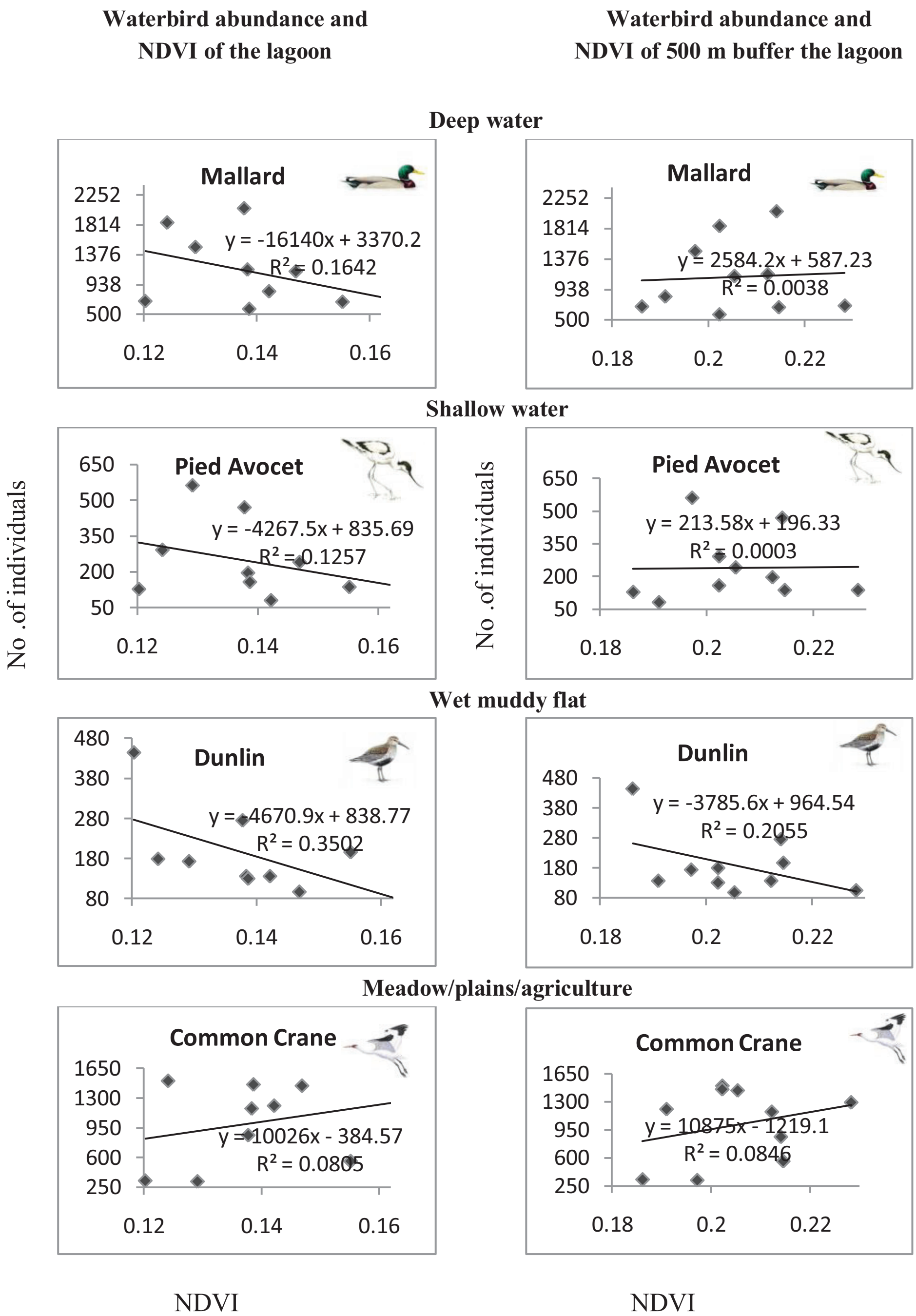

Figure 3-9: Correlation between interannual waterbird abundance based on foraging habitat and the NDVI of the lagoon and 500 m buffer of the lagoon

3.2. Abundance of the major waterbird guilds and NDVI

3.2.1. Abundance of waterbird guild based on the body size of species

3.2.1.1. Seasonal abundance of waterbird guild based on body size and the NDVI of the lagoon

The medium body size guild is moderately correlated with the NDVI of the lagoon (R^2= 0.36) followed by large body size guild (R^2=0.27). The small body sizes guild did not show any correlation with the NDVI of the lagoon (Figure 3-10).

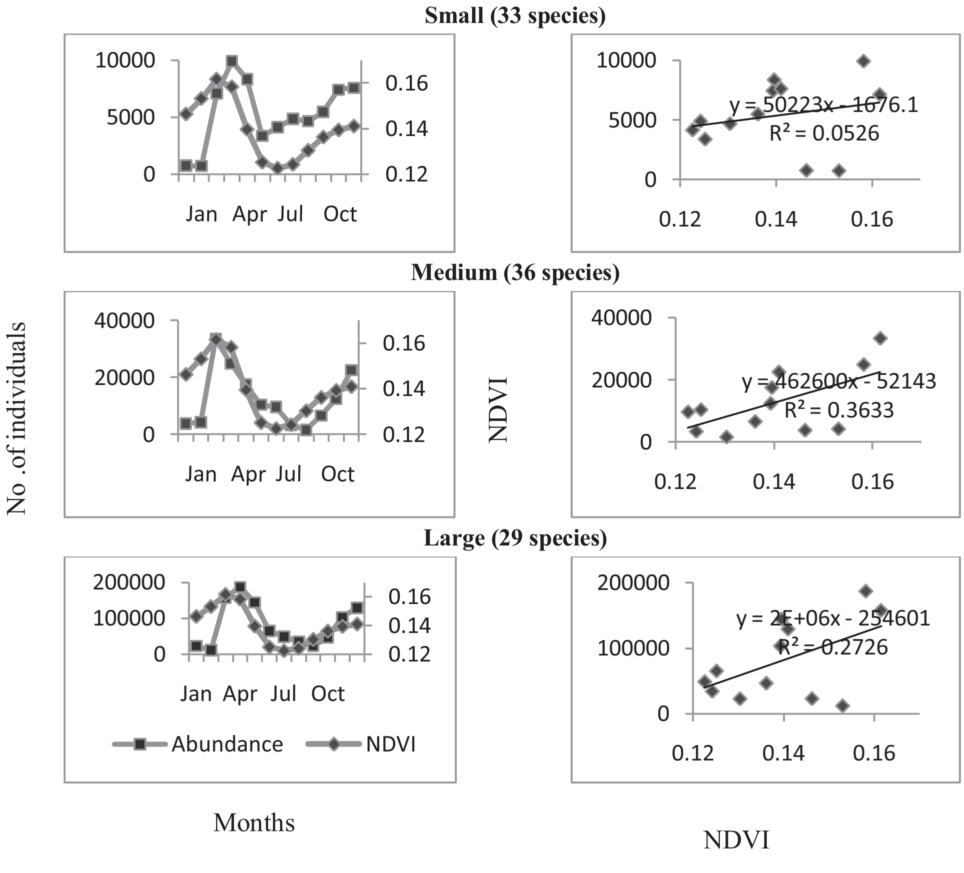

Figure 3-10: Correlation between seasonal waterbird guild based on body size and the NDVI of the lagoon

3.2.1.2. Seasonal abundance of waterbird guild based on body size and the NDVI of 500 m buffer of the lagoon

The medium body size guild is moderately correlated with the NDVI of 500 m buffer of the lagoon (R^2= 0.39). Large body size guild was moderately correlated (R^2=0.29). The small body size group did not show any correlation with the NDVI of 500 m buffer of the lagoon (Figure 3-11).

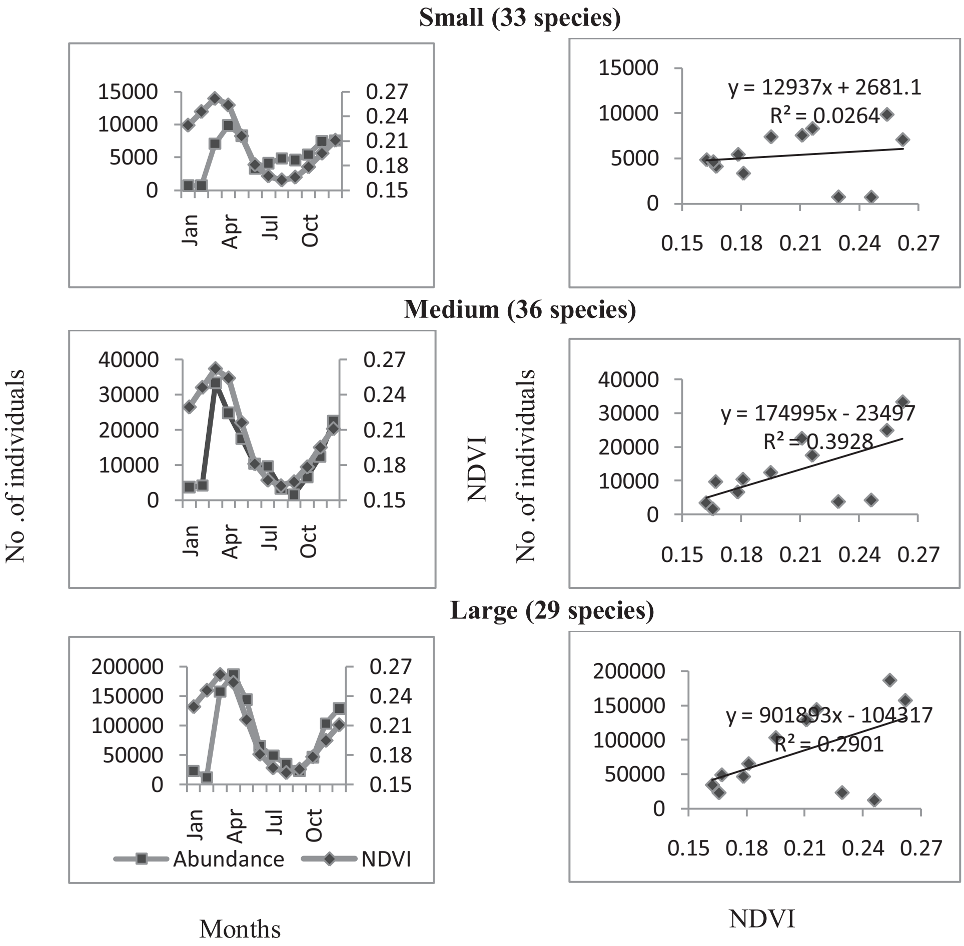

Figure 3-11: Correlation between seasonal waterbird abundance based o body size and the NDVI of 500 m buffer of the lagoon

3.2.1.3. Interannual abundance of waterbird guild based on body size and the NDVI of the lagoon

The small, medium and large body size guild is weakly correlated with the NDVI of the lagoon (Figure 3-12).

3.2.1.4. Interannual abundance of waterbird guild based on body size and the NDVI of 500 m buffer of the lagoon

The large body size guild and medium body size guild is moderately correlated with the NDVI of the 500 m buffer of the lagoon (R^2= 0.26 & 0.22). The correlation in small body size was very weak (Figure 3-12).

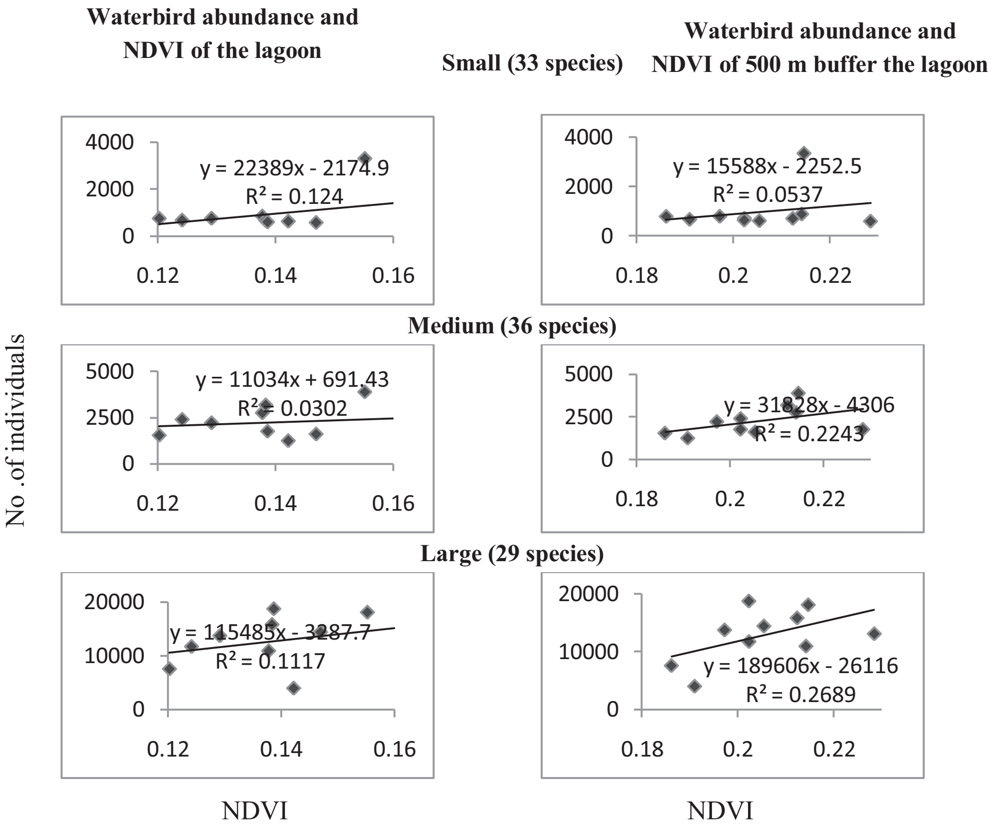

Figure 3-12: Correlation between interannual waterbird guild based on body size and the NDVI of the lagoon and 500 m buffer of the lagoon

3.2.2. Abundance of waterbird guild based on forage type of species

3.2.2.1. Seasonal abundance of waterbird guild based on forage type and the NDVI of the lagoon

Carnivorous guild is moderately correlated with the NDVI of the lagoon (R^2= 0.27). Herbivorous and omnivorous guild is weakly correlated (R^2= 0.14 &0.15). The higher correlation in the carnivorous species could be due to the availability of sufficient nesting habitat for the species breeds in the lagoon (Figure 3-13).

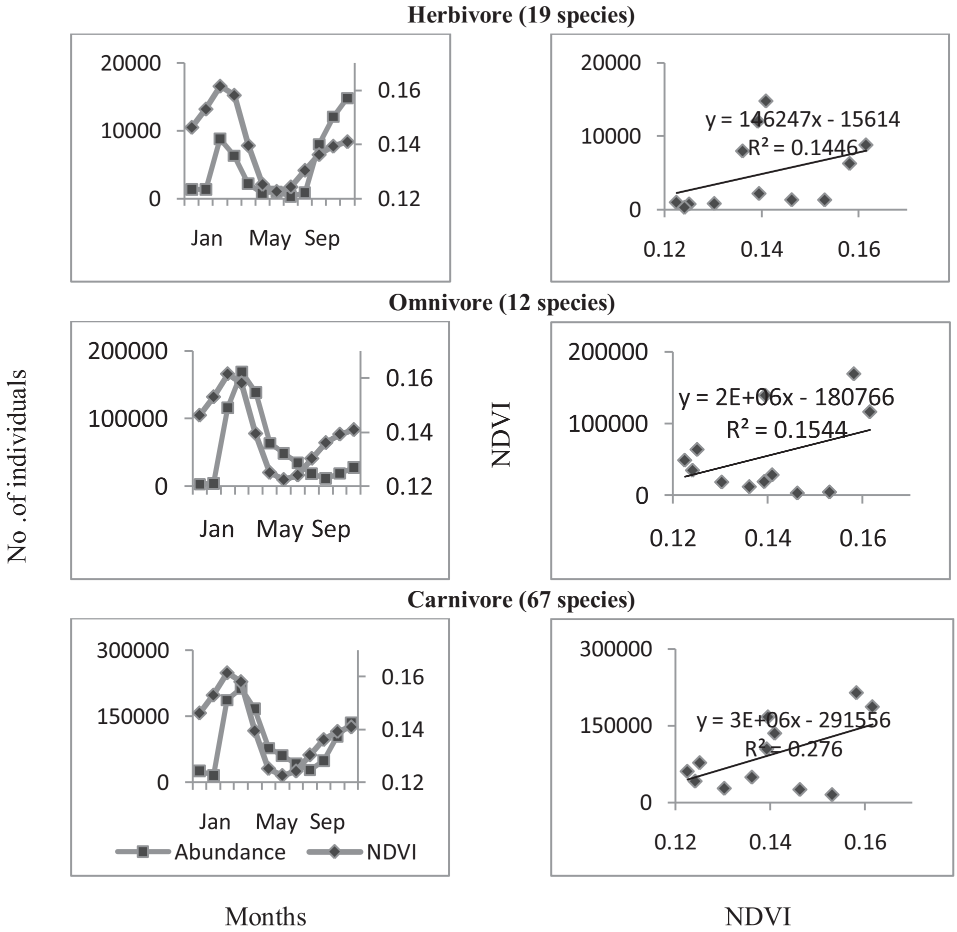

Figure 3-13: Correlation between seasonal waterbird guild based on forage type and the NDVI of the lagoon

3.2.2.2. Seasonal abundance of waterbird guild based on forage type and the NDVI of 500 m buffer of the lagoon

The carnivorous guild is moderately correlated with the NDVI of 500 m buffer of the lagoon (R^2= 0.30) followed by omnivorous guild (R^2= 0.21). The herbivorous guild is weakly correlated with the NDVI of 500 m buffer of the lagoon (Figure 3-14)

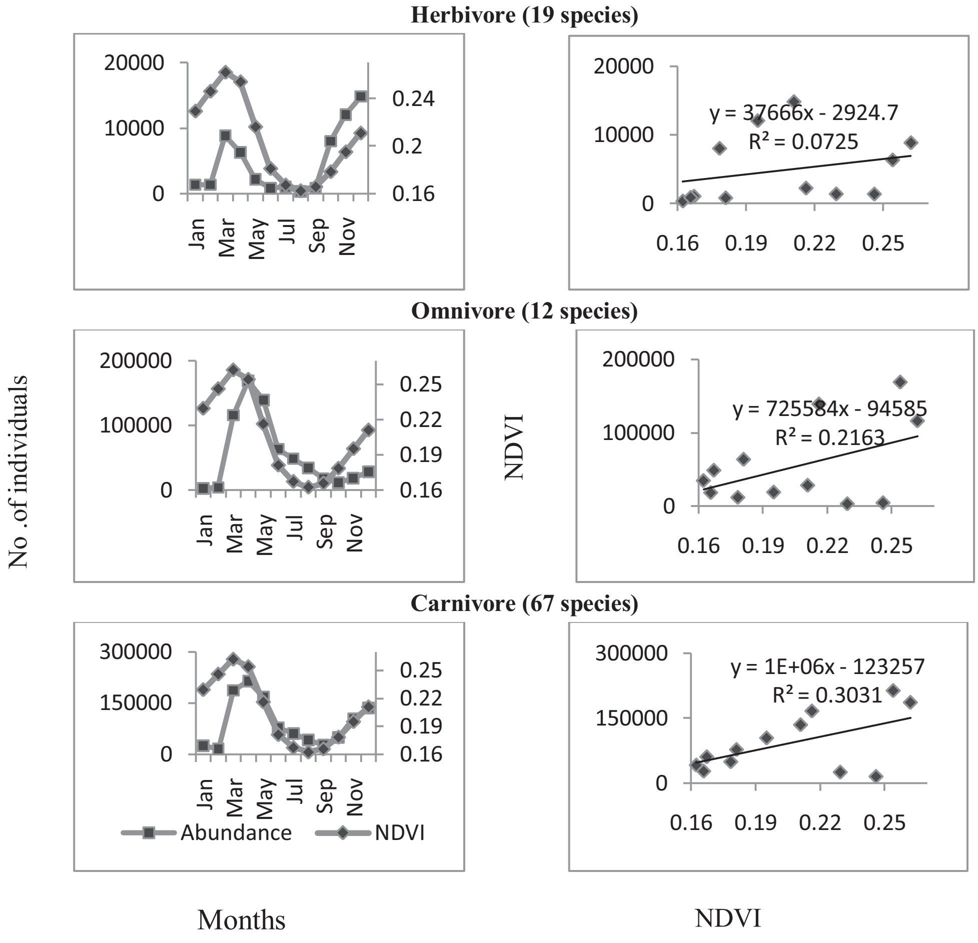

Figure 3-14: Correlation between seasonal waterbird guild based on forage type and the NDVI of 500 m buffer of the lagoon

3.2.2.3. Interannual abundance of waterbird guild based forage type and the NDVI of the lagoon

The carnivorous and omnivorous guild is weakly correlated with the NDVI of the lagoon (R^2= 0.14 & R^2= 0.13). There herbivorous guild did not correlate with the NDVI of the lagoon (Figure 3-15).

3.2.2.4. Interannual abundance of waterbird guild based on forage type and the NDVI of 500 m buffer of the lagoon

Carnivorous guild is moderately correlated with the NDVI of the 500 m buffer of the lagoon (R^2= 0.27). The herbivore was weakly correlated (R^2= 0.12). There was no correlation in the omnivore group (Figure 3-15).

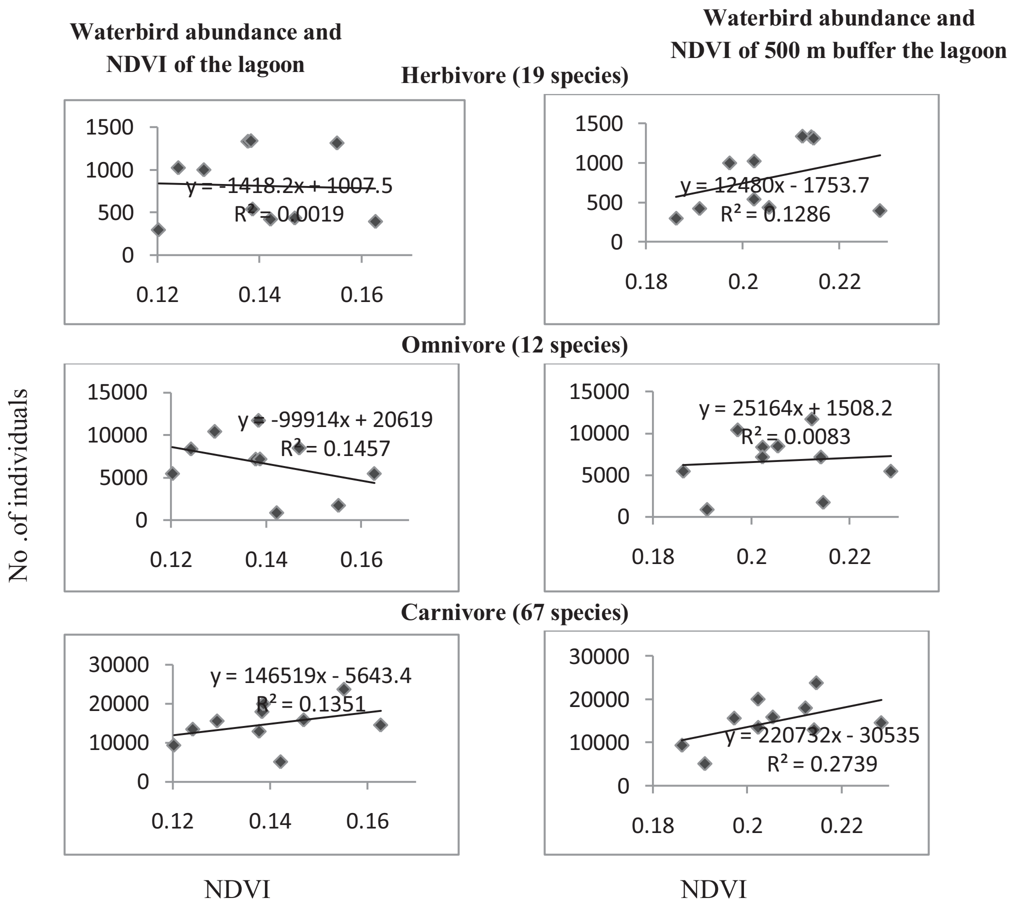

Figure 3-15: Correlation between interannual waterbird guild based on forage type and the NDVI of the lagoon and 500 m buffer of the lagoon

3.2.3. Abundance of waterbird guild based on foraging habitat of species

3.2.3.1. Seasonal abundance of waterbird guild based on foraging habitat and the NDVI of the lagoon

The guild forage near wet muddy flat is moderately correlated with the NDVI of the lagoon (R^2= 0.34). Deep water and shallow water guild is weakly correlated with the NDVI of the lagoon (R^2= 0.13). The correlation in meadow/plain/agriculture guild was very poor (Figure 3-16).

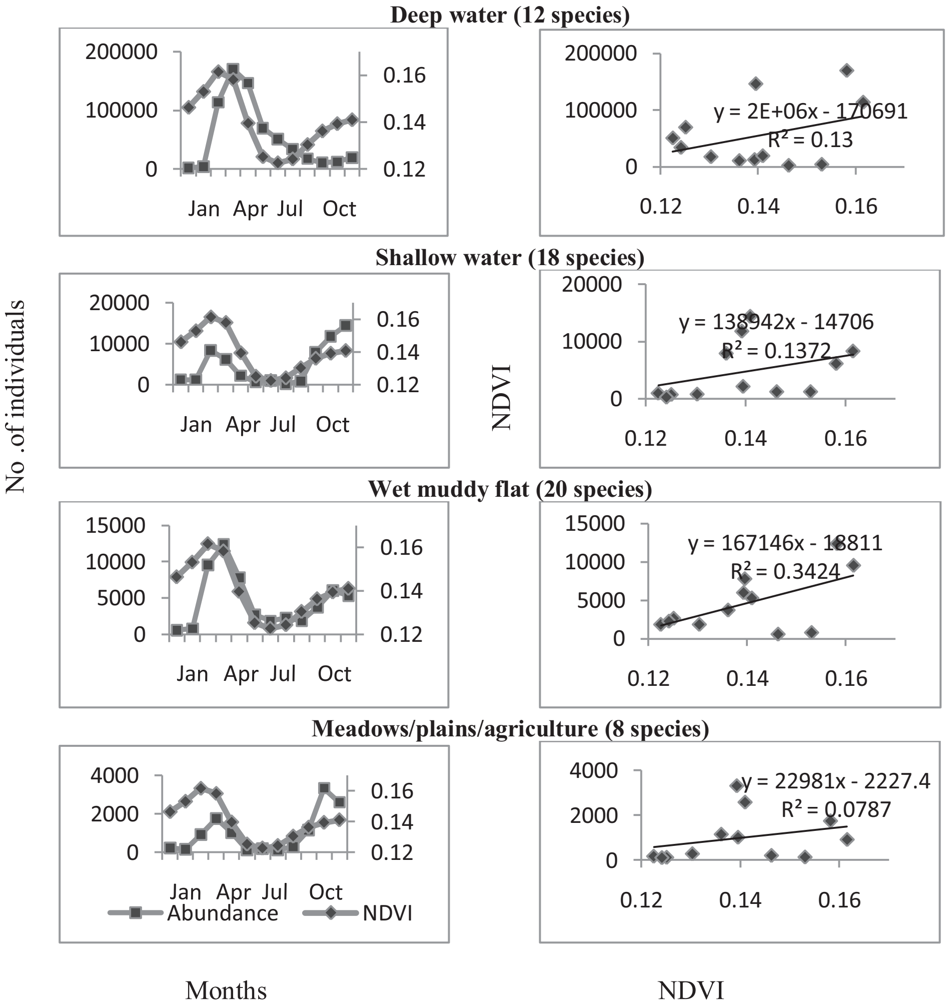

Figure 3-16: Correlation between seasonal waterbird guild based on foraging habitat and the NDVI of the lagoon

3.2.3.2. Seasonal abundance of waterbird guild based on foraging habitat and the NDVI of 500 m buffer of the lagoon

The guild prefer to forage in wet muddy flat is more correlated with the NDVI of 500 m buffer of the lagoon (R^2= 0.30). Deep water guild is weakly correlated with the NDVI of the 500 m buffer of the lagoon (R^2= 0.19). The shallow water and meadows/plain/agriculture guild did not correlate to the NDVI of 500 m buffer of the lagoon (Figure 3-17)

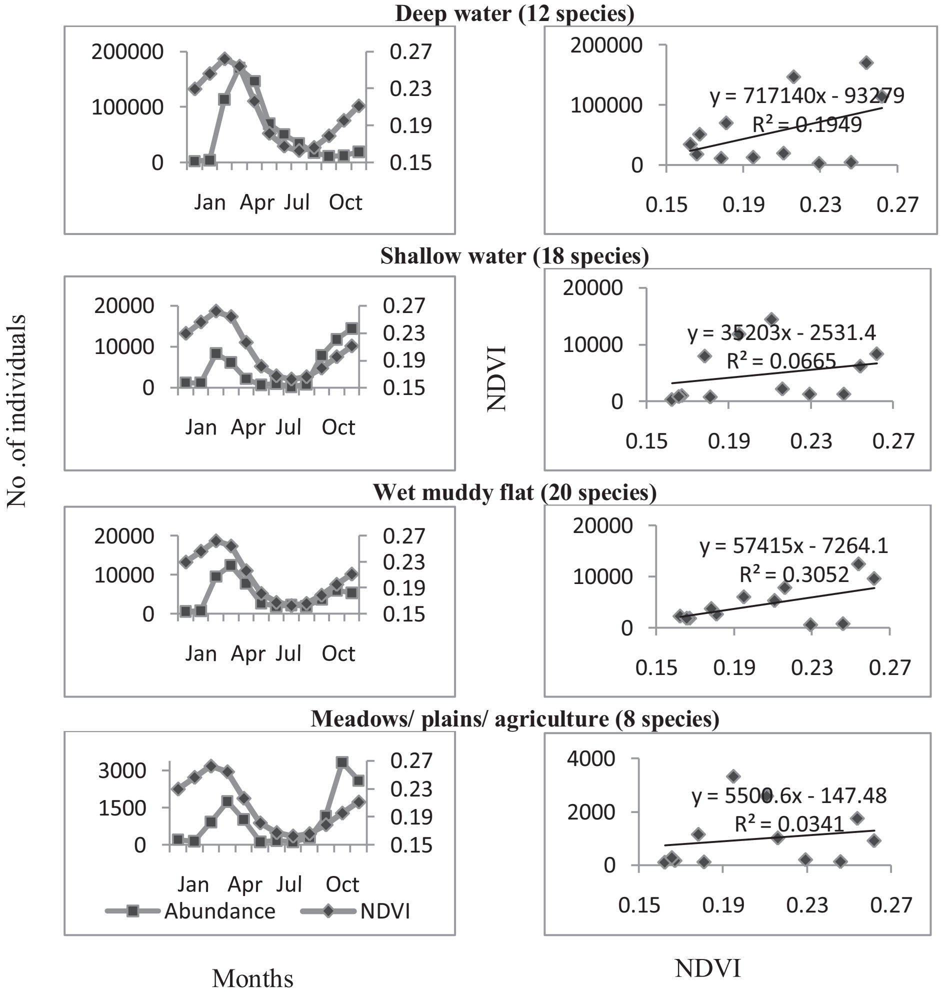

Figure 3-17: Correlation between seasonal waterbird guild based on foraging habitat and the NDVI of 500 m buffer of the lagoon

3.2.3.3. Interannual abundance of waterbird guild based on foraging habitat and the NDVI of the lagoon

The guild belong to meadows/plain/agriculture is strongly correlated to the NDVI of the lagoon (R^2= 0.52). Correlation in other guilds was very weak (Figure 3-18).

3.2.3.4. Interannual abundance of waterbird guild based on foraging habitat and the NDVI of 500 m buffer of the lagoon

The guild prefer to forage in meadows/plains/agriculture habitat is strongly correlated to the NDVI of 500 m buffer of the lagoon (R^2= 0.57). Other guilds showed poor correlation ((Figure 3-18).

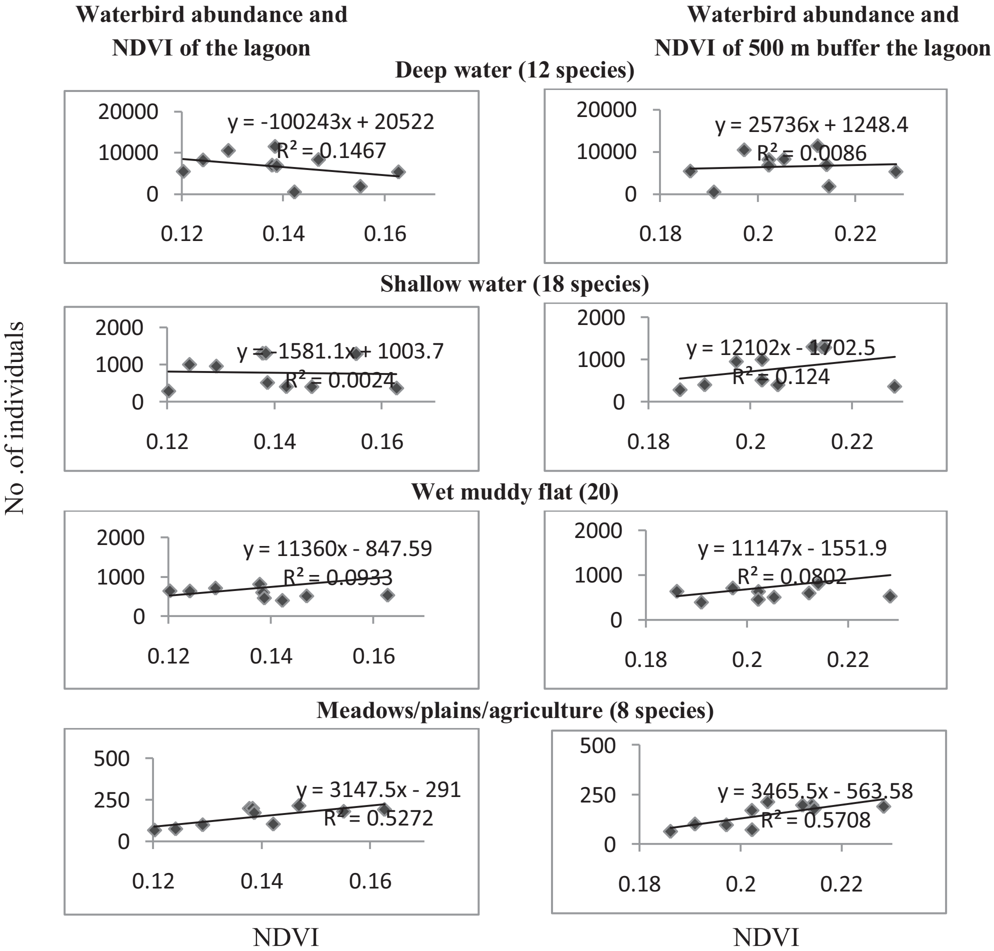

Figure 3-18: Correlation between interannual waterbird guild based on foraging habitat and the NDVI of the lagoon and 500 m buffer of the lagoon

3.3. Diversity of waterbirds and NDVI

3.3.1. Seasonal waterbird diversity and the NDVI of the lagoon

The family Anatidae showed strong correlation with the NDVI of the lagoon (R^2= 0.68). The diversity and the NDVI followed the trend in most of the seasons. The Scolopacidae family showed weak correlation with the NDVI of the lagoon (R^2= 0.16). The family Ardeidae did not show any correlation with the NDVI of the lagoon (Figure 3-19).

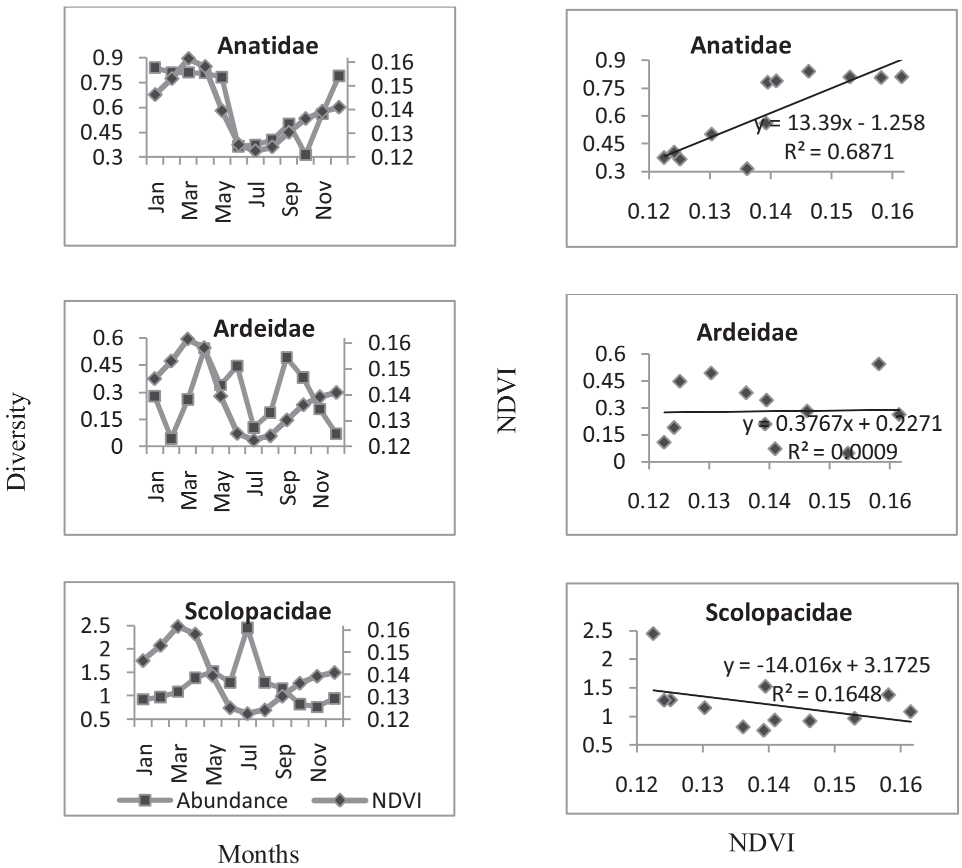

Figure 3-19: Correlation between seasonal waterbird diversity and the NDVI of the lagoon

3.3.2. Seasonal waterbird diversity and the NDVI of 500 m buffer of the lagoon

The family Anatidae was strongly correlated with the NDVI of the 500 m buffer of the lagoon (R^2= 0.78). The diversity and the NDVI followed the trend in most of the seasons. The family Ardeidae and Solopacidae did not show any correlation with the NDVI of the lagoon (Figure 3-20).

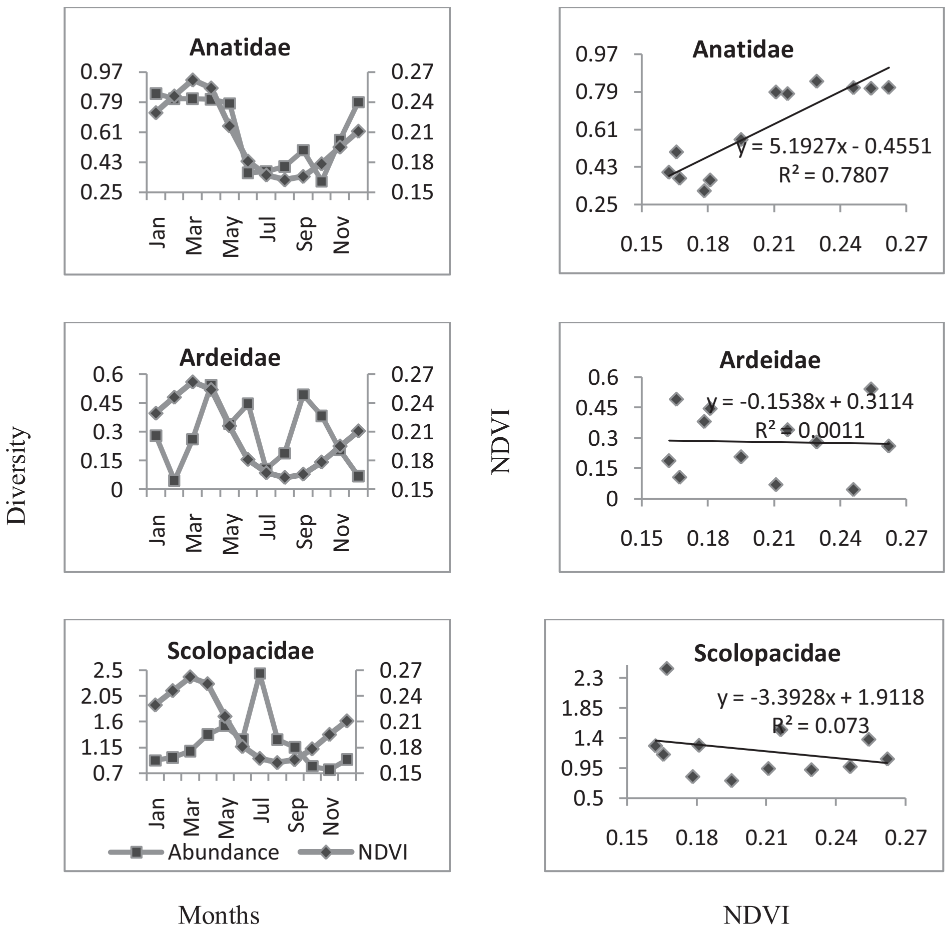

Figure 3-20: Correlation between seasonal waterbird diversity and the NDVI of 500 m buffer from the lagoon

3.3.3. Interannual waterbird diversity and the NDVI of the lagoon

The Anatidae family was moderately correlated with the NDVI of the lagoon (R^2= 0.34). There was no significant correlation in the family Ardeidae and Scolopacidae (Figure 3-21).

3.3.4. Interannual waterbird diversity and the NDVI of 500 m buffer of the lagoon

The Anatidae family was weakly correlated with the NDVI of the 500 m buffer of the lagoon (R^2= 0.16). There was no significant correlation in the family Ardeidae and Scolopacidae (Figure 3-21).

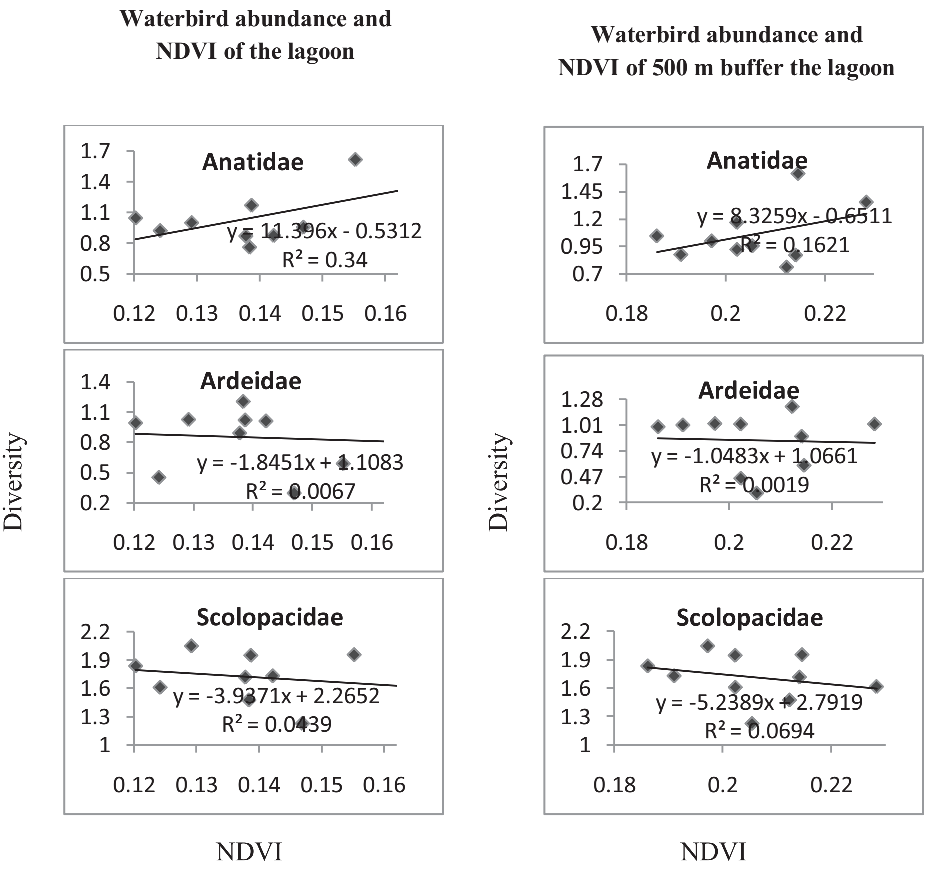

Figure 3-21: Correlation between interannual waterbird diversity and the NDVI of 500 m buffer from the lagoon

3.4. Water level and NDVI of the lagoon

3.4.1. Seasonal water level and NDVI of the lagoon

The water level and NDVI of the lagoon is strongly correlated (R^2= 0.83) correlation each other (Figure 3-22). The water level increased from January to March and then it decreased subsequently and lagoon dried in the months of July to September and again the water level gradually increased in the following months.

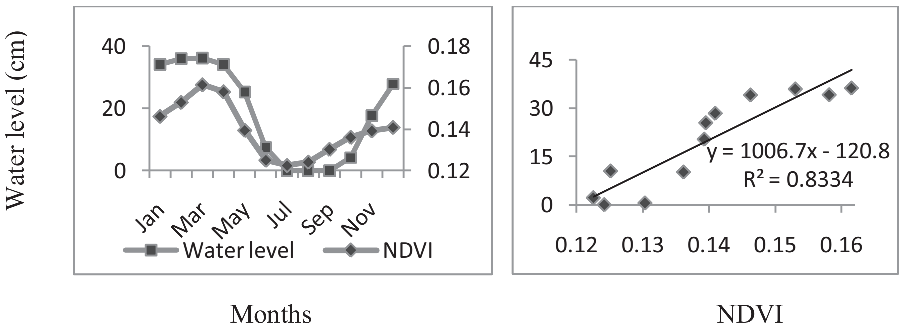

Figure 3-22: Seasonal correlation between water level and the NDVI of the lagoon

3.4.2. Interannual water level and NDVI of the lagoon

The interannual water level and NDVI of the lagoon is moderately correlated (R^2= 0.35). The interannual NDVI decreased with increasing water level during different years in the lagoon (Figure 3-23).

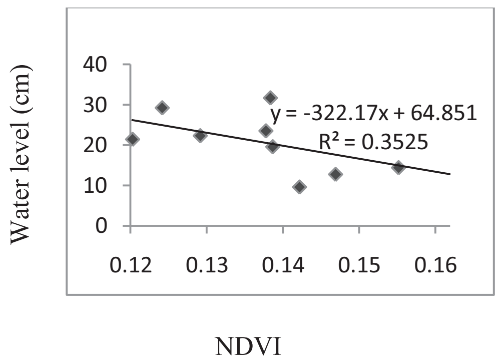

Figure 3-23: Interannual correlation between water level and NDVI of the lagoon

4. Discussion

The MODIS NDVI has used as surrogate for monitoring the seasonal and interannual abundance and diversity in the Fuente de Piedra lagoon, Spain. In order to understand the interaction of waterbird, the analysis has done at two spatial scales-NDVI of the lagoon and NDVI of the 500 m buffer. Three criteria such as body size, forage type and foraging habitat at individual waterbird species and major waterbird guild has been done and the results are very promising. The major aspects of the results are discussed in this chapter.

4.1.1. Seasonal abundance of individual waterbird species and NDVI

Forage type of the individual waterbird species is strongly correlated with the NDVI of the lagoon ($R^2 \geq 0.58$) and it indicates that the lake productivity is sufficient to support the birds of various food requirements. The herbivorous Northern Shoveler prefers major food as plant material (Euliss and Jarvis 1991, Mouronval *et al.* 2007), the omnivorous common coot is an opportunistic feeder (Mark and Daniel 1994) and grazes extensively in the wetland rich in macrophytes. The strong correlation of carnivorous Black-headed Gull with the NDVI of the lagoon is surprising. Even though this relationship is not expected naturally, the reason behind this could be the availability of food materials and nesting habitats in the islands and marsh land of the lagoon (Philipp and Stefan 2005, Malickiene and Budrys 2002).

The second strongest correlation was based on body size. Except the large body size species Greater flamingo, the small and medium body size species strongly correlated with the NDVI of the lagoon ($R^2 \geq 0.43$). The highest correlation in the small body size Black-winged Stilt (R^2= 0.89) could be due to its adaptability to various food material such as chironomid midges, shore flies, house flies, and brine shrimp, main aquatic invertebrate prey, water scavenger beetles, biting midges in different seasons (Dostin and Morton 1989, Yih-Tsong *et al.* 2009). The weak correlation in the large body size species may be its partial migratory behaviour during dry seasons and the intake of omnivorous forage type (Ramesh and Ramachandran 2005, Amat *et al.* 2005).

In the foraging habitat, only wet muddy flat species, Dunlin is strongly correlated with the NDVI of the lagoon (R^2= 0.80) followed by shallow water species. The wet muddy flat and shallow water habitat is rich in insects, small invertebrates, primarily chironomidae larvae, molluscs and polychaetes (Mouristen 1994, Davis and Smith

1998) which form the major diet of the species. The weak correlation in deep water species could be due to less availability of food resources (Mouronval *et al.* 2007) and in the habitat meadows/plain/ agriculture is due to the less availability of its preferred food such as plants, cereals, plant tubers due to the change in agriculture pattern to olive plantation in and around the lagoon (Naugle *et al*. 2000, Aviles *et al.* 2002).

The analysis result shows that the abundance of waterbird species is more influenced by the NDVI of 500 m buffer of the lagoon in all the three classification criteria (forage type, body size and foraging habitat). The strongest correlation was in forage type was $R^2 \geq 0.62$, followed by body size and foraging habitat. The advantage for buffer could be the availability of food sources (Thomas 1982, Ashkenazi & Dimentman 1998, Perrow *et al.* 1997, Robledano 2011, Marchant and Higgins1990, Goutner 1997). The surrounding habitat of the lagoon increases the availability of foraging range, nesting and roosting areas (Cézilly *et al.* 1995, Farmer and Wiens, 1999, Ashley *et al*. 2000, Elmberg *et al.* 2010).

4.1.2. Interannual abundance of individual waterbird species and NDVI

The interannual abundance of individual waterbird species and the NDVI is moderately correlated with the forage type, foraging habitat and weakly correlated with body size. Among this omnivorous species and herbivorous species in forage type and wet muddy flat species, Dunlin in the foraging habitat is moderately correlated with the NDVI of the lagoon. The moderate to weak correlation may be due to the variation in climatic factors, changes in biomass of lagoon and surrounding habitat (Greenwood et al 1995, Kingsford et al. 1999, Clausen 2000, Broyer and Calenge 2010).

4.2. Abundance of major waterbird guilds and NDVI

4.2.1. Seasonal abundance of major waterbird guilds and NDVI

The abundance of major waterbird guild is moderately correlated to the NDVI of the lagoon. The medium and large body size animals are more correlated with the NDVI of the lagoon. The reason behind this correlation is the individual species in this group is predominantly herbivorous in nature and opportunistic feeders (Sanders 2000). They occupy different microhabitats and utilize maximum resources available from the lagoon and utilize the area for nesting and roosting (Erwin and Hatfield 1995). The second most moderate correlation was based on foraging habitat, the wet muddy flat guild. The species belong to this category are waders and shoreliners and it prefer to eat insects, invertebrates from the mudflats and emergent vegetation of the lagoon (Mittlebach 1988, Campeau *et al.* 1994). The most surprising observation is that the comparatively better correlation of Carnivorous species with the NDVI of the lagoon. This could be due to the availability of abundant food resources through food web of the wetland ecosystem (Dies *et al.* 2005, Webb *et al.* 2010).

The correlation of waterbird guilds and NDVI of the 500 m buffer of the lagoon is more correlated than the NDVI of the lagoon. The Medium and large body size group showed comparatively showed better correlation with the NDVI of 500 m buffer of the lagoon. The correlation indicates that food resource required for the species present in this lagoon and its adjacent areas (Andersson 1981). The species forage in wet muddy flats was moderately correlated with the NDVI of 500 m buffer. This correlation could be the result of availability of large foraging habitat and nesting habitat (Lodge 1985) for the species belong to this guild. The significantly poor correlation in the food type could due to the partial intake of non-vegetable matter of breeding ducks (Moreno-Mateos *et al.* 2009).

4.2.2. Interannual abundance of major waterbird guilds and NDVI

The interannual abundance of major waterbird guilds was strongly correlated with the foraging habitat, and weakly correlated forage type and body size. In the foraging habitat, only the meadows/plains/agriculture guild in foraging guild has the strong correlation. This relationship could be due to shallow water areas and grassland of the lagoon as a source of abundant food such as grasses, aquatic plants, small crustaceans and shrimps (Safran *et al.* 2000). The shallow and wet muddy flat has no correlation with the NDVI of the lagoon. This could be the result of drying upon lakebed from June to October of every year (Amat *et al.* 2005). The correlation in forage type and body size was very weak and this may the lack of sufficient food materials during different years (Green and Robins 1993, Guillemain *et al.* 2000). The interannual abundance of major waterbird guilds and NDVI of the 500 m buffer showed more correlation than the NDVI of the lagoon. The high correlation is due to the presence of reed stems and it support large number of breeding and wintering waterbird (Moreno-Mateos et al 2009).

4.3. Diversity of waterbirds and NDVI

The seasonal analysis of the diversity is strongly correlated with the NDVI of the lagoon (R^2 = 0.68) while Scolopacidae and Ardeidae is weakly correlated. The Anatidae family is moderately correlated with the inter-annual NDVI of the lagoon. The strong seasonal correlation is mainly due to the herbivorous feeding nature of duck species and the use of lagoon and surrounding habitat for nesting and roosting (Erwin and Hatfield 1995). No correlation in the Ardeidae and Scolopacidae family is due to the carnivorous feeding nature or the lack of sufficient food materials in the lagoon (Guillemain *et al.* 2000). The correlation showed same trend with the NDVI of 500 m buffer of the lagoon with Anatidae as top most family with strong (R^2 = 0.78). The higher diversity is due to the higher productivity of the lagoon (Abrams 1995).

4.4. Water level and NDVI of the lagoon

The strong correlation with water level and NDVI of the lagoon indicates the role of water level on determining the productivity of the lagoon. The lagoon is rich in phytoplankton from December to March and from June to July (Garcia and Niell 1993). This very high primary productivity of the lagoon increases the food availability in higher trophic level and attracts variety of species of different foraging guilds to the Fuente de Piedra lagoon. Moreover, water level plays another role for creating various microhabitats in the lagoon (Weller 1999).

5. Conclusion

The present study reveals that MODIS NDVI can be used as an efficient tool for monitoring seasonal and interannual waterbird abundance and diversity.

Based on seasonal waterbird abundance of individual species and NDVI, forage type is more correlated followed by body size and foraging habitat. In the forage type omnivorous (Common Coot, R^2=0.69), carnivorous (Black-headed Gull, R^2=0.60) and herbivorous (Northern Shoveler R^2= 0.58) species are strongly correlated. In the body size criteria small body size Black-winged Stilt (R^2= 0.89) is strongly correlated with the NDVI. Foraging habitat also important for the wet muddy flat species (Dunlin, R^2= 0.80). The correlation seasonal NDVI of 500 m buffer of the lagoon is stronger than the NDVI of the lagoon (for example Common Coot, R^2=0.80, Black-headed Gull, R^2=0.68, Northern Shoveler R^2= 0.62, Dunlin, R^2= 0.88). The interannual waterbird abundance based on individual species was moderately to weakly correlate with the NDVI of the lagoon and NDVI of the 500 m buffer. Only omnivorous and herbivorous species in forage type (Common Moorhen, R^2= 0.48 and Northern Shoveler R^2= 0.27) and wet muddy flat species (Dunlin R^2=0.35) is moderately correlated with the NDVI of the lagoon.

The analysis of abundance of major waterbird guild shows that the seasonal abundance is moderately correlated with the body size, foraging habitat and forage type. In the body size classification, medium and large guild is moderately (R^2=0.36 and 0.27) with the NDVI of the lagoon. Only wet muddy flat guild in foraging habitat (R^2=0.34) and carnivorous guild in forage type (R^2=0.27) is moderately correlated with the NDVI of the lagoon. The seasonal NDVI of 500 m buffer of the lagoon showed moderately higher correlation with respect to NDVI of the lagoon. The correlation moderately significant correlation with the NDVI of 500 m buffer of the lagoon is medium and large body size (R^2=0.39 & 0.29), carnivore in forage type (R^2=0.30). In the interannual abundance of NDVI, only the meadow/plain/agriculture guild in foraging habitat is strongly correlated with the NDVI of the lagoon and the NDVI of the 500 m buffer of the lagoon (R^2=0.52 &0.57).

Among the three families selected, only the Anatidae family is strongly correlated with the NDVI of the lagoon (R^2=0.68) and the NDVI of 500 m buffer of the lagoon (R^2=0.78). The interannual diversity analysis the correlation was moderate in Anatidae with respect to NDVI of the lagoon.

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7. Appendices

7.1. Checklist of waterbirds present in the Fuente de Piedra lagoon

Family/Scientific Name	Body size	habitat	behaviour	food
Podicipedae				
Tachybaptus ruficollis	26	WVW	WSD	C
Podiceps cristatus	48	WVW	WSD	C
Podiceps auritus	35	WVW	WSD	C
Podiceps nigricollis	31	WVW	WSD	C
Phalacrocoracidae				
Phalacrocorax carbo	85	OW	diver	C
Phalacrocorax aristotelis	73	OW	diver	C
Ardeidae				
Botaurus stellaris	75	WR/V	wader	C
Ixobrychus minutus	35	WR/V	wader	C
Nycticorax nycticorax	62	WR/V	wader	C
Ardeola ralloides	45	WR/V	wader	C
Bubulcus ibis	48	WR/V	wader	C
Egretta garzetta	60	WR/V	wader	C
Egretta alba	92	WR/V	wader	C
Ardea cinerea	93	WR/V	wader	C
Ardea purpurea	80	WR/V	wader	C
Ciconia nigra	97	MS	wader	O
Ciconidae				
Ciconia ciconia	103	MS	wader	O
Plegadis falcinellus	60	SWB/T	wader	O
Threskiornithidae				
Platalea leucorodia	127	SWB/T	wader	O
Threskiornis aethiopicus	60	SWB/T	wader	O
Phoenicopteridae				
Phoenicopterus ruber	132	OSW	wader	O
Phoenicopterus minor	120	OSW	wader	H
Anatidae				

Anser fabalis	78	M/GS	grazer	H
Anser anser	78	M/GS	grazer	H
Tadorna ferruginea	65	M/GS	grazer	H
Tadorna tadorna	60	M/GS	grazer	H
Anas penelope	46	SW/S	dabbling	H
Anas strepera	51	SW/S	dabbling	H
Anas crecca	36	SW/S	dabbling	H
Anas platyrhynchos	55	SW/S	dabbling	H
Anas acuta	57	SW/S	dabbling	H
Anas querquedula	39	SW/S	dabbling	H
Anas clypeata	49	SW/S	dabbling	H
Marmaronetta angustirostris	40	SW/S	dabbling	H
Netta rufina	55	SW/S	WSD	H
Aythya ferina	45	SW/S	WSD	H
Aythya nyroca	40	SW/S	WSD	H
Aythya fuligula	44	SW/S	WSD	H
Aythya marila	46	SW/S	WSD	H
Oxyura leucocephala	45	SW/S	WSD	H
Oxyura jamaicensis	39	SW/S	WSD	H
Rallidae				
Rallus aquaticus	25	MMS	wader	O
Porzana porzana	20	MMS	wader	O
Gallinula chloropus	29	MMS	wader	O
Porphyrio porphyrio	47	MMS	wader	O
Fulica atra	39	MMS	wader	O
Fulica cristata	42	MMS	wader	O
Alcedinidae				
Alcedo atthis	18	OW	PF	C
Gruidae				
Grus grus	107	GA	wanderer	O
Haematopodidae				
Haematopus ostralegus	42	MNW	wader	C
Recurvirostridae				
Black-winged stilt	35	MNW	wader	C

Pied Avocet	44	MNW	wader	C
Burhinidae				
Burhinus oedicnemus	42	MPA	wanderer	C
Glariolidae				
Glareola pratincola	26	MPA	wanderer	C
Charadridae				
Charadrius dubius	17	MNWP	MW	C
Charadrius hiaticula	18	MNWP	MW	C
Charadrius alexandrinus	16	MNWP	MW	C
Pluvialis squatarola	28	MNWP	MW	C
Pluvialis apricaria	27	GA	wanderer	O
Vanellus vanellus	30	G/M	wanderer	C
Scolopacidae				
Calidris canutus	25	MNW	MW	C
Calidris alba	20	MNW	MW	C
Calidris minutilla	14	MNW	MW	C
Calidris temminckii	14	MNW	MW	C
Calidris ferruginea	20	MNW	MW	C
Calidris alpina	19	MNW	MW	C
Lymnocryptes minimus	19	MNW	MW	C
Tringa erythropus	31	MNW	MW	C
Tringa totanus	25	MNW	MW	C
Tringa stagnatilis	23	MNW	MW	C
Tringa nebularia	32	MNW	MW	C
Tringa ochropus	22	MNW	MW	C
Tringa glareola	20	MNW	MW	C
Actitis hypoleucos	19	MNW	MW	C
Arenaria interpres	23	MNW	MW	C
Phalaropus fulicarius	21	MNW	MW	C
Phalaropus lobatus	18	MNW	MW	C
Philomachus pugnax	30	MPA	wanderer	C
Gallinago gallinago	28	MPA	wanderer	C
Limosa limosa	40	MPA	wanderer	C
Limosa lapponica	37	MPA	wanderer	C

Numenius phaeopus	41	MPA	wanderer	C
Numenius arquata	54	MPA	wanderer	C
Laridae				
Larus marinus	67	WMAS	wanderer	C
Larus audouinii	48	WMAS	wanderer	C
Larus ridibundus	37	WMAS	wanderer	C
Larus genei	40	WMAS	wanderer	C
Larus minutus	26	WMAS	wanderer	C
Larus fuscus	52	WMAS	wanderer	C
Larus cachinnans	55	WMAS	wanderer	C
Sternidae				
Sterna hirundo	35	OW	PF	C
Sterna sandvicensis	40	OW	PF	C
Sterna caspia	52	OW	PF	C
Sterna nilotica	38	OW	PF	C
Sterna albifrons	23	OW	PF	C
Chlidonias hybridus	26	OW	dipper	C
Chlidonias niger	24	OW	dipper	C

WVW= Well vegetated water; OW= Open water; WR/V= Water with reeds/vegetation; MS= Meadow, Swamps; SWB/T= Shallow water with bushes/trees; OSW= Open shallow water; M/GS= Meadow/Grassy swamps; SW/S= shallow water/swamps; MMS= Marsh, meadows, swamps; GA= Grassland, agriculture land; MNW= Mudflats near water; MPA= Mudflats, plains, agriculture; MNWP= Mudflat near water, pasture; G/M= Grassland/mudflats; WMAS= Waters, meadows, agriculture, swamps; WSD= Water surface diver; PF= Plunch fisher; MW= Mudflat wanderer; H=Herbivore; O=Omnivore; C=Carnovore