Effects of wetland landscape changes on Waterfowl population dynamics: Fuente de Piedra Lagoon (Malaga, Spain)

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by

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Abstract

Waterfowl are known to be very dependant on wetlands for various essential resources critical for their survival at various stages of their life cycle. In Fuente de Piedra lagoon, little is known about spatiotemporal changes of the landscape structure inherent to water level fluctuations and how these changes are related to waterfowl communities occurring thereof. In this study, the landscape was systematically characterised into four distinct classes (namely deep water, shallow water, wet-muddy flat and land) using a high resolution DEM reclassified using historic water level data from 1991to 2008. The classes represented waterfowl microhabitats and these were validated using Landsat NDVI imagery to check for consistency of the delineation approach. The waterfowl community was divided into four guilds (swimmers, waders, shoreliners and 'others') and then a three-level hierarchy (from guild to family to species) formed under each guild. Swimmers included mostly anatidae such as ducks, while waders included the gruidae and recurvirostridae such as cranes and stilts respectively. Shoreliners were mostly sandpipers. Spatiotemporal changes of each landscape class were quantified in FRAGSTATS and correlated with the total population numbers of the waterfowl in the three-level hierarchy to assess strength and significance of relationships and identify preferred microhabitats. Results showed that as water levels fluctuate, the landscape composition also changes i.e. the areal cover of each class varied as well. High water levels >20cm meant more areal cover by deep water class and less by other classes, while less water was related to more land and varying percentage covers by shallow water and wet-muddy flat class. Swimmers were found to have preference of deep water shown by a significant ($p < 0.001$) R of 0.523 with this class, while waders showed a relatively strong correlation with the shallow water class. For both these groups, the guild level showed the best correlations with the landscape classes hence preferable over use of a dominant family or an indicator species in making inferences about these groups. Shoreliners showed unexpected results by having a relatively highest positive correlation of 0.463 with shallow water compared to 0.424 with wet-landscape class. They were also found to be significantly ($p<0.001$) positively related to spatiotemporal changes in total perimeter of the wet-muddy class. The family level was identified as best to use if any inferences about shoreliner community are to be made. The preferred microhabitat for shoreliners could not be conclusively determined from this study. All the groups had consistent negative significant ($p<0.001$) relationships with the land class. The conclusion made was that presence of water and its temporal fluctuations were critical in determining waterfowl species abundance through influencing landscape spatial structural changes. The effects vary from guild to guild as well as among levels of the community hierarchy. Therefore, management efforts could focus on manipulating landscape composition and configuration through effective water level management strategies that will ensure a balance within the waterfowl community in Fuente de Piedra lagoon.

Key words: Waterfowl, landscape ecology, DEM, water level, spatiotemporal, NDVI, Landsat, Fuente de Piedra, Malaga.

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Abbreviations

AEWA	**:**	Agreement on the Conservation of African-Eurasian Migratory Waterbirds
CA	**:**	Class Area
DEM	**:**	Digital Elevation Model
DN	**:**	Digital Number
ED	**:**	European Datum 1950
EWFD	**:**	European Water Framework Directive
ESE	**:**	East-South-East
EU	**:**	European Union
F de P	**:**	Fuente de Piedra lagoon
GIS	**:**	Geographic Information Systems
GloVis	**:**	Global Visualization Viewer
ITC	**:**	International Institute for Geo-information Science and Earth Observation
MODIS	**:**	Moderate resolution Imaging Spectroradiometer
MWS	**:**	Modelled Water Surface
NASA	**:**	National Aeronautics and Space Administration
NDVI	**:**	Normalised Difference Vegetation Index
NDWI	**:**	Normalised Difference Water Index
NOAA	**:**	National Oceanic and Atmospheric Administration
R	**:**	Pearson’s Correlation Coefficient
RMSE	**:**	Root Mean Square Error
RS	**:**	Remote Sensing
SVWS	**:**	Single Value Water Surface
TE	**:**	Total Edge
TIFF	**:**	Tagged Image File Format
USGS	**:**	United States Geological Survey
WGS	**:**	World Geodetic System
WNW	**:**	West-North-West

Definition of terms

Waterfowl (synonyms used in this study are waterbirds, wetland birds, birds) : are birds with unique anatomical, morphological and behavioural adaptations that enable them to utilise wetlands and other aquatic systems for survival (Weller 1999).

Wetlands: are unique biotic communities ecologically separate from rivers, streams, and deep lakes (Batzer et al. 1999) involving diverse plants and animals that are adapted to shallow and often dynamic water regimes (Weller 1999).

Landscape ecology: is a holistic approach to ecological studies which includes quantitative assessment of not only the biotic but also the physical components of an ecosystem (Liding, Yang et al. 2008). It helps link ecology to the practice of monitoring, managing and planning changes in landscapes.

Landscape class (synonyms used in this study are microhabitat, landscape unit): is a division in a landscape mosaic with distinct biophysical attributes which make it able to meet to the needs of a particular single or group of waterfowl species.

Guild : describes a group of birds that exploit the same class of an environmental resource in a similar way based on their morphological and physiological adaptations Weller (1999). In this case study, the guild is resource and management oriented i.e. focusing on linking waterfowl to specific delineated landscape units exploitable for forage and cover by the specific waterfowl.

Habitat: is space or place in which an organism lives (in this case waterfowl) assuming the presence of sufficient resources for the bird's maintenance during a portion of its annual cycle (Weller 1999).

1. Introduction

1.1. Background

Waterfowl form an important part of the biotic community of wetland systems (Weller 1999). They heavily rely on the wetlands as providers of resources they need to survive and reproduce in a species – habitat relationship (Weller 1999; Özesmi 2001). In this regard, any alteration of the wetlands will result in both direct and indirect knock-on effects on the waterfowl population numbers and their diversity in any ecosystem. This is because the composition and structure of the wetland landscapes influences bio-ecological processes (Honnay, Piessens et al. 2003) related to the survival needs of the waterfowl e.g. food and space. Therefore changes in the wetland landscapes will result in changes in species diversity and composition (Jones, Lanthier et al. 2009). Shifts in waterfowl community structure occur with certain species favoured or disadvantaged depending on extent and magnitude of change of a specific landscape unit exploitable by a particular species. It is therefore not surprising that waterfowl are useful bio-indicators (Veraart, de Groot et al. 2004) of aquatic ecosystem quality, productivity and stability.

Waterfowl population decline has been related to human wetland encroachments (Chari, Abbasi et al. 2003), and low species richness to pollution from intensive agriculture (Fernandez, Selma et al. 2005) because these activities disturb the biophysical balance in the wetland ecosystem. Waterfowl species diversity has also been used as a surrogate (Ma, Wang et al. 2009) to assess the impact of changing hydrological flow regimes on wetland configuration and quality. This has been based on the fact that waterfowl will either respond differently or in a similar way to habitat changes caused by hydrological dynamics such that at any moment in time, the waterfowl community structure (from groupings to single species level) reflects not only the quality but also the capacity (Fernandez, Selma et al. 2005) of the wetland system to meet the needs of that community. The intricate relationship between wetland landscape variability in space and time and waterfowl is well appreciated and demonstrated in many ecological studies (Jefferies 2000; de Boer 2002; Richman and Lovvorn 2004; Green and Sadedin 2005). This relationship also forms the scientific basis upon which the RAMSAR Convention (http://www.ramsar.org) derives guidance in implementation of wetland ecosystems' conservation, protection and management (Jones, Lanthier et al. 2009).

In landscape ecology, the relationships between wetland structure and waterfowl have been explored from various dimensions. Some have considered climatic variations of temperature and precipitation (Sorenson, Goldberg et al. 1998) as important in influencing the wetland characteristics and the resultant waterfowl diversity (Weller 1999). Seasonal temperature and rainfall gradients (Guillemain, Fritz et al. 2002) have been related to thousands of waterfowl migrations (Bethke 1993; Weller 1999; Guillemain, Fritz et al. 2002; Lagos, Paolini et al. 2008; Reis 2008). The prevailing biophysical conditions and quality of wetlands along the migration flyways have been known to influence the waterfowl community structures and compositions (Ma, Wang et al. 2009) at each stopover wetland. This knowledge has been used to guide multilateral initiatives such as the AEWA (Austin, Peachel et al. 2000) in their conservation and management programmes by focusing strategies of implementation. For example, monitoring population dynamics of a particular species or group of species can indicate stability and capacity (Fernandez, Selma et al. 2005) of a wetland to provide resources for many other waterfowl. Therefore management efforts can be more focused based on such information. Bárcena, Real et al (2004) concluded that blooms in food availability and vegetation cover in most wetland basins and complexes in Europe influence seasonal fluctuations of breeding waterfowl species. Similarly, population dynamics of the abundant and rare species of waterfowl (McKinstry and Anderson 2002) have been used as good indicators of impacts of deterioration and modification of wetland conditions due to extreme climatic conditions such as drought (Sorenson, Goldberg et al. 1998) and human activities such as industrial groundwater pollution (Reis 2008). This is because these factors alter the normal state of the hydrology (Vargas, Barlow et al. 2008) causing changes in landscape structure. This impacts on the species numbers and diversity either in a negative or positive way depending on the waterfowl characteristics, sensitivity to changes (Weller 1999) and adaptability (Kosztolányi, Javed et al. 2009). Others have preferred to use guilds (Landres 1983) in similar studies arguing that it gives more comprehensive and representative results compared to using single-indicator species which may not fully represent the diversities of behaviours and adaptations to exploit various resources by a large community of waterfowl (Verner 1984).In the Guadalquivir Marshes and Donana wetland complex (Spain) for example, wintering waterfowl such as the graylag geese *(Anser anser)* (Rendon, Green et al. 2008) were found to be a suitable indicator group for the assessment of impacts of recharge and drawdown on wetland landscape structure. Therefore such knowledge makes it easier to monitor and manage the quality of the wetland systems to improve waterfowl conservation activities overally.

It is widely acknowledged in various ecological studies that among all factors driving wetland ecosystems, the local hydrology is of prominence (Bryant and Rainey 2002; DeVogel, Magee et al. 2004; Desgranges, Ingram et al. 2006; Rodríguez-Rodríguez, Benavente et al. 2006; Jiahu, Xijun et al. 2007; Kohfahl, Rodriguez et al. 2008). Hydrology with specific mention to water level fluctuations, determines the structure i.e. its configuration and composition (Weller 1999), and complexity (Fernandez, Selma et al. 2005) of wetland habitats. This is realised in the changes of nutrient cycles (Weller 1999), food webs (Jefferies 2000) as well as available and accessible suitable microhabitat (Demétrio Luis, Leonardo et al. 2009) for various bird species and guilds. For example, fluctuations in water levels determine spatial extent and temporal periods of cycles of inundation (Brinson, Lugo et al. 1981) which facilitate wetland nutrient balance and productivity through processes of aerobic and anaerobic decomposition. Therefore, the amount and type of food (Özesmi 2001), and total areal extent of specific microhabitats available for different waterfowl species or guilds (such as swimmers and waders) determined by these processes will dictate the waterfowl community structure at any given moment. In other words, different waterfowl guilds or species will be affected differently by the hydrological dynamics through alteration of their specific microhabitats. For example when a landscape is dominated by deep water, diving and swimming waterfowl such as ducks are expected to dominate the community structure (Guillemain, Fritz et al. 2002). Similarly in conditions of low water levels and wet-muddy flats, wader and shoreline species (Hailey and Goutner 2002)will predominate the community structure. It is therefore imperative that any comprehensive study of waterfowl entails a component focusing on the habitat spatio-temporal characteristics inherent to prevailing hydrological dynamics. These purported relationships have been researched using diverse innovative approaches.

Researchers have applied various rudimentary, conventional and integrated approaches to gain a deeper understanding of the inherent relationships between the waterfowl and their habitat as earlier mentioned.

These include direct field observations and measurements of the waterfowl and landscape attributes such as vegetation/land cover, water depth and bird species counts and identification and soil structure and type (Connor and Gabor 2006; Rendon, Green et al. 2008; Vargas, Barlow et al. 2008). Integrated approaches such as GIS and RS have over the past years gained preference by many researchers (Welch, Remillard et al. 1988; Lihua, Wenze et al. 2002; Sedano, Gong et al. 2005; Melesse, Nangia et al. 2007; Miwei 2009) thus making them key in exploring the spatio-temporal domain of these studies. The edge for GIS and RS has been its powerful analytical capabilities (Hebb 2003), and its easy integration with other techniques. The prominent use of GIS and RS has been in the mapping of the wetland cover i.e. its change and dynamic behaviour (Mertens 2008), determining the rate and status of wetland degradation, (Madani 2005; Chen and Rao 2008) and in monitoring landscape transformation in high-value wetland habitats (Castaneda, Herrero et al. 2005). Other quantitative studies in landscape ecology successfully covered wetland hydro-geologic processes (DeVogel, Magee et al. 2004) related to climatic conditions.

Relative to the above, landscape modelling (Desgranges, Ingram et al. 2006) approaches integrating GIS, RS and other analysis techniques have been used in the understanding of relationships between wetland landscape structure and waterfowl community dynamics. For example expert-knowledge based landscape models (Musacchio and Coulson 2001) have been useful in studies exploring habitat evolution (Vargas, Barlow et al. 2008). Li, Lu et al.(2001) were able to simulate landscape gradients, calculate habitat diversity metrics (Marc, Ülo et al. 2009) of delineated ecoregions and correlate these to waterfowl communities. The power of these models has been in their ability to allow objective landscape structure quantification, scenario development (Kennedy and Wimberly 2009) and easy visualisation through computer graphics programmes. Output from these models has been used not only in conservation and management but also in landscape ecological planning processes (Musacchio and Coulson 2001) targeted at policy development to ensure balance in wetlands use as habitat and for other human activities.

The central theme in the all research initiatives earlier discussed has been and still is the support and enhancement of monitoring, management, conservation, protection and restoration of wetland ecosystems and their waterfowl communities through accurate scientific information. However, against a wide diversity of waterfowl taxonomy (Weller 1999) and more than 1634 RAMSAR designated wetlands totalling over 139 million hectares area (Jones, Lanthier et al. 2009), there still remains much to be researched concerning waterfowl-wetland relationships from global to local scale. Many grey areas still remain in the field of landscape ecology, with some wetlands having little to no research done on them to understand their landscape structure dynamics relative to the prevailing waterfowl communities. One such wetland of interest is the F de P lagoon (the largest playa lake in Andalusia, Spain).

1.2. Statement of Problem and Motivation

In the past decades, the Spanish government guided by the European Water Framework Directive (EWFD), has undertaken to implement strategies to protect, (Castaneda, Herrero et al. 2005), and encourage the management of its wetland ecosystems using scientific rather than political criteria (Rodríguez-Rodríguez, Benavente et al. 2006). Most of the studies on these wetland ecosystems have been anchored on the principles of multilateral agreements such as RAMSAR and AEWA (Austin, Peachel et al. 2000) looking towards waterfowl and wetland conservation and wise use. Apart from ecological benefits accrued in the short to long term, the immense economic value of such initiatives has been well acknowledged in many environmental economics studies (Barbier, Acreman et al. 1997). Most studies undertaken in this regard have focused more extensively on wetland functional status monitoring (Castaneda and Herrero 2009), changing natural hydrological regimes (Castaneda, Herrero et al. 2005; Rodríguez-Rodríguez 2007) and spatial distribution of macrophytes and riparian vegetation in the playa lakes. While it is appreciated that some research has been focused on wetland-waterfowl relationships e.g. (Comín, Cabrera et al. 1999; Veraart, de Groot et al. 2004; Real, Olivero et al. 2008; Wang 2008), much is still unknown about the in-depth landscape dynamics and their effects on waterfowl communities in other Spanish wetlands such as Fuente de Piedra. This has somehow cast a shadow over conservation and management initiatives according to some local conservationists.

Looking at Fuente de Piedra, most research done thereof has been focusing more on the flagship species – the greater flamingo (*Phoenicopterus rubber)* with little to no attention given to the other 160 or so waterfowl species occurring in the lagoon. No research so far has been undertaken to attempt to investigate the relationship between landscape changes and the broad spectrum of the waterfowl communities in the lagoon. Relative to this ,while it is well known that irrigation agriculture around the lagoon negatively affects the water levels in the lagoon (Kohfahl, Rodriguez et al. 2008), there has been no investigation to try to see how this impacts the different levels of waterfowl community structure. Furthermore, little is known on how well waterfowl community structural changes reflect wetland landscape changes and ecosystem quality in general. Scarcity of scientific knowledge on these aspects of the wetland ecosystem can be an impediment for effective and comprehensive monitoring and management strategy development and implementation. Moreso, F de P is also an important wetland hosting several endangered as well as threatened waterfowl species (Birdlife International 2009) such that its management is not only of national but also regional importance. Being a RAMSAR site, more scientific knowledge about the wetland and its waterfowl community goes a long way in contributing to the cause of the convention in general. The economic and aesthetic value of this wetland ecosystem can not be overemphasised. As such, the motivation to engage in this research is immerse.

This research endeavours to increase knowledge and understanding about relationships between waterfowl population dynamics and the changes in wetland landscape conditions caused by water level fluctuations in F de P lagoon on a hyper-temporal scale. The relationships may or may not be different at varying levels of waterfowl community structure. Therefore, a hierarchical approach is here used to attempt to find out whether focussing on a single species or on a group of species yields the same or different results. Dominant and predominant species are used in this study considering the argument that it is easier to assess effects of change on a community using abundant or predominant species than using rare or least prevalent species in an ecosystem (Lagos, Paolini et al. 2008). The reason is that abundant or predominant species can show much population variability and more dynamic trends which can be easier to relate to any landscape parameters of interest than the latter which may show very low variation though this may not always be the case. The findings will serve as a basis for development of new plans while focusing and improving the already existing ecosystem and waterfowl monitoring, management and conservation efforts in F de P lagoon. The scope of management could be expanded and improved to include other waterfowl species besides the flamingos based on the outcome of this research. Furthermore, the approach used in this research could serve as an example for possible adoption and implementation in other similar wetlands.

1.3. Overall Objective

- To investigate how landscape structural changes due to water level fluctuations are related to waterfowl population dynamics in F de P lagoon from 1991to 2008 using GIS and RS and ultimately provide recommendations for improvement of monitoring and management of the wetland ecosystem.

1.3.1. Specific Objectives

- To investigate if predefined landscape classes (i.e. deep water, shallow water and wet-muddy flat and land) can be consistently derived from a DEM using historic water level data for the past 17 years in F de P.
- To investigate how waterfowl populations are correlated to the derived landscape classes at three hierarchical levels (guild, family and species level) and attempt to identify preferred microhabitats for the waterfowl.
- To assess how shoreline bird populations are related to temporal changes of the shoreline perimeter of the wet-muddy flat landscape class at three hierarchical levels (guild, family and species level).

1.4. Research Questions

Q1: Can landscape classes (deep water, shallow water, wet-muddy flat and land) be consistently and accurately derived using a high resolution DEM and historic water level data on a hypertemporal scale?

Q2: What is the relationship between population dynamics of swimmers (at the three levels of waterfowl community hierarchy) and areal fluctuations of the delineated landscape classes within the study period? Can the swimmers' preferred landscape class be identified as well?

Q3: What is the relationship between population dynamics of waders (at the three levels of waterfowl community hierarchy) and areal fluctuations of the delineated landscape classes within the study period? Can the waders' preferred landscape class be identified?

Q4: How do shoreliners (at the three hierarchical levels) correlate with and areal fluctuations of each of the delineated landscape class within the study period? Can the shoreliners' preferred landscape class be identified?

Q5: What is the relationship between shoreliners' population dynamics and the total perimeter length of the wet-muddy landscape class within the study period?

Q6: Do waterfowl show similar relationships with the landscape class areal changes at all community hierarchical levels? Which level is best to use as basis of make inferences about the different groups?

1.5. Hypotheses

H_0^1: Landscape classes can not be accurately** derived using a DEM and water-level data.
H_1^1: Landscape classes can be accurately** derived using a DEM and water-level data.

H_0^2: Population dynamics of swimmers are not significantly* related to areal fluctuations of deep water landscape class between 1991 and 2008.
H_1^2: Population dynamics of swimmers are significantly* related to the areal fluctuations of deep water landscape class between 1991 and 2008.

H_0^3: Population dynamics of waders are not significantly* related to the areal fluctuations of shallow water landscape class between 1991 and 2008.
H_1^3: Population dynamics of waders are significantly* related to the areal fluctuations of shallow water landscape class between 1991 and 2008.

H_0^4: Population dynamics of shoreliners are not significantly* related to the areal fluctuations of wet-muddy flat landscape class between 1991 and 2008.
H_1^4: Population dynamics of shoreliners are significantly* related to the areal fluctuations of wet-muddy flat landscape class between 1991 and 2008.

H_0^5 : Shoreliner population numbers are not significantly* correlated to fluctuations in wet-muddy face total perimeter length within the study period.
H_1^5 : Shoreliner population numbers are significantly* correlated to fluctuations in wet-muddy face total perimeter length within the study period.

** Significance will be tested at $\alpha = 0.01$ and 0.05*
*** Accurate considered as $R^2 \geq 0.70$*

1.6. Innovation

This research attempts to apply an integrated approach of using historical water level data and high resolution DEM to model four landscape classes depicting the waterfowl habitat structure in F de P lagoon on a hypertemporal scale for the first time. Furthermore, historic Landsat data is used to validate the accuracy of the modelled classes. An attempt is made to investigate the wetland landscape-waterfowl relationships at three hierarchical levels of waterfowl community to have a deeper, comprehensive and comparative insight into these relationships for the first time.

1.7. Thesis outline

Chapter one of this report introduces the research topic and explores the background literature in as far as how and why waterfowl are related to wetland landscapes. Several examples of research work in and around this relationship are discussed and how this knowledge is important in landscape monitoring, management and conservation activities for waterfowl and wetlands in general. Discussion is also made on various approaches used in investigating these relationships and how GIS and RS have been integrated in these processes as well. The focus of this study is introduced in this chapter as well. Chapter two introduces the study area, and explains the materials and methods used in this study. The subsequent chapter three deals with the outputs and results from the processes executed in chapter two. Lastly, the discussion of results and conclusions are made in chapter four expounding on the ecological interpretation of the results relative to the objectives of this study. Recommendations are also made in the same chapter. Appendices and then references respectively make up the last sections of this report.

1.8. Research Approach

This research follows five basic steps which culminate in the write up of the thesis report as shown in the flow chart (Figure 1-1). The steps include, (1) data acquisition, (2) data pre-processing/ preparation, (3) modelling, (4) validation and (5) statistical analyses to arrive at conclusions of this study.

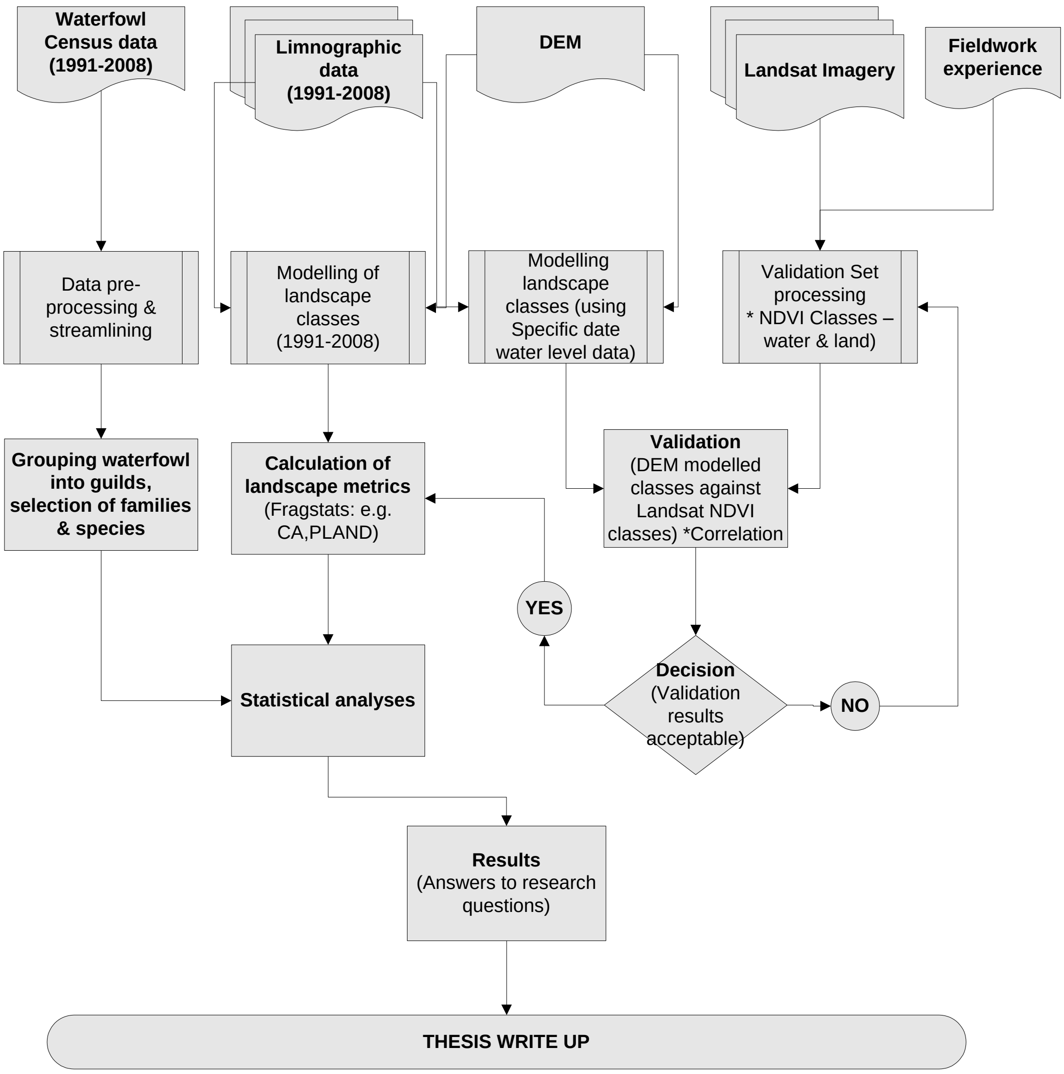

Figure 1-1: Research approach flow chart showing the main steps undertaken in this study

Basically, water level data is used together with a reconstructed high resolution DEM to delineate four landscape classes representing potential waterfowl microhabitats in the study area. A separate specific date water level dataset was used together with corresponding date Landsat imagery in the validation process. Waterfowl data was prepared and subjected to statistical analyses to explore relationships with landscape class metrics calculated in Fragstats software. Results were assessed to answer the research questions. The details of each of these steps are explained in detail under the methodology chapter of this report.

1.9. Conceptual Framework

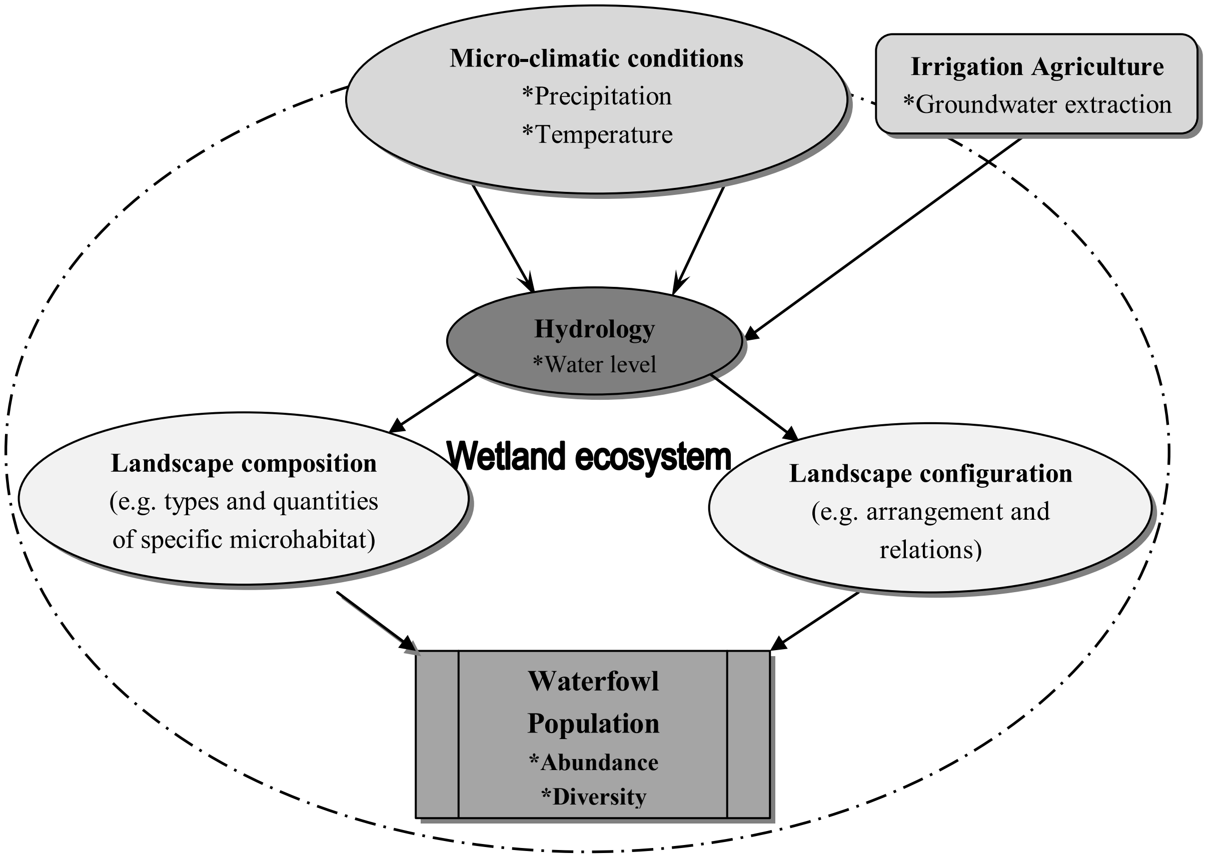

Figure 1-2: Conceptual diagram showing the main components of the F de P lagoon ecosystem particularly focusing on the influence of hydrology on the landscape structure an ultimately waterfowl population dynamics

The concept illustrated on Figure 1-2 shows that the local hydrology is directly influenced by natural micro-climatic conditions such as precipitation and as well by human activities such as irrigation agriculture around the lagoon in this case. This influences the changes in landscape structure in terms of composition and configuration which determines the waterfowl community structure prevailing in the lagoon at any given time. Therefore in essence waterfowl (as single species or in groupings) are related to the landscape and therefore can be useful indicators of the state and quality of the ecosystem and can help guide wetland management activities more precisely.

The basic assumption made underlying this concept is that:

- delineated landscape classes represent microhabitat units meeting the needs of the specific bird species or guilds under investigation i.e. the delineated spatial units are suitable, accessible, and exploitable microhabitats for the birds in terms of forage and space.

2. Materials and Methodology

2.1. Study Area

The F de P lagoon is the largest saline water inland wetland in the autonomous region of Andalucía (area approximately 1,364 ha) located in the far north of the province of Malaga, central southern Spain *(37 º 6 'N and 4 ° 46' W)* at 412m elevation. The site is about 20 km northwest of the city of Antequera, province of Malaga (see Figure 2-1).

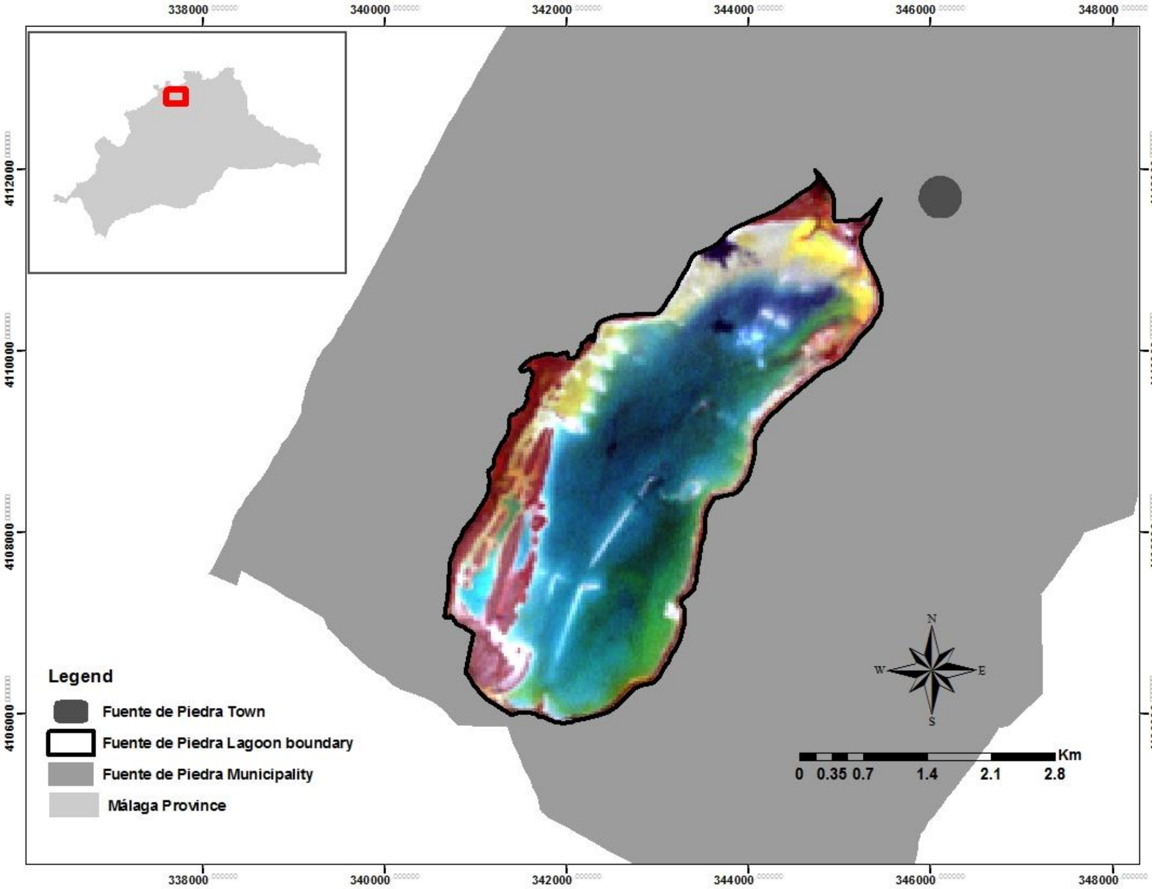

Figure 2-1: Map of study area (the lagoon is shown in RGB 4-3-1 of Landsat)

2.1.1. Fauna

The site is designated by the state as a Nature Reserve, and is also an EU Special Protection Area for birds. The fauna diversity is represented by 8 amphibians, 13 reptiles, 172 birds and 19 mammals. The site is of special importance because of its nesting colony (12,000 pairs in 1988) of the greater flamingo *(Phoenicopterus ruber)*. F de P is one of the most important breeding sites for this species in the Mediterranean region, second only to the Camargue, France (Birdlife International 2009). Other nesting birds include the rare Slender-billed gull *(Larus genei) and* Gull-billed tern *(Gelochelidon nilotica)*, while the Greylag goose *(Anser anser),* the Shelduck *(Tadorna tadorna)* and Red-crested Pochard *(Netta rufina)* are amongst the wintering species. The fields surrounding the lagoon support at least 20 nesting pairs of Montagu's Harriers *(Circus pygargus)* and the Eurasian Stone-curlew (*Burhinus* *oedicnemus)*, as well as up to 250 wintering Common crane *(Grus grus)* (Birdlife International 2009). Endangered species such as the White headed duck *(Oxyura leucocephala)* are also known to winter in this wetland. In this regard, the wetland has been listed as a RAMSAR Important Bird Site number 276 since 1983 (Jones, Lanthier et al. 2009) making its protection and conservation a top priority.

2.1.2. Flora

The flora in the site comprises halophilic vegetation, which appears in the perimeter of the lagoon. It is conditioned by the variations of duration of ponding, salinity and soil texture which result in horizontal zonation features. The tamarisk *(Tamarix africana and Tamarix canariensis*) are the only tree species that exist in the area perimeter of the lagoon. Vegetation further from the water comprises plant species such as the Glasswort (*Sarcocornia perennis alpine)*, the alkali seep weed *(Suaeda vera)*, the Sickle grass (*Parapholis incurve), Aeluropus littoralis* and *Puccinellia festuciformis*. Vegetation closest to the water and well supported by the flooding is a community consisting of species such as *Suaeda splendens,* Purple glasswort *(Salicornia ramosissima)* and *Halopeplis amplexicaulis*. Finally, the vegetation that colonizes the waters is formed by lacustrine macrophytes widgeon grass *(Ruppia maritime), Zannichellia obtusifolia* and *Althenia orientalis* and participating algae Common stonewort *(Chara vulgaris), Chara aspera,* the bearded stonewort *(Chara canescens)* and the tassel stonewort (*Tolypella Hispanic)*.

2.1.3. Hydrogeology

The F de P lagoon is situated at the centre of an endorheic basin that has no drainage to the outside i.e. precipitation that falls within it does not flow out but may only leave the drainage system by evaporation and seepage. The boundaries of the discharge area of the hydrogeological unit coincide with those of a saline basin substrate hence the water of the lagoon has high mineral content (Rodríguez-Rodríguez, Benavente et al. 2006). The salinity varies markedly throughout the hydrological year and between different hydrological years. The hydrogeological unit falls in the Jurassic carbonate aquifer of Sierra de Humilladero (6 km^2) and the Sierra de Mollina (12 km^2) and has high permeability due to karstification (see Figure 2-2). Groundwater in these two masses serves to supply several villages in its surroundings. Five streams drained into the lagoon, but none of them permanently anymore.

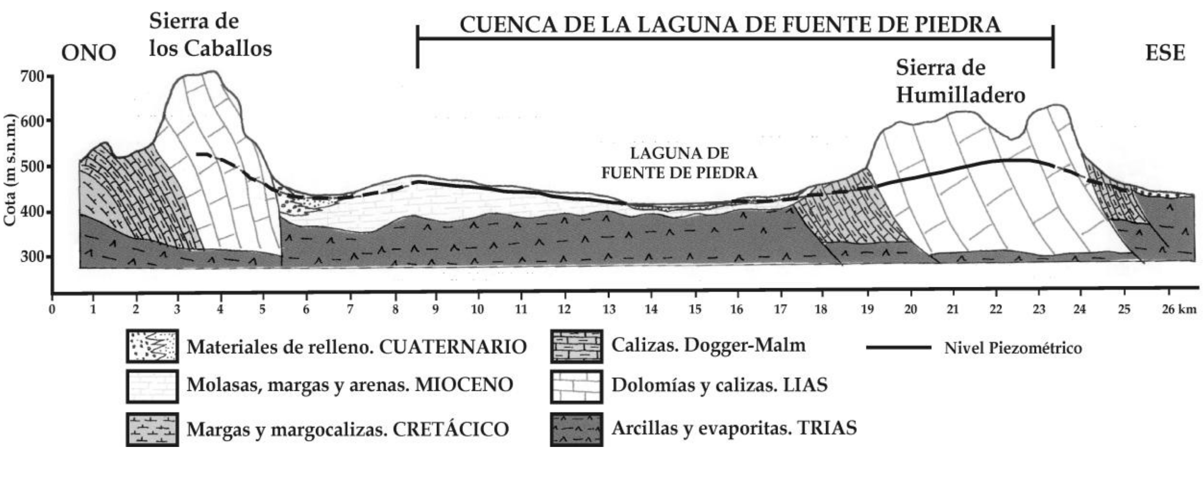

Figure 2-2: WNW-ESE hydrogeological cross section of F de P basin showing the underlying types of geologic materials and the relative water level across the basin. (Adapted from (Rodríguez-Rodríguez 2007))

2.1.4. Climatic conditions

Semi-arid Mediterranean climatic conditions are prevalent in the study area with mean precipitation around 450 mm and the annual average temperature ranging between 15 to 17°C. Intense sunshine combined with low humidity results in the high Potential evapotranspiration (ETP) in the excess of 800 mm per year, of which about half is processed between June to August (Rodríguez-Rodríguez, Benavente et al. 2006). The high ETP against low mean precipitation is the cause of the lake's desiccation in the peak summer periods as shown on the water balance schematic (Figure 2-3).

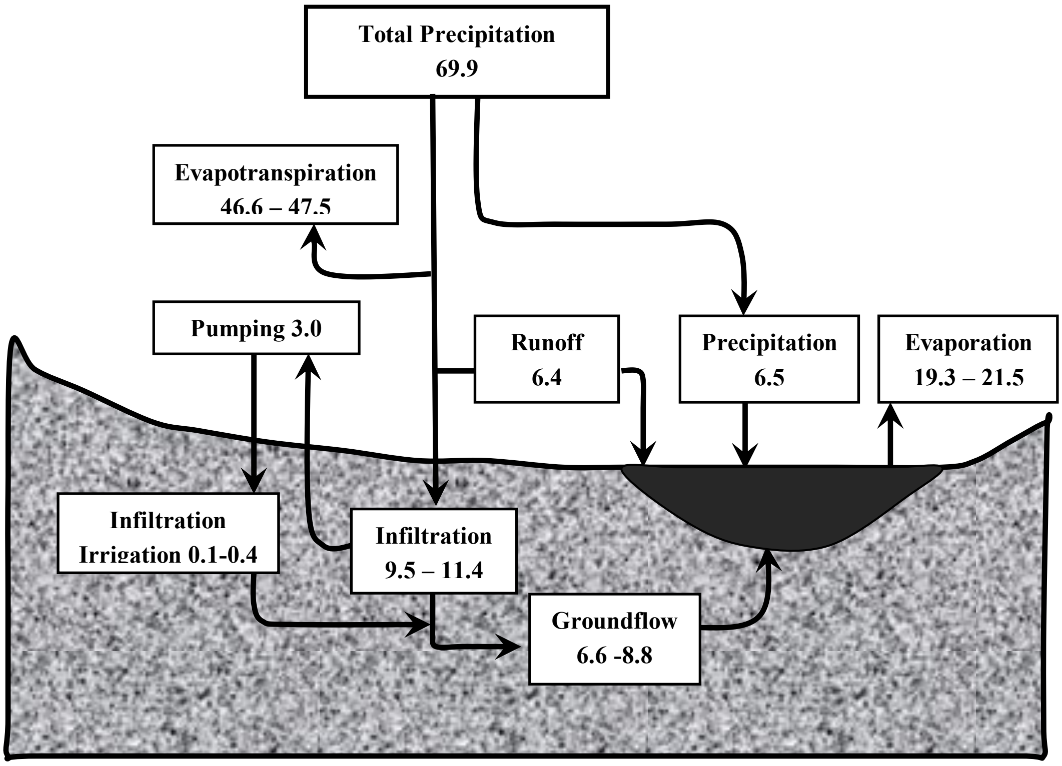

Figure 2-3: F de P lagoon water balance system showing the water deficit usually experienced in the playa in summer (adapted from (Lucena, Linares et al. 2005))

2.2. Waterfowl data preparation and pre-analyses

Census data was acquired and updated from the F de P Nature Reserve Office during the field visit in September 2009. The dataset was in Excel format in separate workbooks and therefore needed to be consolidated and streamlined into a more useable and consistent format. The data was arranged into monthly time steps per year from 1991 to 2008 excluding 1992 where there were no records. The 120 waterfowl species were assessed per individual species and then as families e.g. Recurvirostridae, Rallidae, scolopacidae etc separately. Descriptive statistical pre-analysis output is shown in the appendices section (Appendix 1). Relevant background literature on habitat and diet preferences, behaviour and physiological adaptations was searched and assessed. It was noted that the census data included records of all bird species sited in the lagoon even if they were not waterfowl e.g. the Montagu's harrier (*Circus pygargus)* a bird prey. Such were removed and not included in the scope of the study together with 7 species considered as vagrant species (occurring on average less than twice within the study period). Incomplete and inconsistent records were also removed in the selection process resulting in 84 species in 11 families being selected (see Figure 2-4).

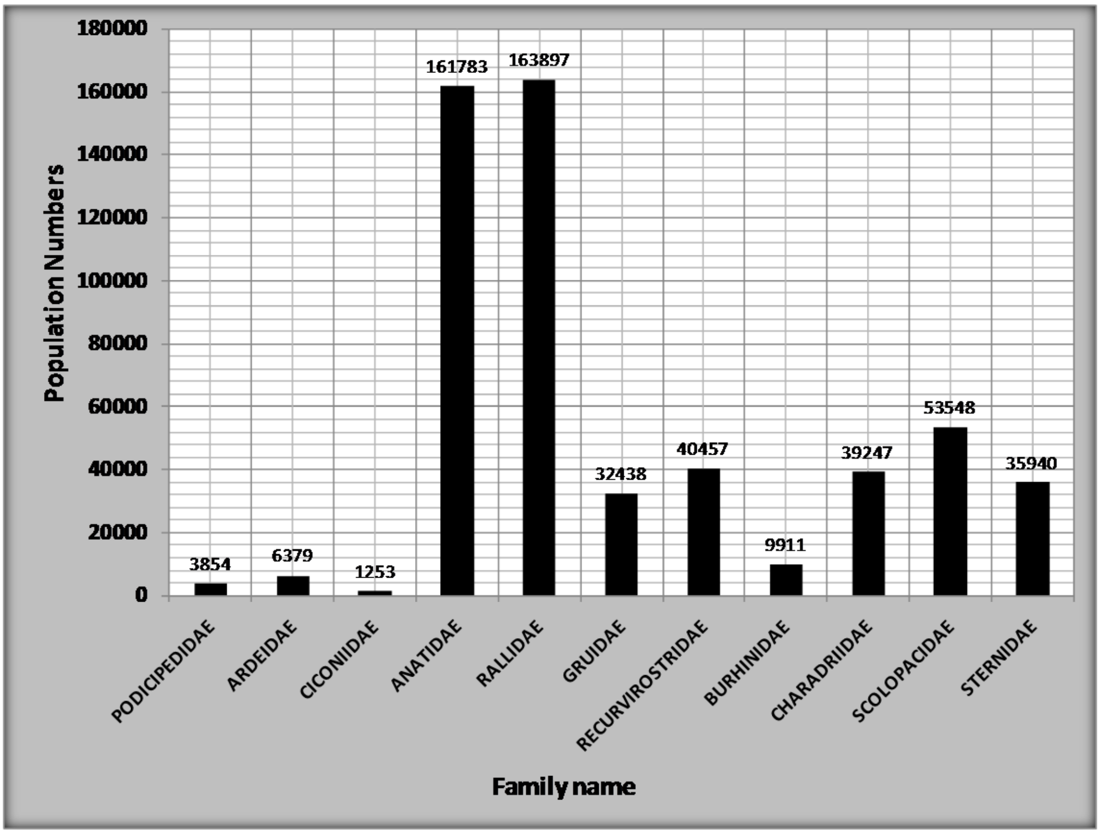

Figure 2-4: Bar graph showing summary of waterfowl abundance in each of the 11 selected families considered in this study from 1991 to 2008. The Laridae family is not included on this graph for convenience of visualisation

The Laridae is the dominant family in the lagoon (in the context of this study excluding the flamingos) with a total count of 786,096 over the past 17years. In this family, the Lesser black-backed gull (Larus fuscus) is the most abundant. The Anatidae family is third most abundant after the Rallidae, predominated by the mallard (*Anas platyrhynchos*). The Recurvirostridae dominates the wader group as shown on the graph while the Scolopacidae are the most abundant of all shoreliners.

It is widely acknowledged in ecological studies that delineation of guilds is a subjective process which is based on the objectives of a particular researcher (Wiens 1992). Several approaches have been used such as the diet or forage based approach (Maheswaran and Rahmani 2001) , interspecies similarities (taxonomic) based approach (Atkinson, Austin et al. 2006), the common habitat based approach (Weller 1999) and other quantitative approaches which use statistics. In this study, an integrated approach was adopted incorporating use of microhabitat preferences, foraging tactics, taxonomy and to some extent diet. Waterfowl were grouped into four guilds namely swimmers, waders, shoreliners and others (general species which do not fall in any of the three earlier guilds) based on these criteria. Basically, the criterion considered microhabitat preferences related to adaptations in physiology and behaviour by the waterfowl e.g. leg and bill length and foraging tactics. Furthermore, we assume that waterfowl grouped into a guild or group use similar resources in a particular landscape class in a similar way and will respond in almost a similar way to changes in that landscape class . An illustration of how similar criteria have been used in guild delineation is shown in Figure 2-5.

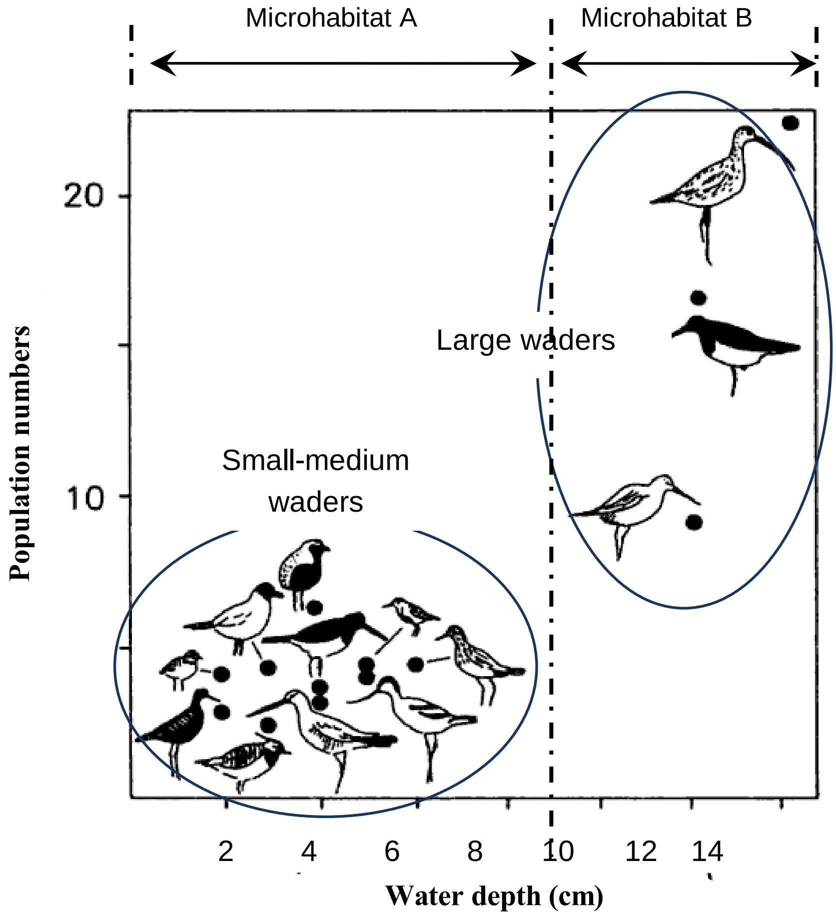

Figure 2-5: Shows an example of how a community of waders can be separated into two guilds based on their physiological adaptations (leg-length and beak shape and length) to exploit different microhabitats (A and B) defined by water depth. (Modified from Wiens (1992))

In order to have a comparative in-depth assessment of the relationship between wetland landscape changes and the waterfowl, one dominant family and three predominant species under each guild were selected to form a three-level hierarchy as shown in Figure 2-6. The species were also selected considering that their census records showed considerable variation over the study period as shown on the box plots (Figure 2-7a, b, c and d).

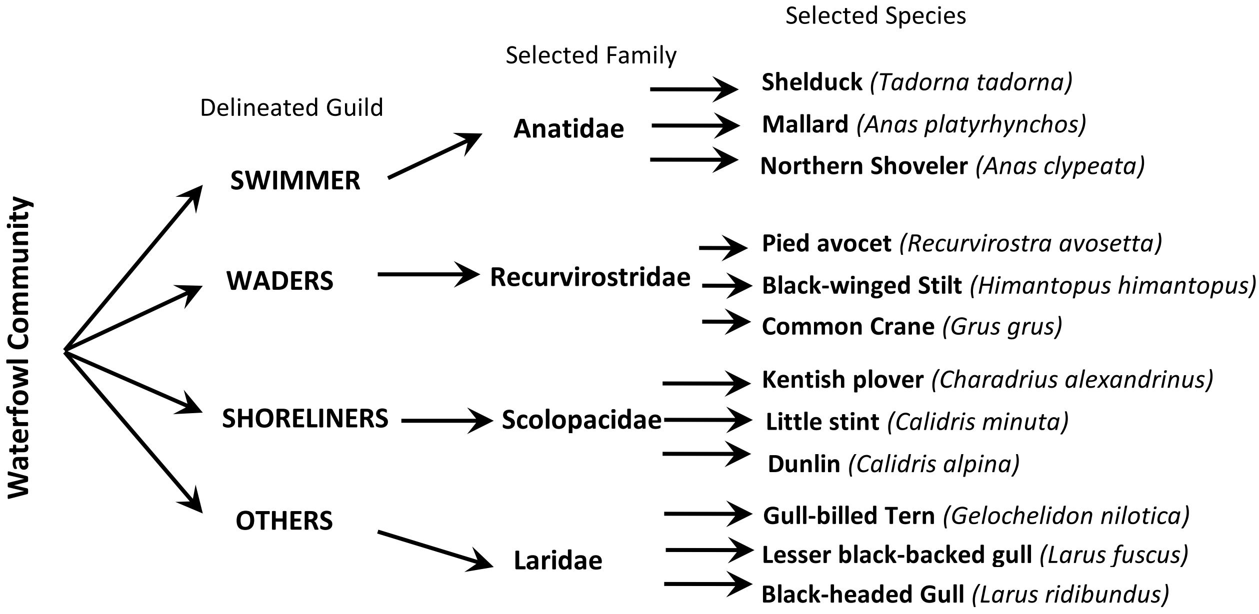

Figure 2-6: Diagram showing the three-level hierarchy of the selected families and species under each guild. Important to note is that all selected species do not necessarily fall under the selected family.

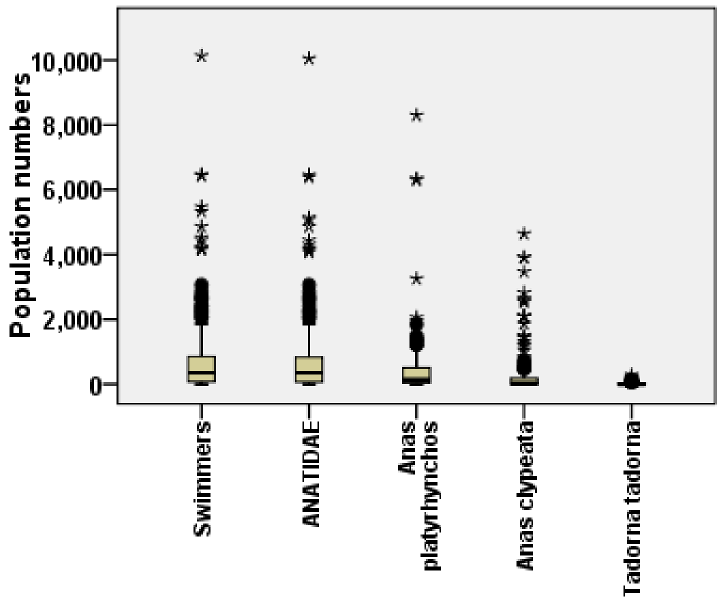

Figure 2-7a: Box plots illustrating the data ranges of population numbers for swimmers together with the selected family and the three predominant species under this guild.

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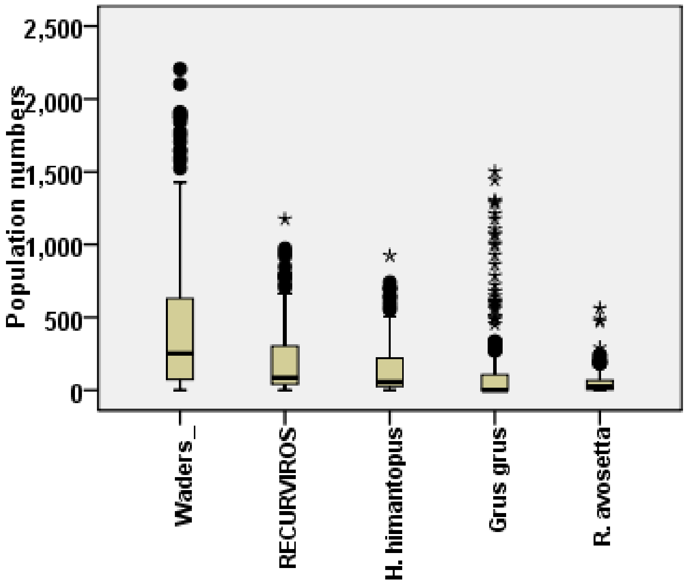

Figure 2-8b: Box plots illustrating the data ranges of population numbers for waders together with the selected families and the three predominant species under this guild. The black-winged stilt is the most abundant species in this guild.

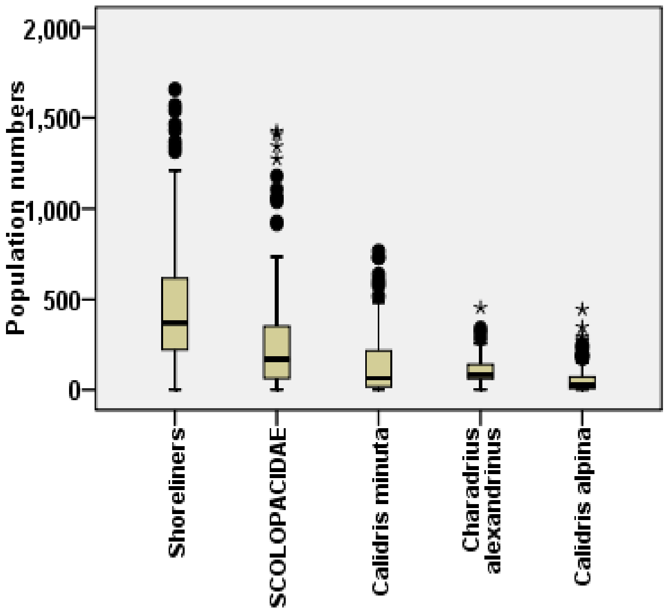

Figure 2-8c: Box plots illustrating the data ranges of population numbers for shoreliners together with the selected family and the three predominant species under this guild.

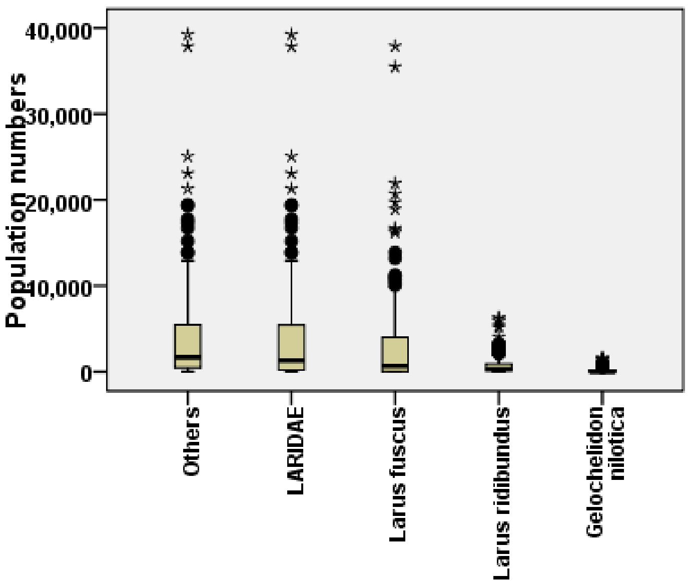

Figure 2-8d: Box plots illustrating the data ranges of population numbers for others together with the selected family and the three predominant species under this guild.

An overview of waterfowl microhabitat preferences, diet and foraging tactics under each guild is also shown in Table 2-1. Swimmers such as geese, ducks and swans have been known to generally prefer deep water where they dabble or dive to forage. They possess special adaptations such as webbed feet and waterproof plumage for easy exploitation of this microhabitat. Waders search, stalk and strike as they feed mostly in shallow waters with access and use limited by features such as leg-length and beak shape and length. Shoreliners use their specially adapted beaks to feed by searching and grabbing while others probe for insects and worms generally. The guild defined as 'Others' is composed of species whose habitat preferences can not be clearly defined in the context of this study such as gulls. Figure 2-8 shows some of the selected species used in this study.

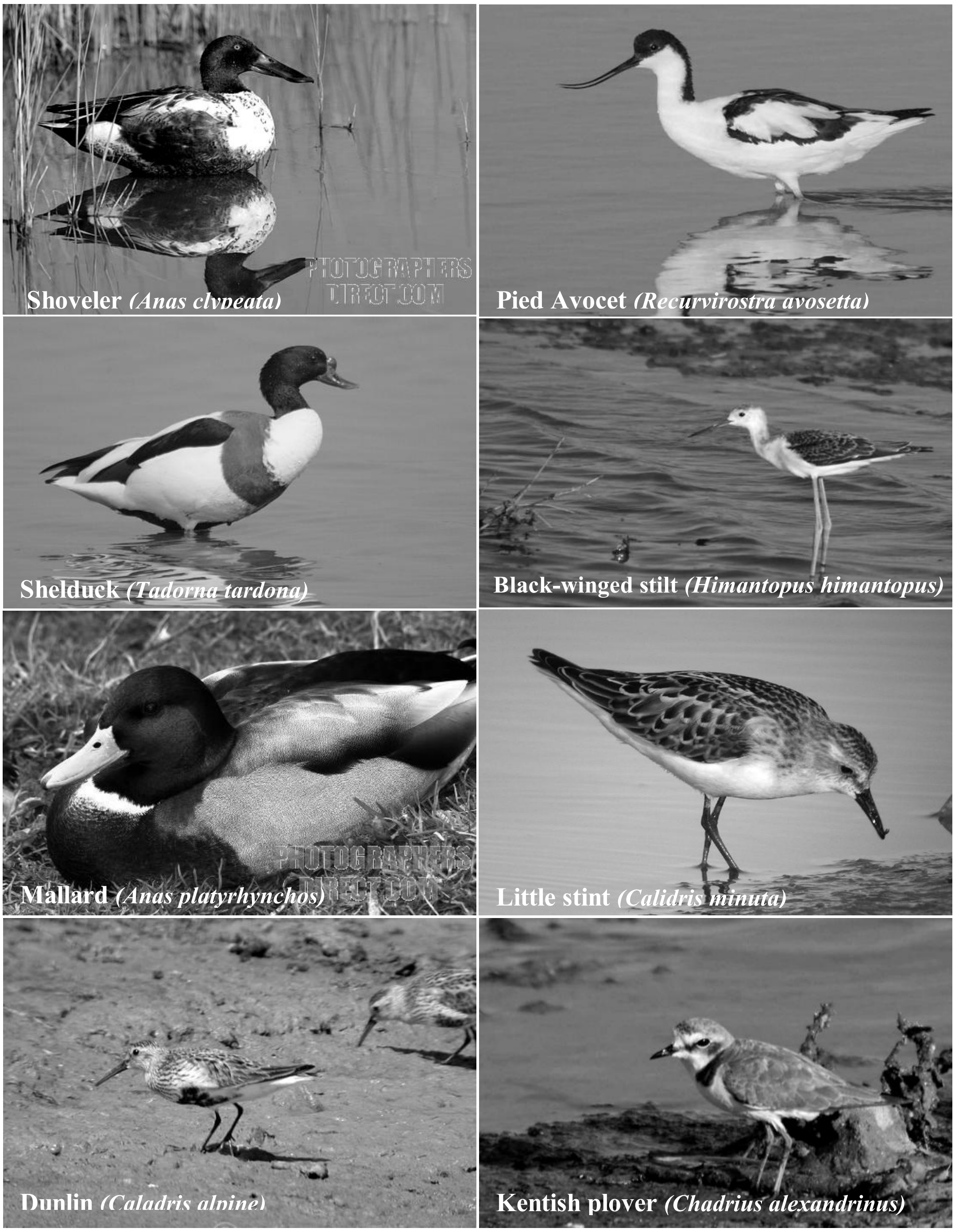

Figure 2-8: Pictures of some of the selected waterfowl species found in F de P lagoon

Table 2-1: The three-level hierarchy of the all families and example species under each guild as well as their tactics, special adaptations, diets and microhabitat preferences. The selected families marked with an asterisk (*). (Modified from (Weller 1999))

Guild	Family	Group Common names	Diet	Tactics	Special adaptations	Species examples	Microhabitat preference
Swimmers	**PODICIPEDIDAE**	Grebes	Fish and invertebrates	Swim & dabble/diver	Webbed feet	*Tachybaptus ruficollis*	Deep water
	PHALACROCORIDAE	Pormorants and Shags	Fish		Waterproof plumage	*Phalacrocorax aristotelis*	
	ANATIDAE*	Ducks, Geese and Swans	Herbivorous and invertebrates		Specialised beaks	*Anser anser, Anas platyrhynchos*	
Waders	**ARDEIDAE**	Herons,Bitterns and Egrets	Fish, frogs, invertebrates	Search & strike	Specialised beak lengths and shapes	*Bubulcus ibis, Ardea cinerea*	Shallow water
	CICONIIDAE	Stocks	Fish,insects, frogs	Stalk	Special leg length for access	*Ciconia nigr, Ciconia ciconia*	
	THRESKIORNITHIDAE	Spoonbills and Ibises	Invertebrates	Dipping search		*Plegadis falcinellu*	
	GRUIDAE	Cranes	Omnivorous			*Grus grus*	
	RALLIDAE	Coots, Rails, Cracks and Moorhens	Omnivorous			*Rallus aquaticu, Fulica atra*	
	RECURVIROSTRIDAE*	Stilts and avocets	Aquatic mollscs, insect larvae, worms			*Himantopus himantopu*	
	BURHINIDAE	Stonecurlews	insects, small invertebrates			*Burhinus oedicnemus*	
	HAEMATOPODIDAE	Oystercatchers	Invertebrates, Insect larvae			*Haematopus ostralegus*	
			Bivalves, molluscs				
Shoreliners	**CHARADRIIDAE**	Plovers, Lapwigs and Datterels	insects, worms	Search & grab	Special beak lengths	*Charadrius alexandrinus*	wet-muddy flat &
	SCOLOPACIDAE*	Sandpipers	invertebrates	Others probe	Special vision	*Calidris alpin,Tringa stagnatilis*	very shallow water
Others	**GLAREOLIDAE**	Pranticoles and coursers	insects	Plunge dive, hawking	Aerodynamic body shape	*Glareola pratincola*	generalists
	LARIDAE*	Gulls	carnivorous, scavengers	Surface grab	Strong special beaks	*Larus marinu,Larus fuscus*	
	STERNIDAE	Terns	fish, insects			*Gelochelidon nilotic, Chlidonias niger*	
	ALCEDINIDAE	Kingfishers	Fish			*Alcedo atthis*	

2.3. Landscape classes modelling approach

Two approaches were considered in this regard which were (1) The Modelled Water surface (MWS) Approach and (2) The Single Value Water Surface (SVWS) Approach (NOAA 2009). Both approaches use a DEM, water level information and GIS to delineate layers that represent inundation extent and depth (NOAA 2009).The MWS approach creates a water surface from a DEM and interpolation of many points either by inverse distance weighting and kriging. The output is an inundation depth raster showing the modelled extent of water cover over an area. The approach has been applied mostly in time series monitoring of wetland inundation processes (Bryant and Rainey 2002) and also in storm surge inundation modelling (NOAA 2009). While the approach yields good results some of its main setbacks include the need for good spatially representative field measurement data for water level to enhance the accuracy of the interpolation without which the method is not feasible. It is also regarded as intensive and not suitable in cases where quick results are needed (NOAA 2009). The SVWS approach on the other hand generates maps that depict inundation representing a water surface based solely on a DEM and a single numerical value representing a water level (measured or assumed) which is then applied consistently over a study area (NOAA 2009). This approach simply delineates a contour (Chen and Rao 2008) or a boundary (Manju, Chowdary et al. 2005)based on selected value or values depending on the purpose of a particular study. Table 2-2 shows a comparison of the two approaches by the NOAA Coastal service centre.

Table 2-2: Comparison of the MWS and the SVWS Approach.(Adapted from (NOAA 2009))

	Modeled Water Surface Approach	Single Value Water Surface Approach
Data Readily Available	Sometimes	√
Quickly Create Multiple Scenarios	X	√
Accounts for Hydrodynamics of Water Rise	√	X

In light of the above mentioned advantages and disadvantages of the two approaches, the SVWS approach was selected and modified for this study. The main SVWS steps are (1) preparation of water level data to make it consistent 2) selection of water level value to depict against a vertical reference level (3) generation of an accurate DEM of the area (4) computation of water surface extent using DEM in GIS environment and (5) visualisation .The modifications made in the context of this study included the use monthly water level measurements instead of the actual daily measurements. This was considered as a matter of availability and convenience because the actual daily measurements were not complete and also the data needed to be streamlined to correspond with the monthly time step of the waterfowl data. Furthermore, instead of delineating water and land only, the water surface was further divided into three sub-units using selected water level ranges representing the three landscape units exploitable by the specific waterfowl guilds under investigation. The ranges were selected based on background literature on waterfowl habitat preferences considering morphological and physiological adaptations, forage and space needs (DuBowy 1991; Wiens 1992; Putman 1994; Weller 1999; Richman and Lovvorn 2004; Rendon, Green et al. 2008). For example the shallow water class water level range was set considering the leg-length range from the smallest wader to the biggest in that class. The water level ranges used in this study are shown on Table 2-3. The landscape classes (land, wet-muddy, shallow water and deep water) were adopted after Castaneda, Herrero et al.(2005)'s baseline inventory and characterisation and categorisation of small playa lakes of Spain.

Table 2-3: Water level ranges used in the SVWS classification approach to delineate the four landscape classes from the DEM.

Landscape class	Water level range
land	≤ 0 cm
wet-muddy flat	0 - 3cm
shallow water	3 - 20cm
deep water	> 20cm

An existing centimetre resolution, DEM of the study area reconstructed by Wang (2008) was adopted for use in this study. A basic assumption made in this approach is that the DEM contains a set of numeric landscape descriptors of acceptable accuracy which can be used to extract characteristic features and attributes of the landscape (Pain 2004). The delineation of the landscape classes was done in ArcGIS by basically reclassification of the DEM using the selected water level ranges earlier mentioned. All layers were used in the RASTER format to avoid data loss from file conversion operations.

2.4. Calculation of landscape metrics in FRAGSTATS

As earlier highlighted in the introduction, the quantification of spatial heterogeneity is necessary to elucidate relationships between ecological processes and spatial patterns. The measurement, analysis and interpretation of spatial patterns are founded on the notion that the patterning of landscape elements (patches) strongly influences ecological characteristics, including vertebrate populations(Li, Lu et al. 2001). Therefore, the ability to quantify landscape structure is prerequisite to the study of landscape function and change (Liding, Yang et al. 2008; Marc, Ülo et al. 2009). A wide variety of metrics for landscape composition (e.g. the number of different habitat types and their extent) and configuration (the spatial arrangement of those classes) have been calculated with FRAGSTATS (McGarigal, Cushman et al. 2002) . The relationship between landscape metrics and bird species population dynamics and their habitat preferences have been studied most extensively revealing that most bird species respond more strongly to landscape composition than to the configuration of the landscape (Marc, Ülo et al. 2009).Of all the landscape composition metrics, patch size has given the most important relationships with bird species richness and numbers, i.e. fragmentation plays an important role for birds (Applegate 2009). Landscape metrics have been used also to determine the landscape preferences of bird species and to show the significance of landscape patterns on waterfowl populations (Li, Lu et al. 2001). Table 2-4 shows examples of correlations of some landscape metrics and some bird species from other studies.

Table 2-4: Examples of correlations between four landscape metrics (class area, percentage landscape, proximity and edge density) and abundance of different species of birds.(Significance: * p<0.05, ** p<0.01, *** p<0.001, **** p<0.0001) (Adapted from (Marc, Ülo et al. 2009))

Taxa	Landscape metrics	Dependent variables	Pearson's R	References
Birds	Agricultural land (ha)	Number of hooded crane	0.79**	Liu et al. (2003)
	Proportion forest	Abundance of female cowbirds	0.62**	Fauth et al. (2000)
	Proportion forest	Abundance of indigo buntings	−0.77**	Fauth et al. (2000)
	Proximity index	Abundance of indigo buntings	−0.35**	Fauth et al. (2000)
	Edge density	Abundance of wood thrushes	0.37**	Fauth et al. (2000)

One aspect of landscape ecology considered in this study is that, at varying spatial levels, the composition and structure of the landscape mosaic influences bio-ecological processes (Honnay, Piessens et al. 2003) and hence the prevailing waterfowl population dynamics.

Based on the objectives of this study and the earlier discussed background literature, two landscape metrics selected for use this study were Class Area (CA) and Total Edge (TE). Other metrics such as number of patches, percentage landscape and patch richness were realised to be redundant and hence not useful for the purpose of this study. The input datasets were in grid format processed from the SVWS approach earlier discussed. The main steps taken in this stage are shown in the flow diagram (Figure 2-9). The steps included, (1) batch command file preparation for easy and quick bulk calculation, (2) Parameterisation of the Fragstats run i.e. setting the commands on how the software should treat the data fed into it, (3) Selection of metrics (the desired outputs) to be calculated at each of the three spatial levels (i.e. patch, class and landscape), (4) Running the Fragstats to execute the set commands and lastly (5) display, preview and export of output results in Excel format for further statistical analysis.

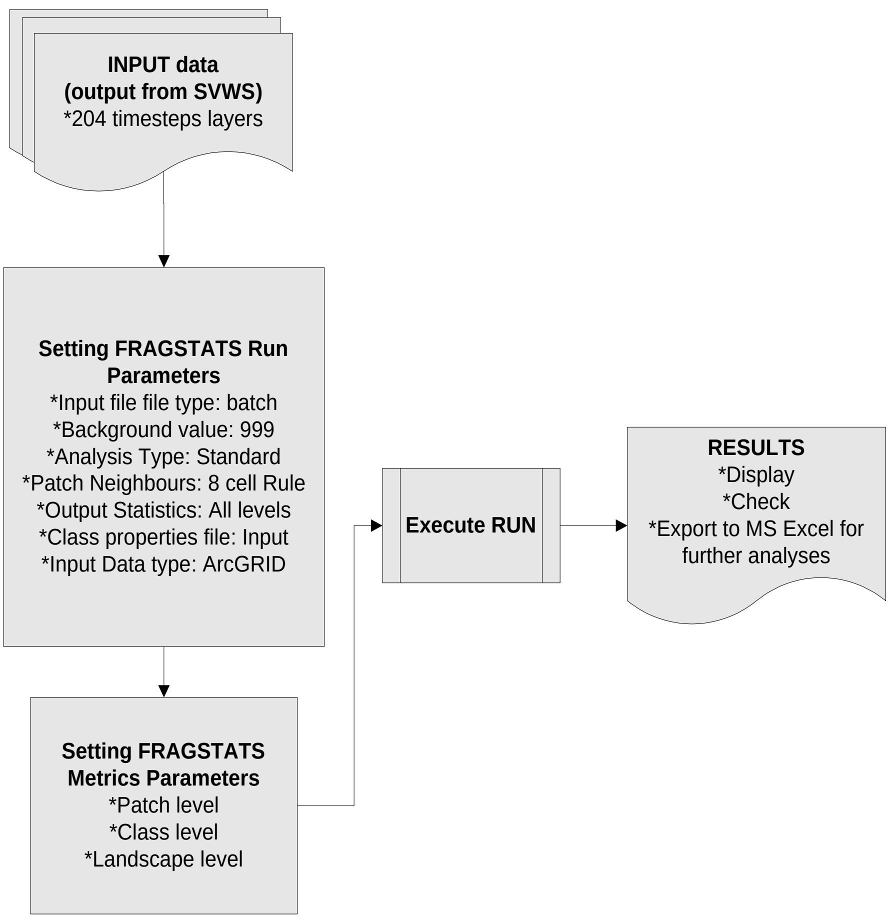

Figure 2-9: Flow diagram showing the main steps undertaken in the FRAGSTATS module of data processing.

2.5. Validation dataset preparation and processing

Three major steps were followed in the processing of the validation dataset. These were data access and screening, pre-processing and processing.

2.5.1. Data Access and Screening

Three image types were considered for use in this stage namely MODIS, ASTER and Landsat. Images were selected and downloaded the following criteria (1) availability, (2) accessibility, (3) appropriate dates, (4) spatio-temporal resolution and (5) cloud cover (Mertens 2008). MODIS had the best temporal resolution but fell short because of its course resolution which did not give the desired detail. ASTER had the edge of the best resolution of the three imagery but scarcity and poor temporal resolution made it unusable in this study. Therefore Landsat was selected because it had the best accessibility (free online access) and a reasonable spatial resolution to give enough required detail. Two data sources used were the ITC Geodata warehouse and the online USGS GloVis database (http://glovis.usgs.gov/). Thirty-one good quality images were selected and downloaded ultimately and an overview of the datasets is shown on Table 2-5. Furthermore, care was taken to compile a dataset that will at least cover all the different variations in water level that occurred in the lagoon during the period for which waterfowl census data was available. This would ensure representativeness of the sample to capture most if not all the variations of the lagoon landscape from dry moments up to and including the wet moments.

The Landsat imagery selected for the validation set covered the moments with the variation in water levels ranging from -32 cm to 63 cm, which compared well to the range of all the measured water levels. This range is well within and covers the first, inter-quartile and third quartile ranges of the complete dataset to be used in the final analyses as shown on Figure 2-10. However, it is noted that the validation set range does not cover the upper extreme wet periods such as the 161 cm water level of April 1998 which appear as an outlier on the box plot.

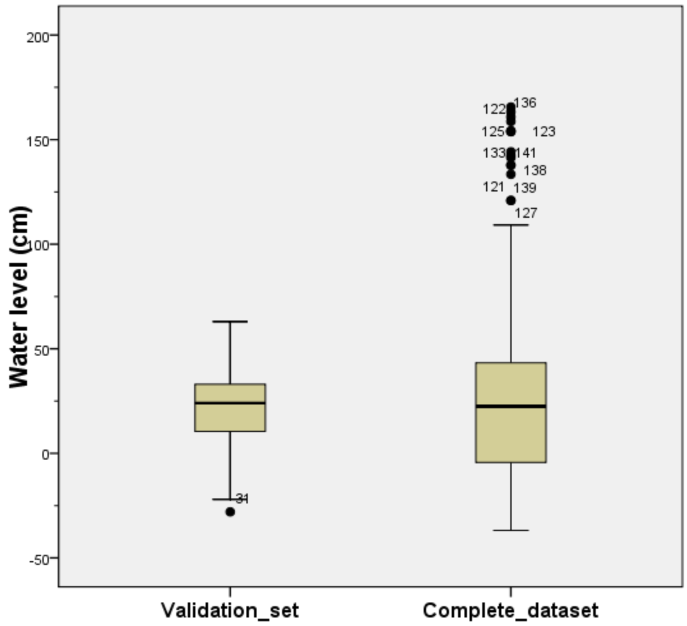

Figure 2-10: Box plots showing the water level range covered by the validation set used against the complete dataset range. The validation set coincided well with the complete dataset hence useable.

Table 2-5: List of imagery used for validation (All GloVis images were in .TIFF format while those from ITC were in .IMG format)

Platform	Sensor	Date	Resolution	Water Level (cm)	Source
Landsat	MSS	7/13/1991	30m	-5	ITC Geodata warehouse
Landsat	MSS	5/10/1994	30m	11	ITC Geodata warehouse
Landsat	TM	8/20/1999	30m	-7	USGS GloVis
Landsat	TM	12/12/2000	30m	24	USGS GloVis
Landsat	TM	8/9/2001	30m	-15	USGS GloVis
Landsat	TM	2/1/2002	30m	47	USGS GloVis
Landsat	TM	3/21/2002	30m	46	USGS GloVis
Landsat	TM	4/22/2002	30m	43	USGS GloVis
Landsat	TM	5/24/2002	30m	26	USGS GloVis
Landsat	TM	6/17/2002	30m	14	USGS GloVis
Landsat	TM	7/27/2002	30m	-12	USGS GloVis
Landsat	TM	4/25/2003	30m	35	USGS GloVis
Landsat	MSS	7/6/2003	30m	-8	USGS GloVis
Landsat	TM	8/23/2003	30m	-22	USGS GloVis
Landsat	MSS	10/18/2003	30m	20	USGS GloVis
Landsat	MSS	1/22/2004	30m	51	USGS GloVis
Landsat	MSS	4/27/2004	30m	63	USGS GloVis
Landsat	TM	5/29/2004	30m	58	USGS GloVis
Landsat	TM	4/30/2005	30m	10	USGS GloVis
Landsat	TM	11/19/2006	30m	24	USGS GloVis
Landsat	TM	12/21/2006	30m	26	USGS GloVis
Landsat	TM	1/6/2007	30m	24	USGS GloVis
Landsat	TM	2/7/2007	30m	31	USGS GloVis
Landsat	TM	3/11/2007	30m	27	USGS GloVis
Landsat	TM	4/28/2007	30m	13	USGS GloVis
Landsat	TM	5/14/2007	30m	14	USGS GloVis
Landsat	TM	11/16/2008	30m	27	USGS GloVis
Landsat	TM	12/2/2008	30m	34	USGS GloVis
Landsat	TM	6/4/2009	30m	13	USGS GloVis
Landsat	TM	7/6/2009	30m	-11	USGS GloVis
Landsat	TM	9/8/2009	30m	-32	USGS GloVis

2.5.2. Pre-processing

Four basic steps (shown in Figure 2-11) were followed to preprocessing and preparation of the data. These were, (1) layer stacking bands 1-5 & 7, (2) conversion from .TIFF to .IMG format, (3) reprojection from WGS 84 to ED 50 Zone 30N (datum used in Fuente de Piedra) and (4) Subsetting of study area. Since temporal reflectance of a given target vary due to atmosphere and sun-target-sensor geometry (Weirong and Guoqing 2004), simple haze correction was done in ERDAS Image Interpreter for this study. There was no need to geocode or geo-reference the images since all the USGS images were already processed Level 1B. They were only reprojected as earlier mentioned. Only three images from the ITC geodataware house were geocoded and georeferenced based on one of the USGS GloVis downloaded images as reference. The RMSE was kept below 0.6.

2.5.3. Processing

This stage of information extraction after pre-processing covered further manipulation of data in four dimensions culminating in the output of 31image maps classified into two classes (water and land). The main steps undertaken here included (1) Calculation of NDVI, (2) Unsupervised classification, (3) Classification of NDVI images with optimum number of classes, (4) Reclass into two classes, and (5) calculation of areal coverage of each of the classes.

Prior to the selection of the index and classification method to use in this research, other viable approaches used in other similar studies were taken into consideration from relevant literature. These included the Single-Band approach (Haobo, Jindi et al. 2005) in waterbody delineation, the Normalised Difference Water Index (NDWI) (McFeeters 1996) and the conventional supervised classification.
In the Single band approach, the water sensitivity of Band 4 of Landsat Near IR band (0.76μm - 0.90μ m) was used. It has been used in mapping wetlands (Manju, Chowdary et al. 2005) for delineating the water bodies on the same basic principle of the water spectral reflectance characteristics. The water was distinguishable from other features on the scene by a characteristic black or dark appearance. However, the main setback of this method has been its failure to exploit other useful bands such as band 1 for Landsat which also have some level of sensitivity to water. It has been also acknowledged in the study mentioned above that this approach tends to provide unreliable results for shallow waterbodies especially in periods of low water level.

The NDWI has been used more often in turbidity estimations (McFeeters 1996) in water bodies and partly in the delineation open water features. In essence, it is a more useful index for the former than the latter function.

The Normalised Difference vegetation Index (NDVI) has been regarded as the most widely used index in remote sensing studies for various purposes (Knight, Lunetta et al. 2006). Seasonal trajectories of NDVI have been used in landcover classification to characterize different land cover types shrub, grass, wetlands, boreal forests, snow, ice, and water (Nemani and Running 1997; Zhao, Yan et al. 2009). Computed from the formula (Equation 1), NDVI has been considered easy to use and interpret and shows relatively less variation with scattering angle (Lihua, Wenze et al. 2002).It partly eliminates some effects of the solar zenith angle, sensor's observing angle and atmosphere conditions though it is sensitive to both atmospheric aerosols and soil background (Zhao, Yan et al. 2009).The water pixels have been delineated based on their characteristic negative NDVI values (i.e. values ≤ 0). However variations in the range of values for identifying water pixels have been noted in several studies, for example , -0.28 to 0.50 (Manju, Chowdary et al. 2005), -0.45 to -0.002 (Melesse, Jordan et al. 2001). These ranges vary with type of imagery used and the environmental conditions prevalent in a particular area at a particular time.

$$NDVI = \left(\frac{\rho_{nir} - \rho_{red}}{\rho_{nir} + \rho_{red}} \right)$$

(Equation 1)

where ρ_{nir} and ρ_{red} are the reflectance values in the respective bands (Tucker 1979).

In light of the advantages of NDVI over the other possible approaches, NDVI was selected and used in this study. The main processing steps are highlighted in Figure 2-11.

As for the image classification method, supervised classification was considered against unsupervised classification. While supervised classification has leverage of permitting user control on the onset of the process (Lihua, Wenze et al. 2002), it has a major disadvantage of limiting the separation to the best of the ability or skill of the user. Reis (2008) maintains that using the ISODATA algorithm in unsupervised classification yields better results in classification considering the fact that full radiometric data on the image is automatically utilised without limitation or bias of the user. Unsupervised classification is simpler (Khan, de Bie et al. 2010) than supervised classification, because the cluster signatures are automatically generated by the ISODATA algorithm. Comparative studies of the two methods show that unsupervised classification yields results of better accuracy (Lihua, Wenze et al. 2002) than supervised classification. It is against this backdrop that unsupervised classification was selected and used in this research. Furthermore, lack of historical ground data to use for training made unsupervised classification an ideal choice over supervised classification. An overview of the steps taken in this regard is shown on the flow chart (Figure 2-11).

Prior to undertaking the unsupervised classification of the NDVI images, divergence statistics were calculated to determine the optimum number of classes (Khan, de Bie et al. 2010) for the classification. The ISODATA runs were carried out to define 3–35 classes with class increase intervals of two, convergence was set at one and the number of iterations was predetermined at 25 with zero values classified. The run with a clear distinguished peak in the divergence separability was selected as optimal for classification of the NDVI images. In this case it was 30 classes (see Figure 3-1 under the results section).

After classification of the all the other NDVI images into the 30 classes in ERDAS using a batch command file created in Notepad, the images were reclassed into 2 classes i.e. water and land based on NDVI profiles for each of the classes in ERDAS. Classes with NDVI values ≤ 0 were reclassed as water while those with NDVI value > 0 as land. To assist in the reclassification process, visual interpretation in RGB 4-3-1 and Band 4 only was used as well.

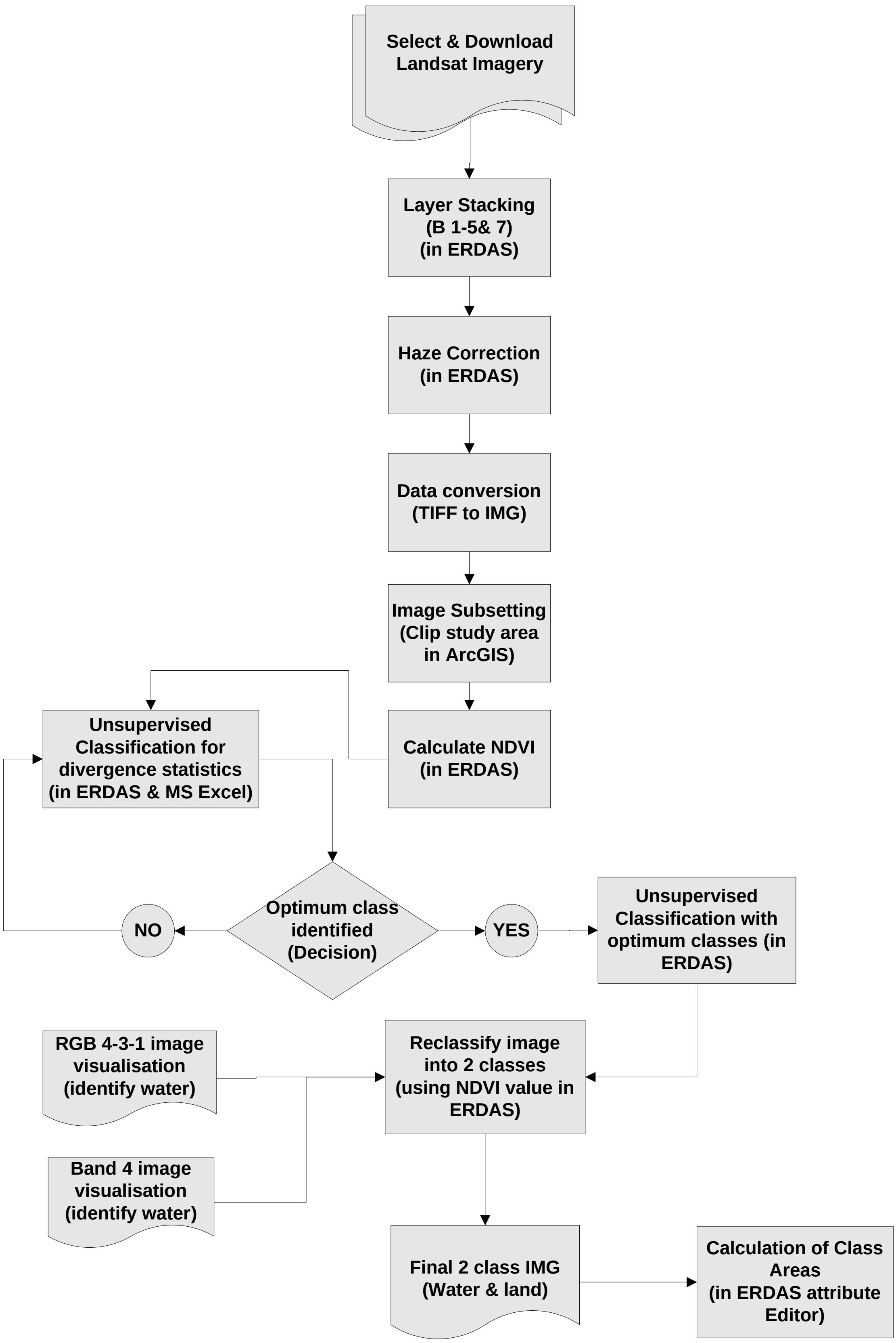

Figure 2-11: Process flow chart showing the main steps undertaken in the processing of the validation dataset

3. Results

3.1. Optimum number of class determination and NDVI classification output

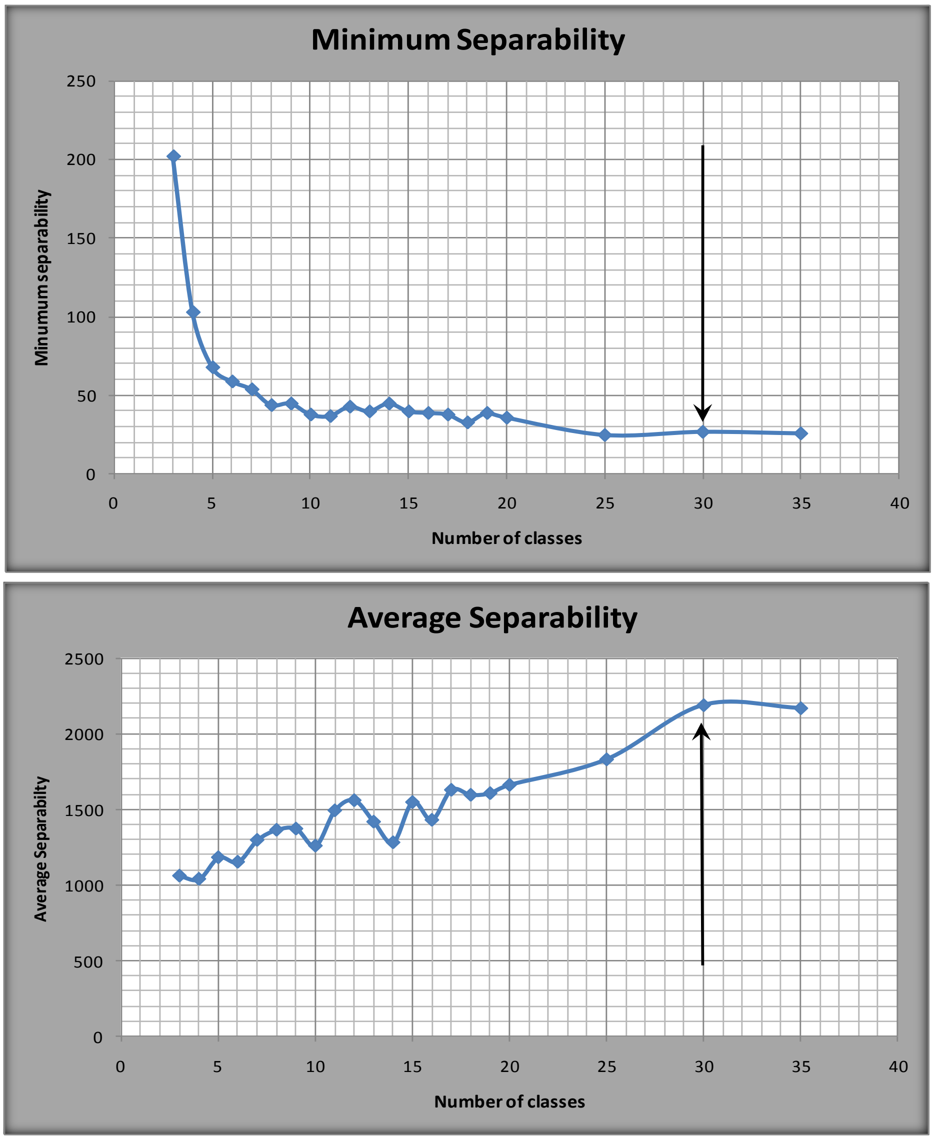

Figure 3-1: Divergence Statistics (Average and Minimum) to identify the optimal number of classes (=30) to run an unsupervised ISODATA classification of 31 Landsat NDVI images for F de P lagoon

The divergence statistics results in Figure 3-1 showed that 30 was the optimum number of classes for use in the unsupervised classification in this study marked by the peak on the average separability graph and the corresponding minimum separability value. The results of classification using this optimum number of classes are shown on Figure 3-2.

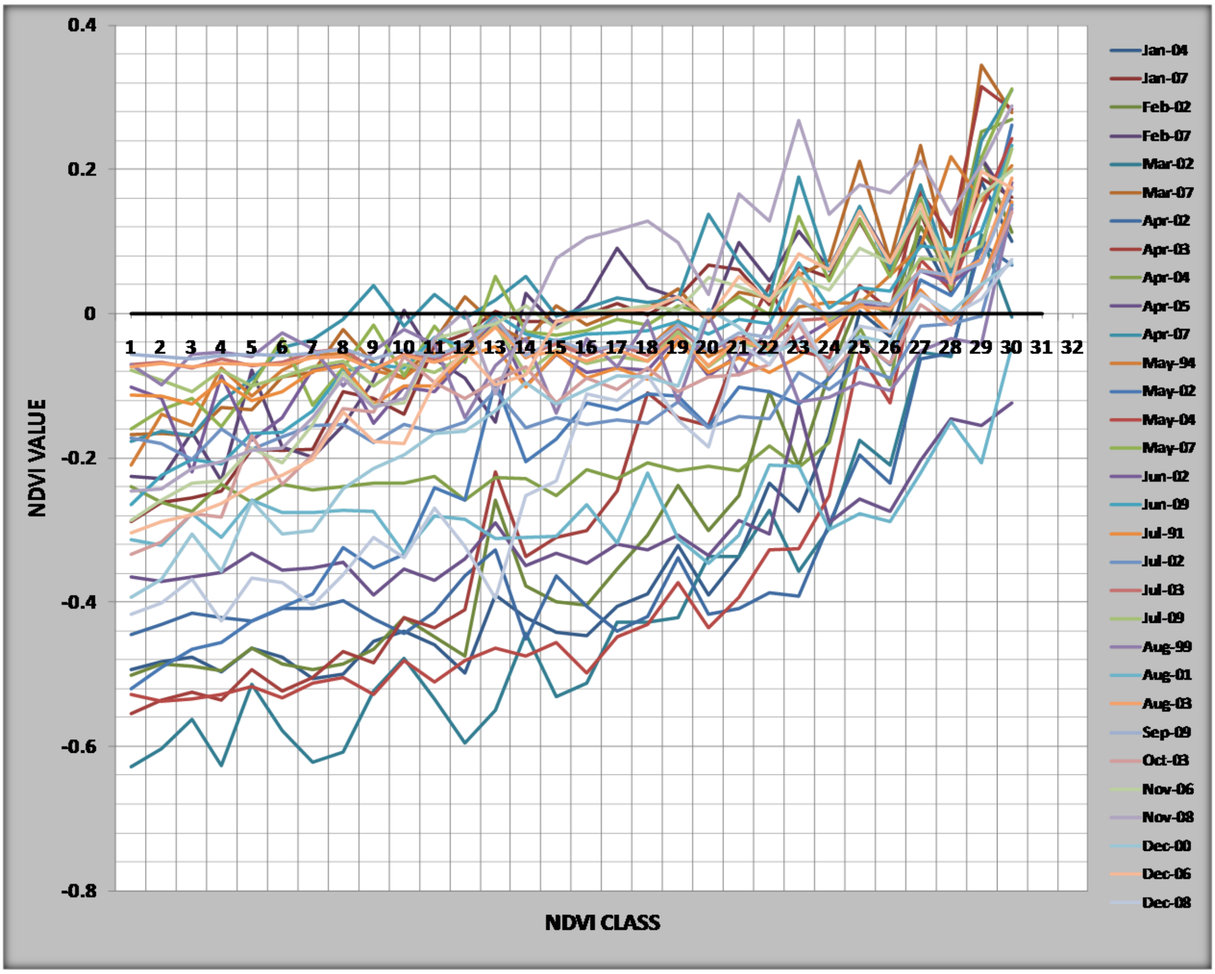

Figure 3-2: Graph showing the variation of NDVI values for the 30 classes on each of the 31 images used in validation. NDVI values ≤ 0 were classified as water while values > 0 were classified as land. Note: The line graphs are not NDVI profiles for the classes.

Generally it was realised that high water levels were related very low NDVI values e.g. for class 7 in January 2004, water level of 52cm corresponded to NDVI value of -0.50592. Low water levels were more related to relatively low NDVI values though the values were realised to vary with changing moments. For example in May 2007, NDVI value of -0.12719 against 2cm water level and in June 2003 -0.06793 against -8cm.

Examples of output maps from the reclassification process are shown in Figure 3-3 against the SVWS classified output maps. Similarities and some differences are shown on the map outputs from the two approaches. The modelled output maps for example appear more refined and less patchy compared to the NDVI classified maps. It can be seen also that there are some overestimations and underestimation of areal covers for the landscape classes.

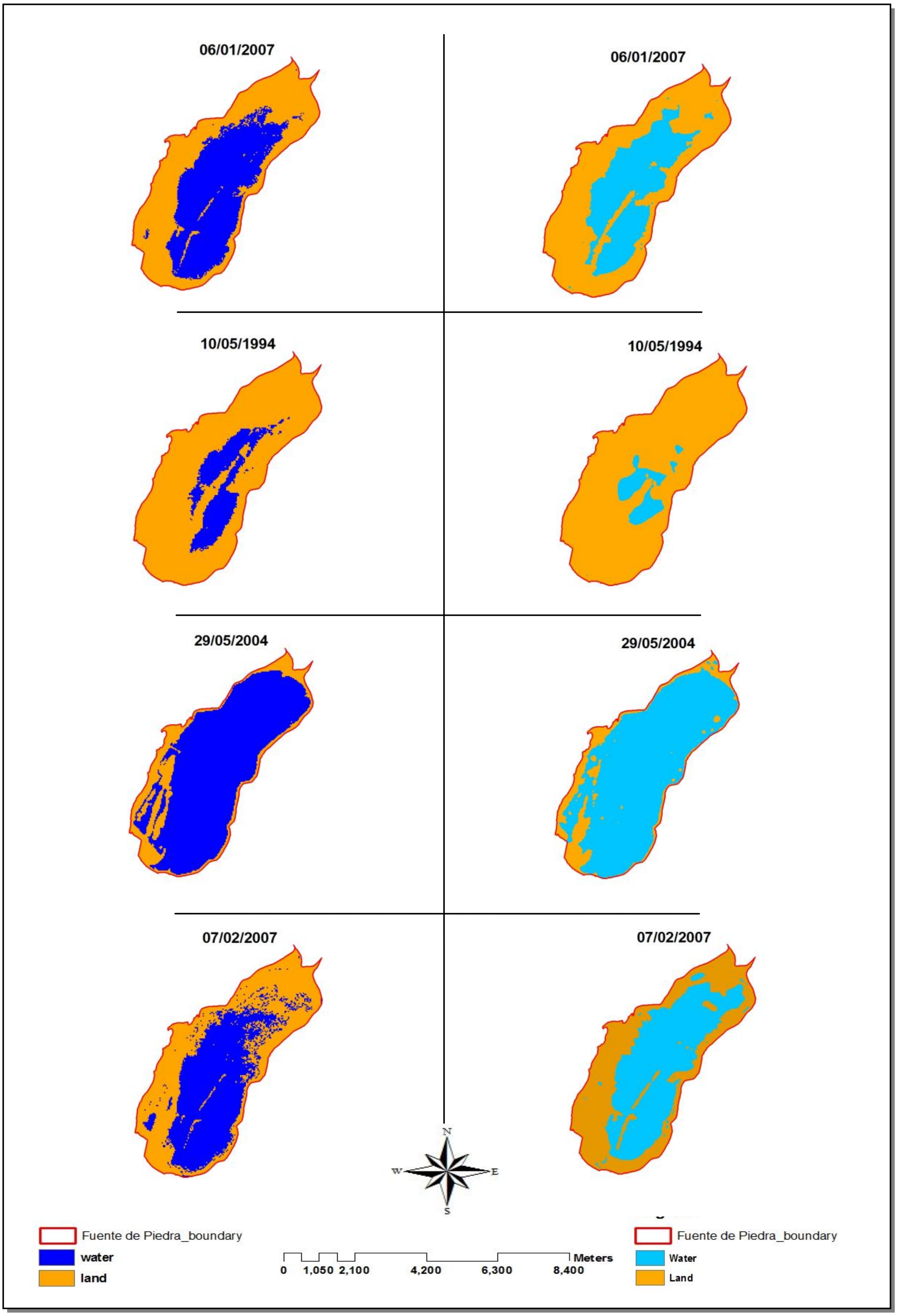

Figure 3-3: Examples of the output maps from the Landsat NDVI classification process compared to the corresponding date SVWS classified output. The variations in outputs for corresponding dates can be seen as well. Variations were highest during moments of low water levels and dryness.

3.2. Validation results of SVWS classification approach

The validation results showed a significant ($p < 0.001$) and high positive correlation (slope = 0.536) for water areal cover from the SVWS modelled landscape classes and the Landsat classification process. The R^2 was also high at 0.8208 as shown on the graph (Figure 3-4). The same results apply for the land class since the two classes are complementary. The Landsat total areal cover was overestimated by a marginal 0.009km^2 most likely possibly due to spatial resolution (Stefanov and Netzband 2005) differences between the DEM (at 15m x15m) and the Landsat imagery (30mx30m) used in the validation process and user errors as well.

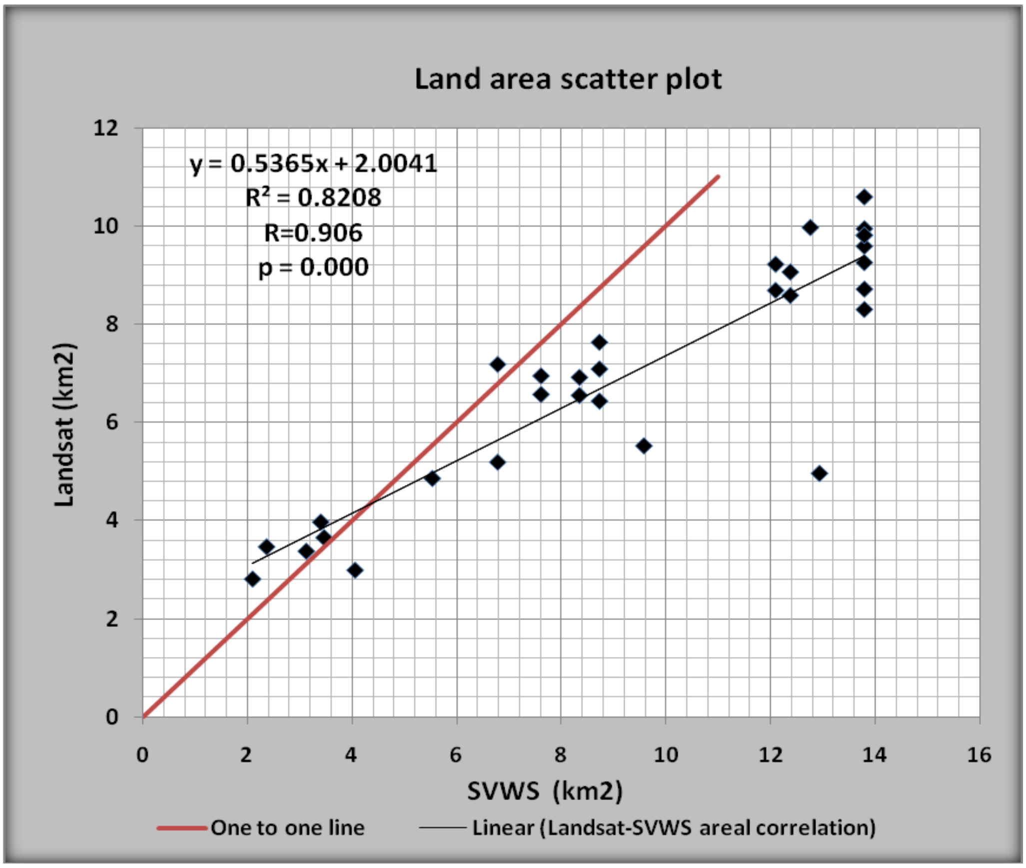

Figure 3-4: Scatter plot showing the correlation between areal cover of land from SVWS approach and Landsat NDVI classification.

The validation results also indicated that there are underestimations as well as overestimations of the measurements in this approach as indicated by the deviation the deviation of the best fit line from the one to one fit line. At high water levels the Landsat classification gave lower values, compared to the SVWS approach, while at low water levels, the SVWS gave lower estimations. In moments of very low water levels (below 5cm), the approach did not give reliable estimations. For water levels below zero, the SVWS approach assumed a dry (no water) classification yet the Landsat classification indicated some water presence in the lagoon. However, based on the results, the SVWS gave consistent results and was thus considered reasonably reliable for the further analysis performed in this study i.e. for hypertemporal modelling the landscape classes for all the other moments desired in this study.

3.3. SVWS classification approach results

3.3.1. Map outputs showing landscape changes with water level

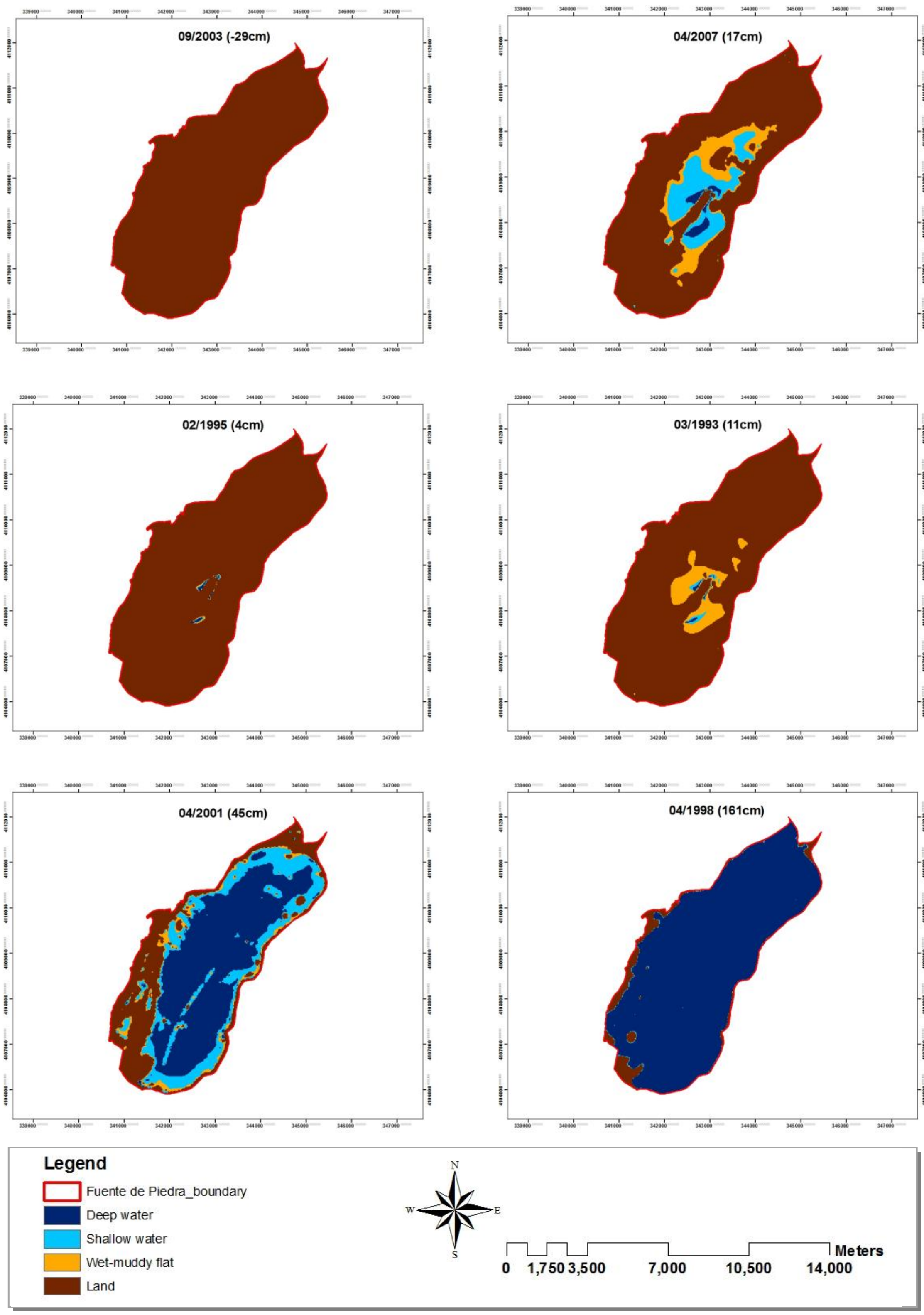

Figure 3-5: Examples of the output maps from the SWVS classification using the DEM and the monthly average water level measurements. The four landscape classes' dynamics with water level changes are clearly depicted from the maps.

The output maps (Figure 3-5) show that as water level increases, deep water also increase as well while other landscape units diminish in size. In moments of very high water level such as in April 1998 where water level was 161 cm, over 95% of the landscape was delineated as deep water. A more balanced composition of the landscape classes was realised for average water levels between 20 and 35 cm. However it was noted that the approach fails to clearly distinguish landscape classes for water levels below zero centimetres by giving a single class (land) which may not be always the case as evidenced by the Landsat NDVI classification outputs for the same moments. For example water level of -29 cm was classified as 100% land class just like zero cm water level.

3.3.2. Landscape class areal cover calculation output

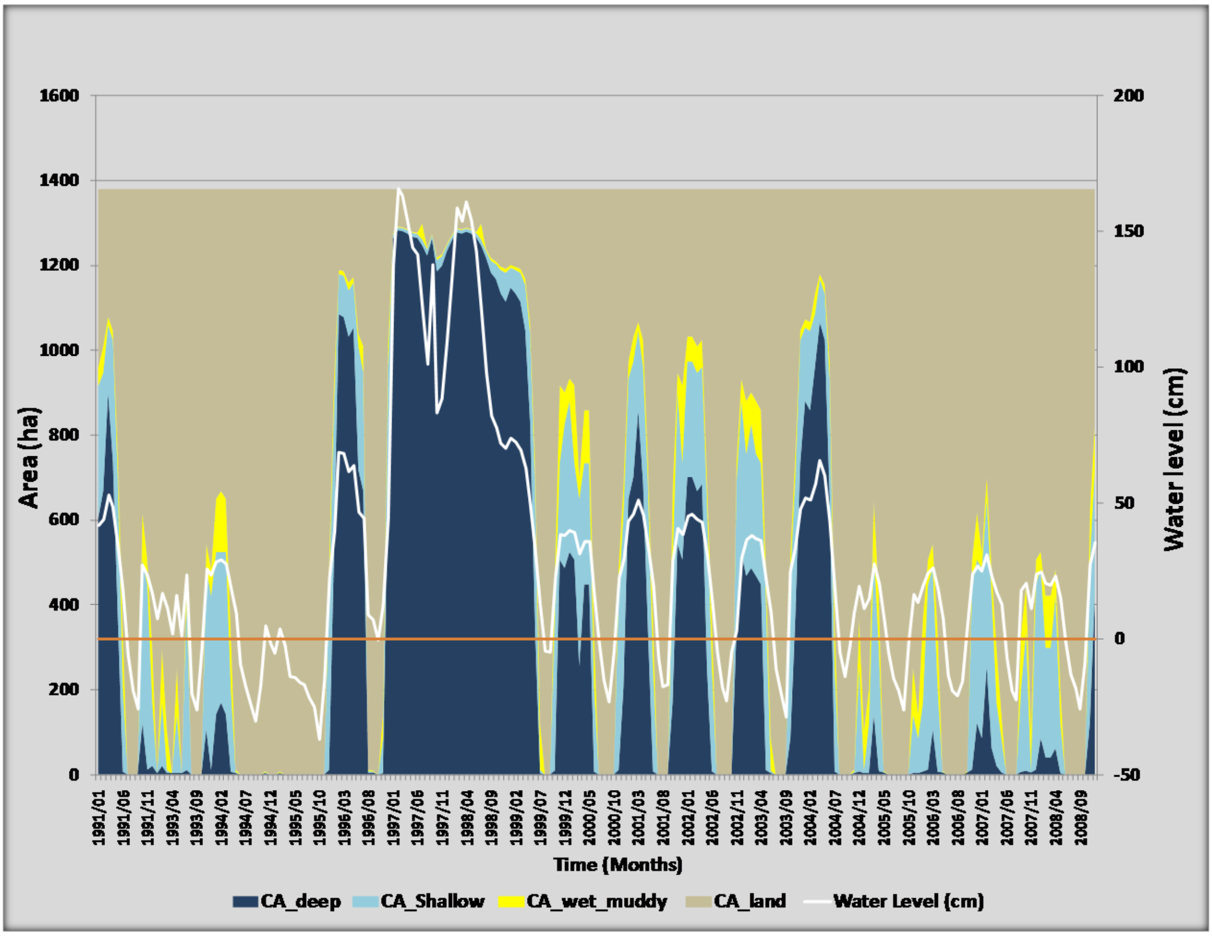

Figure 3-6: Graph showing the hypertemporal areal covers changes of each of the modelled landscape classes from 1991-2008 relative to water level fluctuations for the same time span.

The graph (Figure 3-6) shows how water level fluctuations influence the variation in the landscape composition and possibly configuration. The different landscape classes change in a complementary way in response to water level changes. For example, during moments of high water levels such as between 1997 and 1998, the deep water class constituted the greatest percentage of the entire landscape while in no-water moments such as between 1994 and 1995, the land class dominated. As earlier mentioned, a near balanced composition of the landscape is seen during moments of average water levels of around 25 to 35 cm e.g. between 1999 and 2003. The dynamics of these landscape class changes are expected to influence the waterfowl community dynamics in the lagoon.

3.4. Statistical analyses outputs

Table 3-1: Pearson's correlation analysis results for Swimmers, Anatidae, the Mallard *(Anas platyrhynchos)*, Northern Shoveler *(Anas clypeata)* and the Shelduck *(Tadorna tardona)* against areas of the four landscape classes. Also shown are the p-values from significance testing.

		CA_deep	CA_Shallow	CA_wet_muddy	CA_land
Swimmers	Pearson Correlation - R	**.523****	.025	-.007	**-.502****
	p-value	.000	.722	.916	.000
ANATIDAE	Pearson Correlation - R	**.504****	.036	.002	**-.489****
	p-value	.000	.607	.981	.000
Anas platyrhynchos	Pearson Correlation - R	**.304****	-.011	-.024	**-.281****
	p-value	.000	.872	.733	.000
Anas clypeata	Pearson Correlation - R	**.442****	.069	.032	**-.444****
	p-value	.000	.328	.654	.000
Tadorna tadorna	Pearson Correlation - R	.111	**.349****	**.253****	**-.243****
	p-value	.115	.000	.000	.000

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

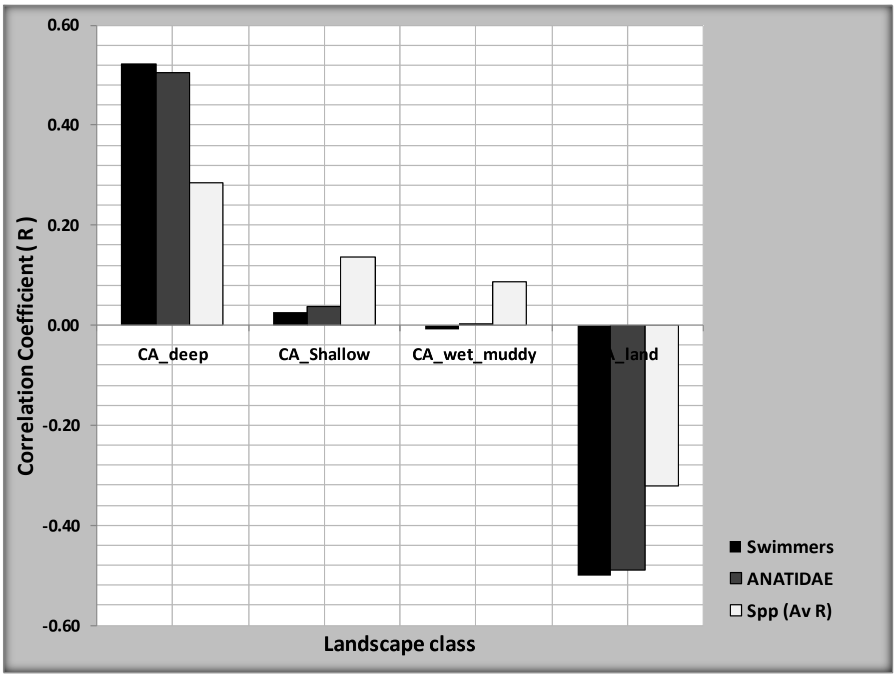

Figure 3-7: Graph showing the variation of Pearson's 'R' at each of the three hierarchical levels for swimmers. Note that (Spp (Av R)) is the averaged 'R' for the three species so as to give a single value for the species level. Basically consistent declining trends from deep water class to land class are seen from the graphs.

Results in Table 3-1 show that a statistically significant positive correlation exists between the deep water class area and the swimmers at all three hierarchical grouping levels with the exception of the Shelduck at species level. The strength of the relationship decreases with decrease in the hierarchy from guild to species level as illustrated by the graphs (Figure 3-7). It is relatively strongest at guild level (R= 0.523), followed by family level (R=0.504) and generally weakest at species level. A significant negative correlation at all three levels is realised against the land class area following the same trend as with the deep water class i.e. strongest at guild level (R= -0.502), and weakest at species (R = -0.281). The shallow water and wet-muddy flat classes both had insignificant low positive and negative relationships with the waterfowl at all levels respectively save for the Shelduck which had stronger significant positive relationship with the latter than the former class. Generally, the results show that the temporal changes in the deep water landscape class area do have a relationship with the swimmers. If area of deep of water decreases, it will be expected that the abundance of the members of this guild will decrease also in the magnitude indicated by the strength of the shown correlation coefficients. The opposite can be said of the land class area against the swimmers in general. When the land class area increases, the swimmers are going to decrease in abundance though the magnitude will vary as indicated by the negative 'R' values at all community levels.

Table 3-2: Pearson's correlation analysis results for Waders, Recurvirostridae and Black-winged stilt *(Himantopus himantopus)*, Pied Avocet *(Recurvirostra avosetta)* and the Common crane *(Grus grus)* against areas of the four landscape classes.

		CA_deep	CA_Shallow	CA_wet_muddy	CA_land
Waders	Pearson Correlation - R	**.143***	**.379****	**.241****	**-.282****
	p-value	.041	.000	.001	.000
RECURVIROSTRIDAE	Pearson Correlation - R	**.295****	**.363****	**.253****	**-.422****
	p-value	.000	.000	.000	.000
Himantopus himantopus	Pearson Correlation - R	**.227****	**.350****	**.262****	**-.354****
	p-value	.001	.000	.000	.000
Recurvirostra avosetta	Pearson Correlation - R	**.331****	**.243****	.124	**-.404****
	p-value	.000	.000	.078	.000
Grus grus	Pearson Correlation - R	-.061	**.301****	**.234****	-.064
	p-value	.389	.000	.001	.364

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

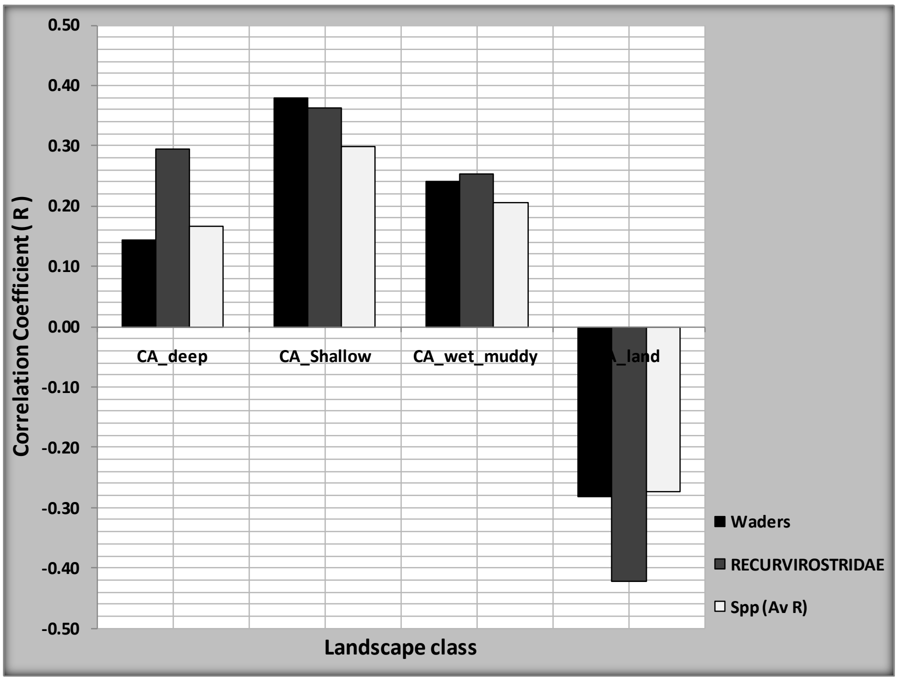

Figure 3-8: Graph showing the variation of Pearson's 'R' at each of the three hierarchical levels for waders. Note that (Spp (Av R)) is the averaged 'R' for the three species so as to give a single value for the species level.

Of the four landscape classes, shallow water relatively has the strongest positive correlation with waders at guild level (R=0.379) than at family (R=0.363) and species levels. Despite the deviation shown by the Pied avocet *(R. avosetta)* having a stronger relationship with deep water, a general trend of decreasing strength of relationship with shallow water from guild to species level can still be seen from the results (see Figure 3-8). Significant positive correlations are also seen for the wet-muddy flat at all levels with the exception of the Pied avocet at species level. The pied avocet however has the strongest significant correlation of 0.331 with the deep water class while the Common crane *(Grus grus)* has a negative insignificant relationship with the same class. Significant negative correlations are seen for the waders at all levels with the land class save for the common crane which has a negative insignificant correlation as shown on Table 3-2. The relationship with the land class is relatively strongest at family level followed by species and weakest at guild level with R = -0.282. Well marked is a consistent relationship trend (from guild to species level) with shallow water class not withstanding the relevance of other correlations shown.

Table 3-3: Pearson's correlation analysis results for Shoreliners, Scolopacidae, the Dunlin (Caladris alpine), Little stint (Calidris minuta) and the Kentish plover (Chadrius alexandrinus) against areas of the four landscape classes. Also shown are the p-values from significance testing.

		CA_deep	CA_Shallow	CA_wet_muddy	CA_land
Shoreliners	Pearson Correlation - R	.002	**.413****	**.373****	**-.174***
	p-value	.974	.000	.000	.013
SCOLOPACIDAE	Pearson Correlation - R	.042	**.463****	**.424****	**-.232****
	p-value	.556	.000	.000	.001
Calidris alpina	Pearson Correlation - R	.108	**.393****	**.405****	**-.271****
	p-value	.123	.000	.000	.000
Charadrius alexandrinus	Pearson Correlation - R	**-.296****	**-.213****	**-.163***	**.365****
	p-value	.000	.002	.020	.000
Calidris minuta	Pearson Correlation - R	-.049	**.456****	**.399****	**-.142***
	p-value	.486	.000	.000	.043

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

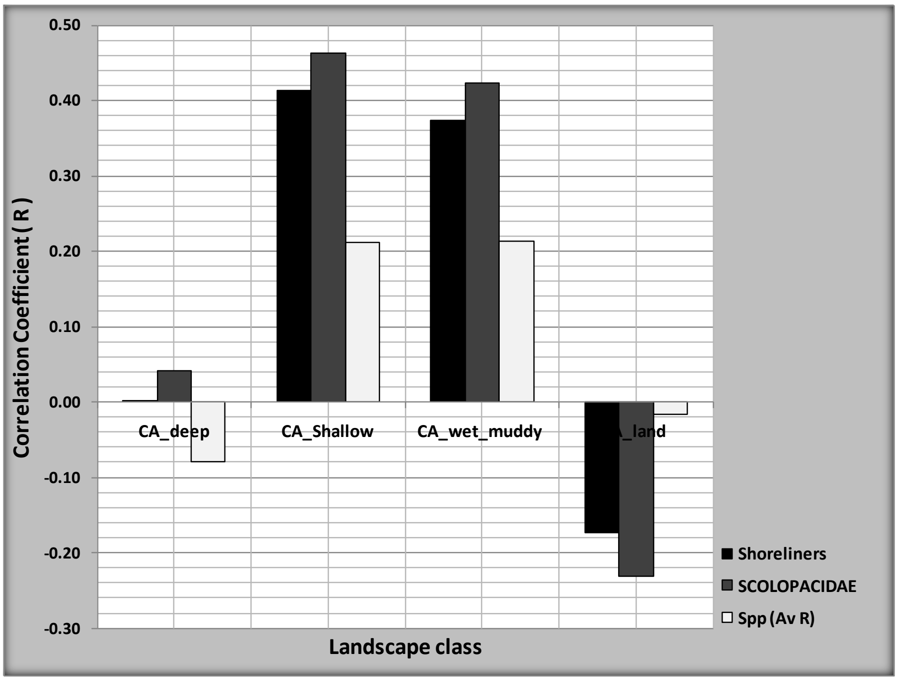

Figure 3-9: Graph showing the variation of Pearson's 'R' at each of the three hierarchical levels for shoreliners. (Spp (Av R) is the averaged 'R' for the three selected species)

At guild level, the shoreliners show significant correlations of 0.413 and 0.373 with the shallow water and wet muddy flat classes respectively and a negative significant correlation with the land class. The same trend is followed at family level. However at species level, there are variations amongst the species. The dunlin has the strongest correlation with the wet-muddy class followed by the little stint and lastly the Kentish plover which has a significant negative correlation. Generally, significant negative correlations exist at all levels against the land class. The deep water class has positive, insignificant and low correlations with the shoreliners at all levels with the exception of the Kentish plover and the little stint which both have negative significant and insignificant correlations with the same class respectively. As illustrated by the graphs (Figure 3-9), consistent trends of decreases in R with decrease in the hierarchy (from guild to species) are seen against shallow water class and wet-muddy class.

Table 3-4: Pearson's correlation analysis results for Others, Laridae and Lesser black-backed gull *(Larus fuscus)*, Black-headed gull *(Larus ridibundus)* and Gull-billed tern *(Gelochelidon nitlotica)* against areas of the four landscape classes.

		CA_deep	CA_Shallow	CA_wet_muddy	CA_land
Others	Pearson Correlation - R	.088	**.439****	**.320****	**-.257****
	p-value	.211	.000	.000	.000
LARIDAE	Pearson Correlation - R	.086	**.431****	**.313****	**-.253****
	p-value	.219	.000	.000	.000
Larus fuscus	Pearson Correlation - R	.023	**.419****	**.299****	**-.188****
	p-value	.739	.000	.000	.007
Larus ridibundus	Pearson Correlation - R	**.330****	**.260****	**.220****	**-.419****
	p-value	.000	.000	.002	.000
Gelochelidon nilotica	Pearson Correlation - R	-.016	.039	.055	-.003
	p-value	.824	.584	.434	.963

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

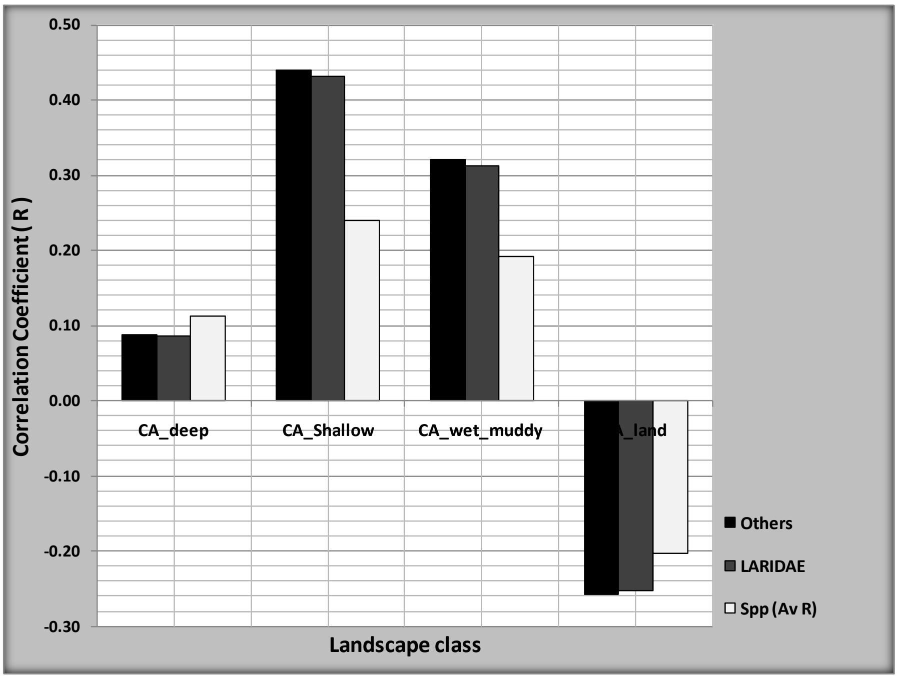

Figure 3-10: Graph showing the variation of Pearson's 'R' at each of the three hierarchical levels for others. (Spp (Av R) is the averaged 'R' for the three selected species)

A consistent general trend of a decrease in strength (from guild to species level) of a positive significant relationship between generalists and shallow water class is shown on Table 3-4 with the exception of the gull billed tern. The same trend is followed with the wet-muddy class even after the averaging of the species 'Rs' as shown on Figure 3-10. The black-headed gull shows a relatively strongest negative correlation with the land class compared to other species. Apart from the black-billed gull, an increase in strength from species to guild level of a significant negative correlation with land class is seen. All community levels have insignificant, low correlations with the deep water class save for the black-headed gull which had a significant positive relation with this class. The gull-billed tern has no significant correlations with any of the landscape classes. In general, consistent trends of decreasing positive correlations (from guild to species level) with shallow water and wet-muddy classes can be seen from the results.

Table 3-5: Pearson's correlation analysis results for Shoreliners, Scolopacidae the Dunlin *(Caladris alpine)*, Little stint *(Calidris minuta)* and the Kentish plover *(Chadrius alexandrinus)* against Total edge for wet-muddy class. Also shown are the p-values from significance testing.

	TE_wet_muddy	
	Pearson Correlation - R	p-value
Shoreliners	**.496****	.000
SCOLOPACIDAE	**.559****	.000
Calidris alpina	**.503****	.000
Calidris minuta	**.521****	.000
Charadrius alexandrinus	**-.228****	.001

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

The Shoreliners show significant correlations against the wet-muddy class shoreline perimeter at all levels. Positive relationships are seen at all levels with the exception of the Kentish plover which has a negative correlation as show on Table 3-5. The relationship is strongest at class level with an R of 0.559 followed at species level by the little stint and the dunlin with R of 0.52 and 0.503 respectively. Basically it can be seen that the shoreline perimeter does have a consistent significant positive relationship with the shoreliner population at all levels.

4. Discussion and Conclusion

4.1. Delineation of landscape classes using DEM

The attempt made in this research to explore the F de P landscape structure using the DEM and historic water level data yielded positive results as earlier highlighted. The landscape classes (deep water, shallow water, wet-muddy flat and land) were successfully extracted using the modified SVWS approach by basically reclassifying the DEM based on predefined water level ranges. The delineated classes have shown much agreement with the similar classes from the Landsat classified images as confirmed by a good R^2 of 0.81 and a significant slope (with $p < 0.001$) from the validation process. The level of consistency shown by the results indicates that the approach can be used with acceptable levels of confidence for landscape characterisation. A few issues are worth noting while upholding these positive results. First, since the depicted inundation extents are inherently tied to the accuracy of the elevation surface (Thompson, Bell et al. 2001) i.e. the quality of the DEM used, it is worth mentioning how Wang (2008) processed the DEM used in this study. To ensure high accuracy of the DEM, she reconstructed it using elevation data measured at a series of discrete points in the lagoon and then used interpolation in ArcGIS to create DEM. A high point density was maintained to capture detailed variations in the elevation surface to centimetre level. In essence the accuracy of this DEM used here was acceptable and its spatial resolution of 15mx15m was well suited for assessing the spatial dynamics of the ecological processes of interest that are operating in the lagoon landscape.

Besides this, it was appreciated from the results that the SVWS approach fails to model the landscape structure in conditions of subzero water level. This was because the DEM contains terrain elevation information up to minimum of zero meters (which is the lowest point in the F de P basin) of which it is impossible to do any classification below this minimum. This means that in subzero water level moments, this approach will not give an accurate reflection of the prevailing landscape structure.

Water level ranges used in the delimiting of landscape classes from the DEM were guided by the background knowledge about the waterfowl species to ensure that the wetland landscape classes were as representative of the waterfowl preferred microhabitats as possible. It is worth noting that this is a subjective process well acknowledged in many landscape ecology studies. For example, Weller (1999) insists that for meaningful inferences to be made concerning waterfowl and their habitat dynamics, adequate knowledge is required to ensure that delineated habitat zonation features reflect the preferences of the targeted study species or waterfowl community. Richman and Lovvorn (2004) also confirm this notion in their study of a small North American diving duck – the Lesser Scaup *(Aythya affinis)* where they define foraging microhabitat ranges of 1.8 metres as deep water, 90 cm as shallow water and < 20cm as very shallow based a posteriori knowledge of behaviour and adaptations of this species to its habitat. The water ranges used in this study also compared well with those used by Wang (2008) in her study of five selected species in F de P though she defined more classes ranging from deep water at > 1m to shallow and dry at 30cm and 0 cm respectively. However in this study where almost an entire community was under investigation, setting appropriate ranges to suite the preferences of all the individual species may have been unrealistic hence the choice of using water level ranges for guilds was a better option for simplicity and focus. The drawbacks of taking this approach were that the defined ranges may not be preferable for all species in a guild hence the possibility of negatively affecting the expected correlation results landscape structural changes. For instance, we set a range of >20 cm to be deep water ideal for swimmers which are mostly anatidae. But a closer look at this guild reveals that some members thereof such as the Eurasian Teal (*Anas crecca*) will not find water levels > 20cm ideal for them but prefer muddy flats. Therefore selecting accurate water level ranges means accurately characterising the landscape structure and this has a significant bearing on the final outcome of the study when relationships with waterfowl communities are being explored. Furthermore, the assumption that waterfowl in a guild are expected to respond in almost a similar way to biophysical changes in the landscape may not resonate well with our findings. Though there were significant correlations which were relatively higher at guild level for most of the groups, this does not directly translate to imply that all species in the guild are responding the same way to landscape structural changes. However we have some indication pointing to that, which gives us some measure of confidence to make inferences about the community.

Secondly, the use of NDVI in the classification of the Landsat imagery for validation yielded good results demonstrating the useability of NDVI for this purpose. However, a challenge was realised that Landsat NDVI identified wet and moist soil as water (realised by characteristic negative values) which was not well in agreement with the SVWS classification. This was the case especially when water levels were below zero of which in theory there should be no water in the lagoon e.g. in September 2003 water level was -23 cm but Landsat classification identified water. One of the reasons is highlighted by Zhao, Yan et al. (2009) that NDVI is sensitive to soil background moisture. The wetness during dry moments is explained by Rodríguez-Rodríguez (2007) in his hydrogeologic study of Spanish wetlands, where he mentions that high evaporation rates sometimes contribute to fast salinisation which cause a net discharge of ground water into the lagoon's sediment. Otherwise the lagoon would desiccate under dry summers (Castaneda and Herrero 2009). Furthermore, the presence of salt precipitates has been known to interfere with scene spectral properties (Madani 2005) which alters DN values thus negatively affecting NDVI calculation. To limit such effects, Haobo, Jindi et al.(2005) employed a thresholding technique to separate water from wet soil and dry land. Despite these shortcomings, NDVI has been used successfully in delineation of water bodies and land in many studies as earlier alluded to in chapter 2 of this report hence its success in this study is no exception. Care however should be taken to try to limit the negative impacts related to its shortfalls otherwise the output thereof may be of limited use or no value.

4.2. Waterfowl grouping into guilds

The entire waterfowl community of F de P was successfully separated into four basic guilds (swimmers, waders, shoreliners and others) and the three hierarchical levels of guild, family and species level to explore the waterfowl – landscape relationships in detail. The guilds defined in this study may provide one way to streamline the tasks of environmental assessment and resource monitoring in F de P lagoon. Verner (1984) rejects the idea of using indicator species insisting that many population changes have multiple causes, hence monitoring specific environmental changes is more meaningful if birds are grouped one way or the other e.g. by habitat preferences, major strategy (e.g. resident vs. migrant species), or feeding guild. This supports the idea implemented in this study where we used a combination of criteria such as physiological adaptations, habitat preferences and to some extent tactic to discriminate the waterfowl community into the four guilds as earlier mentioned. Furthermore, the guilds defined in this study seem to be oriented by taxa (i.e. families) hence one might argue along the line of thought of Landres (1983) that species within taxonomic groups can be too distinct to be put in one guild. However an equally counter school of thought by Jacques (2003) is that guild membership can be considered to some extent based on phylogenetic relationships because species tend to share similar life history traits and adaptations through common evolutionary history. This to some greater extent supports the idea implemented in this study. Of the numerous studies in which the guild concept has been applied, e.g. (DuBowy 1991; Wiens 1992; Putman 1994; Suter 1994; Victor and Javier Lopez De 2000) it is acknowledged that guilds are investigator-defined units oriented towards a certain research goal. Therefore a key aspect worth considering in this regard is making all efforts to ensure that the process of guild delineation is more objective and contextual.

It is also important to note that there were some species which were not easy to designate into any of the four guilds based on their behaviour, adaptations and habitat preferences. For instance, members of the rallidae family such as the common moorhen (*Gallinula chloropus)* are adept swimmers in as much as they are waders. Such species can distort or exaggerate population trends of any guild to which they are assigned to since they are competent in using either of the landscape classes they are adapted to.

4.3. Waterfowl relationship to landscape classes

The statistically significant ($p<0.001$) positive correlation shown between the deep water class area and the swimmers at all three hierarchical levels confirms to a greater extent that deep water is the preferred microhabitat for this guild. This relationship was consistent at all three levels of the hierarchy showing that if water levels decline, there are possibilities of this guild's population being negatively impacted. The hierarchy also showed that if there are any inferences to be made about this group related to landscape changes, the guild level will be more ideal since it gave the strongest correlation. The negative correlation with the land class also confirmed that the species in this guild are more hydrophilic and will shy away from land most of the time. What it implies is that when the land class increases, chances are high that the abundance of swimmers will also fall. Similar findings were made by Suter (1994) in his study of diving ducks in 20 major Swiss lakes north of the Alps. He concluded that as deep water area reduced in size, food abundance and availability also declined for these species hence reduction in their population numbers. Others studies (Bethke 1993; Guillemain, Fritz et al. 2002; Paillisson, Reeber et al. 2002; Richman and Lovvorn 2004) basically confirm the strong relationship of swimmers (which are mostly members of the anatidae family) with presence of deep water where they frequent to feed mostly and at times to rest. The Shelduck *(Tardona tardona)* showed no relationship with deep water but with shallow water and wet-muddy flat among all the selected species in this guild. This was not a surprise considering that this species is known to be semi-terrestrial and common on mudflats than in deep waters (Rendon, Green et al. 2008). Furthermore, while we found that swimmers have a preference of deep water, the strength of the relationship was a bit lower than expected (at $R = 0.523$ maximum). This could indicate that the spatiotemporal dynamics of the deep water class are not the only parameter influencing the swimmers' population changes at F de P. There could be other factors as well that are making a contribution. One possibility could be what is explained by Colwell and Dodd (1997), that the habitat preferences and use by such species will vary with season and stage of the birds' life cycles. In this regard, we reckon that we do not explicitly account for seasonality of habitat use by the species in this study hence the results we see. In other words, the population trends of this guild may also be influenced by residential status (Ma, Wang et al. 2009) which was not covered in the scope of this study.

Regarding waders, the results generally reflected what we expected according to background literature i.e. waders have the strongest significant positive relationship with shallow water class. McCabe (1991) and Weller and Spatcher (1965) confirm this relationship in their studies of egrets, herons, avocets and rails where they realised a dominance of these species in what they call sheet water (shallow waters) and less abundant in deep waters. Others waders such as yellowlegs and greenshanks have been known also prefer such habitats for which they have adapted long legs for easy access of these habitats. The significant correlation with deep water and wet-muddy flat shown by the results indicate that members of this guild can exploit any of these microhabitats despite the fact that they prefer shallow water. The variations in the leg-lengths for example will limit the extent to which any member of this guild can go in terms of water depth. So the three landscape classes can be accessible to them. The results in other words indicate that there are overlaps in the microhabitat classes (Hubbard 1982) delineated in this study. It is common in nature to have habitat overlaps for certain species. An unexplained result of a high significant positive relationship between the Pied avocet *(Recurvirostra avocetta)* and deep water was seen. This is unrealistic considering that this species' legs are approximately 8–10.5 cm long and can not swim (Birdlife International 2009) and the deep water class range is > 20cm. Another aspect that is coming out clear from the results is that absence of water will have a negative effect on this guild at all levels of community hierarchy. This was seen from the significant negative correlations with the land class. From the trends shown by the hierarchy, we can see that the guild level will be more ideal to use for any inferences concerning waders and the landscape since it had the relatively highest correlation with the target preferred microhabitat – shallow water.

Findings pertaining to shoreliners suggest that these species are more related to shallow water area than the wet-muddy flat which is not what we expected based on background literature from other similar studies. Weller (1999) cites Capen and Low (1980) confirmed that plovers, killdeer and sandpipers prefer to exploit more fluid muddy areas since these areas are ideal habitat for a number of groups of tiny crustaceans, nematodes and annelids which they prey upon. Similarly, a study in Mozambique of big and small waders (which are shoreliners in this study) by de Boer (2002) showed variable use of mainly the inter-tidal mudflats as preferred habitat by these species. These species have special adaptations such as beaks with special sensitivity to detect prey when they probe the soil and the beak length also discriminates access to different resources within the mudflat (Colwell and Dodd 1997; Cunningham and Johnson 2006). Furthermore, some which do not probe such as the Kentish plover 'run and grab' of which sight mostly used to search for prey hence they avoid shallow water. Also they are limited by leg-length which may not allow them into shallow water. So based on this reasoning we may not accept the relationship shown by the results with regards to shallow water. However, we can still appreciate that a significant relationship is exists with wet-muddy flat class second after shallow water. The results also give some insight that when considering making inferences or assessments regarding shoreliners, it is better to use the family than the guild or single species considering that at this level we have the strongest correlations generally. The negative correlations with the land class also suggest that absence of water will negatively affect abundance of these species. The results of the Kentish plover were not consistent with literature because they suggested that this species is more related to land such that even very low water levels are likely to negatively affect its abundance. Based on what is known in literature and comparing with these results, we can not confidently ascertain the preferred habitat of shoreliners in F de P.

The guild defined as others also shows some consistent trend through the hierarchy. Strong correlations with the shallow water class followed by wet-muddy flat do not necessarily imply that these are the preferred habitats for these species based on background literature. Members of the laridae are just known to utilise any part of the landscape in which they are found as opportunist feeders and scavengers (Hailey and Goutner 2002; Paillisson, Reeber et al. 2002) hence the results may have no clear meaning to discuss here. However,we can deduce that water availability is important for the species in this guild save for the Gull-billed tern *(Gelochelidon nitlotica)* which stands out as the only species in this entire study not related in any way to the landscape structure at F de P. This may be explained by the fact that the Gull-billed Tern does not normally plunge dive for fish like the other white terns, but feeds on insects taken in flight, and also often hunts over wet fields, to take amphibians and small mammals, as well as small birds and habitat types(Birdlife International 2009).

Lastly, significant positive correlations between shoreliners and wet-muddy flat total edge or perimeter confirmed our expectation of a positive relationship. This relationship which is relatively strongest at family levels suggests that wetland landscape configuration (in as far as the wet-muddy area is concerned) is of importance to the shoreliners and is better understood in the level of family than in guild or species level. While Weller (1999) acknowledges the difficulty of relating wetland configuration parameters such as total edge to waterfowl, we have managed to successfully relate at least one such parameter with shoreline birds. The results suffice to shed some light about this relationship for the first time in F de P. This is despite fact that the correlations found may not be as strong as those found in other studies cited by Weller (1999) e.g. (Hirano and Higuchi 1988) and (Nilsson 1978) which had R = 0.82 and 0.91 respectively for shore perimeter against certain waterfowl species.

4.4. Conclusion

From the findings, we can conclude that swimmers at F de P lagoon are to a greater extent related to and prefer deep water > 20cm. If the available deep water area increases or decreases, we can expect the abundance of these species most likely to respond in a similar trend. Also to make balanced inferences concerning this group of birds and the landscape changes, it is best to consider the guild level than family or species level. For the waders, we can conclude that, these species indeed have a significant relationship with and have preference for shallow water (of range between 3 – 20 cm) though they seem to have significant relationships with the wet-muddy area as well. We also realise that the guild level is best to make inferences about this group compared to the family and species level. Regarding shoreliners, we can not affirmatively conclude a clear strong relationship with the wet-muddy class as expected seeing the results indicate a stronger relationship with shallow water which is not consistent with literature and known facts about this group. However we can at least appreciate the fact that the correlation with the wet-muddy class is significant at all levels which can allow us to reject the Null hypothesis that the wet-muddy class does not have a significant relationship with shoreliners and conclude that the species are significantly ($p<0.001$) related to the wet-muddy class. Concerning the shoreliner – wet muddy perimeter relationship, we can conclude that a significant positive relationship exists implying that configuration of this landscape class in important to this group. Furthermore, this relationship together with the one earlier mentioned can be better understood if considered at family level rather than at guild and species level. In the context of this study, we can not make a clear conclusion regarding the guild defined as 'others' save to describe what the results showed that they are significantly positively correlated to shallow water and wet-muddy class and that presence of water is also important for these species.

We have managed also to demonstrate an approach of consistently characterising a wetland landscape, defining its structure (composition and configuration) using a DEM and historic water level data on a hypertemporal scale with good accuracy levels. We also show the potential of GIS and RS use in landscape ecological studies though there is still room for improvement of this approach. We have a better appreciation and understanding that indeed water level fluctuations in Fe de P have a profound influence of the landscape structural patterns and that these are related to and are reflected by the waterfowl community structures prevailing at any given moment. Overally, all the species groups had consistent negative significant ($p<0.001$) relationships with the land class. We can conclude that presence of water is a critical factor determining waterfowl species abundance through directly influencing landscape structural changes. The effects vary from guild to guild as well as among levels of the waterfowl community hierarchy. Therefore, management efforts could focus on manipulating landscape composition and configuration through effective water level management strategies that will ensure a balance within the waterfowl community in F de P lagoon.

4.5. Recommendations

The management F de P Reserve can enhance its monitoring and management activities in a number of areas considering the findings of this study. These areas include the following.

1. A mechanism can be developed to ensure that there is always water in the lagoon since we have confirmed that abundance of waterfowl is significantly tied to availability of suitable habitat which is directly influence by water level changes. In other words, the lagoon should not be let to dry up if there is to be any waterfowl present at any time in the lagoon.
2. Management at F de P has certain moments of pumping water into the lagoon specifically targeting the flamingo population, it is important to note that this changes the wetland landscape structure which has varying implications on other species as well. Therefore care should be taken to have balances and checks in place to ensure that other species are taken into consideration when such activities are undertaken otherwise there could be gains for the flamingo but losses for other important species. A fact is that the more species there are supported by the lagoon landscape, the more aesthetic beauty there is and this could translate to more tourism revenue generated from bird watchers.
3. More often than not, it may not be possible or realistic for management to create conditions that serve all the species in the community. Therefore, choices could be made as to which species are going to be of focus at any given time and then water levels be manipulated to alter the landscape in favour the selected target species. For example, if the swimmers are priority, then water levels must be kept well in ranges > 20cm to ensure that deep water is present for these species.
4. If quick assessments are to be made concerning the waterfowl community relative to the landscape quality, for swimmers and waders we recommend that the guild be considered while for shore birds – the family will be a better option. In other words, we would not recommend use of indicator species to make inferences about groups or the community in general.

Areas of potential future research after this study include the following:

1. It is not explicitly clear how the water level fluctuations influence food abundance, availability, and accessibility for waterfowl in F de P. Relative to this, a confounding factor that is not well accounted for in this research that could be considered for future research is adaptability of certain species to changing habitat conditions. This may also involve investigating how the optimum foraging concept (Verner 1984; Weller 1999; Guillemain, Fritz et al. 2002) is applicable in the waterfowl community in F de P.
2. Furthermore, our study did not explicitly consider aspects of intra and inter species competition to see how such factors together with behavioural aspects such as territoriality influence species prevalence and abundance. This is one area that can be good to explore.
3. Pumping back treated waste water into the lagoon from F de P town is likely to be changing the natural rhythm of inundation and drying of the lagoon and somehow adding more nutrients in the lagoon. The extent of change and impacts on the hydrological conditions, the landscape structure and the waterfowl community due to this exercise are unknown. This can be an interesting area to investigate in the future.

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6. Appendices

6.1. Appendix 1: Descriptive Statistics showing summaries of the waterfowl data used in this study

Descriptive Statistics

	N	Range	Minimum	Maximum	Sum	Mean	Std. Deviation	Variance	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Swimmers	204	10128	0	10128	165644	811.98	1341.872	1800620.679	3.429	.170	15.108	.339
Waders_	204	2206	0	2206	90446	443.36	510.818	260934.873	1.631	.170	1.969	.339
Shoreliners	204	1659	0	1659	92795	454.88	320.713	102856.650	1.426	.170	2.262	.339
Others	204	39257	0	39257	822089	4029.85	5967.435	3.561E7	2.895	.170	11.248	.339
ANATIDAE	204	10048	0	10048	161783	793.05	1320.739	1744352.041	3.472	.170	15.554	.339
RECURVIROSTRIDAE	204	1174	0	1174	40457	198.32	231.506	53595.085	1.670	.170	2.475	.339
SCOLOPACIDAE	204	1424	0	1424	53548	262.49	287.309	82546.300	1.918	.170	3.919	.339
LARIDAE	204	39257	0	39257	786096	3853.41	6046.507	3.656E7	2.850	.170	10.864	.339
PODICIPEDIDAE	204	396	0	396	3854	18.89	60.295	3635.545	3.827	.170	15.071	.339
PHALACROCORIDAE	204	3	0	3	7	.03	.304	.092	9.396	.170	89.391	.339
ARDEIDAE	204	1471	0	1471	6379	31.27	158.656	25171.853	7.957	.170	64.970	.339
CICONIIDAE	204	309	0	309	1253	6.14	30.997	960.832	7.915	.170	67.694	.339
THRESKIORNITHIDAE	204	3	0	3	5	.02	.231	.054	11.309	.170	138.676	.339
RALLIDAE	204	17324	0	17324	163897	803.42	2647.020	7006712.333	4.529	.170	21.191	.339
ALCEDINIDAE	204	1	0	1	1	.00	.070	.005	14.283	.170	204.000	.339
GRUIDAE	204	1502	0	1502	32438	159.01	328.319	107793.251	2.327	.170	4.773	.339
HAEMATOPODIDAE	204	2	0	2	3	.01	.156	.024	11.452	.170	137.227	.339
BURHINIDAE	204	867	0	867	9911	48.58	132.453	17543.781	3.708	.170	15.239	.339
GLAREOLIDAE	204	6	0	6	52	.25	.917	.841	4.115	.170	17.567	.339
CHARADRIIDAE	204	838	0	838	39247	192.39	119.891	14373.756	1.896	.170	5.990	.339
STERNIDAE	204	1623	0	1623	35940	176.18	332.913	110830.767	2.307	.170	5.106	.339
Anas platyrhynchos	204	8299	0	8299	86393	423.50	922.474	850958.458	5.924	.170	41.528	.339
Anas clypeata	203	4640	0	4640	61695	303.92	747.039	558067.344	3.478	.171	12.846	.340
Tadorna tadorna	204	291	0	291	4538	22.25	42.522	1808.156	3.027	.170	11.805	.339
Himantopus himantopus	204	923	0	923	29961	146.87	185.861	34544.253	1.752	.170	2.589	.339
Recurvirostra avosetta	204	562	0	562	10496	51.45	79.006	6241.894	3.437	.170	15.901	.339
Grus grus	204	1502	0	1502	32438	159.01	328.319	107793.251	2.327	.170	4.773	.339
Gallinula chloropus	204	555	0	555	18017	88.32	95.832	9183.854	1.988	.170	4.992	.339
Calidris alpina	204	444	0	444	10567	51.80	68.412	4680.142	2.434	.170	7.611	.339
Charadrius alexandrinus	204	454	0	454	21101	103.44	65.509	4291.449	1.634	.170	4.226	.339
Calidris minuta	204	766	0	766	27217	133.42	160.128	25640.855	1.686	.170	2.786	.339
Larus fuscus	204	37900	0	37900	623728	3057.49	5493.515	3.018E7	3.274	.170	14.275	.339
Larus ridibundus	204	6296	0	6296	156727	768.27	1129.378	1275494.917	2.654	.170	8.329	.339
Gelochelidon nilotica	204	1623	0	1623	34672	169.96	326.530	106621.683	2.346	.170	5.241	.339
Valid N (listwise)	203											

6.2. Appendix 2: List of software and their application in this study

Software	Application in study
ArcGIS	File conversion, geodata management
	Map production
	GIS Data manipulation (e.g. Clippng)
	Georeferencing
	DEM classification (using SVWS)
ERDAS IMAGINE	Data display
	RASTER DATA file format conversion (e.g. TIFF to IMG)
	Calculation of NDVI
	Unsupervised classification (using ISODATA algorithym)
	NDVI image reclassification (using Redcode tool)
	Class area calculation
FRAGSTATS	Calculation of landscape metrics (TE and CA)
XLSTATS	Data exploration (descriptive statistics, normality tests)
MS EXCEL	Data exploration (descriptive statistics, normality tests)
	Data visualisation (e.g. Graph plots)
	Data sorting and streamlining
SPSS	Statistical analysis (correlation and significance testing)
	Data exploration (descriptive statistics, normality tests)
	Graph plots

6.3. Appendix 3: All datasets explored in this study

Data	Period	Format	Source	Remarks
Waterfowl census data *	1991 - 2008	Macro MS EXCEL	Fuente de Piedra Nature Reserve Office	Period before 1991 not processed and not consistant
Waterfowl name codes *		MS EXCEL	Fuente de Piedra Nature Reserve Office	Codes used to decode some of the species name which were in code
Limnographic data *	1984 - 2008	MS EXCEL	Fuente de Piedra Nature Reserve Office	Approx 90% complete dataset (some missing values)
Evaporation data				
Water Quality data	200-2008	MS EXCEL	Fuente de Piedra Nature Reserve Office	Incomplte dataset (salinity, Condictivity, pH, DO)
Vegetation Map (Fuente de Piedra lagoon)	2003	Paper map	Fuente de Piedra Nature Reserve Office	Derived from 1998 Orthophoto
Vegetation sample point data	2009	Shapefile (Point)	Primary data (Auther Maviza Sept.2009)	% cover, species compositions (partly processed 97 sample points)
Lagoon landcover field data	2009	Shapefile (Polygon)	Primary data (Auther Maviza Sept.2009)	% cover, species compositions (partly processed)
Imagery				
ASTER	2001 - 2009	RASTER	USGS GloVis & ITC Geodata warehouse	Data time series not continuous (at least one image per year)
Landsat *	1990 - 2009	RASTER	USGS GloVis & ITC Geodata warehouse	Data time series not continuous (at least one image per year)
MODIS NDVI (13Q1)	2000 - 2009	RASTER	USDA FAS MODIS NDVI Data Access	Complete 16day NDVI product data (Raw, unprocessed)
Orthophotos (Malaga, Spain) *	1998	RASTER	Fuente de Piedra Nature Reserve Office	
Orthophotos (Malaga, Spain) *	2005	RASTER	Fuente de Piedra Nature Reserve Office	
Topomap		JPEG	ITC	

Only data marked with * was used in this study