Institute of Landscape and Plant Ecology
University of Hohenheim
Limnology and Landscape Ecology Prof. Dr. Klaus Schmieder (Supervisor)

Development of Assessment Tools for Lake Sevan (Armenia) by the Application of Remote Sensing Data and Geographic Information Systems (GIS) Techniques

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Agyemang Thomas Kwaku
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Examination Committee

Supervisor and Review	Prof. Dr. Klaus Schmieder
Co-Reviewer	Prof. Dr. Joachim Sauerborn
Additional examiner	PD Dr. Horst Tremp
Vice-Dean and Head of the Committee	Prof. Dr. Andreas Fangmeier

DECLARATION

The data collection, analyses, discussions, conclusions and write-up of this PhD dissertation were completed independently and by myself. Other sources of information and resources used are marked and cited.

This thesis was generated out of my own contributions within the ‘Sevan Management Information System (SEMIS)’ project.

Agyemang Thomas Kwaku

Stuttgart, 08/03/2011..

DEDICATION

This research is dedicated to my children Irvine, Perry, Casper, Marina and my wife, Patience.

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SUMMARY

Lake Sevan is the biggest source of water in Armenia. Its littoral zone, in addition to being a food source and a substrate for macrophytes, algae and invertebrates, provide refuge and spawning habitats for both young & old organisms especially fishes. Between 1933 and 1960s, the lake level had been lowered by 20 m below the original level by increasing the lake outflow intermittently for irrigation and electricity generation. This evidently had ecological and economical consequences on the lake ecosystem.

Therefore, this research assessed the Lake's surface area development from 1933 to 2009 by using remote sensing data and GIS techniques. Landsat orthorectified satellite images of Lake Sevan were obtained for the years 1976, 1987-1989, 2001, 2002, 2004-2007 and 2009. From 1933 to 2001, the Surface Area of Lake Sevan generally decreased due to irrigation and electricity generation, resulting in the loss of about 182 km^2 of its surface area. There had been a general increase in the surface area from 2001 to 2009 due to the increase of inflow of the lake through the Arpa-Voratan tunnels (transferring over 200 x 10^6 m^3 of water annually). Hence, a gain of about 23 km^2 of surface area had been obtained by 2009. The lowering of the water-level affected the littoral zone of Lake Sevan and, hence its ecosystem from physical conditions to primary production and fish community. Since the littoral zone of Lake Sevan plays very crucial roles in its ecological functions it is critical that one takes into account its development when one is considering developing sustainable lake management systems. It is in this vein that this project assessed the effects of water level fluctuation on the littoral zone of Lake Sevan from 1976 to 2005. Between 1976 and 2005, the Littoral Zone of Lake Sevan generally increased by 8 % (11 Km^2). This shows that satellite imagery analysed through GIS is good for monitoring long term trends in Lake surface areas and littoral zones because they are routinely available and cost-effective in terms of time and expertise as compared to topographic maps.

The importance of assessing the accuracy of spatial data classifications derived from remote sensing methods and used in geographic information system (GIS) analyses has been regarded as a critical component of many projects. In this project, supervised classified QuickBird satellite imageries of both submersed macrophytes and landcover types (emersed vegetation) of the Gavaraget, Tsovazard and Masrik Regions of the study

area were validated in a GIS environment. The results of these assessments were represented by error matrices presenting the overall accuracy, the user and producer accuracies in each category, as well as the kappa coefficients.

For submersed macrophytes at the vegetation level, the overall accuracy ranging between 77-88% was achieved in all the investigation years. Alga blooms in the different years impacted on the accuracy of the classification. However, even through severe algal blooms user accuracies between 55% and 95% were achieved. On the other hand, at the growth type level, the overall accuracy was as high as over 70% and as low as below 49%.

For emersed vegetation types, predominantly high overall accuracies of more than 70% were obtained in 2 of the investigation years. Above all, in 2008, only slight overall accuracy could be obtained. For reeds areas, high user accuracies of more than 78% could be obtained, while for shrubs, trees, no vegetation and grasses in the different years, very different classification accuracies were attained.

The kappa coefficients for all the regions and areas of interest ranging from 0.16 and 0.72 emphasize that the agreements between the classified remote sensing data and the groundtruth data are not coincidental or by chance. This promotes the fact that high resolution remote sensing data can be reliably applied in recording submersed macrophytes and emersed vegetations.

Landscape metrics, the quantification of the spatial structure of patches, classes of patches, or entire patch mosaics (i.e., landscapes), provide important information about the composition or configuration of a landscape. Therefore, to quantitatively characterize littoral vegetation structures, their diversity and their spatial distribution patterns landscape metrics were calculated. The area metrics gave information about the inter-annual vegetation dynamics in the regions of interest and indicated the basis for change detection during the research period. Generally, submersed macrophytes, increased in 2007 due to increased water transparency. In 2008, the submersed macrophytes decreased drastically due to the strong algal bloom which decreased the water transparency and therefore inhibited the classification possibilities, thereby increasing the no data class astronomically. However, concerning the emersed vegetation, the reeds decreased drastically due to the water level increase during the research period.

The landscape metrics provided an insight on how the artificial water level fluctuations are affecting the lakeshore vegetations, their spatial distributions and structural dynamics. Therefore the results could serve as guidelines of the lake water level manipulations for Lake Sevan authorities as to how fast the water level should be raised. Especially is the die-back of the emersed macrophytes a case for concern. Also, the spatial composition and configuration of landscape elements play a crucial role in the ecological functionality and biological diversity, therefore, their quantification through landscape metrics should be part of any landscape analyses and research work.

Habitat models allow the assessment of the quality of habitat for a species within a study area. Hence, they play crucial role in the sustainable management of the resources in the area under investigation. As such, two habitat suitability models (one for fishes and one for birds) were built in a GIS environment in this project. While the Crucian Carp (*Carassius auratus Gibelio Bloch*) was chosen as lead species for the fish habitat, the Common Coot (*Fulica atra*) and the Great Crested Grebe (*Podiceps cristatus*) were chosen for the bird habitat models based on expert knowledge on Lake Sevan.

Five fish habitat suitability classes were assigned in the model. There was a similar trend in the fish habitat areas in all the landscapes in Gavaraget, Tsovazard and Masrik regions. The habitat areas increased in 2007 and decreased in 2008. The increases in all the regions were the same (around 43%) while the highest reduction occurred in Gavaraget (47%) followed by Masrik (38%) and Tsovazard (25%) respectively. Apart from the reductions in habitat areas in 2008, there were severe decreases in the quality of the habitat areas in all the regions of interests. The increases and decreases were as a result of interannual fluctuations due to water level fluctuations and algal blooms of Lake Sevan.

Also, for the bird habitat model, five classes were assigned. Tsovazard and Masrik had a similar trend in habitat areas with an initial increase in 2007 followed by a decrease in 2008. However, Gavaraget had reductions in 2007 and 2008. Again, in addition to the severe reductions in the habitat areas in 2008, there were severe decreases in the quality of the habitat areas in all the regions of interests. The changes in emersed macrophyte vegetations and the lake water level fluctuations effected the different changes in the bird habitat areas.

Since the Crucian Carp is an economically important fish species in Lake Sevan, a GIS-based analysis of its habitat could play an important role in the decision-making process with regards to measure planning and control. In addition, it can serve as lead species indicator for the evaluation of the health or state of the aquatic macrophytes. The Common Coot and the Great Crested Grebe were found at all the regions of interest of Lake Sevan; therefore, they can be used as lead species indicators for the ecological health of the aquatic emersed macrophytes.

The developed methodologies can be transferred and used in other geographically similar areas. The results produced so far can be used for large public and other organizations, the Internet, local mass media and other communication means to increase awareness creation and support. In addition, monitoring the temporal and spatial dynamics of inland waters is crucial for the understanding of freshwater ecosystems. Remote sensing and GIS offer a good way to get, display, analyse, query and assess such information of physical and biological parameters. Therefore, spatially resolved information in interdisciplinary combination of different methods and scientific views can add to the understanding of the lake ecosystem.

ZUSAMMENFASSUNG

Der Sevansee stellt die größte Süßwasserressource Armeniens. Seine Litoralzone bietet neben Nahrungsressourcen und Substraten für Algen und Invertebraten auch Schutz- und Laichgebiete für juvenile und adulte Tierarten vor allem Fische. Zwischen 1933 und 1960 wurde der Seespiegel zur Bewässerung und Energiegewinnung um fast 20 m abgesenkt, mit drastischen Konsequenzen für das gesamte Seeökosystem.

Innerhalb des vorliegendne Projektes wurde deshalb mittels Fernerkundungs- und GIS-Techniken die Veränderung der Seeoberfläche infolge der Wasserstandsmanipulationen dokumentiert. Hierfür wurden orthorektifizierte Landsat TM-Szenen aus den Jahren 1976, 1987-1989, 2001, 2001, 2004-2007 und 2009 verwendet. Zwischen 1933 und 2001 nahm die Seeoberfläche um 182 km² ab. Zwischen 2001 und 2009 nahm sie aufgrund von Zuleitungen aus dem Arpa-Vorotan-Tunnelsystem (welches jährlich mehr als 200 Mio m³ zuleitet) und Begrenzungen des Abflusses wieder um ca 23 km² zu. Die Seespiegelabsenkung beeinträchtigte die Litoralzone des Sevansees und das entsprechende Ökosystem von den physikalischen Bedingungen bis hin zu Primärproduktion und Fischlebensgemeinschaft. Da die Litoralzone entscheidende ökologische Funktionen für den gesamten See bereitstellt ist es äußerst wichtig deren Entwicklung zu verfolgen, wenn ein nachhaltige Seenmanagementsystem entwickelt werden soll. Entsprechend wurde innerhalb dieser Studie auch die Flächenveränderung der Litoralzone in den letzten Jahrzehnten untersucht. Zwischen 1976 und 2005 nahm die Litoralzone um 8 % (11km²) zu. Die Ergebnisse unterstreichen die Eignung der GIS-Verarbeitung von Satellitendaten zum Monitoring Seeoberflächenveränderungen und Flächenveränderung der Litoralzone, da seit den 1970er Jahren kontinuierlich bis heute Satellitendaten hoher Qualität erhältlich sind, während topographische Karten zu verschiedenen Zeitpunkten in vielen Ländern nicht verfügbar sind.

Die Validierung der Klassifikationsgüte ist ein zentraler Bestandteil in Fernerkundungsprojekten. Innerhalb des vorliegenden Projektes wurden mittels überwachter Klassifikation von Quickbird Satellitenbildern ermittelte Bedeckungen von submersen und emersen Vegetationsstrukturen in den Untersuchungsgebieten Gavaraget, Tsovazard und Masrik der Litoralzone des Sevansees in einer GIS-Umgebung validiert. Die Ergebnisse wruden in einer Fehlermatrix präsentiert, welche Werte zur

Gesamtgenauigkeit sowie zur Nutzer- und Erzeugergenauigkeit sowie Kappa-Koeffizienten zur Beurteilung der Zufallswahrscheinlichkeit des Ergebnisses beinhaltet.
Die für submerse Makrophyten für die verschiedenen Untersuchungsjahre ermittelten Gesamtgenauigkeit liegen mit 77-88% auf einem hohen Güteniveau. Algenblüten führten in einzelnen Jahren in bestimmten Gebieten zu Beeinträchtigungen der Klassifikationsgüte. Noch stärker durch Algenblüten beeinträchtigt wurde die Klassifikationsgüte in einzelnen Jahren auf dem Niveau der Wuchstypen, wo die Gesamtgenauigkeiten zwischen 55% und 95% lagen. Auf Artniveau wurden hingegen teilweise recht hohe Gesamtgenauigkeiten von über 70% erzielt, aber auch niedrige von unter 49%.

Für emerse Vegetationstypen wurden ebenfalls überwiegend hohe Gesamtgenauigkeiten von über 70% erzielt, wobei in den 2 Untersuchungsjahren die Werte allerdings stark schwanken. Vor allem im Jahr 2008 konnten in den meisten Untersuchungsgebieten nur geringe Gesamtgenauigkeiten erzielt werden. Vor allem für Schilfbestände Flächen konnten hohe Nutzergenauigkeiten von über 78% erzielt werden, während für Büsche, Bäume, unbewachsene Flächen und Grasland in den verschiedenen Jahren sehr unterschiedliche Klassifikationsgüten erreicht wurden.

Die ermittelten Kappa-Koeffizenten schwanken zwischen 0.16 und 0.72 sehr stark, wobei überwiegend Werte über 0.6 erzielt wurden, .d.h. die Übereinstimmungen zwischen Klassifikationsergebnis und Felddaten sind nicht zufällig. Folglich können hochaufgelöste Fernerkundungsdaten verlässlich zur Kartierung von submersen und emersen Vegetationsstrukturen eingesetzt werden.

Landschaftsmaße bieten wichtige Informationen zur Zusammensetzung und räumlichen Verteilung von Landschaftsstrukturen. Deshalb wurden Landschaftsmaße zur Charakterisierung von Vegetationsstrukturen der Litoralzone, ihrer Vielfalt und ihrer räumlichen Verteilung berechnet.

Flächenmaße ergeben Informationen über die interannuelle Vegetationsdynamik in den verschiedenen Untersuchungsgebieten und stellen die Basis für die von Veränderungen über die Untersuchungsjahre. Generell kann ein Trend zur Zunahme der submersen Vegetationsstrukturen von 2006 nach 2007 festgestellt werden, der unabhängig von der

Erhöhung des Wasserspiegels vor allem auf die hohe Wassertransparenz infolge der ausgebliebenen Algenblüte zurückgeführt werden kann. Im Gegensatz dazu nahmen die submersen Vegetationsflächen in 2008 überall stark ab, wobei dies einerseits direkt auf die Beschattung durch Algen zurückgeführt werden kann, andererseits auch eine Folge der eingeschränkten Klassifikationsmöglichkeiten infolge der durch die Algenblüte stark reduzierten Wassertransparenz ist, die zu einer starken Zunahme der nodata Klasse führte. Bei den emersen Vegetationsstrukturen ist über die drei Untersuchungsjahre vor allem der starke Rückgang der Schilfröhrichte infolge des Wasserspiegelanstiegs auffallend.

Die berechneten Landschaftsmaße ergeben einen Einblick in den Einfluss von Wasserstands- und Wassertransparenzschwankungen auf die räumliche Verteilung und die strukturelle Dynamik der Vegetationsstrukturen der Uferzone des Sevansees. Die Ergebnisse können als Leitlinie für die zuständigen Behörden des Sevansees dienen, welche die Geschwindigkeit des Wasserspiegelanstieges steuern. Die räumliche Zusammensetzung der Vegetationsstrukturen bildet die Basis für ihre ökologische Funktionsfähigkeit und ihre biologische Vielfalt. Insofern ist die Quantifizierung durch Landschaftsmaße ein essenzieller Bestandteil jeglicher Landschaftsanalyse.

Habitatmodelle ermöglichen die Beurteilung der Habitateignung für eine bestimmte Tierart innerhalb eines Untersuchungsgebietes. Zwei Habitatmodelle, eines für Fische und eines für Wasservögel, wurden innerhalb des Projektes in einer GIS Umgebung entwickelt. Während die Karausche (*Carassius auratus Gibelio Bloch*) als Leitart für Fischhabitate gewählt wurde, wurden die Bläßralle (*Fulica atra*) und der Haubentaucher (*Podiceps cristatus*) für die Vogelhabitatmodelle gewählt, basierend auf Expertenwissen lokaler Experten am Sevansee.

Für die Beurteilung der Flachwasserzone als Fischhabitat wurden innerhalb des Modells 5 Eignungsklassen berechnet. In allen Untersuchungsgebieten ergab sich über die Untersuchungsjahre ein ähnlicher Trend. Die Habitatflächen stiegen von 2006 nach 2007 stark an und reduzierten sich wieder nach 2008. Während die Habitatzuwächse 2007 in allen Untersuchungsgebieten in etwa gleich bei ca. 43% lagen, waren die Verluste jeweils recht unterschiedlich, in Gavaraget bei 47%, in Masrik bei 38% und in Tsovasard bei 25%. Unabhängig von den Flächenverlusten der Habitate nahm auch die Habitatqualität stark ab.

Die Schwankungen können sowohl auf den Rückgang der Makrophyten, als auch auf den Anstieg des Wasserspiegels zurückgeführt werden.

Auch für die Vogelhabitatmodelle wurden fünf Eignungsklassen gebildet. Für die Untersuchungsgebiete Tsovasard und Masrik ergaben sich zeitlich ähnliche Trends mit Habitatflächenzunahmen zwischen 2006 und 2007 und Abnahmen zwischen 2007 und 2008, wobei die Ausmaße in beiden Untersuchungsgebieten sehr unterschiedlich waren. In Gavaraget ergab sich jedoch eine stetiger Abnahme der Habitatflächen über die Untersuchungsjahre. Wie auch bei den Fischhabitaten ergab sich für 2008 auch eine starke Abnahme der Habitatqualität.

Da die ökonomische Bedeutung der Karausche für den Sevansee sehr hoch ist, leistet die GIS basierte Habitateignungsanalyse eine wichtigen Beitrag zur Entscheidungsunterstützung bei Maßnahmenplanungen und Erfolgskontrolle. Zusätzlich kann die Karausche auch als Indikator für die ökologische Funktionsfähigkeit der submersen Makrophytenstrukturen dienen. Auch die in allen Untersuchungsgebieten vorkommenden Bläßrallen und Haubentaucher können als Leitarten für die Funktionsfähigkeit der emersen Vegetationsstrukturen dienen.

Die entwickelten Methoden können auf geographisch ähnliche Gebiete übertragen werden.Sie können für die Kommunikation von Entwicklungszielen zur Bewusstseinsbildung der Öffentlichkeit eingesetzt werden. Die Überwachung der zeitlichen und räumlichen Dynamik von Binnengewässern essenziell für das Verständnis von Süßwasserökosystemen. Fernerkundung und GIS bieten gute Mittel zur Erfassung Analyse, Abfrage, Darstellung und Beurteilung physischer und biologischer Parameter. Räumlich aufgelöste Informationen aus der interdisziplinären Kombination verschiedener Methoden können zum Verständnis von Seeökosystemen beitragen.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Importance of Lake Sevan

Lake Sevan is the largest water body in the Transcaucasus Regions as well as the single biggest source of water in Armenia. It is a very important source of drinking water for Armenia and its adjoining countries (Markosyan and Nazaryan, 2003).

The Sevan basin has a unique and relatively abundant flora and fauna. According to Barseghyan (1990), the watershed is known to contain over 1,500 species of flower– and seed-producing plants, and more than 250 species of spore-producing plants such as mosses and lichens. Additionally, a large number of endemic (local varieties specific to the Sevan Basin) and relict (representatives of old disappearing flora) species can be found in the watershed. Many of these endemic and endangered plants have highly restricted areas of coverage and are sensitive to changes in environmental conditions.

The importance of Lake Sevan in the economy of Armenia can scarcely be exaggerated: it is the main source of irrigation water and provides cheap electricity, fish, recreation, and tourism. Lake Sevan and the wetlands of the basin are significant breeding, resting, foraging and wintering area for migratory waterfowl and other birds. It is difficult to overestimate the role of Lake Sevan and its basin for Armenia. The main economic activities in the basin are agriculture and fisheries. Approximately 20% of the livestock in the country is raised in the basin. About 90% of fish catch and 80% of crayfish catch of Armenia is from Lake Sevan (Jenderedjian et al., 2005). LakeNet (2005) refers to Lake Sevan as a source of recreation, tourism, and irrigation for the agriculture sector that accounts for 33% of Armenia's GDP. It was further stated that 80% of the nation's valued crops are supported by irrigation. Furthermore, hydropower provides 8% of total energy production in the country.

Compared to its other uses, the aesthetic values of Lake Sevan are the most difficult to quantify, although they are extremely important. These properties create one of the most spectacular and pleasing features of landscape on the earth. These aesthetic features bring out a pleasing range of emotional, spiritual and intellectual responses in humans.

Lake Sevan also plays a significant role in history of Armenians, with several villages and towns often arising on or near the lake shores. Specific lifestyles have developed in some locations based entirely on lakes and their resources; an example being the making of several artefacts of the lake. The ability of Lake Sevan to store large quantities of water helps protect the lives and property of downstream communities during rainy or spring seasons. At the same time, its water level may rise significantly, thereby affecting people living along the shoreline. It can also moderate the local climate by reducing the range of atmospheric temperature fluctuations in the atmosphere through the absorption of large quantity of heat with its large water volumes. Some villages and towns use the lake as a waste or sewage disposal.

1.2 The Sevan Problem

In 1933, the outflow of Lake Sevan was increased for irrigation and electricity generation with a 40m-deep channel excavation in river Hrazdan's bed. Starting from 1949, the level of the lake began dropping at a rate exceeding 1 m per year till the early 1960s. To stabilize the lake water level, two river tunnels (Figure 1) were completed in 1981 (Arpa - 48.3 km) and 2004 (Vorotan -22 km) to redirect up to 250 million m^3 and 165 million m^3 water respectively into Lake Sevan each year (Chilingaryan et al., 2002; Jenderedjian et al., 2005). Around 19 m below its original level, the lake level drawdown was stopped. At this point, there had been a reduction of the total lake surface area by 12 %, the average depth by 34.2 % as well as the lake volume by 42.2 %. The recently adopted Sevan rehabilitation program envisions raising the total level of the lake by 6 meters within 30 years (Deheryan, 2005). Therefore, the lake level has been raised more than 1.2m between 2003 and 2006 (Garibyan, 2007) submerging a lot of shore vegetation under water as shown Figure 2.

Figure 1: Artificial Vorotan-Arpa hydro-structure transferring water into Lake Sevan

Figure 2: Section of artificial forest submerged by rising waters of Lake Sevan

The lowering of the water-level drastically affected the littoral zone (and especially macrophytes) of Lake Sevan and, hence also affecting its ecosystem from physical conditions to primary production and fish community. Macrophytes in the littoral zone, in addition to being a food source and a substrate for algae and invertebrates, provide a refuge habitat for young fishes, lowering their predation rates, as well as providing feeding and spawning habitat for older age classes of some species and other organisms (Northcote and Atagi, 1997; Kalff, 2002).

1.3 Research Objectives

This research was generated out of my own contributions within the 'Sevan Management Information System (SEMIS)' project which sought to develop measures for a sustainable shore management of Lake Sevan.

This research focuses on the fact that shore macrophyte vegetation has changed immensely due to the direct loss of littoral area by the lowering of the lake level, the consequential increase of shore erosion and the unstable growing conditions due to the water level fluctuations. Therefore, many important functions of the lake ecosystem (including the direct retention of nutrients and toxic substances during the growth period as well as the formation of biotic structures for biofilms for epiphytic algae and macroinvertebrates; and for providing measures for protection and redevelopment of juvenile fishes) had been severely affected.

Hence, the changes between 2006 and 2008 in the aquatic macrophyte vegetation will be used as biological indicators in order to develop measures to manage the lake ecosystem more sustainably. Therefore, the objectives of this project are:

1. To review the relevant literature about the topic under discussion
2. To review the historical development of Lake Sevan's surface area from 1933 to 2009 using remote sensing and GIS tools
3. To apply remote sensing and GIS techniques in assessing the effects of Lake Sevan's water level fluctuations on its littoral zone
4. To assess the accuracy of supervised classifications of QuickBird Satellite imageries of aquatic macrophytes of Lake Sevan
5. To apply landscape metrics to the shore vegetation for the monitoring of changes during the investigation period 2006-2008 evaluation of specific ecosystem functions
6. To develop habitat models for fishes and birds monitoring of changes during the investigation period 2006-2008 so as to protect these highly suitable areas for the sustainable development of these organisms.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Aquatic Macrophytes

2.1.1 Definition

Aquatic plants are described as those whose parts involved in photosynthesis are submersed or float on the water surface either permanently or at least for several months each year (Federal Office for the Environment (FOEN), 2005).Alwadie (2008) quoting Arber (1963), Sculthorpe (1967) and Cook (1974) defined an aquatic plant as one that is normally found growing in association with standing water whose level is at or above the surface of the soil. Standing water includes ponds, shallow lakes, marshes, ditches, reservoirs, swamps, bogs, canals, and sewage lagoons. Aquatic plants, though less frequently, also occur in flowing water, in streams, rivers, and springs.

Federal Office for the Environment [FOEN] (2005) referred to macrophytes as the conspicuous plants that dominate wetlands, shallow lakes, and streams. Kalff (2002) further explained that the term "aquatic macrophytes" refers to aquatic plants large enough to be visible to the naked eye. These include the aquatic angiosperms (flowering plants), pteridophytes (ferns), charophytes and bryophytes (mosses, hornworts, and liverworts). The macrophytes are often the principal primary producers not only in the littoral zone of lakes but also in shallow rivers, and they dominate wetlands.

2.1.2 Classification

Wetzel (1983) referencing Arber (1920) and Sculthorpe (1967) stated that aquatic macrophytes could be grouped into four general categories based on attachment. These are submersed, emersed, floating-leaved (all three attached to the substratum) and freely floating macrophytes. These categories are normally found in confined areas of the littoral zone (Ramey, 2006) as shown in Figure 3.

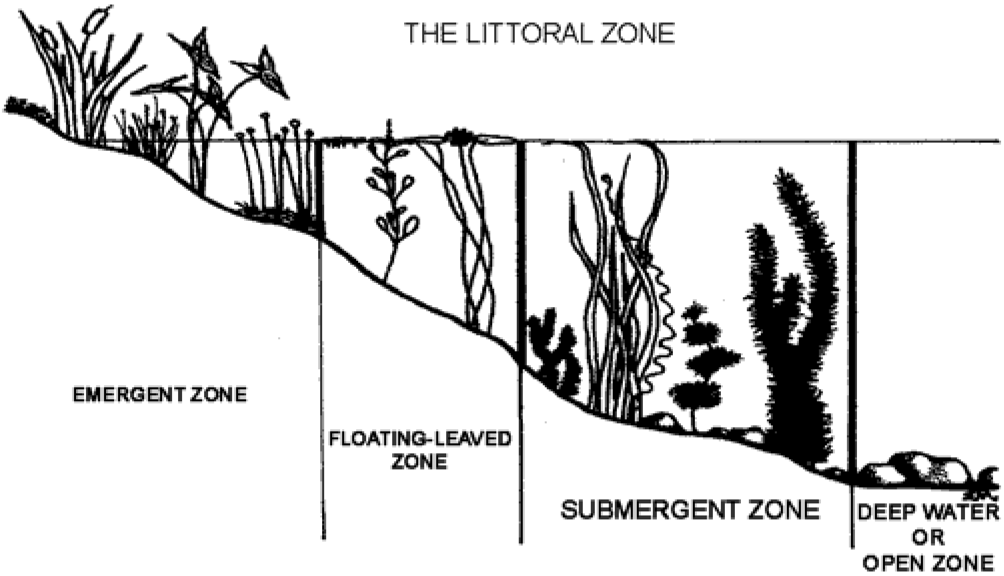


Figure 3: Distribution of Aquatic Macrophytes in the Littoral Zone

Source: (Maine Volunteer Lake Monitoring Program [VLMP], 2009)

Submersed plants grow entirely or almost entirely underwater. Some submersed species produce flowers which are pollinated underwater or at the water surface (e.g. *Zostera noltii*) while other species have branches and leaves that reach and spread across the water just below the surface (e.g. *Potamogeton pectinatus*) as shown in Figure 4 below. Some produce flowers that float on the surface (e.g. *Nymphaea alba*) while others have flower stalks that emerge up to six inches above the water (e.g. *Myriophyllum spicatum*) (Ramey, 2006). Submersed macrophytes occur at all depths within the photic zone, but the vascular angiosperms occur only to about 10 m. They have highly variable leaf morphology ranging from finely divided to broad leaves. Their reproductive organs are aerial, floating or submersed (Wetzel, 1983).

		
Myriophyllum spicatum	*Potamogeton pectinatus*	*Ceratophyllum demersum*

Figure 4: Examples of Submersed Aquatic Macrophytes
Source: (Kristinsson, 1999; Murray et al., 2006)

Emersed aquatic plants are those rooted in the sediments and protrude up above the water's surface. Thus, emersed plants grow out of the water (or during low-water times, in exposed sediments). They are rooted to the bottom, but their stems, leaves and flowers are above the water. Some emersed plants have no particular stems - just leaves reaching for the skies (e.g. *Typha* spp.) while others are very large-leaved, with big spikes of flowers (e.g. *Sagittaria sagittifolia*) as seen in Figure 5. Some are small plants which grow inches above the water (e.g. *Bacopa* spp.) whiles others are tall and leafy e.g. *Hygrophila* spp. (Ramey, 2006). Wetzel (1983) added that these plants occur on water-saturated or submersed soils, from the point at which the water table is about 0.5 m below the soil surface to where the sediment is covered with approximately 1.5 m of water. Their reproductive organs are aerial.

		
Typha angustifolia	*Schoenoplectus tabernaemontani*	*Sagittaria sagittifolia*

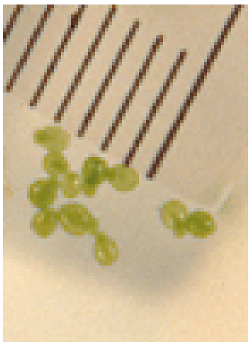
Figure 5: Samples of Emersed Aquatic Macrophytes
Source of *Sagittaria* spp.: (Wikipedia, 2010)

Floating-leaved macrophytes are primarily angiosperms that are anchored to submersed sediments at water depths from about 0.5 to 3 m, but have all their leaves floating on the water's surface as shown in Figure 6. Their reproductive organs are floating or aerial. The floating leaves are either on long, flexible petioles (e.g. the water lilies *Nuphar* and *Nymphaea*) or on short petioles from long ascending stems (e.g. *Brasenia*, *Potamogeton natans*) (Wetzel, 1983; Ramey, 2006).

Nymphaea alba	*Persicaria amphibia*

Figure 6: Floating-leaved Aquatic Macrophyte Samples
Source: (Murray et al., 2006)

Free-floating macrophytes are those that are typically not rooted to the substratum, but live unattached within or upon the water (Figure 7). These plants occur in diverse forms and habits ranging from large plants with rosettes of aerial and / or floating leaves and well developed submersed roots (e.g. *Eichornia*, *Trapa*), to minute face-floating or submersed plants with few or no roots (e.g. *Lemnaceae*, *Salvinia*). Their reproductive organs are floating or aerial (e.g. aquatic *Utricularia*) but rarely submersed (e.g. *Ceratophyllum*) (Wetzel, 1983).



Wolffia arrhiza	*Lemna minor*	*Spirodela polyrhiza*

Figure 7: Examples of Floating Aquatic Macrophytes
Source: (Murray et al., 2006)

2.1.3 Ecological and Environmental Roles of Macrophytes

Macrophytes perform many functions in water bodies. Some of the most common are described below.

Macrophytes provide food (i.e. seeds, leaves) for fishes and other wildlife. Furthermore, they trap particles and associated nutrients, the plants and sediments forming an important substrate for bacteria and periphyton. In addition, macrophytes serve as habitat for substrate-associated invertebrates (zoobenthos) feeding on periphyton, detritus and associated mircroorganisms, and their zoobenthic predators. They also provide a day time refuge for pelagic zooplankton in shallow lakes. Moreover, they provide a habitat for feeding, breeding and hiding of littoral fish and for pelagic or riverine fish species feeding in shallow water. Finally, the macrophyte-dominated littoral zone serves as a habitat for water-fowl, songbirds, amphibias, reptiles and mammals (Bloesch, 2003; Schmieder, 2004; Federal Office for the Environment [FOEN], 2005).

Furthermore, macrophytes stabilise shorelines and sediments, and therefore can reduce shoreline erosion through their dampening effect on wave energy. They can also reduce water levels through increase in evapo-transpirational water losses (Wetzel, 1983; Schmieder, 2004).

Macrophytes are important suppliers of organic matter to inland waters, and their decomposition can have a major effect on dissolved oxygen concentrations depending on its abundance, the availability of light, and time of day. Again, their decomposition greatly affects the cycling of nutrients and contaminants which in turn affects water clarity. Decaying material produced by macrophytes accumulate in the sediments over many years playing an influential role in making a water body shallower. Additionally, debris from these plants contribute to the formation of peat deposits, particularly as the lake becomes shallower over time and aquatic plants grow more abundantly (Wetzel, 2001; Kalff, 2002; Schmieder, 2004; Federal Office for the Environment [FOEN], 2005).

Uprooted plants can form floating islands called tussocks that can be significant navigational hazards and block access to parts of the waterbody. It should be noted that, tussocks also provide bird and wildlife habitat. In waterbodies where canopy-forming macrophytes e.g. water hyacinth or water lettuce, grow extremely well, these plants may completely cover the water body's surface and cause major habitat, recreational (swimming), navigational, fishing and flood control problems. Furthermore, such plants reduce the underwater light climate, negatively affecting submersed phytoplankton. Some macrophytes (e.g. water lettuce) provide habitat for certain species of mosquitoes which in turn cause a lot of human health-related problems (Wetzel, 2001; Kalff, 2002; Federal Office for the Environment [FOEN], 2005).

2.2 Biological Indicators (Bioindicators)

2.2.1 What are Bioindicators?

Organisms living in an ecosystem reflect the sum of the environmental factors acting on the system such that plants, animals and microorganisms adapt to the conditions prevailing at a particular site. The biological community is affected by any changes in these local factors, influencing either the species composition (presence or absence of certain species) or specific characteristics such as population density/structure, life cycles, growth habit or biological functions. Organisms whose biological functions are closely correlated with specific environmental factors are known as bioindicators. Such species integrate a wide range of factors and reveal effects that can scarcely, if at all, be recorded using conventional methods of measurement. In particular, they provide direct evidence of biological effects. They may indicate not only chemical aspects of water quality but also structural features of waterbodies - and thus habitat quality. In addition, bioindicators reflect the sum of effects over a certain period, providing information on adverse impacts occurring prior to the investigation (Kramer and Botterweg, 1993; Federal Office for the Environment [FOEN], 2005). Kohler and Schneider (2003) referring to Arndt et al. (1996) defined bioindicators as ‘organisms or communities of organisms, which react to environmental influences by alterations of their life functions and/or by their chemical composition. Thereby it is possible to draw conclusions concerning their environmental conditions.’

After much careful study, environmental scientists have determined that the presence, condition, and numbers of the types of fish, insects, algae, and plants can provide accurate information about the health of a specific river, stream, lake, wetland, or estuary. These types of plants and animals are called biological indicators. These species are selected for their sensitivity or tolerance (more frequently sensitivity) to various kinds of pollution or its effects, e.g. metal pollution or oxygen depletion (Thomas et al., 1992; United States Environmental Protection Agency (US EPA), 2005).

According to Markert et al. (2003), bioindicators contain information on the quality of the environment (or a part of the environment). Furthermore, Kaiser (2001) making references to (Blandin, 1986) and (Landres et al., 1988), stated that bioindicators enable the characterisation of the state of an ecosystem or an ecocomplex and an indication as early as possible of their natural or provoked modifications (mainly with reference to biochemical, cytological, physiological, ethnological or ecological variables, practically and with certainty). Kaiser (2001) continued that these bioindicators have characteristics which reveal the presence or absence of environmental conditions that cannot be revealed in other species or in the environment as a whole. These characteristics or changes serve to evaluate the level of environmental contamination and the consequences for the state of health of other organisms or the environment as a whole.

On the other hand, biomarkers are measurable biological parameters at the sub-organismic (genetic, enzymatic, physiological, morphological) level in which structural or functional changes indicate environmental influences in general and the action of pollutants in particular in qualitative and sometimes also in quantitative terms. Examples: tanning of human skin caused by UV radiation; changes in the morphological, histological or ultra-structure of organisms or monitor organs (e.g. liver, thymus, testicles) following exposure to pollutants (Markert et al., 2003). Also, Kaiser (2001) defined a biomarker as an indicator organism whose change can be observed or measured at the molecular, biochemical, cellular, physiological or behavioural level of an individual representing a larger group or population. They also reveal the present or past exposure of the individual to at least one pollutant chemical substance. Biomarkers are indicators of biological evaluation that provide information on the state of health of individuals, whereas bioindicator species account for the quality of the eco-environment.

2.2.2 Types of Bioindicators

According to United States Environmental Protection Agency [US EPA] (2005), an indicator is a sign or signal that relays a complex message, potentially from numerous sources, in a simplified and useful manner. It further explained that an ecological indicator is a measure or an index of measures, or a model that characterises an ecosystem or one of its critical components. An indicator may reflect biological, chemical or physical attributes of ecological condition. The primary uses of an indicator are to characterize current status and to track or predict significant change. With a foundation of diagnostic research, an ecological indicator may also be used to identify major ecosystem stress.

Cairns et al. (1993) outlined three types of indicators namely:

1. **Compliance indicators** designed to verify whether the objectives of maintenance and / or restoration of the quality of a site have been met.
2. **Diagnostic indicators** designed to facilitate investigation of the cause of the disturbances observed.
3. **Early warning indicators** designed to reveal the first signs of disturbances or allow for management actions to be implemented before conditions have deteriorated to the point where compliance indicators are affected.

On the other hand, Kohler and Schneider (2003) making reference to Arndt et al. (1987) and Kohler (1982) stated that bioindicators (including aquatic macrophytes) can be used in three ways for the assessment of environmental factors and environmental impacts. These are:

a. **Indicators**: These plants (individual species, groups of species or communities) are used to provide information on the status of an ecosystem.
b. **Monitors**: These plants allow for qualitative and quantitative assessment of toxic effect in an environment. Reaction indicators show an impact by visible symptoms and/or by other physiological reactions (e.g. activity of photosynthesis, respiration). Accumulation indicators accumulate toxic substances from the environment: passive monitors are collected from their natural habitat while active monitors are placed in the respective environment under investigation.
c. **Test species**: These are used under controlled environmental conditions in the laboratory to indicate the influence of toxic substances.

2.2.3 Selection of Indicators

Federal Office for the Environment [FOEN] (2005) stated that in order to be able to choose good indicators, what has to be indicated is taken into consideration. It was explained that almost any species can be an indicator of something but since one’s knowledge of the autecology of the majority of species is minimal and, even were that not the case, one’s resources are limited, and hence one must therefore select those organisms which are potentially most useful for the particular problem in hand. It further recommended that if organisms are to serve as bioindicators, the following conditions need to be fulfilled:

A. Our knowledge of how the organism responds to specific environmental factors should be as detailed as possible.
B. The response should be clear, quantifiable and readily evaluable.
C. Use of the bioindicator should be standardizable, easily managed and financially acceptable.
D. Minimum intervention in the environment should be required, and use of the indicator species should not pose ethical problems.

Additionally, Hellawell (1989) stated that, in selecting indicators for environmental protection, the following attributes may be particularly desirable. Ideal indicators should, of course, unambiguously indicate by their presence very narrowly defined environmental parameters. This ideal is rarely realised, but good environmental indicators

a) are *readily identified* – taxonomic uncertainties can confuse data interpretation;
b) may be *sampled easily*, that is, without the need for several operators or expensive equipment, and *quantitatively*;
c) have *cosmopolitan distribution* – the absence of species with very narrow ecological requirements and limited distribution may not be associated with pollution, etc.;
d) are associated with *abundant autecological data* – this is of considerable assistance in analysing survey results and devising pollution, or biotic, indices;
e) have *economic importance as a resource or nuisance or pest*: species which are economically important (fish) or are nuisances (some algae) have intrinsic interest;
f) *readily accumulate pollutants*, especially so as to reflect environmental levels since this facilitates understanding of their distribution in relation to pollutant levels;
g) are *easily cultured in the laboratory*, which also assists in relating experimental studies of their responses to pollutants and fields observations;
h) have *low variability*, both genetic and in their role (niche) in the biological community.

Groups of organisms often used as bioindicators for watercourse systems include: fish, diatoms, benthic macroinvertebrates (bottom-dwelling animals) and aquatic macrophytes. In ecotoxicology, individual cells and multicellular organisms are used as bioindicators in the first and second steps respectively in standardized test systems (Hellawell, 1989).

2.2.4 Use of Bioindicators

A variety of effects can be produced on aquatic organisms by the presence of harmful substances or natural substances in excess, the changes in the aquatic environment that result from them, or by physical alteration of the habitat. With reference to Thomas et al. (1992), some of the most common effects on aquatic organisms are:

a) changes in the species composition of aquatic communities,
b) changes in the dominant groups of organisms in a habitat,
c) impoverishment of species,
d) high mortality of sensitive life stages, e.g. eggs, larvae,
e) mortality in the whole population,
f) changes in behaviour of the organisms,
g) changes in physiological metabolism, and
h) histological changes and morphological deformities.

It was further explained that, as all of these effects are produced by a change in the quality of the aquatic environment, they can be incorporated into biological methods of monitoring and assessment to provide information on a diverse range of water quality issues and problems, such as:

1. the general effects of anthropogenic activities on ecosystems,
2. the presence and effects of common pollution issues (e.g. eutrophication, toxic metals, toxic organic chemicals, industrial inputs),
3. the common features of deleterious changes in aquatic communities,
4. pollutant transformations in the water and in the organisms,
5. the long-term effects of substances in water bodies (e.g. bioaccumulation and biomagnification),
6. the conditions resulting from waste disposal and of the character and dispersion of wastewaters,
7. the dispersion of atmospheric pollution (e.g. acidification arising from wet and dry deposition of acid-forming compounds),
8. the effects of hydrological control regimes, e.g. impoundment,
9. the effectiveness of environmental protection measures, and
10. the toxicity of substances under controlled, defined, laboratory conditions, i.e. acute or chronic toxicity, genotoxicity or mutagenicity.

Again, Thomas et al. (1992) added that bioindicators can also be useful for:

a) providing systematic information on water quality (as indicated by aquatic communities),
b) managing fishery resources,
c) defining clean waters by means of biological standards or standardised methods,
d) providing an early warning mechanism, e.g. for detection of accidental pollution, and
e) assessing water quality with respect to ecological, economic and political implications.

2.2.5 Advantages of Bioindication

Bioindication is often able to clearly determine if a water body has healthy aquatic life. It can also help to determine the extent of ecological damage. Some kinds of damage may be clearly visible, such as an unusual colour in the water, increased turbidity or the presence of dead fish. However, many forms of damage cannot be seen or detected without detailed examination of the aquatic biota.

Aquatic organisms integrate effects on their specific environment throughout their lifetime (or in the case of laboratory tests, during the period of exposure used in the test). Therefore, they can reflect earlier situations when conditions may have been worse. This enables the biologist to give an assessment of the past state of the environment as well as the present state. The length of past time that can be assessed depends on the lifetime of the organisms living in the water under investigation. Micro-organisms, such as ciliated protozoa, periphytic algae or bacteria, reflect the water quality of only one or two weeks prior to their sampling and analysis, whereas insect larvae, worms, snails, and other macroinvertebrate organisms reflect more than a month, and possibly several years (Thomas et al., 1992).

When biological methods are carried out by trained personnel they can be very quick and cheap, and integrated into other studies. Compared with physico-chemical analysis, much less equipment is necessary and a large area can be surveyed very intensively in a short time, resulting in a large amount of information suitable for later assessment. Recent developments in water quality assessment, especially for the purpose of effluent control, have begun to include bioindicators and tests such as bioassays (as in Germany under the "Waste Water Levy Act"). The costs of chemical analytical equipment, trained personnel and materials, repairs and energy consumption are enormous due to the number of different polluting substances that now have to be legislated and controlled. In some situations biological methods can offer a cheaper option. The advantages of bioindication, however, do not eliminate the need for chemical analysis of water samples. Agencies and individuals responsible for establishing assessment programmes must integrate both methods to provide a system which is not too expensive and which provides the necessary information with maximum efficiency (Thomas et al., 1992).

Bioindication helps provide an ecologically based assessment of the status of a water body and helps prioritize water bodies for proper management based on the severity of biological damage. It can directly measure the combined impacts of any and all stressors on the resident aquatic biota and can be used to determine the effectiveness of permit controls. The biological data so obtained are essential for successful aquatic life use attainability analyses and site-specific criteria derivations. Also, the public views the status of biological organisms as a measure of a pollution-free environment (United States Environmental Protection Agency (US EPA), 2002).

Acute toxicity testing is particularly useful in cases of emergency and accidental pollution where it can minimise the amount of chemical analysis required. When investigating a fish-kill, samples of the water are usually taken for analysis in order to determine the cause. However, if a toxicity test (using an aquatic organism in samples of the contaminated water) is conducted immediately in parallel to the chemical analyses it is possible to ascertain whether toxic concentrations are present in one, or all, of the samples taken. This initial “screening” enables the chemical laboratory to focus their efforts on the most toxic water samples and helps the water quality managers and decision-makers prepare (or stop) further action. Immediate remedial action may, therefore, be possible although the reaction of the biota in the test does not necessarily give specific information about the type of substance causing the toxicity, or an indication of the concentration present (Thomas et al., 1992).

2.3 Remote Sensing

2.3.1 What is Remote Sensing?

"Remote sensing is the technique (and to some extent, art) of acquiring information about the Earth's surface without actually being in contact with it. This is done by sensing and recording reflected or emitted energy and processing, analyzing, and applying that information" (Canada Centre for Remote Sensing [CCRS], 2007).

According to Aronoff (2005), remote sensing is ‘the science, technology, and art of obtaining information about objects from a distance – takes us well beyond the limits of human capabilities. It allows us to collect information over regions too costly, too dangerous, or too remote for human observers to directly access. Remotely sensed data takes many forms, including aerial photography, digital satellite imagery, and radar’.

Generally, Remote Sensing involves the process of recording/observing/perceiving (sensing) objects or events at far away (remote) places, where the sensors are not in direct contact with the objects or events being observed. The electromagnetic radiation is normally used as a physical carrier or medium through which information travels from the objects/events to the sensors in remote sensing. The output of a remote sensing system is usually an image representing the scene being observed. A further step of image analysis and interpretation is required in order to extract useful information from the image. The human visual system is an example of a remote sensing system in this general sense. In a more restricted sense, remote sensing usually refers to the technology of acquiring information about the earth's surface (land and ocean) and atmosphere using sensors onboard airborne (aircraft, balloons) or spaceborne (satellites, space shuttles) platforms (Centre for Remote Imaging Sensing and Processing [CRISP], 2001).

2.3.2 Remote Sensing Applications

Satellite imagery is able to cover large regions in a short period of time. Since the 1970s, a lot of Satellite data have been archived by different data providers which serve as sources of powerful potential historical data. Furthermore, the spatial and spectral qualities have been improving since the 1970s.

The applications of remote sensing described here are representative, but not exhaustive. There are a number of other applications that are practiced but are very specialized in nature, and not covered here (Canada Centre for Remote Sensing (CCRS), 2007; Short, 2009). The various applications include:

- Agriculture (crop type mapping, crop monitoring, crop damage assessment)
- Forestry & Ecology (clear cut mapping, species identification, burn mapping, environmental monitoring, wildlife habitat)

- Geology (structural mapping, geologic units, minerals & petroleum exploration)
- Hydrology (flood delineation, soil moisture)
- Sea Ice (type & concentration, ice motion)
- Land Cover (rural / urban change, biomass mapping)
- Mapping (planimetry, DEMs, topo mapping)
- Oceanography (ocean features, ocean colour, oil spill detection)
- Meteorology (storm / Hurricane / tornado detection and monitoring, real-time surveillance of clouds, temperature variations, water vapour, and moving fronts)

2.4 Geographic Information Systems (GIS)

2.4.1 What is GIS?

Chang (2008) defined geographic information system (GIS) as ‘a computer system for capturing, storing, querying, analyzing, and displaying geographically referenced data. Also called geospatial data, geographically referenced data are data that describe both the locations and characteristics of spatial features such as roads, land parcels, and vegetation stands on the Earth's surface’.

Summarizing, Environmental Systems Research Institute [ESRI] (2009) stated that ‘a geographic information system (GIS) integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information. GIS allows us to view, understand, question, interpret, and visualize data in many ways that reveal relationships, patterns, and trends in the form of maps, globes, reports, and charts. A GIS helps you answer questions and solve problems by looking at your data in a way that is quickly understood and easily shared. GIS technology can be integrated into any enterprise information system framework.’

Environmental Systems Research Institute [ESRI] (2008) explained that GIS is a spatial database containing datasets that represent geographic information in terms of a generic GIS data model—features, rasters, attributes, topologies, networks, and so forth. Additionally, it is a set of intelligent maps and other views that show features and feature relationships on the earth’s surface. Various map views of the underlying geographic information can be constructed and used as “windows into the geographic database” to support query, analysis, and editing of geographic information. Each GIS has a series of two-dimensional (2D) and three-dimensional (3D) map applications that provide rich tools for working with geographic information through these views. Furthermore, a GIS is a set of information transformation tools that derive new information from existing datasets. These geoprocessing functions take information from existing datasets, apply analytic functions, and write results into new derived datasets. Geoprocessing involves the ability to program your work and to automate workflows by assembling an ordered sequence of operations.

These three GIS views are represented in ESRI® ArcGIS® by the catalog and the geodatabase (a GIS is a collection of geographic datasets), the map (a GIS is an intelligent map view), and the toolbox (a GIS is a set of geoprocessing tools). Together, all three are critical parts of a complete GIS and are used at varying levels in all GIS applications (Environmental Systems Research Institute [ESRI], 2008).

2.4.2 GIS Applications

Some of the numerous important GIS applications include (Chang, 2008; Environmental Systems Research Institute [ESRI], 2009):

- Natural resources management (land-use planning, natural hazard assessment, riparian zone monitoring)
- Forestry (sustainable forest management, harvest route planning, timber market analysis, mapping and modelling of forest fires and their behaviours)
- Agriculture (precision farming promoting site-specific farming activities such as herbicide or fertilizer application)
- Environmental Management & Conservation (pollution monitoring, environmental impact assessment, water quality mapping & planning, habitat & species management & protection)
- Law enforcement (crime records and analysis of their spatial patterns by location and time)
- Emergency planning (fire, medical, disaster)
- Land records management
- Business (market analysis)
- Transportation applications (infrastructure & fleet management, in-car navigation systems finding the shortest route between an origin and destination and providing turn-by-turn directions to drivers)
- Utilities (water & waste water management, network design & facility management for telecommunications, electricity, gas and power companies)

- Education & Science (research, knowledge transfer)
- Health (epidemiological & public health monitoring)
- Government (census, revenue collection, economic development).

2.4.3 GIS Data Sources

GIS data can be obtained from a variety of sources. These include satellite images, orthophotos, geocoding (street addresses), text files with x and y co-ordinates, digital elevation models (DEMs), computer-aided designs (CADs). Two important GIS sources of field data are survey data and global positioning system (GPS) data. Despite the increased availability of high-resolution remotely sensed data and GPS data, maps are still a dominant source for creating new GIS data. Digitizing, either manual digitizing or on-screen digitizing and scanning, converts an analogue map to its digital format (Jackson and Woodsford, 1991; Chang, 2008; Environmental Systems Research Institute [ESRI], 2009).

2.5 Remote Sensing & GIS Applications in the Aquatic Environment

To understand freshwater ecosystems, monitoring the temporal and spatial dynamics of inland waters is very essential. Remote sensing therefore offers a good way to get such information of physical and biological parameters. Water constituents such as phytoplankton, suspended minerals and dissolved organic matter were mapped in Lake Constance using multispectral airborne scanner data and a physically based processing scheme (Heege and Fischer, 2004). Again, suspended matter of Lake Sevan (Armenia) were mapped with MODIS sensors (Heblinski et al., 2010). Landsat-7 ETM+ was used to assess lake water clarity on a regional level in Michigan, U.S.A (Nelson et al., 2003). (Brezonik et al., 2005) also remotely sensed lake water quality characteristics including chlorophyll a and coloured dissolved oxygen demand based on Landsat TM. Sawaya et al. (2003) surveyed aquatic vegetation from high resolution QuickBird and IKONOS satellite imageries and obtained good results.

Using Geographic Information System, the distribution of submerged macrophytes in the littoral zone of Lake Geneva (Switzerland) was modeled from bathymetry, wave exposure, current strength, water quality, soil type and harvesting practice (Lehmann, 1998). The ability of GIS to store and analyse data enabled Schmieder (1997) to plot geographically referenced maps of single species distribution areas, to analyse changes of distribution area of species based on data from the whole littoral zone of Lake Constance and to calculate summarising indices like a macrophyte index of nutrient load in the littoral zone. A Geographic Information System was used to relate field-acquired data on the distributions of floating, emergent, and submersed aquatic plants in a small number of lakes to the same distributions mapped on simultaneously acquired Thematic Mapper images of the lakes (Steeves et al., 1999). Several ecological assessment tools such as structural diversity of the littoral vegetation and habitat suitability models of Lake Constance had been developed using the combination of remote sensing and GIS techniques (Woithon and Schmieder, 2004). These can be applied in the monitoring of changes and the support of management decisions. Recently, Heblinski et al. (2011) accurately classified submersed aquatic vegetation and sediment structures in the littoral zone of Lake Sevan, documenting its spatial vegetation dynamics induced by the fluctuations of the water level and interannual variations in phytoplankton blooms. These methods proved to be cost-effective, time saving and good for wetlands monitoring worldwide.

2.6 Landscape Metrics

2.6.1 Introduction

Studying the factors affecting the distribution of biodiversity is one of the central objectives of ecology. From a local perspective, most studies point to the relationship between the number of species and the internal structure of the habitat. The structural complexity of the habitat and disturbance mechanisms, along with competition processes, would explain the abundance of species (Atauri and de Lucio, 2001).

The loss of biodiversity has generated a lot of concerns which have spurred land managers to seek better ways of managing landscapes at a variety of spatial and temporal scales. Several developments have made possible the ability to analyze and manage entire landscapes to meet multi-resource objectives. The developing field of landscape ecology has provided a strong conceptual and theoretical basis for understanding landscape structure, function, and change. Growing evidence that habitat fragmentation is detrimental to many species and may contribute substantially to the loss of regional and global biodiversity has provided empirical justification for the need to manage entire landscapes, not just the components. The development of GIS (geographical information systems) technology, in particular, has made a variety of analytical tools available for analyzing and managing landscapes. In response to this growing theoretical and empirical support and to technical capabilities, public land management agencies have begun to recognize the need to manage natural resources at the landscape scale. Investigations of ecological phenomena at broad spatial scales often require quantifiable descriptions of landscape pattern and structure for testing relationships or making predictions about the landscape and the phenomena in question (McGarigal and Marks, 1995).

Landscape ecology involves the study of landscape patterns, the interactions among patches within a landscape mosaic, and how these patterns and interactions change over time. In addition, landscape ecology involves applying these principles to formulate and solve real-world problems (McGarigal and Marks, 1995). Landscape ecology considers the development and dynamics of spatial heterogeneity and its effects on abiotic and biotic processes and the management of spatial heterogeneity (Risser et al., 1984). Landscape ecology is largely founded on the idea that the patterning of landscape elements (patches) strongly influences ecological characteristics, including vertebrate populations. The ability to quantify landscape structure is prerequisite to the study of landscape function and change (McGarigal and Marks, 1995). Therefore, much emphasis has been placed on developing methods to quantify landscape structure to correlate with ecological processes (O'Neill et al., 1988; Turner, 1990a; Turner, 1990b; Turner and Gardner, 1991).

2.6.2 What are Landscape Metrics?

Measuring and describing the spatial structure of patches, classes of patches, or entire patch mosaics (i.e., landscapes), landscape metrics provide important information about the composition or configuration of a landscape, e.g., the proportion of each land cover type present, or the size or shape of landscape elements. A major benefit of landscape metrics lies in their usefulness for comparing alternative landscape configurations e.g., comparing different landscapes mapped in the same manner, evaluating the same landscape at different times, or comparing the same landscape under alternative scenarios (Gustafson, 1998; Botequilha Leitão et al., 2006).

Two fundamental aspects of landscape structure measured by landscape metrics are composition and configuration. *Landscape composition* refers to features associated with the presence and amount of each patch type within the landscape but without being spatially explicit. In other words, landscape composition encompasses the variety and abundance of patch types within a landscape but not the placement or location of patches within the landscape mosaic. Landscape composition is important to many ecological processes and organisms (McGarigal and Marks, 1995). Although composition metrics are not spatially explicit, they still have important spatial effects (Gustafson, 1998; Botequilha Leitão et al., 2006). On the other hand, *landscape configuration* depicts the spatial character and arrangement, position, or orientation of landscape elements (McGarigal et al., 2002). Since landscape composition and configuration affect ecological processes independently and interactively, it is important that the component of landscape pattern being quantified by a particular metric is understood properly (Botequilha Leitão et al., 2006).

Not all landscape metrics can be classified easily as representing landscape composition or landscape configuration. Landscape metrics, such as mean patch size and patch density, are not really spatially explicit at either the patch or landscape level because they do not depend explicitly on the spatial character of the patches or their relative location. It is not important that all metrics be classified by the simple composition versus configuration dichotomy. What is important, however, is the recognition that landscape structure consists of both composition and configuration and that various metrics have been developed to represent these aspects of landscape structure separately or in combination (McGarigal and Marks, 1995).

2.6.3 Main Levels of Landscape Metrics

There are three main levels of landscape metrics which are patch, class and landscape levels.

2.6.3.1 Patch Level

A relatively homogeneous area that differs from its surroundings is termed as a patch. A patch is a polygon in vector data and classified as a particular land cover type. On the other hand, a patch is a cluster of like-valued cells based on either a four or eight neighbour adjacency rule in raster or grid data. In patch-level metrics, characteristics of individual patches such as size and shape are quantified resulting in a unique value for each patch. Since patch-level characteristics are not interpreted directly in many applications, they are normally used as basis for computing characteristics of an entire class of patches or of the entire patch mosaic (Botequilha Leitão et al., 2006). The computed values for each individual patch may have little interpretive value. However, sometimes patch indices can be important and informative in landscape-level investigations. The utility of the patch characteristic information will ultimately depend on the objectives of the investigation (McGarigal et al., 2002).

2.6.3.2 Class Level

A set of patches of the same patch type (i.e. land cover type) make a class. While class is a set of polygons classified as the same patch type in vector data, it is a set of like-valued cells in raster or grid data, regardless of their patch affiliation. The quantification of characteristics of an entire class such as total extent, average patch size and degree of aggregation, and returning a unique value for each class, is termed class-level metrics. In the broadest sense, most of the class-level metrics can be interpreted as fragmentation indices since they measure the configuration of a particular patch type (Botequilha Leitão et al., 2006). McGarigal et al. (2002) further explained that class indices separately quantify the amount and spatial configuration of each patch type and thus provide a means to quantify the extent and fragmentation of each patch type in the landscape.

2.6.3.3 Landscape Level

A landscape is a set of all patches within the area of interest. It is the entire collection of polygons, regardless of patch type, in a vector data, whilst it represents the entire collection of cells, regardless of class value, in raster or grid data. Landscape-level metrics measure and describe the overall composition and configuration of the patch mosaic without reference to individual patches or patch types (Botequilha Leitão et al., 2006). Since most of the landscape-level metrics measure the overall landscape pattern, they can be interpreted broadly as landscape heterogeneity indices (McGarigal et al., 2002; Botequilha Leitão et al., 2006).

2.7 Habitat Modelling

2.7.1 Introduction

Majka et al. (2007) defined Habitat as a place where an animal lives or the living and non-living characteristics of a landscape that an animal uses. Although habitat is fundamentally a description of what animals use and where animals are found, most ecologists assume that habitat also is what animals need to survive and reproduce. It was further explained that habitat is often broken down into several components, depending on what the animal is doing in a particular area or with a particular element of the landscape. Five components usually listed include food, water, hiding cover (prey) or ambush cover (predators), thermal cover (against heat or cold or both), and nest sites (or other special needs for reproduction). A 6th component, namely the minimum amounts and spatial arrangement of the first 5 components is added by some ecologists. Survival and reproduction require that an animal has enough of each habitat component within the range of its daily, seasonal, or annual activities.

2.7.2 Habitat Modelling Approaches

Habitat models allow the assessment of the quality of habitat for a species within a study area. In the GIS environment, habitat suitability models relate suitability to raster-based layers such as land use/land cover, elevation, topographic position, human disturbance (e.g. distance from roads, road density, housing density, etc), or other important factor available as a GIS layer. Each of these raster layers, which has several to many classes, is called a factor (Majka et al., 2007). For instance, the factor land cover may include classes such as reeds, grasses, and bushes.

The two common ways to build these models are:

a) Literature review and expert opinion-based habitat suitability models
b) Empirical and statistical techniques for estimating habitat suitability

The most common habitat suitability modelling technique is based on literature review and expert opinion. While literature-based models are subject to uncertainty and errors when translating literature-based habitat studies to a habitat suitability score, they are relatively easy to create, do not require new collection of detailed field data for all species in the linkage zone, and can be applied to multiple study areas, allowing for rapid analyses and linkage designs. The procedure requires a biologist to assign a weight to each factor and a habitat suitability score to each class within a factor. Suitability scores for all habitat factors are then combined to form a single habitat suitability map with a suitability score for each pixel (Majka et al., 2007).

If presence-absence data or abundance is available for the species in the study area, then empirical statistical models can be created by relating the species occurrence data to habitat factors. Statistical techniques such as generalized linear or generalized additive models (e.g. logistic or Poisson regression), artificial neural networks, classification and regression trees

(CARTs), and genetic algorithms can all be used to create a map of a species probability of occurrence at any pixel in the landscape. With these models, data is typically extracted from the GIS layers, assembled into a site by occurrence matrix, analysed with a statistics package such as R, S-Plus, or SAS, and then fed back into the GIS software to create a map depicting probability of occurrence. While empirical models are probably more accurate than rule-based or literature-review based models, they require gathering a good set of field observations for every species in the linkage area, which can take a considerable amount of time (Majka et al., 2007).

2.7.3 Estimating Habitat Suitability

Before Habitat Suitability can be estimated, each of the different classes within every factor is assigned a suitability score. Biologically meaningful thresholds are set to divide the habitat suitability scores into categories, paying particular attention to the suitability threshold required to support breeding habitat. To combine multiple habitat factors into one aggregate habitat suitability model, weights are first assigned to each factor that reflect their relative importance, and second, the weighted factors are combined in one of the many potential algorithms. The weighted arithmetic mean is the most commonly used algorithm to combine weights, which allows a deficiency in one factor to be compensated by other factors, while weighted geometric mean better reflects a situation in which one habitat factor limits suitability in a way that cannot be compensated by other factors (Majka et al., 2007).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

3.1.1 Study Area

Lake Sevan of Armenia, which lies on geographical co-ordinates $40^{o}08'$- $40^{o}49'$N and $44^{o}58'$- $45^{o}42'$E, is situated 60 km to the north-east from the city of Yerevan (Figure 8). The lake is one of the greatest freshwater high-mountain lakes of Eurasia as well as one of the highest and largest alpine lakes in the world. Lake Sevan is 1,896 m above the Baltic Sea Level. It has a surface area of 1,243 km^2, length of 75 km, and an average width of 19 km (Markosyan and Nazaryan, 2003; Garibyan, 2007).

Figure 8: Map of Armenia (showing Lake Sevan) in Europe and the World and its adjoining countries
Source: (Graphic Maps, 2006b)

Differing by age and origin, Lake Sevan consists of two parts, namely Major Sevan - with a surface area of 916 km^2 - and Minor Sevan - with a surface area of 328 km^2 (Figure 9). Before the artificial lowering of its water level in 1933, the lake level was 1,916.2 m above the Baltic Sea level. The catchment basin of Lake Sevan (4891 km^2) which belongs to the basin of the river Araks lies in a large tectonic depression surrounded by mountains, in the north-west of which the watershed area of the basin lowers up to the Lake's level. From here starts the only river which flows out of the lake – the river Hrazdan. Twenty eight rivers flow into the lake. The total length of the watershed line is nearly 400 km. Lake Sevan with its basin was finally formed 25-30,000 years ago. Compared with plain reservoirs, the total sunbeam on the surface of lake is rather high. The morphometrics of the lake have greatly changed as a result of the lowering of its level by 20 m. Whilst, the catchment basin increased by 172 km^2 and its ratio to the lake's surface area became equal to 30, the surface area of the lake decreased by 12 %, the average depth by 34.2 %, the highest depth by 19 %, and the lake volume by 42.2 % (Oganessian, 1994).

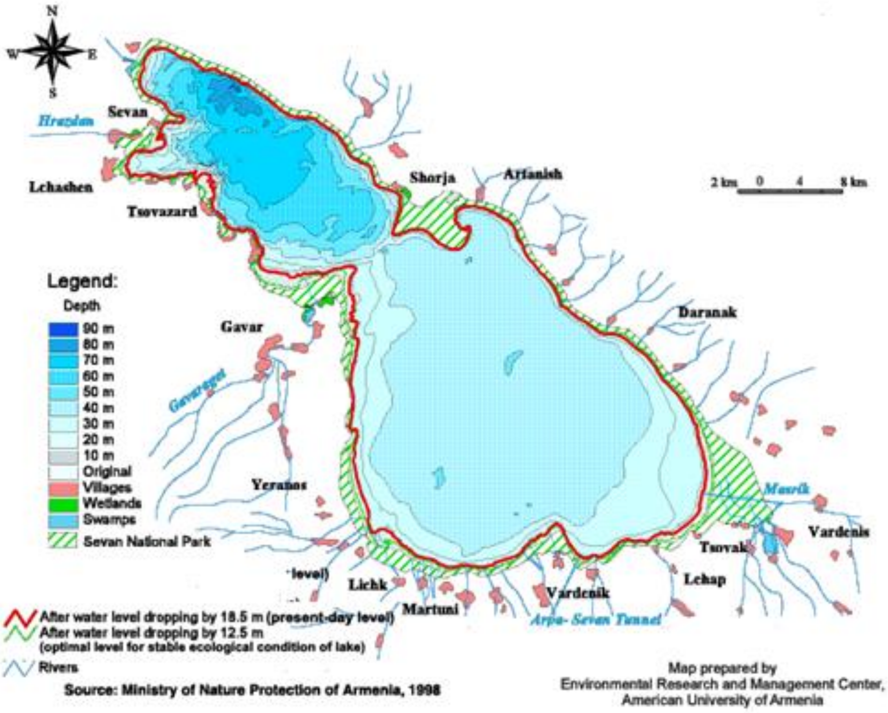


Figure 9: Lake Sevan catchment area showing the Sevan National Park, adjoining districts and the water depth at various sections of the Lake

The field data acquisitions were focussed on five selected areas namely: Hrazdan, Tsovazard, Argichi, Gavaraget and Masrik regions as shown in (Figure 10) below.

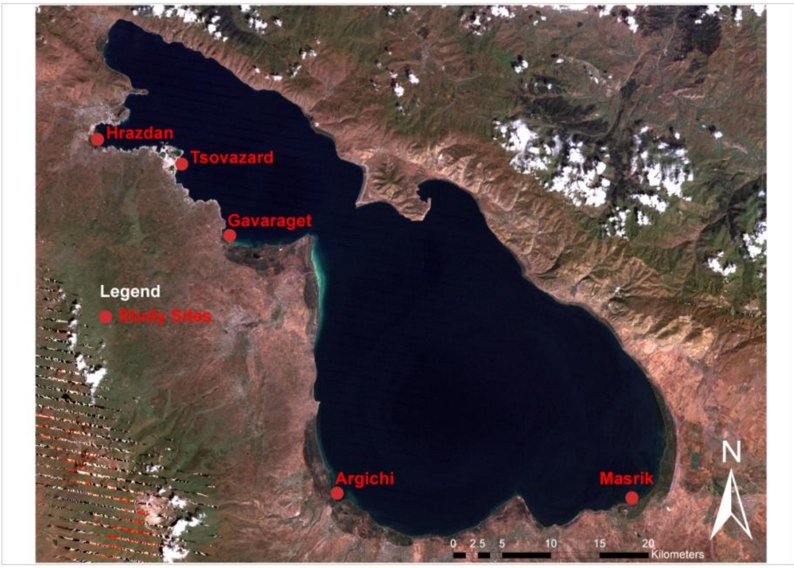


Figure 10: Study Area sites used for field data acquisition. However, detailed analyses were done on Gavaraget, Tsovazard and Masrik regions due to the availability of remote sensing data for these areas for the entire period under investigation

The Lake Sevan watershed is located at the intersection of the Caucasian, Iranian and Mediterranean flora regions, each of which has its own distinctive plant assemblies. The range in altitude, sharp fluctuations in relief and soil variability, create numerous landscape types that promote diversity in flora and plant associations. More than 150 of the plant species in the basin are considered to be threatened or endangered and require assistance to survive (Red Data Book of Armenia, 1989).

The waters of Lake Sevan, the marshes around the lake and the mouths of rivers, function as habitats for a number of aquatic and marsh animals. This group includes the fish living in the lake, amphibians, reptiles, birds and certain mammals. Since 1940, more than 10,000 hectares of marshes, and Gilly Lake in the south end of Lake Sevan, have been drained and lost through the lowering of Lake Sevan. Although no recent inventory of terrestrial animals living in the basin has been conducted, existing information indicates that at least 222 species of mammals, birds, and reptiles still live in or visit the basin. The Sevan wetlands were previously used by up to 160 species of migratory birds, only 50 of which are now recorded (Parparova, 1979; Red Data Book of Armenia, 1987).

Jenderedjian et al. (2005) stating the main effects resulting from the destabilization of most of the hydrological and ecological processes due to the artificial lowering of the lake listed the following:

i. Draining of the wetlands
ii. Worsening of the water quality
iii. Changed species succession
iv. Biodiversity loss
v. Inaccessible lake shore areas due to formation of impassable bushes by plantation of alien species e.g. *Hippopae ramnoides* in dried areas of former lake bottom
vi. Reduction of numbers of breeding waterfowl from 60 breeders to only about 25 species.

3.1.2 Remote Sensing Data

The following remote sensing sensors were used to integrate data into the research work: LANDSAT (MSS / TM / ETM+), Aster and QuickBird. The Landsat data were used in the calculations of surface area of the lake whiles the Aster provided the digital elevation data. The supervised classifications were derived from the QuickBird data. The subsequent subheadings give a short overview about these sensors, their main characteristics and the integrated datasets.

3.1.2.1 LANDSAT

LANDSAT satellites are a series of civil earth observation satellites of NASA. They cover the main natural resources of earth surface. The series of 6 satellites was started in 1972 and included different production series such as MSS, TM and ETM+ (See Table 1).

Table 1: Main Characteristics of LANDSAT (1-7) Satellites used for the Assessment of Surface and Littorl Zone areas, and as background for Field Mapping

	LANDSAT 1, 2, 3	LANDSAT 4, 5	LANDSAT 7
Sensor	Multispectral Scanner (MSS)	Thematic Mapper (TM)	Enhanced Thematic Mapper plus (ETM+)
Spatial Resolution	80m	30m (MS) 120m (TIR)	30m (MS) 60m (TIR) 15m (PAN)
Spectral Resolution	4 Channels 1 0.50 - 0.60 µm. Green 2 0.60 - 0.70 µm. Red 3 0.70 - 0.80 µm. NIR 4 0.80 - 1.10 µm. NIR	7 Channels 1 0.45 - 0.52 µm. Blue 2 0.52 - 0.60 µm. Green 3 0.63 - 0.69 µm. Red 4 0.76 - 0.90 µm. NIR 5 1.55 - 1.73 µm. MIR 6 10.4 - 12.5 µm. TIR 7 2.08 - 2.35 µm. MIR	8 Channels 1 0.45 - 0.52 µm. Blue 2 0.52 - 0.60 µm. Green 3 0.63 - 0.69 µm. Red 4 0.76 - 0.90 µm. NIR 5 1.55 - 1.73 µm. MIR 6 10.4 - 12.5 µm. TIR 7 2.08 - 2.35 µm. MIR 8 0.52 - 0.90 µm. PAN

Source: (United States Geological Survey (USGS), 2006a)

According to United States Geological Survey [USGS] (2009), the Landsat Orthorectified data collection consists of a global set of high-quality, relatively cloud-free orthorectified MSS, TM and ETM+ imagery from Landsats 1-5 and 7. The National Aeronautics and Space Administration (NASA) in contract with Earth Satellite Corporation, Rockville, Maryland, acquired and processed the Landsat data as part of NASA's Scientific Data Purchase program. Ground control points are fixed, and images have been registered to the Universal Transverse Mercator (UTM) map projection and coordinate system and the World Geodetic System 1984 (WGS84) datum. United States Geological Survey [USGS] (2009) further explained that all image bands have been individually re-sampled using a nearest neighbour algorithm, and positional accuracy on the final image product has a Root Mean Square Error of better than 100 meters (MSS) and 50 meters (TM and ETM+). When possible, data were collected when vegetation was at peak greenness. Peak greenness was determined from global 1-kilometer Advanced Very High Resolution Radiometer (AVHRR)

Normalized Difference Vegetation Index (NDVI) data. When peak greenness data were not available, images from other times of the year were substituted

The Landsat datasets of the following dates were acquired for research project: 18.06.1976 (MSS), 4.06.1987 (TM), 08.08.1989 (TM), 23.09.2000 (ETM+), 06.06.2001 (ETM+), 14.06.2004 (ETM+), 22.08.2005 (ETM+), 07.08.2006 (ETM+), 25.07.2007 (ETM+) and 30.07.2009 (ETM+). The Landsat data were used to calculate Sevan's surface area over different years, as background for field mapping and for general planning tasks in the research work.

3.1.2.2 QuickBird

The QuickBird satellite is the first constellation of spacecraft that DigitalGlobe is developing that offers highly accurate, commercial high resolution imagery of the Earth. QuickBird’s global collection of panchromatic and multispectral imagery is designed to support applications ranging from map publishing to land and asset management among others. The spatial resolution is up to 60 cm (nadir) in panchromatic and 2.4 m (nadir) in multispectral mode. QuickBird’s image bands lies at 450-520 nm (Blue), 520-600 nm (Green), 630-690 nm (Red), 760-900 nm (NIR) and 445-900 nm (PAN) (DigitalGlobe, 2009).

QuickBird images (from 2006 to 2008) of research areas Gavaraget, Masrik and Tsovazard were acquired and used for supervised macrophyte classifications by the EOMAP Company (based in Gilching, Germany).

3.1.2.3 ASTER

ASTER (Advanced Space-borne Thermal Emission and Reflection Radiometer) is an imaging instrument flying on Terra, a satellite launched in December 1999 as part of NASA's Earth Observing System (EOS). ASTER is a cooperative effort between NASA, Japan's Ministry of Economy, Trade and Industry (METI) and Japan's Earth Remote Sensing Data Analysis Centre (ERSDAC). ASTER is being used to obtain detailed maps of land surface temperature, reflectance and elevation. The three EOS platforms are part of NASA's Science Mission Directorate and the (National Aeronautics and Space Administration, 2004).

A set of three ASTER-DEMs (with specifications shown in Table 2) were integrated to have a more detailed elevation model of Sevan's basin (Figure 11) by EOMAP Company.

Table 2: Specifications of ASTER Digital Elevation Model (DEM) used for a detailed elevation model of Sevan's basin

	Relative DEM	Absolute DEM
X/Y-Resolution	30m	30m
Z-Resolution	1m	1m
Ground Control Points	No	yes (supplied by the user)
Accuracy	>= 7m	>= 10m

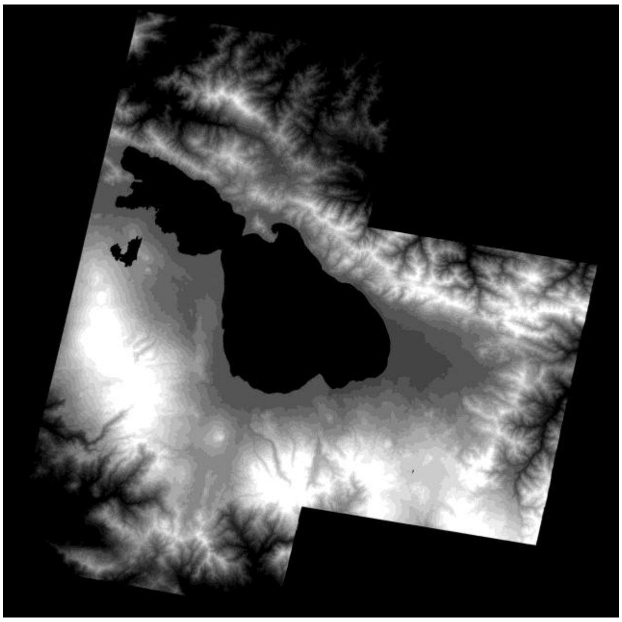


Figure 11: ASTER DEM - stretched for elevations between 1200m and 3000m

3.1.3 Topographic Maps

A digital map of Lake Sevan (Figure 12) was obtained by digitizing a topographic map on the base of 1: 50 000 scale (produced in 1988 by the State Geodetic & Cartographic Institute, Moscow- former USSR) and georeferenced in ArcGIS environment by Hovik Sajadyan (SEMIS project member). The bases for its Coordinate System were 1942 Ellipsoid of Krasovsky and Gauss-Krueger map projection. Layers digitised included:

1. Boundaries of lake Sevan basin,
2. Boundaries of "Sevan" national park,
3. Horizontals and isobaths (5, 10, 15 m) and relief of lake Sevan basin,
4. Hydrography (Lakes and reservoirs)
5. Infrastructure (roads, railways, gas pipelines, electric lines)

6. Settlements (towns, villages).

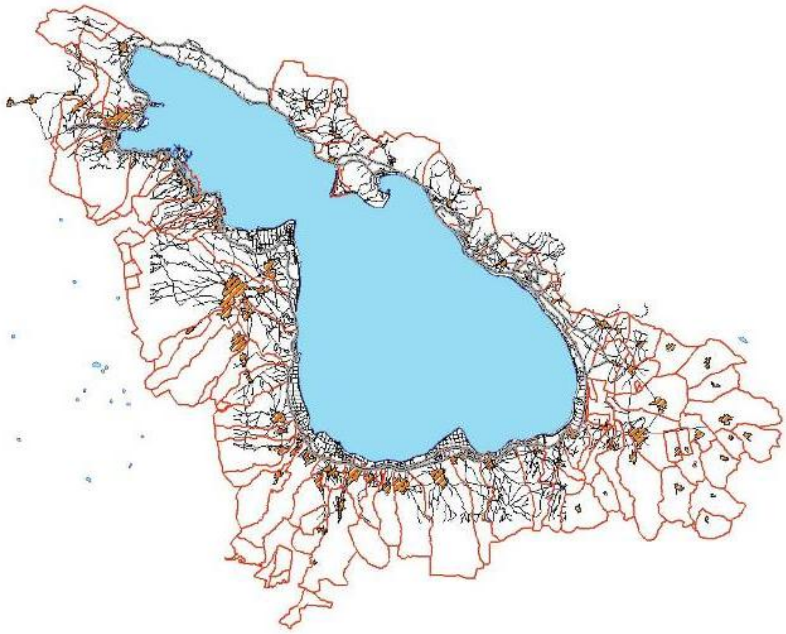


Figure 12: Digitized Map of Lake Sevan Basin with surrounded villages. This map was used in the surface and littoral zone areas calculations

3.1.4 Global Positioning System (GPS)

The term "GPS" is an abbreviation of the satellite-based positioning system– **G**lobal **P**ositioning **S**ystem- which had been developed by the US Ministry of Defence. Since 2000 the satellite signals are no longer impaired by artificial deviations, so GPS systems can be used and applied relatively easily to a broad range of positioning and geo-referencing tasks. A GPS system consists of the space segments (24 satellites), the control segments (ground stations) and the user segments (GPS receiver) (El-Rabbany, 2002). Depending on the analysis method of the receiver and the obtainable precision of navigation, a distinction can be made between simple stand-alone positioning system (GPS), differentially corrected positioning system (DGPS) and positioning system based on carrier phase analysis (geodetic GPS). A GPS receiver (see 3.1.6.1 ArcPad) was used in the field mapping of macrophyte vegetation along the lake shore.

3.1.5 Habitat Modelling Organisms

3.1.5.1 Crucian Carp (*Carassius* spp.)

<u>Distribution and Description</u>

The *Carassius* spp. which occurs in lakes, water courses and wetlands have 10 to 59 cm sizes with a deep body and rounded cross-section (Figure 13). It has large head and eyes with a small mouth and a forked tail. Its scales are large while its single dorsal fin has 3-4 stout spines at the leading edge. Its colour ranges from olive-bronze to deep golden along dorsal surface, fading to silvery-white along the belly. Whiles it may live for 41 years, its growth may be up to 3kg in weight. It is native to central Asia, China and Japan but has been introduced worldwide as a pond and aquarium species (McDowall, 2000; IUCN/SSC Invasive Species Specialist Group [ISSG], 2006; FishBase, 2009; FishBase, 2010).

Figure 13: Crucian Carp (*Carassius* spp.) of Lake Sevan caught during Field Data acquisition by the Fish Survey Team
Source: (Rubenyan and Hayrapetyan, 2008)

<u>Habitat and Diet</u>

Carassius spp. are normally found in rivers, lakes, ponds, lagoons and ditches with cold, slow-flowing water and aquatic vegetation (Rubenyan and Hayrapetyan, 2008; FishBase, 2009). They are able to withstand prolonged exposure to salinities above 15 ppt (FishBase, 2009). They are very hardy fish and can tolerate low levels of dissolved oxygen, survive water temperatures ranging from 0^{o} to $38^{o}C$, and can live in acidic waters where the pH can be as low as 4.0. Crucian carp are also very tolerant of pollution, especially organic types (McDowall, 2000; IUCN/SSC Invasive Species Specialist Group [ISSG], 2006; Lambeth Parks & Greenspaces, 2006).

The Crucian carp prefers small, nutrient-rich ponds and lakes rich in macrophytes in lowland areas. The juveniles feed mainly on zooplankton in the water column, but as they grow and mature they switch to a bottom feeding habit which consist of a variety of aquatic plants (including filamentous algae), pieces and seeds of aquatic weeds, detritus, crustaceans, worms, small insects and snails (McDowall, 2000; FAO, 2004; IUCN/SSC

Invasive Species Specialist Group [ISSG], 2006; Lambeth Parks & Greenspaces, 2006; Rubenyan and Hayrapetyan, 2008; FishBase, 2009).

Reproduction and Lifecycle

Sexual maturity is reached at 1-2 years of age, and reproduction occurs annually for about 6-7 years (Schofield et al., 2005). The Crucian Carp spawns in shallow water amongst macrophytes and submersed vegetation, and lays at once up to several hundred thousand small eggs (1-2 mm diameter) (McDowall, 2000; Rubenyan and Hayrapetyan, 2008). The presence of aquatic vegetation is very important for spawning since they serve as the substrata for the eggs, which are adhesive (FAO, 2004). Individual fish can spawn 3-10 lots of eggs at intervals of 8-10 days. Cold water during winter is essential for proper ova development (FishBase, 2009). The eggs hatch in around a week and the young attach to aquatic plants for several days while yolk sac is absorbed (McDowall, 2000; IUCN/SSC Invasive Species Specialist Group [ISSG], 2006).

3.1.5.2 Common Coot (*Fulica atra*)

Description and Distribution

The Common Coot is a black bird with white bill, greenish legs and reddish eyes (Figure 14). While its weight ranges between 610 g and 1200, its length is between 36 cm and 39 cm (Cramp et al., 1980; del Hoyo et al., 1996; Wildlife Information Network [WIN], 2010).

They can be found in Europe, North Africa, Azores, Canaries, eastwards through Central Asia to Japan, south to the Indian Subcontinent and Sri Lanka. During winters they migrate to western and north-eastern Africa, south-east Asia and the Philippines. Most populations in warm and temperate regions are resident, often making nomadic dispersive movements according to changing water levels and seasonal rainfall. Populations in northern Eurasia are fully migratory however, migrating on a broad front through continental Europe and across the Sahara. The species nests in dispersed solitary pairs, although it is largely gregarious with flocks (sometimes of several thousand individuals) frequently forming during the winter. Adults undergo a post-breeding flightless moult period, with flocks of moulting birds congregating from June-September. The species is diurnally active and roosts at sunset solitarily or in flocks (Urban et al., 1986; del Hoyo et al., 1996; Snow and Perrins, 1998; Taylor and van Perlo, 1998; BirdLife International, 2009a; Wildlife Information Network [WIN], 2010).

Figure 14: The Common Coot (*Fulica atra*) swimming on a lake
Source: (Bartz, 2008)

Habitat and Diet

The Common Coot inhabits large, still or slow-flowing waters and shows a preference for shallow water with adjacent deeper water (e.g. > 2 m) for diving, and muddy substrates, and plentiful vegetation - marginal, emergent, floating or submergent vegetation. Habitats include eutrophic and mesotrophic lakes, pools, ponds, reservoirs, barrages, gravel-pits, canals, drainage ditches, dykes, oxbow lakes, fish ponds, creeks, rivers and river deltas, as well as open marshes, freshwater meadows, flood-lands, freshwater and saline lagoons, salt-pans, clay-pans and sewage ponds. It frequently makes use of temporary pools and seasonally inundated marshes when breeding (Africa), and may extend to quiet estuaries or inshore waters in the winter. It generally avoids closely overgrown, narrowly confined and very shallow waters, and those overshadowed by trees or cliffs. If solitary, the species roosts at sunset on small islets, mudbanks, sandbanks, rocks in water, floating mats of vegetation, floating logs, or branches of trees over water, preferring to roost on open water, in shore vegetation or in meadows adjacent to water if in flocks (Urban et al., 1986; Sibley and Monroe Jr., 1990; del Hoyo et al., 1996; Snow and Perrins, 1998; Taylor and van Perlo, 1998; BirdLife International, 2009a; Wildlife Information Network [WIN], 2010).

The Common Coot being omnivorous, eats primarily vegetable matter such as algae, the vegetative parts of aquatic and terrestrial plants (e.g. waterweeds, bulrushes, reeds and grasses), the seeds of waterweeds, sedges, water-lilies, grasses and cereal crops, clubmoss *Selaginella* and aquatic fungi (e.g. *Leptomitus*). Animal matter included in its diet are molluscs, adult and larval insects (especially flies, caddisflies, Odonata, Lepidoptera, beetles and bugs), worms, leeches, shrimps, spider, small fish, fish eggs, frogs, birds and bird eggs, and small mammals (Urban et al., 1986; del Hoyo et al., 1996; Taylor and van Perlo, 1998; BirdLife International, 2009a).

Breeding

The nest of the Common Coot consists of a platform of vegetation that may be resting on the bottom of shallow water, floating or on a foundation of trampled plant matter in emergent vegetation. The species may also nest on artificial platforms, islands, rafts, tree stumps, tree forks or in bushes up to 3 m above the water (del Hoyo et al., 1996; Taylor and van Perlo, 1998; BirdLife International, 2009a). According to Samraoui and Samraoui (2007) their nest site selection is strongly influenced by spatial patch structure and vegetation structure which may also act as a cue of habitat quality. Both parents build nest, incubate and care for chicks and may split brood temporarily or permanently. Average clutch size ranges between 6 and 10 eggs. While hatching of eggs is asynchronous, the parent broods on the nest for three to four days. The young are fed by parents for up to two months although also self-feeding by 30 days. They fledge for 55-60 days, but become independent by six to eight weeks, and may remain in parents' territory up to 14 weeks (Cramp et al., 1980; Sibley and Monroe Jr., 1990; del Hoyo et al., 1996; Wildlife Information Network [WIN], 2010).

3.1.5.3 Great Crested Grebe (*Podiceps cristatus*)

Description and Distribution

Being a medium to large aquatic bird, the Great Crested Grebe is the largest of the grebes. It has a long neck and head with a distinctive black double crest. However, the juveniles have a striped black and white head and neck. Its white face with a red eye, has a black line from the base of the bill to the eye (Figure 15). It has dark brown wings, satin white underparts, a black crown, dark olive-green feet and, during flight, prominent white patches are visible on its wings. The adult male is slightly bigger than the adult female. This species can be found throughout Australia, Europe, Africa and Asia to Australasia, but not New Guinea (Australian Musuem, 2006). The majority of this species is fully migratory although some populations may only undergo local dispersive movements (del Hoyo et al., 1996; BirdLife International, 2009b).

Figure 15: The Great Crested Grebe captured by the lenses of the Bird Survey Team

Source: (Aghababyan and Ananian, 2008)

Habitat and Diet

The Great Crested Grebe prefers large deep open bodies of freshwater, therefore, it is most commonly found inhabiting backwaters of slow-flowing rivers and artificial waterbodies (e.g. reservoirs, fish-ponds, gravel pits and ornamental lakes), lagoons, lakes, swamps, reservoirs, salt-fields, estuaries and bays (del Hoyo et al., 1996; Australian Musuem, 2006; BirdLife International, 2009b).

The Great Crested Grebe's diet consists predominantly of large fish as well as insects, crustaceans (e.g. crayfish, shrimps) and molluscs, occasionally also adult and larval amphibias. Its invertebrate consumption is highest during the breeding season (del Hoyo et al., 1996; BirdLife International, 2009b).

Breeding

The Great Crested Grebe being monogamous, maintains pair-bonds throughout the year. Its nest is constructed from a mass of dead water-plants, weeds and mud, usually attached to reeds, fallen or drooping branches or a submerged stump (Australian Musuem, 2006). The nest is a platform of aquatic plant matter either floating on water and anchored to emergent vegetation or built from the lake bottom in shallow water (del Hoyo et al., 1996; BirdLife International, 2009b). Typical nest sites include reed beds or flooded thickets as well as more open sites such as floating mats of water-weed or kelp fronds. The species breeds on fresh or brackish waters with abundant emergent and submerged vegetation, showing a preference for non-acidic eutrophic water bodies with flat or sloping banks and muddy or sandy substrates (del Hoyo et al., 1996; Snow and Perrins, 1998; Fjeldså, 2004; BirdLife International, 2009b). Both parents take part in incubating the eggs and tending the young (Australian Musuem, 2006).

3.1.6 Softwares

3.1.6.1 ArcPad

For the groundtruth data collection or field mapping, the mobile GIS software ArcPad (ESRI Inc, Redlands, USA) versions 6.0 was used for 2006, and version 7.0 for 2007-2008 Additionally, GPS-System receiver, GPS III Plus (PhaseTrac12™) from Garmin Inc. (Olathe, USA) was attached to the field computer.

3.1.6.2 ArcGIS

For the storing, displaying, querying and analysing of geographic data, the GIS software, ArcGIS Versions 9.1, 9.2 and 9.3 (ESRI Inc, Redlands, USA) were used. Several maps were also created using this software.

3.1.6.3 FRAGSTATS

FRAGSTATS 3.3 is a spatial pattern analysis program for categorical maps which quantifies the areal extent and spatial configuration of patches within a landscape. The landscape subject to analysis is user-defined and can represent any spatial phenomenon. Therefore; it is incumbent upon the user to establish a sound basis for defining and scaling the landscape (including the extent and grain of the landscape) and the scheme upon which patches are classified and delineated. The output from FRAGSTATS is meaningful only if the landscape mosaic is meaningful relative to the phenomenon under consideration (McGarigal et al., 2002).

3.1.6.4 Patch Analyst

(Rempel, 2008a) explained that Patch Analyst 4.0 contains analysis & modelling functions related to polygons, while Patch Analyst (Grid) extends analysis capabilities to grids which require Spatial Analyst. Patch Analyst (Grid) includes a user interface to the PC raster version of FRAGSTATS 2, as well as separate Visual Basic based spatial analysis functions.

Numerous patch metrics are calculated, and these include mean and median patch size, patch size coefficient of variance, edge density, mean shape index, fractal dimension, interspersion and juxtaposition, Simpson's diversity index, and core area index. Summary statistics are reported at either the patch or landscape scale. The various patch metrics follow the definitions in FRAGSTATS (McGarigal and Marks, 1994).

3.1.6.5 Excel

The statistical analyses, matrices and graphs were done using Microsoft Excel software.

3.2 Methods

3.2.1 Computer-Aided Field Mapping

Figure 10 illustrates the five focussed regions (Hrazdan, Tsovazard, Argichi, Gavaraget and Masrik) where field mappings were conducted. The 2006 field campaign was conducted from 12th to 30th September while those of 2007 and 2008 were done in 9th to 30th July and 13th July to 3rd August respectively in Armenia. No mappings were done in the regions Gavaraget and Tsovazard in 2006 since they were only added in 2007. Since all the five regions did not have complete satellite imageries for all the three years, only those with complete satellite data were focused on. These were Gavaraget, Tsovazard and Masrik regions.

Objects mapped were saved as points, lines or polygon shapefiles and these included submersed, floating and emersed macrophytes, sediments, trees, grasses and bushes. The quantity of mapped objects for each region and each year are shown in Table 3.

Table 3: Number of Mapped Objects in each Region for Groundtruthing

Region	**No. of Polygons**		
	2006	**2007**	**2008**
Gavaraget	0	25	85
Tsovazard	25	30	80
Masrik	7	23	86
Total	**32**	**78**	**251**

Sharpened satellite images were used as backgrounds to guide the mapping process as seen in Figure 16.

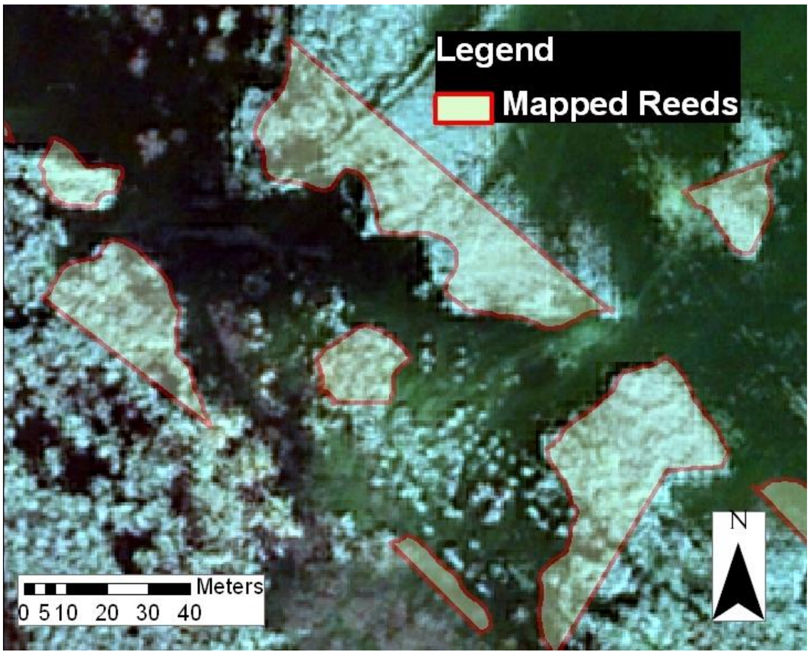


Figure 16: Mapped Reeds (red boundaries) with sharpened Satellite image as background

To ensure and guarantee good quality information from high resolution sensors, a comparison with real conditions or ground reference data (termed Ground Truth) *in situ* is important. This Ground Truth (in this case-field mapping) was used to validate the structures that were derived from the satellite imageries.

A field laptop computer, Toughbook CF-30 (Panasonic, Osaka, Japan) equipped with a GPS receiver and mobile GIS system software, ArcPad -Version 6.0 / 7.0 - (ESRI Inc, Redlands, USA), was used to map shore vegetation in the selected areas. The mapped objects were saved directly in a geo-data format, which were then post-processed with the GIS software ArcGIS Version 9.1 / 9.2 (ESRI Inc, Redlands, USA). A simple GPS device (Garmin GPS III Plus, PhaseTrac 12TM receiver) was used for the mappings in this project. It calculates the distance to the satellites from the signal transmission run-time and yields a precision of 5 to 10 metres. The measuring was carried out during optimal reception conditions (no shading phenomena, clear atmosphere) on Lake Sevan, so that the maximum deviation could be given as 5 metres. The GPS measurements as well as the ArcPad application were based on the global standard reference system World Geodetic System 1984 (WGS 84) which relates to the Ellipsoid WGS 84. The projection type was Transverse Mercator while the projection used was WGS 1984 UTM Zone 38N. As a result, the ground truth data were saved either as point, line and polygon shape files in the UTM coordinate system format.

Aquatic macrophytes plants were identified and mapped by moving slowly along the borders of patches of these macrophytes in a boat and recording the locations of the plant patches directly as shape files with ArcPad and the GPS receiver. Subjectively, every species was assigned an abundance class (between 1 and 5) in a particular patch or designated area. The legend of the species abundance was as follows (Kohler et al., 1995):

1 = very rare

2 = rare

3 = common

4 = abundant

5 = very abundant

At each sampling point, a rake was lowered on a line and dragged along the lake bottom or one dived and swam. The relative amount of plant material retrieved on the rake was used to estimate the areal coverage (abundance) of submersed aquatic plants at that point. Apart from the macrophyte genus and species, additional information on the areal coverage (abundance), depth and site descriptions were collected.

3.2.2 Assessment of the Historical Development of Lake Sevan

The assessment of the historical development of Lake Sevan spans from the year 1933 to 2009. The water levels used for the assessment of the effects of water level fluctuations in the last decades on the total lake area and the littoral zone area are shown in Table 4. Also, the surface areas for the years 1933, 1996 and 2002 were obtained from literature (Garibyan, 2007).

Table 4: Lake Sevan's Water Levels and their accompanying Remote Sensing Data information between 1933 and 2009

Year	Mean Water Level above Baltic Sea Level (m)	Image Type (Landsat)	Date of Acquisition	Water Level on Acquisition Date (m)	Difference from Mean Water Level (m)
1933	1915.89				
1976	1897.65	MSS	18.06.1976	1898.16	-0.51
1987	1897.00	TM	4.06.1987	1897.42	-0.42
1988	1897.65				
1989	1898.13	TM	08.08.1989	1898.04	+0.09
1996	1896.77				
2000	1896.81	ETM+	23.09.2000	1896.60	+0.21
2001	1896.76	ETM+	06.06.2001	1896.78	-0.02
2002	1896.32				
2004	1897.73	ETM+	14.06.2004	1897.86	-0.13
2005	1898.17	ETM+	22.08.2005	1898.23	-0.06
2006	1898.59	ETM+	07.08.2006	1898.55	+0.04
2007	1898.82	ETM+	25.07.2007	1899.01	-0.19
2009	1899.24	ETM+	30.07.2009	1899.37	-0.13

Source: (Garibyan, 2007; Armenia Hydro-Meteorological Institute [ArmHydromet], 2009; United States Geological Survey [USGS], 2010)

All the remote sensing data i.e. satellite images (see Table 4), were viewed with the ESRI GIS software ArcGIS 9.1/ 9.2. Since the band 4 in all the scanners (MSS, TM and ETM+) is ideal for near –Infrared (NIR) reflectance peaks in healthy green vegetation and for detecting water-land boundaries, it was selected and used for the determination of the surface area of Lake Sevan (Campbell, 2008). The satellite images were projected using the UTM Zone 38N map projection and the WGS84 map datum. Those files which were in GEOTIFF format were converted to grid format through reclassification with the Spatial Analyst tool to enable its attribute table. Through the 'Layer properties' of band 4 and submenu 'Symbology', the raster data were stretched using the 'minimum-maximum' type for contrast enhancement as shown in Figure 17 below.

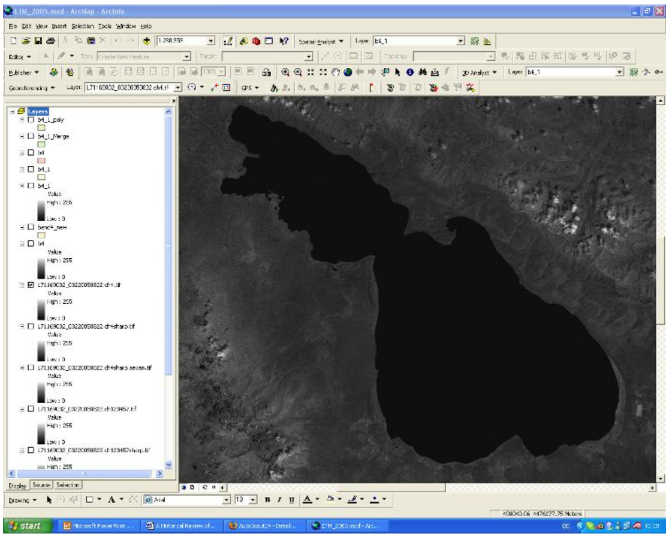


Figure 17: Enhanced Satellite Image of Lake Sevan providing a better preview

Further, the water areas (with cell values between 9 and 24) were selected through the attribute table using a Structured Query Language (SQL) equation as shown in Figure 18.

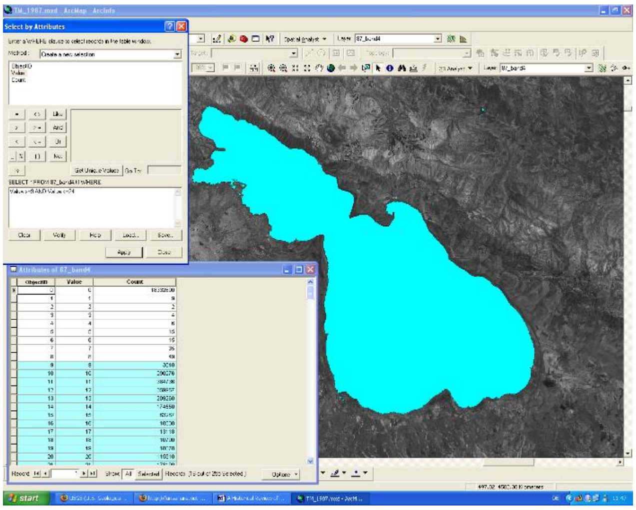


Figure 18: Selected Water Body within Band 4 Raster (Satellite) Data using a Structured Query Language in ArcMap

The selected raster data (water areas) were converted to polygons using the Spatial Analyst tool. The polygons were then merged and dissolved into one single polygon using the ArcToolbox. This was edited to remove all disconnected polygons from the display area as shown in Figure 19.

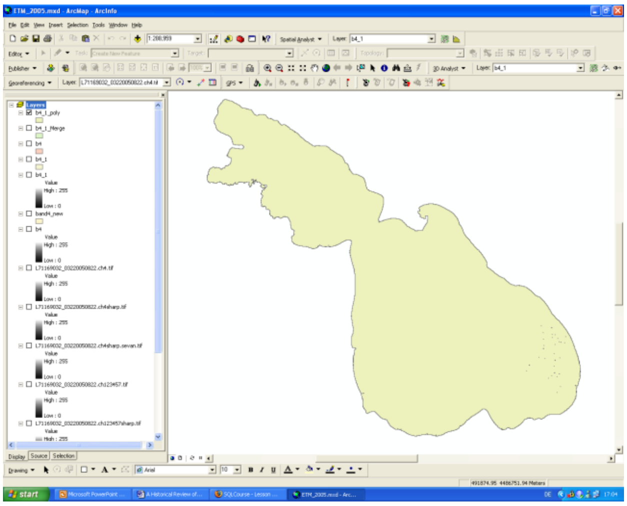


Figure 19: Processed Satellite Image of Lake Sevan into a Polygon Format using Spatial Analyst tool in ArcMap

Finally, the surface area of the lake was calculated using the layer attribute and a VBA script (Environmental Systems Research Institute [ESRI], 2004). The resulting surface area for that particular year was then sent to Microsoft Excel for further analysis.

3.2.3 Effects of Lake Sevan's Artificial Water Level Fluctuation on Its Littoral Zone

The Landsat Satellite Imagery data used were pre-processed and orthorectified, using geodetic and elevation control data to correct for positional accuracy and relief displacement. A digital elevation model (DEM) of Lake Sevan shore was generated by overlaying of manually digitized elevation lines 1888m, 1893m and 1896m (depth contour lines 10m, 5m, 2m) – from maps of 1: 50 000 scale, produced in 1988 by the State Geodetic & Cartographic Institute, Moscow (former USSR) - to satellite image shoreline (elevation 1898m), extracted from satellite image ETM+ 2005 (channel 8 with 15m spatial resolution). From these, an offset of 1880 and a gain of 0.1 were obtained. Therefore, a DEM with 8 bit quantisation and a z-resolution of 0.1m was generated (Heblinski, 2007).

The elevation for each cell was calculated using the following equation:

Elevation = Offset + (Gain * DN)

Where Offset = 1880, Gain = 0.1 and DN = Digital Number of Cell.

The Depth was obtained from the following equation:

Depth = (Elevation – Shoreline elevation) * -1

Where shoreline elevation = 1898.

The Lake polygons for the various years assessed were obtained with the same methodologies described in section 3.2.2 above. For a pragmatic approach, the littoral zone was defined as shore areas with $0 \leq$ depth ≤ 10m in this project. Therefore, all records of the lake polygons which fell under this range were selected and saved as a littoral zone shapefile layer. Using ArcToolbox, this ‘Littoral Zone’ polygon is used to clip the Lake surface area polygon (Figure 19) for each year and the resulting polygon (Figure 20) is the actual littoral zone polygon for that particular year. This shapefile was then dissolved into a single polygon. The littoral zone area was then calculated using a VBA script (ESRI, 2004).

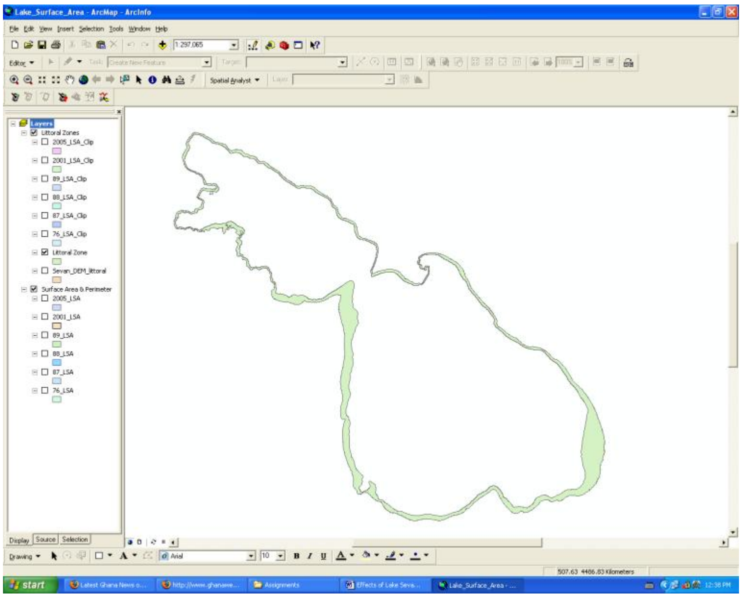


Figure 20: Resulted Littoral Zone polygon after clipping

3.2.4 Validation of Supervised Macrophyte Classification of QuickBird Satellite Data

The aim of validation is to check whether the vegetation classes assigned to both submersed and emersed macrophytes, the macrophyte species as well as their extent or vegetation patches were correctly recognised during the classification of the remote sensing data.

The validation of remote sensing classification quality was based on the comparison of the remote sensing data classification and the groundtruth measurements which were performed simultaneously (or very close) to the acquisition of the satellite data from 2006 to 2008. The macrophyte species were grouped into vegetation and growth types as shown in Table 5.

However, *Persicaria amphibia* which is a floating macrophyte was added to the submersed macrophytes. This is because the algorithms upon which the classifications are based separate the water areas (containing submersed macrophytes) from the non-water areas (containing emersed macrophytes). Therefore, when the leaves of *Persicaria amphibia* are covered with even a small amount of water, they are added to the water areas by the underlying algorithms.

Table 5: Groupings of Macrophytes into Vegetation and Growth Types used for the validations

Species	Species Author	Vegetation Type	Growth Type
Agrostis stolonifera	L.	Emersed	
Bolboschoenus maritimus	(L.) Palla	Emersed	
Carex disticha	Huds	Emersed	
Ceratophyllum demersum	L.	Submersed	Low
Chara spp.	L.	Submersed	Low
Cladophora spp.		Submersed	High
Cyperus spp.	L.	Emersed	
Hippuris vulgaris	L.	Submersed	High
Myriophyllum spicatum	L.	Submersed	High
Phragmites australis	(Cav.) Trin. Ex Steud.	Emersed	
Persicaria amphibia	(L.) Delarbre	Submersed	High
Potamogeton filiformis	Pers.	Submersed	High
Potamogeton pectinatus	L.	Submersed	High
Ranunculus circinatus	Sibth.	Submersed	High
Ranunculus spp.	L.	Submersed	High
Schoenoplectus lacustris	(L.) Palla	Emersed	
Schoenoplectus tabernaemontani	(C.C.Gmel.) Palla	Emersed	
Sparganium erectum	L.	Emersed	
Sparganium ramosum	Huds.	Emersed	
Typha angustifolia	L.	Emersed	
Typha latifolia	L.	Emersed	
Zannichellia palustris	L.	Submersed	Low

Source of species authors: (Werner, 1997; Erhardt et al., 2008; United States Department of Agriculture [USDA], 2010)

Using ArcGIS 9.1/9.2 software, statistics were generated from the classified ArcView / TIFF raster data for the regions Gavaraget, Tsovazard and Masrik. The rasters were then reclassified using ArcGIS extension Spatial Analyst, to combine classes or remove unwanted ones. They were then converted to GRID format for easier geoprocessing activities. Using ArcCatalog and ArcMap tools, shapefile polygons with their attribute table were created from the GPS points (from inaccessible areas during the field mapping). The same numeric values assigned to the reclassified macrophytes in the raster data were assigned to similar ones in the shapefiles. An example map of classified image overlaid by ground truth polygons for Gavaraget region is shown in Figure 21.

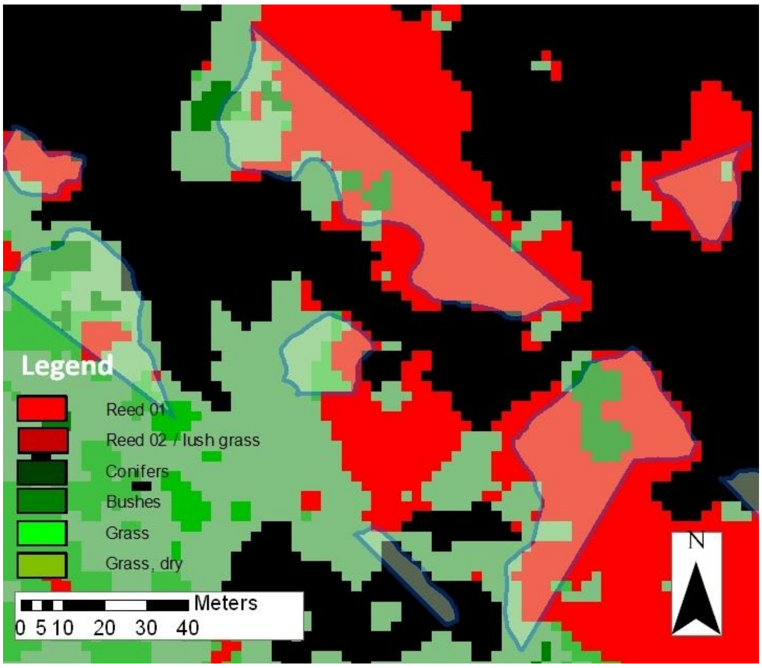


Figure 21: Mapped Reeds (blue outline) being compared with Classified Satellite Image using Spatial Analyst in ArcMap

The shapefiles which have similar boundary shapes with satellite imageries are shifted to align them with the imageries so as to correct spatial shifts and be realistic as possible. The shapefiles are rasterized and then compared to the classified data using Spatial Analyst. Error matrix (Congalton, 2004) and the kappa coefficient were calculated for each comparison using Microsoft Excel software.

3.2.4.1 Submersed Macrophytes

The validation for submersed macrophytes was done at two levels: vegetation type and growth type levels. At the vegetation type level, ‘Submersed’ and ‘No Vegetation’ polygons were created from the groundtruth polygons for each data set. At the growth type level, ‘High Growing’, ‘Low Growing’ and ‘No Vegetation’ polygons were created. The polygons / shapefiles were then converted to raster data format using ArcToolbox. The supervised classification received, revealed several classes as shown in Table 6.

Table 6: Classes of Supervised Classification of Submersed Macrophytes obtained

Vegetation type 1	Very low coverage (<30%) of low growing macrophytes (mainly *Chara* spp. and *Zannichellia palustris*) or very low coverage (<30%) of high growing macrophytes (*Potamogeton pectinatus*) mixed with bright sediments (>70%)
Vegetation type 2	Low coverage (ca. 30-70%) of low growing macrophytes (mainly *Chara* spp. and *Z. palustris*) mixed with bright sediments (ca. 30-70%)
Vegetation type 3	Dense coverage (>70%) of low growing (*Chara* spp. and *Z. palustris*) partly mixed with low coverage (<30%) of high growing (*P. pectinatus*)
Vegetation type 4	Dense coverage (>70%) of high growing (*P. pectinatus*)
Vegetation type 5	Low coverage (ca. 30-70%) of high growing (*P. pectinatus, Myriophyllum spicatum, Ceratophyllum demersum*) sometimes mixed with low coverages of low growing (*Chara* spp. and *Z. palustris,*) macrophytes or with dark sediments
Vegetation type 6	Muddy areas, low coverage (ca. 30-70%) of low growing (*Chara* spp. and *Z. palustris*) macrophytes, mixed with dark sediments, spiked with stumps of died off reed patches and/or trees, low water clarity
Sediment type 1	Very bright (white) sediments
Sediment type 2	Bright sediments
Sediment type 3	Dark sediments and gravel

Source: (Heblinski, 2008)

Sediment types 1-3 were reclassified into ‘No Vegetation’ for all the three levels of validation except 2008 species level of Gavaraget where only sediment types 1-2 were used. While Vegetation types 1-6 were reclassed into ‘Submersed’ at the vegetation type level, vegetation types 1-3 and 6 were grouped into ‘Low Growing’ and vegetation types 4-5 into ‘High Growing’ at the growth type level.

Each class from the groundtruth was compared to the same class in the classified data using Spatial Analyst and thereafter error matrix and kappa coefficient were calculated for each comparison for all levels of validation.

3.2.4.2 Emersed Macrophytes

Classification of terrestrial littoral areas revealed the classes: reed, bushes, dry bushes, broad- leafed trees, conifers, grassland, dry grassland, shrub area, two types of no vegetation coverage and a class of light sediments (Heblinski, 2008). Depending on the region of interest, different combinations of these classes were found as shown in Table 7.

Table 7: Land Cover Classes obtained from Supervised Classification of QuickBird Satellite Data

CLASS	Gavaraget	Tsovazard	Masrik
Reed	+	+	+
Reed / lush grass		+	
Bushes	+	+	+
Bushes (dry)	+		+
Broad-leaf trees	+		+
Conifers	+	+	+
Grassland	+	+	+
Grassland (dry)	+	+	+
Shrub area		+	
No vegetation (light)	+		
No vegetation (dark)	+		
No vegetation		+	+
Sediments (light)		+	

Source: Adapted from (Heblinski, 2008)

The above classes were reclassified into 'Reed' (Reed, Reed/lush grass), 'Bushes' (Bushes, Dry Bushes), 'Trees' (Broad-leaf trees, Conifers), 'Grasses' (Grassland, Dry Grassland, Shrub area) and 'No Vegetation' (all No vegetation, Light sediment) for the validation. Trees for the groundtruth were digitized on-screen from the unclassified remote sensing images. Each class from the classified remote sensing data was compared to the same class in the groundtruth after which error matrix and kappa coefficient were calculated for each result.

3.2.4.3 The Error Matrix

An error matrix (Congalton, 2004) is a square array of numbers organized in rows and columns that express the number of sample units (i.e. pixels, clusters of pixels, or polygons) assigned to a particular category relative to the actual category as indicated by the reference data. The columns typically represent the reference data and the rows indicate the map generated from the remotely sensed data as shown in Table 8: Example of the Error Matrix

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The diagonal entries represent correct classifications or agreement between the map and the reference data, and the off-diagonal entries represent misclassifications, or lack of agreement between the map and the reference data (Stehman and Czaplewski, 1998). Therefore, the error matrix of this project summarizes results comparing the reference field mapping (groundtruth) data to the classified QuickBird satellite images.

Table 8: Example of the Error Matrix

		Groundtruth Data			
		A	B	C	Row Totals
QuickBird Classification	A	AA	AB	AC	
	B	BA	BB	BC	
	C	CA	CB	CC	
	Column Totals				Sample Total

Accuracy parameters derived from the error matrix include overall accuracy, producer's accuracy, user's accuracy and the Kappa coefficient. The overall accuracy is computed by dividing the total correct (i.e. the sum of the major diagonal) by the total number of sample units in the error matrix. Traditionally, the division of the total number of correct sample units in a category by the total number of sample units of that category from the reference data (i.e. the column total) is termed the 'producer's accuracy'. This accuracy measure relates to the probability of a reference sample unit being correctly classified and is really a measure of omission error. On the other hand, if the total number of correct sample units in a category is divided by the total number of sample units that were classified into that category on the map (i.e. the row total), then this result is a measure of commission error. This measure is called 'user's accuracy' or reliability and is indicative o the probability that a sample unit classified on the map actually represents that category on the ground (Story and Congalton, 1986):

producer's accuracy [%] = 100% – *error of omission* [%]

user's accuracy [%] = 100% – *error of commission* [%]

Another measure of map accuracy is the kappa coefficient ($\hat{k}$), which is a measure of the proportional (or percentage) improvement by the classifier over a purely random assignment to classes. It shows the extent to which the correct values of an error matrix are due to "true" verses "chance" agreement. Alternatively, it's a measure of agreement that compares the observed agreement to agreement expected by chance if the observer ratings were independent. It also expresses the proportionate reduction in error generated by a classification process, compared with the error of a completely random classification

(Cohen, 1960; Munoz and Bangdiwala, 1997). This is computed by the following equations (Jensen, 1996; Sim and Wright, 2005):

$$\hat{k} = \frac{ObservedAgreement - ChanceAgreement}{1 - ChanceAgreement}$$

$$\hat{k} = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r}(x_{i+} \cdot x_{+i})}{N^2 - \sum_{i=1}^{r}(x_{i+} \cdot x_{+i})}$$

Where

r = # of rows, columns in error matrix

N = total # of observations in error matrix

X_{ii} = major diagonal element for class i

x_{i+} = total # of observations in row i (right margin)

x_{+i} = total # of observations in column i (bottom margin)

The Kappa coefficient also provides a basis for determining the statistical significance of any given classification matrix. According to Cohen (1960), kappa can be thought of as the chance-corrected proportional agreement, and possible values range from +1 (perfect agreement) via 0 (no agreement above that expected by chance) to -1 (complete disagreement). With these values as references, guidelines for interpreting the kappa were developed as shown in Table 9 below (Landis and Koch, 1977; Munoz and Bangdiwala, 1997; Viera and Garrett, 2005).

Table 9: Kappa Interpretation Guidelines of Landis and Koch

Kappa statistic	Strength of Agreement
<0	Poor
0.01 – 0.20	Slight
0.21 – 0.40	Fair
0.41 – 0.60	Moderate
0.61 – 0.80	Substantial
0.81 – 1.00	Almost Perfect

3.2.5 Landscape Metrics

To quantitatively characterize littoral vegetation structures, their diversity and their spatial distribution patterns landscape metrics (Blaschke, 2000; Woithon and Schmieder, 2004) were calculated using Patch Analyst 4.0 software which uses the Fragstats software interface. Therefore, the following applied spatial analysis indices and their definitions are those based on Fragstats and attributed to McGarigal et al. (2002).

3.2.5.1 Area Metrics

Class area (CA) is a measure of landscape composition; specifically, how much of the landscape is comprised of a particular patch type. CA equals the sum of the areas (m^2) of all patches of the corresponding patch type, divided by 10,000 (to convert to hectares); that is, total class area as shown in the equation below. In addition to its direct interpretive value, class area is used in the computations for many of the class and landscape metrics.

$$CA = \sum_{j=1}^{n} a_{ij} \left[\frac{1}{10{,}000}\right]$$

a_{ij} = area (m^2) of patch ij.

CA is greater than 0 and it is without limit.CA approaches 0 as the patch type becomes increasing rare in the landscape. CA = TA when the entire landscape consists of a single patch type; that is, when the entire image is comprised of a single patch (McGarigal et al., 2002).

Percentage of landscape (PLAND) quantifies the proportional abundance of each patch type in the landscape. Like total class area, it is a measure of landscape composition important in many ecological applications. PLAND equals the sum of the areas (m^2) of all patches of the corresponding patch type, divided by total landscape area (m^2) which includes any internal background present, multiplied by 100 (to convert to a percentage); in other words, PLAND equals the percentage the landscape comprised of the corresponding patch type as shown in the following equation:

$$PLAND = P_i = \frac{\sum_{j=1}^{n} a_{ij}}{A}(100)$$

P_i =proportion of the landscape occupied by patch type (class) i.

a_{ij} = area (m^2) of patch ij.

A = total landscape area (m^2).

Its range is $0 < PLAND \leq 100$. PLAND approaches 0 when the corresponding patch type (class) becomes increasingly rare in the landscape. PLAND = 100 when the entire landscape consists of a single patch type; that is, when the entire image is comprised of a single patch. However, because PLAND is a relative measure, it may be a more appropriate measure of landscape composition than class area for comparing among landscapes of varying sizes (McGarigal et al., 2002).

3.2.5.2 Edge Metrics

Edge density (ED) equals the sum of the lengths (m) of all edge segments involving the corresponding patch type, divided by the total landscape area (m^2), multiplied by 10,000 (to convert to hectares) as shown below.

$$ED = \frac{\sum_{k=1}^{m} e_{ik}}{A}(10{,}000)$$

e_{ik} = total length (m) of edge in landscape involving patch type (class) i; includes landscape boundary and background segments involving patch type i.

A = total landscape area (m^2).

ED is greater than or equal 0 and it is without limit. ED equals 0 when there is no class edge in the landscape; that is, when the entire landscape and landscape border, if present, consists of the corresponding patch type and the user specifies that none of the landscape boundary and background edge be treated as edge. *Edge density* facilitates comparison among landscapes of varying size since it reports edge length on a per unit area basis (McGarigal et al., 2002).

3.2.5.3 Patch Metrics

Patch density is a limited, but fundamental, aspect of landscape pattern. It expresses the number of patches per unit area. PD equals the number of patches of the corresponding patch type divided by total landscape area (m^2). To convert it to hectares, the result is multiplied by 10,000 and 100. It should be noted that the total landscape area (A) includes any internal background present.

$$PD = \frac{n_i}{A}(10000)(100)$$

n_i = number of patches in the landscape of patch type (class) i.

A = total landscape area (m^2).

PD which is greater than 0, is ultimately constrained by the grain size of the raster image, because the maximum PD is attained when every cell is a separate patch. Therefore, ultimately cell size will determine the maximum number of patches per unit area (McGarigal et al., 2002).

3.2.5.4 Shape Metrics

Shape index (SHAPE) equals patch perimeter (given in number of cell surfaces) divided by the minimum perimeter (given in number of cell surfaces) possible for a maximally compact patch (in a square raster format) of the corresponding patch area.

$$SHAPE = \frac{P_{ij}}{min_{P_{ij}}}$$

p_{ij} = perimeter of patch ij in terms of number of cell surfaces.

min p_{ij} = minimum perimeter of patch ij in terms of number of cell surfaces.

SHAPE is greater than or equal to 1 and has no limit. SHAPE equals 1 when the patch is maximally compact (i.e., square or almost square) and increases without limit as patch shape becomes more irregular. *Shape index* corrects for the size problem of the perimeter-area ratio index by adjusting for a square (or almost square) standard and, as a result, is the simplest and perhaps most straightforward measure of overall shape complexity (McGarigal et al., 2002).

3.2.5.5 Diversity Metrics

Shannon's diversity index (SHDI) equals minus the sum, across all patch types, of the proportional abundance of each patch type multiplied by that proportion.

$$SHDI = -\sum_{i=1}^{m}(P_i * lnP_i)$$

P_i =proportion of the landscape occupied by patch type (class) i.

It is noted that P_i is based on total landscape area (A) excluding any internal background present.

SHDI is greater than or equal to 1 and has no limit. SHDI equals 0 when the landscape contains only 1 patch (i.e., no diversity). SHDI increases as the number of different patch types (i.e., patch richness, PR) increases and/or the proportional distribution of area among patch types becomes more equitable. *Shannon's diversity index* is a popular measure of diversity in community ecology, applied here to landscapes. Shannon's index is somewhat more sensitive to rare patch types than Simpson's diversity index (McGarigal et al., 2002).

3.2.5.6 Contagion and Interspersion Metrics

Contagion (CONTAG) measures the extent to which patch types are aggregated or clumped (i.e., dispersion). It quantifies both patch type interspersion (i.e., the intermixing of units of different patch types) as well as patch dispersion (i.e., the spatial distribution of a patch type) at the landscape level. Contagion measures dispersion in addition to patch type interspersion because cells, not patches, are evaluated for adjacency. Landscapes consisting of large, contiguous patches have a majority of internal cells with like adjacencies. In this case, contagion is high because the proportion of total cell adjacencies comprised of like adjacencies is very large and the distribution of adjacencies among edge types is very uneven. All other things being equal, a landscape in which the patch types are well interspersed will either have lower contagion than a landscape in which patch types are poorly interspersed or higher values of contagion may result from landscapes with a few large, contiguous patches, whereas lower values generally characterize landscapes with many small and dispersed patches (McGarigal et al., 2002).

Contagion has the following range: $0 < \text{CONTAG} \leq 100$. CONTAG approaches 0 when the patch types are maximally disaggregated (i.e., every cell is a different patch type) and interspersed (equal proportions of all pairwise adjacencies). CONTAG equals 100 when all patch types are maximally aggregated; i.e., when the landscape consists of single patch. CONTAG is undefined and reported as “N/A” in the “basename”.land file if the number of patch types is less than 2, or all classes consist of one cell patches adjacent to only background (McGarigal et al., 2002).

Interspersion and juxtaposition index (IJI) measures the extent to which patch types are interspersed (not necessarily dispersed); higher values result from landscapes in which the patch types are well interspersed (i.e., equally adjacent to each other), whereas lower values characterize landscapes in which the patch types are poorly interspersed (i.e., disproportionate distribution of patch type adjacencies). It is the observed interspersion over the maximum possible interspersion for the given number of patch types (McGarigal et al., 2002).

Interspersion and juxtaposition index is based on patch adjacencies, not cell adjacencies like the contagion index. As such, it does not provide a measure of class aggregation like the contagion index, but rather isolates the interspersion or intermixing of patch types. Each patch is evaluated for adjacency with all other patch types; like adjacencies are not possible because a patch can never be adjacent to a patch of the same type. The interspersion index is not directly affected by the number, size, contiguity, or dispersion of patches per se, as is the contagion index. Like the contagion index, the interspersion index is a relative index that represents the observed level of interspersion as a percentage of the maximum possible given the total number of patch types. The range is given as $0 < IJI \leq 100$. IJI approaches 0 when the distribution of adjacencies among unique patch types becomes increasingly uneven. IJI equals 100 when all patch types are equally adjacent to all other patch types (i.e., maximum interspersion and juxtaposition). IJI is undefined and reported as "N/A" in the "basename".land file if the number of patch types is less than 3 (McGarigal et al., 2002).

It is important to note the differences between the contagion index and the interspersion and juxtaposition index. Contagion is affected by both interspersion and dispersion. The interspersion and juxtaposition index, in contrast, is affected only by patch type interspersion and not necessarily by the size, contiguity, or dispersion of patches. Thus, although often indirectly affected by dispersion, the interspersion and juxtaposition index directly measures patch type interspersion, whereas contagion measures a combination of both patch type interspersion and dispersion. In addition, contagion and interspersion are typically inversely related to each other. Higher contagion generally corresponds to lower interspersion and vice versa. Finally, in contrast to the interspersion and juxtaposition index, the contagion index is strongly affected by the grain size or resolution of the image. Given a particular patch mosaic, a smaller grain size will result in greater contagion because of the proportional increase in like adjacencies from internal cells. The interspersion and juxtaposition index is not affected in this manner because it considers only patch edges. This scale effect should be carefully considered when attempting to compare results from different studies (McGarigal et al., 2002).

3.2.6 Habitat Modelling

Modelling habitats of species play crucial role in the sustainable management of such resources. These models are characterised by a combination of abiotic and biotic parameters that are suitable for supporting and sustaining those species populations during all stages of their life cycles. A multi-parameter GIS model that includes processing and integration of expert knowledge, literature and structural measures (shape, edge) was applied (Woithon and Schmieder, 2004).

A habitat model was built separately for fishes and birds each. The Crucian Carp (*Carassius auratus Gibelio Bloch*) was chosen as lead species for the fish habitat based on expert knowledge on Lake Sevan (Rubenyan and Hayrapetyan, 2008). For the bird habitat model, the Common Coot (*Fulica atra*) and the Great Crested Grebe (*Podiceps cristatus*) were chosen (Aghababyan and Ananian, 2008).

One of the important factors used was the depth model. The QuickBird raster depth model (Heblinski, 2008) received showed only the height of the water column of the surface of the lake to the top of the macrophytes or to the bottom of the lake (when there were only sediments). Again, the depth values were scaled as follows: for cell values (DN) ≤ 200, the scale was 0.1 m and cell values (DN) > 200, it was 1.0 m (Heblinski, 2008). Therefore, adjustments had to be done to get the real elevation model. First, the depth values were calculated as using the following equations:

Cell values (DN) ≤ 200, Depth = DN * 0.1 m

Cell values (DN) > 200, Depth = [(200 * 0.1) + (DN – 200)] m

Second, shapefiles of supervised classifications of submersed and emersed-only macrophytes in the regions of interest were joined spatially (pixel to pixel) to the depth model shapefile using ArcToolbox. Comparing groundtruth depth data to the depth model, various adjustments were made to the depth model depending on the type of vegetation cover as shown in Table 10: Depth Model Adjustments applied with respect to Vegetation Types to reduce depth model errors

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Table 10: Depth Model Adjustments applied with respect to Vegetation Types to reduce depth model errors

	Vegetation Type	Adjustment (m)
Submersed Macrophytes	Vegetation 1	0
	Vegetation 2	0
	Vegetation 3	+ 0.05
	Vegetation 4	+ 0.20
	Vegetation 5	+ 0.15
	Vegetation 6	+ 0.10
No vegetation	Sediment / No vegetation	0
Emersed Macrophytes	Reeds	+ 0.60

Using an SQL in the depth model attribute data, submersed or emersed was selected and the appropriate adjustment made to the depth value. Where both emersed and submersed existed, the former value was used for the correction. The depth model shapefile was then converted back to raster based on the depth value as a Digital Elevation Model (DEM). Thus, DEMs were generated for each year and each region with respect to their respective water levels.

3.2.6.1 Modelling Habitat of Crucian Carp (*Carassius* spp.)

Since both submersed and emersed macrophytes are used by the Crucian Carp as spawning, refuge and feeding sites, emphasis was put on their morphological and vegetation structures to serve as criteria for the assessment of the ecological habitat quality (Woithon et al., 2004; Rubenyan and Hayrapetyan, 2008).

Using the following criteria based on specialist knowledge (Rubenyan and Hayrapetyan, 2008) and a similar project done on Lake Constance (Woithon et al., 2004), habitat analyses were done in a GIS environment:

- Littoral areas with depth values greater than 0 and less than or equal to 3
- Littoral areas with submersed and / or emersed vegetation
- Littoral areas with high vertical structural diversity of macrophytes
- Littoral areas with macrophytes having many bays at their edges

Depth values greater than 0 and less than or equal to 3 were selected from the DEM and saved as a new layer (DEM_3). From the supervised classifications, submersed and emersed vegetations were mosaicked into one raster (MOS_VEG) for each year and each region. Separate masks created for submersed and emersed for each region during the landscape metrics (section 3.2.5) were merged into one, and used to mask the mosaicked submersed and emersed vegetations (Mask_MOS_VEG). Again, DEM_3 was used to mask the result to get Mask2_ MOS_VEG.

Mask2_ MOS_VEG raster was then converted to a shapefile and a new long integer field 'class' is equated to the field 'ID' was added to the attribute data. In order to quantify macrophytes with many bays at their edges and those with high vertical structural diversity, shape indices (SI) and edge densities (ED) for Mask2_MOS_VEG shapefile were calculated respectively using the spatial statistics option under Patch Analyst 4.0 and saved as Mask2_MOS_VEG_SI_ED shapefile. Since the ED was stored in an info table, it was joined to the shapefile using ArcToolbox. Two separate raster files were created from this shapefile based on the SI and ED fields with filenames MOS_VEG_SI and MOS_VEG_ED respectively. DEM_3, MOS_VEG_SI and MOS_VEG_ED rasters were reclassified on a scale of 1 (minimum) to 10 (maximum) using the method 'natural breaks of Jenks'. While water depth and edge structure of macrophytes play crucial roles in spawning (Rubenyan and Hayrapetyan, 2008) and refuge (Petr, 2000) respectively for the crucial carp, macrophyte patches with many bays provide escape routes during predator attacks (Petr, 2000). Therefore, using the raster calculator and weighting in Spatial Analyst, the Habitat Suitability Index (HSI) was calculated as follows:

HSI = (DEM_3 * 0.35) + (MOS_VEG_SI * 0.30) + (MOS_VEG_ED * 0.35)

The HSI was reclassified into five classes or categories as shown in Table 11.

Table 11: Reclassified Fish Habitat Suitability Index (HSI) into Five Categories

Scale	Class / Categories
1 - 2	Very Poor
3 - 4	Poor
5 - 6	Average
7 - 8	Good
9 - 10	Very Good

Figure 22 below summarises the entire modelling process of the HSI.

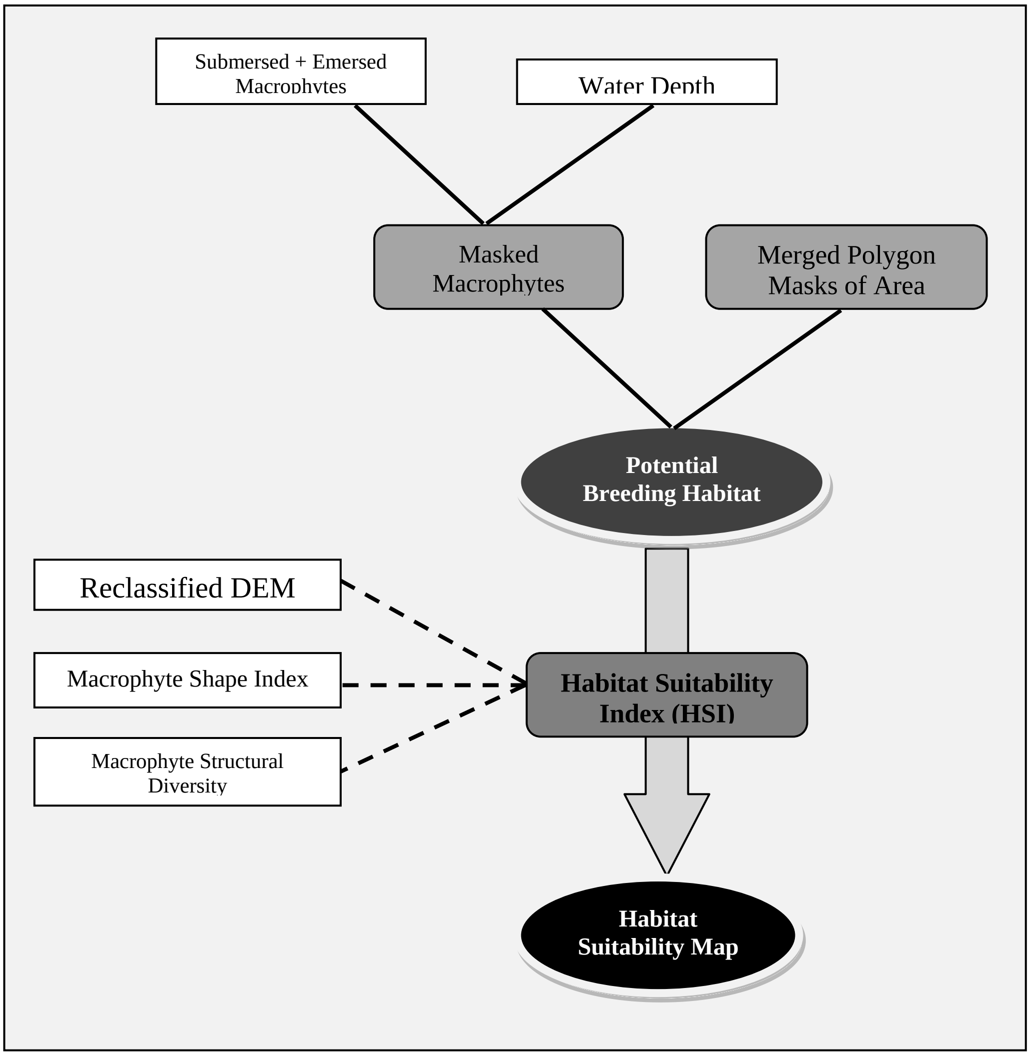

Figure 22: Modelling Steps for Habitat Suitability Map Generation of the Crucian Carp. Factors included were DEM, Shape Index and Structural Diversity of the macrophytes

3.2.6.2 Modelling Habitat of Common Coot (*Fulica atra*) and Great Crested Grebe (*Podiceps cristatus*)

Both the Common Coot and the Great Crested Grebe use reed (emersed macrophytes) as shelter, nesting place, nest material and food searching sites. In addition, reeds serve as a food source for the Common Coot (Aghababyan and Ananian, 2008). Therefore, the vegetation structures play more decisive role than the taxonomical composition when a bird chooses its nest (Woithon et al., 2004). Based on the expert knowledge (Özesmi and Mitsch, 1997; Aghababyan and Ananian, 2008), the following criteria were used in modelling the habitats of these two birds in a GIS environment:

- Emersed macrophytes with depth values less than or equal to 1.5 m
- Littoral areas with high vertical structural diversity of emersed macrophyte
- Littoral areas with emersed macrophytes having many bays at their edges
- Emersed macrophytes with high stem vitality

Depth values less than or equal to 1.5 m are selected from the DEM and saved as a new layer (DEM_15). From the supervised classifications, emersed vegetation rasters were selected and saved as VEG_EM for each year and each region. An emersed mask created for each region during the landscape metrics (section 3.2.5) was used to mask the emersed vegetations to get Mask_VEG_EM. Further, DEM_15 was used to mask the result to get Mask2_VEG_EM.

Mask2_ VEG_EM raster was then converted to a shapefile and a new long integer field 'class' is equated to the field 'ID' was added to the attribute data. In order to quantify emersed macrophytes with many bays at their edges and those with high vertical structural diversity, shape indices (SI) and edge densities (ED) for Mask2_VEG_EM shapefile were calculated respectively using Patch Analyst 4.0 and saved as Mask2_VEG_EM_SI_ED shapefile. Since the ED was stored in an info table, it was joined to the shapefile using ArcToolbox. Two separate raster files were created from this shapefile based on the SI and ED fields with filenames VEG_EM_SI and VEG_EM_ED respectively. The stem vitality (Vitality Index-VI) was quantified by directly reclassifying the emersed macrophyte probabilities or *Red Edge* slope of the remote sensing product (Wallin et al., 1992; Osborne et al., 2001; Woithon et al., 2004). DEM_15, VEG_EM_SI, VEG_EM_ED and VI rasters were reclassified on a scale of 1 (minimum) to 10 (maximum) using the method 'natural breaks of Jenks'. The *Shape* and *Vitality Indices* were highly weighted, because these respective factors provide approach paths (Woithon et al., 2004; Aghababyan, 2008) and bird nest support (Aghababyan, 2008) and must be regarded as particularly important when the Common Coot or Great Crested Grebe chooses its breeding site. Macrophyte edge structure also gives protective cover for bird nests and hatchlings (Aghababyan, 2008). Hence, using the raster calculator and weighting in Spatial Analyst, the Habitat Suitability Index (HSI) was derived as follows:

HSI = (DEM_15 * 0.10) + (VEG_EM_SI * 0.40) + (VEG_EM_ED * 0.20) + (VI * 0.30)

The HSI was reclassified into five classes or categories as shown in Table 12: Reclassified Bird Habitat Suitability Index (HSI) into Five Categories

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Table 12: Reclassified Bird Habitat Suitability Index (HSI) into Five Categories

Scale	Class / Categories
1 - 2	Very Poor
3 - 4	Poor
5 - 6	Moderate
7 - 8	Good
9 - 10	Very Good

Figure 23 below summarises the entire modelling process of the HSI.

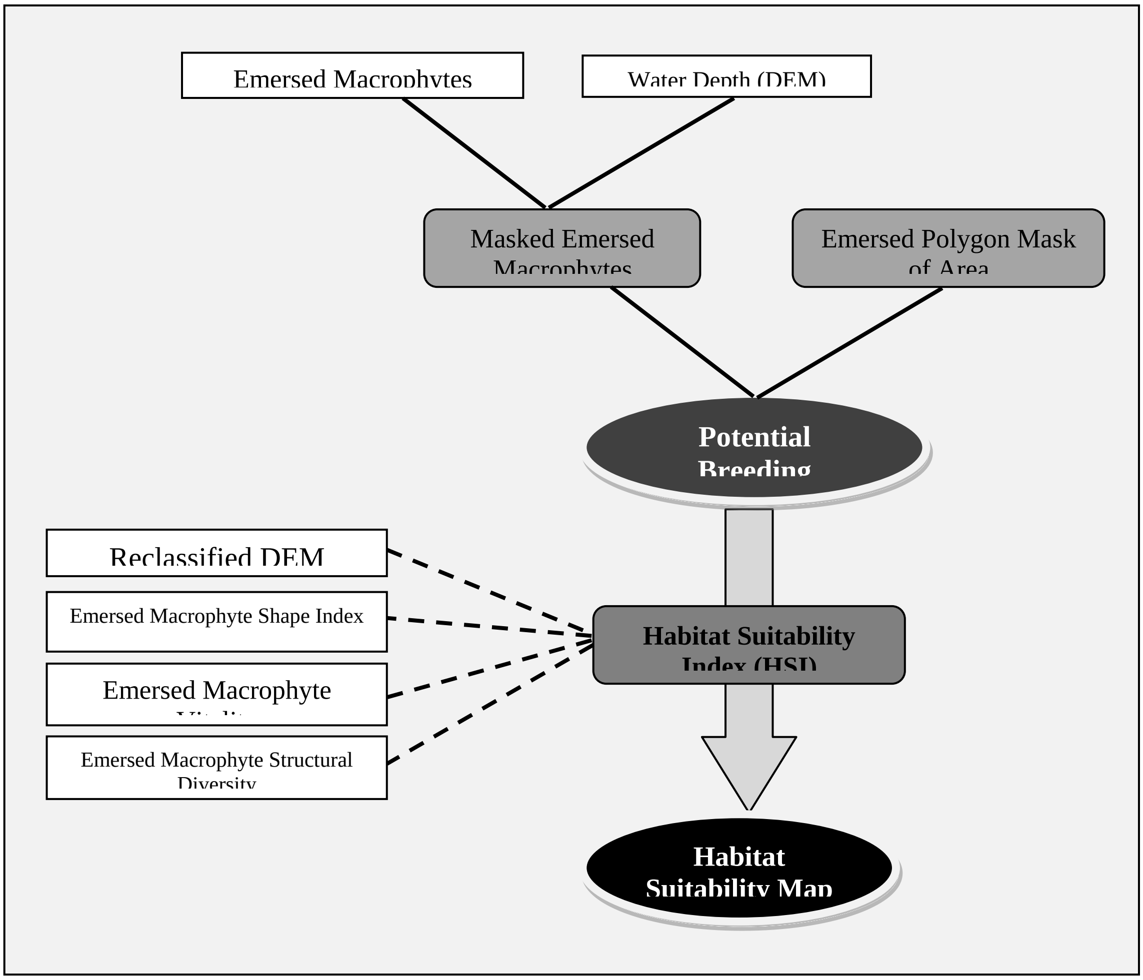

Figure 23: Modelling Steps for Habitat Suitability Map Generation of the Common Coot (*Fulica atra*) and the Great Crested Grebe (*Podiceps cristatus*). Criteria used included DEM, Shape Index, Vitality Index and Structural Diversity of the emersed macrophytes

3.2.6.3 Validation of Bird Habitat Model

Five GPS points (2 for Gavaraget and 3 for Masrik) of bird survey areas were obtained from the SEMIS project (Aghababyan and Ananian, 2008). Since the survey radius was 400 m, a 400 m buffer was created for each point using the ArcToolbox. The buffered points were masked by each area's mask used for the habitat model. The field habitat indices obtained by Aghababyan and Ananian (2008) were compared with combinations of the modelled habitat indices by intersecting the masked buffers with the modelled habitat areas (Table 13). The combinations of the modelled habitat indices were based on the quality of the habitat areas in reference to the habitat definitions provided by bird survey team.

Table 13: Field Habitat Suitability Indices of Birds compared to Modelled Habitat Suitability Indices for validation

Field_HSI	Definition	Modelled_HSI
0	No macrophytes	
1	Macrophytes cover less than 30% of shore	1-2
2	Macrophytes cover 30 to 60% of shore and there are some in water	3
3	Macrophytes cover over 60% of shore and less than 30% of water	4 - 5
4	Macrophytes cover over 60% of shore and over 30% of water	5

CHAPTER FOUR

4.0 RESULTS

4.1 Assessment of the Historical Development of Lake Surface Area

In 1933, the surface area of Lake Sevan was 1416 km^2 but had been reduced drastically over the years till 1976 (Figure 24). There was also another general decrease from 1988 to 2001. The lowest level of the lake's surface was found to be 1234.2 km^2 in 2001. However, there had been a general increase from 2002 to 2009 except 2006.

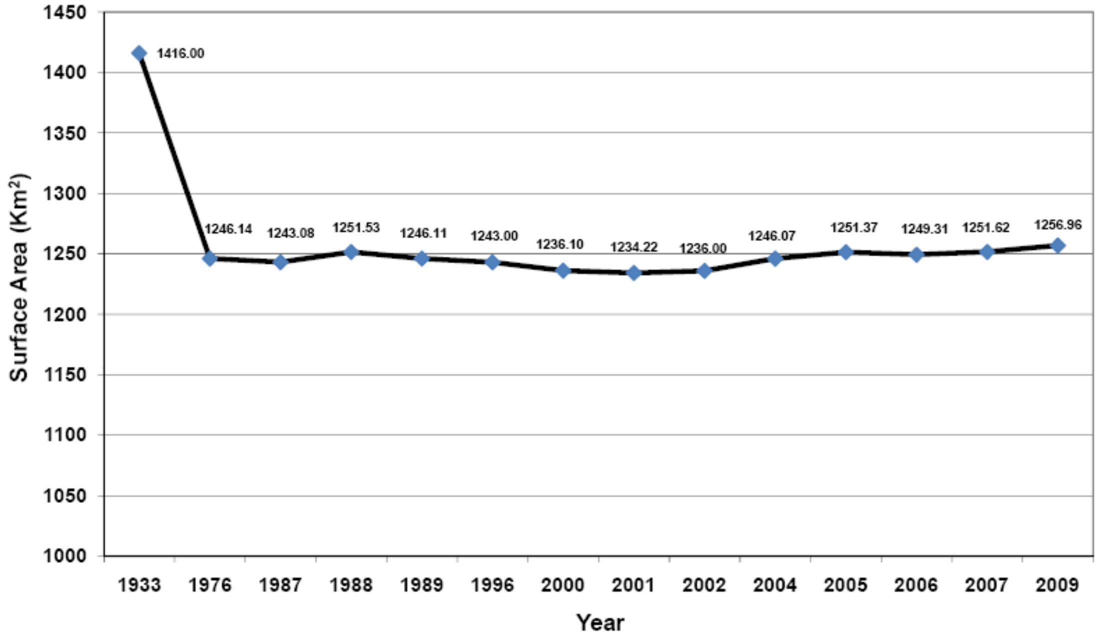

Figure 24: Surface Area Development of Lake Sevan (1933-2009). Drastic changes occurred between 1933 and 1976

By 1976, about 177.6 Km^2 of Lake Sevan's surface area had been lost (Figure 25). There were slight increases in the surface area in the following years. At the end of 1988, a surface area of about 13 Km^2 had been gained. However, this gain was short-lived since a surface area of 5 Km^2 was lost the following year, 1989. This loss continued till the year 2001 which registered the largest surface area loss of about 181.8 Km^2. However, there had been surface area gain from 2002 onwards and the largest gain being about 10 Km^2 in 2004.

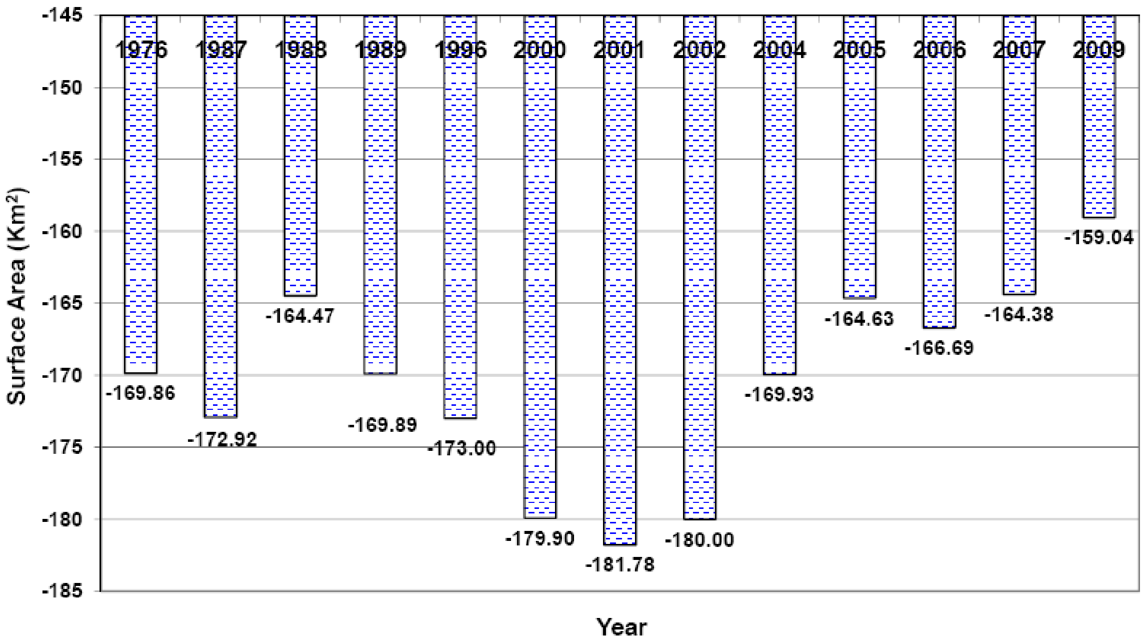

Figure 25: Surface Area Gain / Loss of Lake Sevan with respect to its Original Level in the last Decades. Most of the lake outflow was used for irrigation and power generation resulting in massive losses

4.2 Effects of Lake Sevan's Artificial Water Level Fluctuation on Its Littoral Zone

Whiles there was a decrease of about 1.9% of littoral zone between 1976 and 1987, there was an increase of 5.6% from 1987 to 1988. Again, there was a general reduction of the littoral zone from 1988 to 2001. The year 2001 registered the lowest littoral zone area of about 105.45 km^2 between 1976 and 2005. Also, when compared to the base year of 1976, 2001 had the largest littoral zone loss of 7.44 % (Figure 26). A tremendous increase of 15.4% occurred between 2001 and 2005.

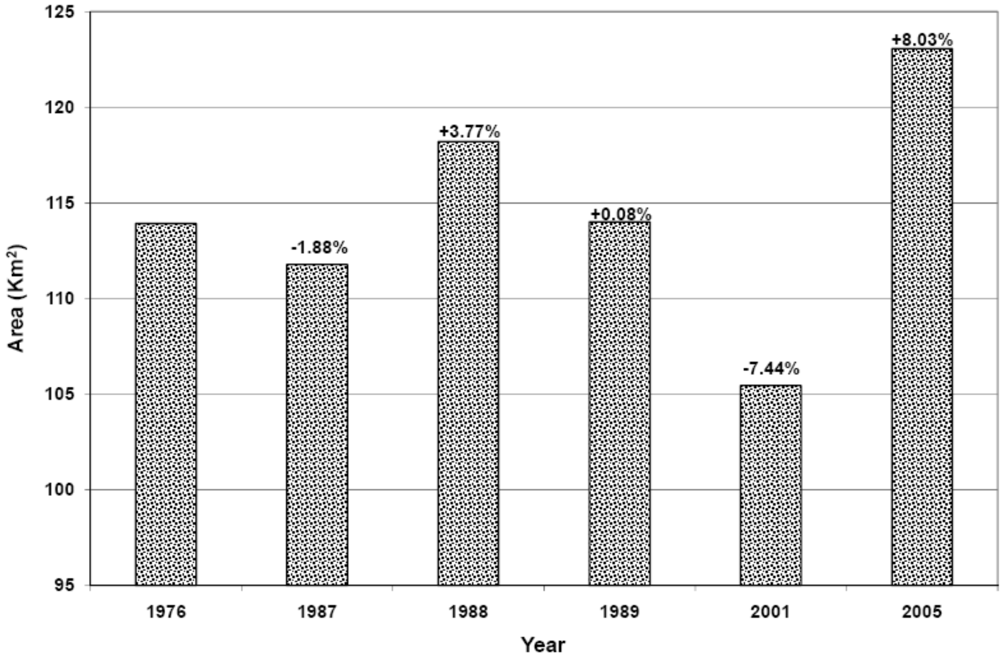

Figure 26: Lake Sevan's Littoral Zone Area development from 1976 to 2005 as a result of the artificial water level fluctuations. 1976 was used as the base year for the percentage calculations.

There was a strong correlation between the Sevan's littoral zone area and the Lake's surface area as an increase in the surface area corresponded to an increase in the littoral zone as seen in Figure 27. This was emphasized by the strong coefficient of determination of 0.90 of the linear regression.

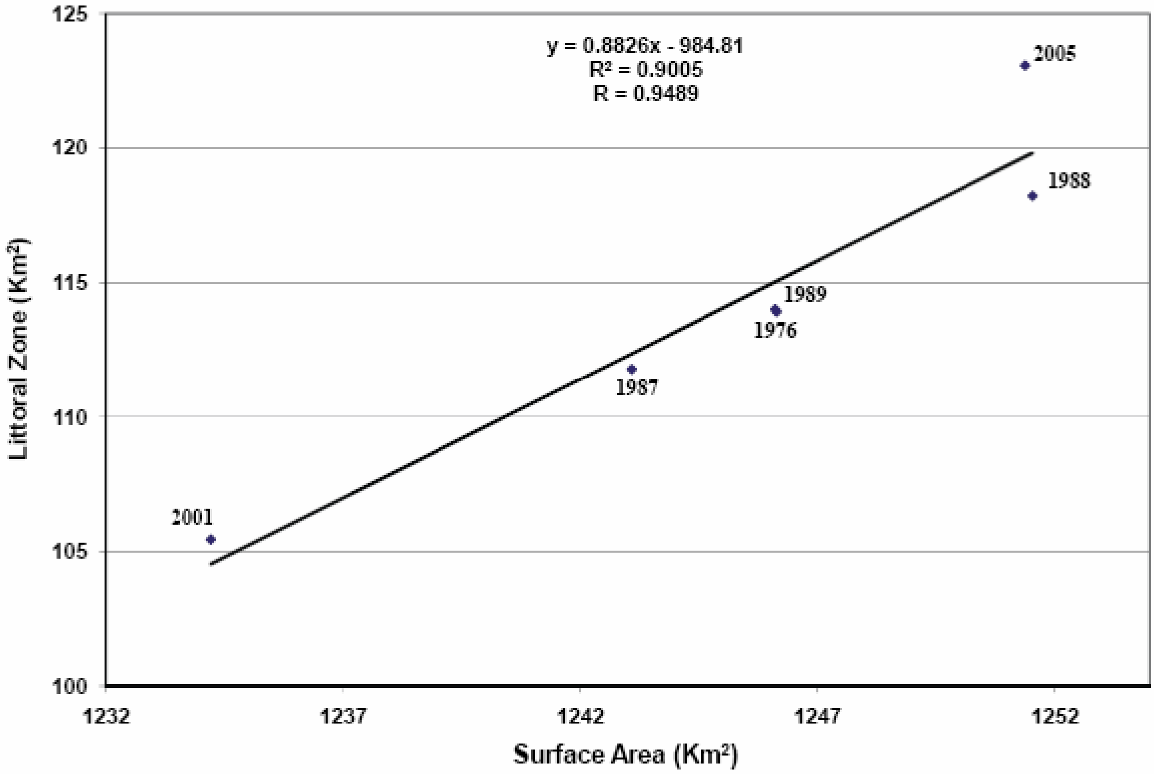

Figure 27: Littoral Zone Area versus Surface Area of Lake Sevan (1976-2005)

4.3 Validation of Supervised Macrophyte Classification of QuickBird Satellite Data

The pixel sizes used for all the validations for 2006 & 2007 and 2008 were 2.8 m and 2.4 m respectively.

4.3.1 Submersed Macrophytes

4.3.1.1 Vegetation Type Level

The user accuracies of submersed macrophytes for all three years in all the three regions of interest (ROI) were very high (>86%) (
Tables 14). However, that of 'No Vegetation' for 2006 and 2007 ranged between 72% and 75%, and for 2008, the user accuracy was only average (55%). Although the producer accuracies of submersed macrophytes in 2006 and 2008 were high, that of 2007 was the highest (87%). The producer accuracies of 'No Vegetation' class for the three years were high, with values ranging from 84% to 89%. While 2007 had the highest overall accuracy of 88%, those of 2006 and 2008 were not more than 79%. The Kappa statistics indicated moderate and substantial agreements between the classified satellite image and the groundtruth data for 2006 & 2008 and 2007 respectively.

Tables 14: Error matrices of submersed macrophytes at the vegetation type level for all Regions of Interests (values represent number of pixels) from 2006 to 2008. User, Producer and Overall accuracies are presented as well as the Kappa coefficients for each year

(a) 2006 Submersed Macrophyte Validation				
	Groundtruth data			
Classified Data	Submersed	No vegetation	Total	**User Accuracy**
Submersed	1198	183	1381	**86.75**
No vegetation	369	929	1298	**71.57**
Total	1567	1112	2679	
Producer Accuracy	**76.45**	**83.54**		
Overall Accuracy	**79.40**			
Kappa	**0.59**			

(b) 2007 Submersed Macrophyte Validation				
	Groundtruth data			
Classified Data	Submersed	No vegetation	Total	**User Accuracy**
Submersed	3175	173	3348	**94.83**
No vegetation	481	1427	1908	**74.79**
Total	3656	1600	5256	
Producer Accuracy	**86.84**	**89.19**		
Overall Accuracy	**87.56**			
Kappa	**0.72**			

(c) 2008 Submersed Macrophyte Validation				
	Groundtruth data			
Classified Data	Submersed	No vegetation	Total	**User Accuracy**
Submersed	4770	300	5070	**94.08**
No vegetation	1861	2308	4169	**55.36**
Total	6631	2608	9239	
Producer Accuracy	**71.93**	**88.50**		
Overall Accuracy	**76.61**			
Kappa	**0.51**			

4.3.1.2 Growth Type Level

The user accuracies for the ‘No Vegetation’ class for the investigated period were average ranging between 55% and 63% (Tables 15). The user accuracies for ‘Low Growing’ macrophytes for the same period were quite low (< 39%). However, for the ‘High Growing’ macrophytes, apart from 2006 which had a user accuracy of 69%, those of 2007 and 2008 were very high (>92%). While the ‘No Vegetation’ class had high producer accuracies (>84%) for all the three years, those of ‘Low Growing’ and ‘High Growing’ macrophytes were less than 67%. The highest overall accuracy was obtained in 2007 (70%) followed by 2006 (55%) and 2008 (48%). Nonetheless, there were fair and moderate agreements between the classified remote sensing image and the ground mapped macrophytes for 2006 & 2008 and 2007 respectively.

Tables 15: Error matrices of submersed macrophytes at the Growth type level for all Regions of Interests (values represent number of pixels) from 2006 to 2008. User, Producer and Overall accuracies are presented as well as the Kappa coefficients for each year

(a) 2006 Submersed Macrophyte Growth Type Validation					
	Groundtruth data				
Classified Data	No Vegetation	Low Growing	High Growing	Total	**User Accuracy**
No vegetation	927	115	574	1616	**57.36**
Low Growing	159	348	397	904	**38.50**
High Growing	22	307	716	1045	**68.52**
Total	1108	770	1687	3565	
Producer Accuracy	**83.66**	**45.19**	**42.44**		
Overall Accuracy	**55.85**				
Kappa	**0.34**				

(b) 2007 Submersed Macrophyte Growth Type Validation					
	Groundtruth data				
Classified Data	No Vegetation	Low Growing	High Growing	Total	**User Accuracy**
No vegetation	1430	296	557	2283	**62.64**
Low Growing	155	451	592	1198	**37.65**
High Growing	15	177	2355	2547	**92.46**
Total	1600	924	3504	6028	
Producer Accuracy	**89.38**	**48.81**	**67.21**		
Overall Accuracy	**70.27**				
Kappa	**0.52**				

(c) 2008 Submersed Macrophyte Growth Type Validation					
	Groundtruth data				
Classified Data	No Vegetation	Low Growing	High Growing	Total	**User Accuracy**
No vegetation	2308	393	1468	4169	**55.36**
Low Growing	278	808	2597	3683	**21.94**
High Growing	22	43	1322	1387	**95.31**
Total	2608	1244	5387	9239	
Producer Accuracy	**88.50**	**64.95**	**24.54**		
Overall Accuracy	**48.04**				
Kappa	**0.29**				

4.3.2 Emersed Macrophytes

Table 16), Reeds were highly correctly mapped by the field measurements resulting in very high user accuracies (>94%). However, this accuracy was reduced to 78% in 2008 (Table 16c). The other classes had user accuracies of less than 54% in both years except Grasses which had 87% in 2007. In 2006, apart from Reeds and No Vegetation classes which had producer accuracies of more than 69%, the rest had low producer accuracies of less than 54%. There were a lot of misclassifications among the other classes in 2006 resulting in an average overall accuracy of 63%. Nonetheless, there was a moderate agreement between the classified data and the groundtruth data. In 2007, apart from the Bushes class, which had average producer accuracy (53%), the rest had producer accuracies higher than 72%. 2007 had the best results of an overall accuracy of 76% and a moderate agreement between the remote sensing classification and the field measurements.

2008 had the worst results with an overall accuracy of 33%. The user and producer accuracies of all the classes except Reeds (user accuracy) and No Vegetation (producer accuracy) fell below 41% (Table 16c). There were high levels of misclassifications among the classes resulting in a slight agreement of the classified remote sensing data with that of the field measurements.

Table 16: Error matrices of emersed macrophytes for all Regions of Interests (values represent number of pixels) from 2006 to 2008. User, Producer and Overall accuracies are presented as well as the Kappa coefficients for each year

(a) 2006 Emersed Macrophyte Validation							
	Groundtruth data						
Classified Data	Reeds	Bushes	Trees	Grasses	No Vegetation	Total	**User Accuracy**
Reeds	5452	200	104	10	14	5780	**94.33**
Bushes	723	476	204	47	5	1455	**32.71**
Trees	328	24	248	5	0	605	**40.99**
Grasses	1257	179	104	936	147	2623	**35.68**
No Vegetation	93	12	28	1209	972	2314	**42.01**
Total	7853	891	688	2207	1138	12777	
Producer Accuracy	**69.43**	**53.42**	**36.05**	**42.41**	**85.41**		
Overall Accuracy	**63.27**						
Kappa	**0.44**						

(b) 2007 Emersed Macrophyte Validation							
	Groundtruth data						
Classified Data	Reeds	Bushes	Trees	Grasses	No Vegetation	Total	**User Accuracy**
Reeds	7069	140	165	77	27	7478	**94.53**
Bushes	1632	307	17	1	0	1957	**15.69**
Trees	510	12	514	0	16	1052	**48.86**
Grasses	47	117	3	1595	75	1837	**86.83**
No Vegetation	0	0	0	274	315	589	**53.48**
Total	9258	576	699	1947	433	12913	
Producer Accuracy	**76.36**	**53.30**	**73.53**	**81.92**	**72.75**		
Overall Accuracy	**75.89**						
Kappa	**0.56**						

(c) 2008 Emersed Macrophyte Validation							
	Groundtruth data						
Classified Data	Reeds	Bushes	Trees	Grasses	No Vegetation	Total	**User Accuracy**
Reeds	2319	388	162	63	50	2982	**77.77**
Bushes	2472	334	375	53	61	3295	**10.14**
Trees	655	72	285	11	33	1056	**26.99**
Grasses	61	48	51	189	119	468	**40.38**
No Vegetation	2076	187	52	1962	1358	5635	**24.10**
Total	7583	1029	925	2278	1621	13436	
Producer Accuracy	**30.58**	**32.46**	**30.81**	**8.30**	**83.78**		
Overall Accuracy	**33.38**						
Kappa	**0.16**						

4.4 Landscape Metrics

4.4.1 Submersed Macrophytes

4.4.1.1 Gavaraget

Area Metrics

There was an increase in the coverage areas of Vegetation classes 3 to 6 in 2007 when compared with those of 2006 (Figures 28-29, 31). However, Vegetation 1 (VEG 1) disappeared in the following years. Whiles Vegetation 2 (VEG 2) and No Vegetation (NVC) classes decreased slightly, No Data class (NDC) did so tremendously in 2007. Apart from Vegetation 2 (VEG 2) and No Vegetation classes which increased astronomically, the rest of the Vegetation classes reduced in area coverage in 2008 (Figures 30-31). Whiles VEG 2 gained about 137 ha, the NVC had 129 ha.

Considering the Vegetation classes, Vegetation 4 (VEG 4) - 19.9% and Vegetation 3 (VEG 3) – 10.4% dominated the landscape in 2006 (see PLAND in Table 17). This changed in 2007 with VEG 4 (36.7%) and VEG 5 (18.2%) dominating. However, VEG 2 became the dominant vegetation cover in the last year with 39.9% of the landscape area. There was a gradual recovery of the total landscape area from 2006 to 2008 (Table 18).

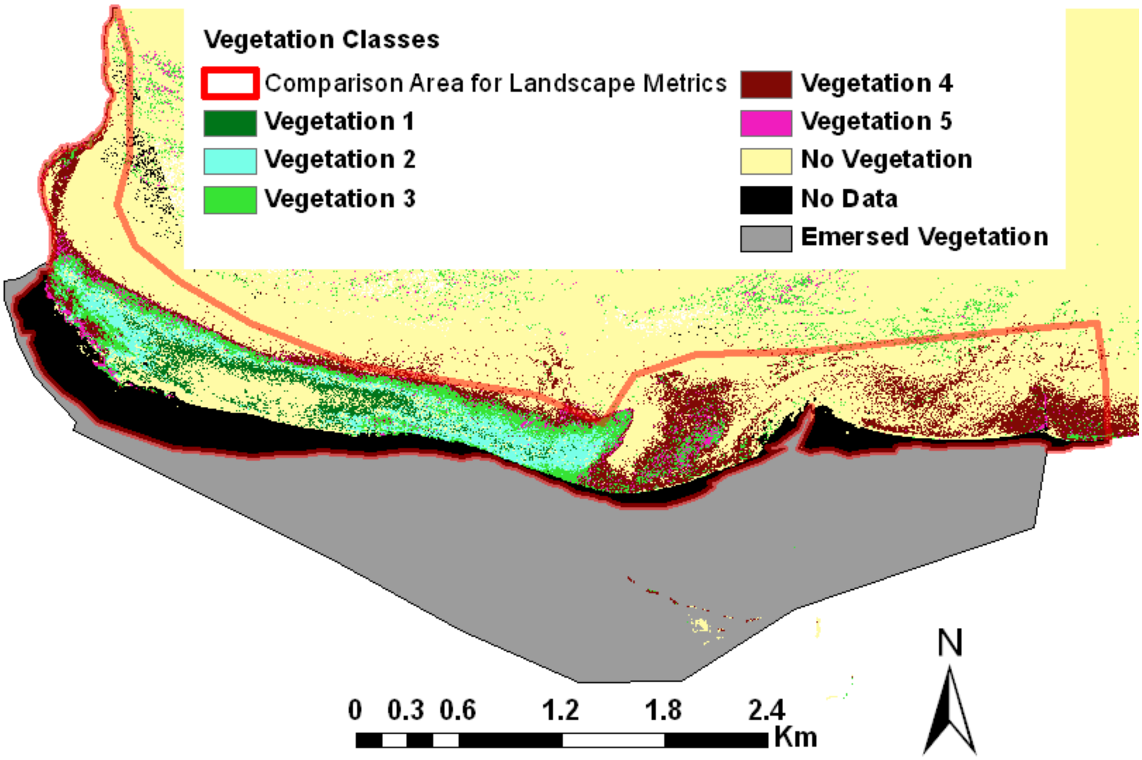

Figure 28: 2006 Supervised Classifications of Submersed Macrophytes in Gavaraget
Source of Classifications: (Heblinski, 2008)

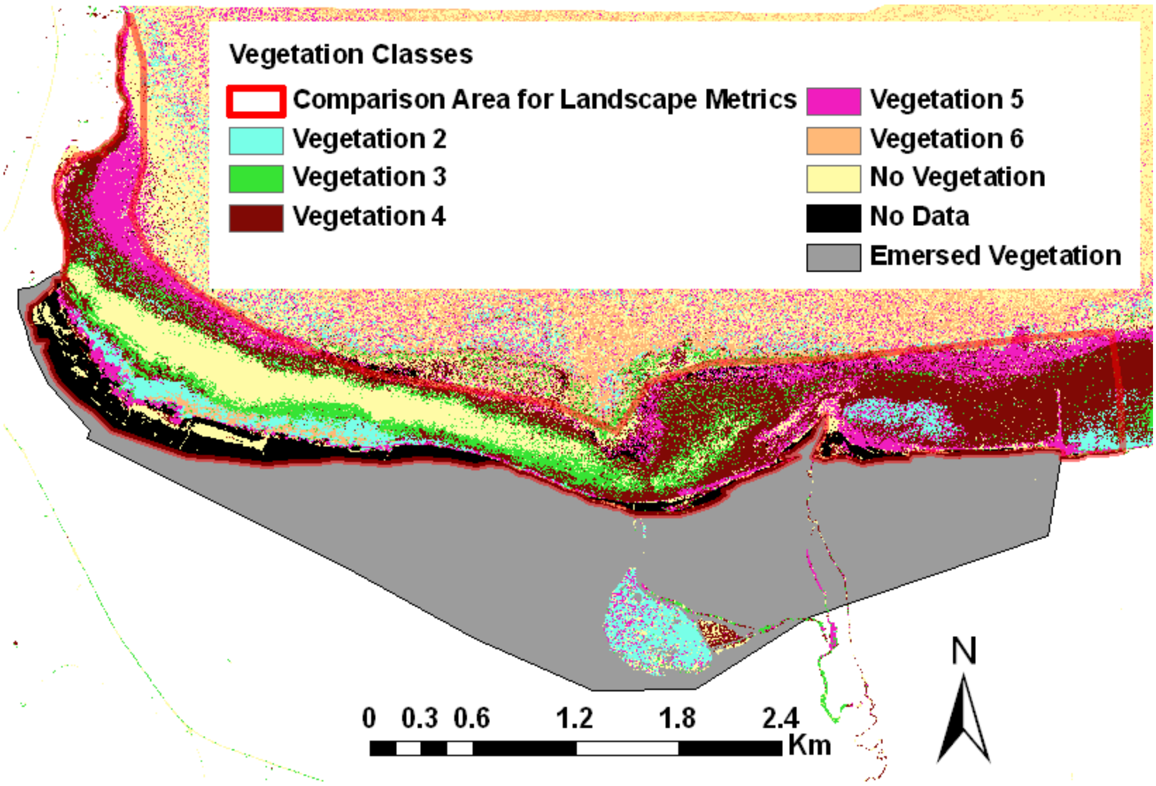

Figure 29:2007 Supervised Classifications of Submersed Macrophytes in Gavaraget
Source of Classifications: (Heblinski, 2008)

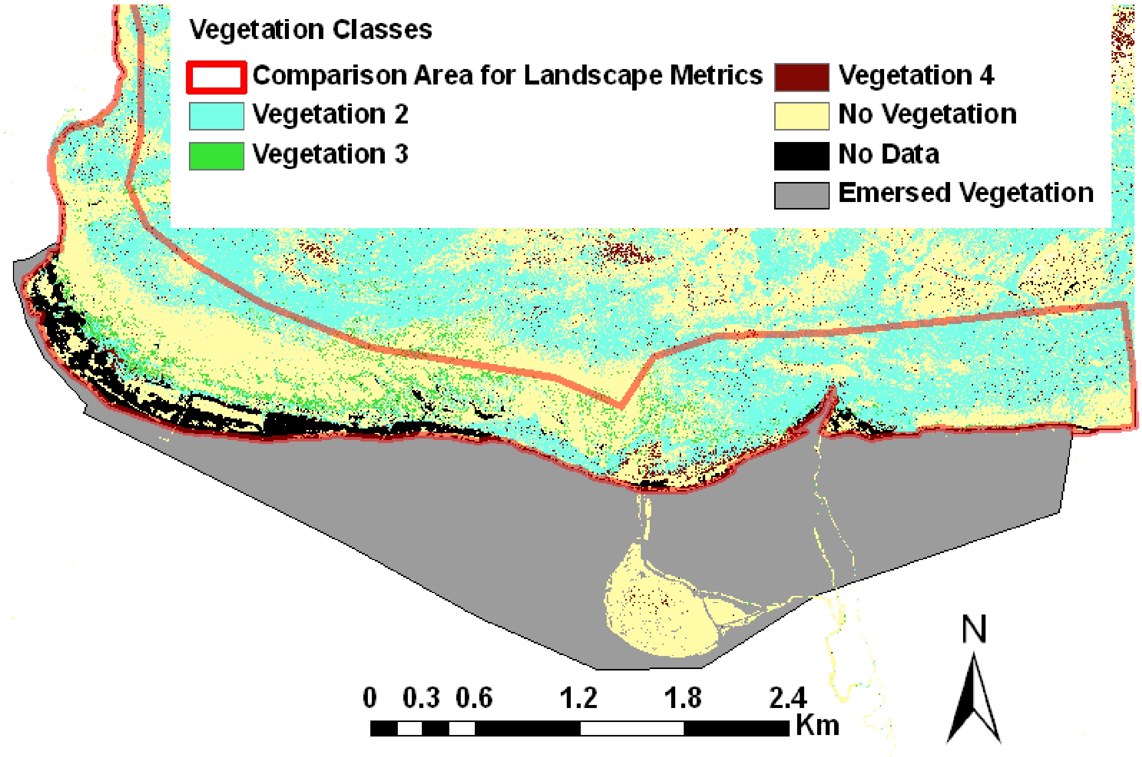

Figure 30:2008 Supervised Classifications of Submersed Macrophytes in Gavaraget
Source of Classifications: (Heblinski, 2008)

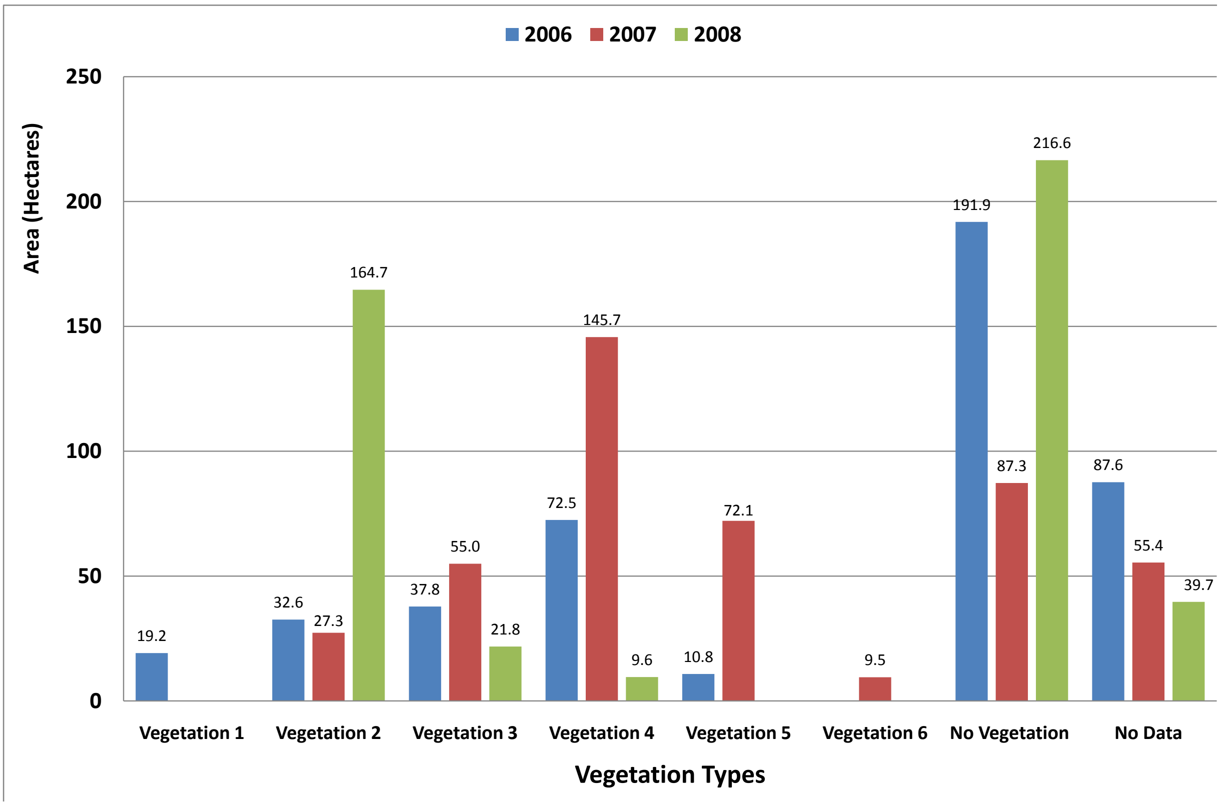

Figure 31: Gavaraget submersed macrophyte vegetation changes from 2006 to 2008

Table 17: Selected Landscape Metrics (Percentage of Landscape, Interpersion and Juxtaposition Index) at the Class Level for Submersed Macrophytes in Gavaraget

Land Cover Types	Year	PLAND	IJI
Vegetation 1	**2006**	3.85	43.92
	2007		
	2008		
Vegetation 2	**2006**	8.94	74.33
	2007	6.88	85.19
	2008	39.91	58.36
Vegetation 3	**2006**	10.36	85.80
	2007	13.85	60.67
	2008	5.28	59.23
Vegetation 4	**2006**	19.88	56.32
	2007	36.72	81.20
	2008	2.32	68.63
Vegetation 5	**2006**	2.96	59.12
	2007	18.17	73.45
	2008		
Vegetation 6	**2006**		
	2007	2.39	94.53
	2008		
No Vegetation	**2006**	52.61	72.30
	2007	22.00	77.10
	2008	52.49	65.63

Table 18: Selected Landscape Metrics (Total Landscape Area, Patch Density, Contagion, Interspersion and Juxtaposition Index, and Shannon Diversity Index) at the Landscape Level for Submersed Macrophytes in Gavaraget

Year	TA (ha)	PD /100 ha	CONTAG	IJI	SHDI
2006	364.66	5618.66	49.23	75.92	1.37
2007	396.83	7090.95	32.90	78.94	1.56
2008	412.59	8608.30	38.72	65.18	0.95
Mask	452.26				

Patch Metrics (PD)

At the landscape level, patch density per 100 ha increased over 20% along the years (Table 17).

Diversity Metrics (SHDI)

The diversity of land cover types in the landscape increased in 2007 and was almost halved in 2008 (Table 17).

Interspersion (IJI) and Contagion (CONTAG) Metrics

Apart from VEG 3 which decreased in its interspersion with other class patches in 2007, all the other class patches were highly intermixed with different other classes (Table 17). While VEG 1 appeared only in 2006 with below average interspersion, Vegetation 6 (VEG 6) was present only in 2007 with a high degree of intermixing with other vegetation class patches. Aside VEG 1, VEG 5, and VEG 6, all the other classes reduced their interspersion with other class patches in 2008.

At the landscape level, the patches of classes were well interspersed in 2007 than in 2006; but 2008 had the least intermixing of class patches. Contagion in 2006 and 2008 being less than 50% show that the class patches in those years were a bit disaggregated. However, the class patches in 2007 were more disaggregated.

4.4.1.2 Comparisons between Regions of Interest (ROI)

The vegetated areas in Gavaraget and Tsovazard increased in 2007 whereas those of Masrik decreased. There were more than 130 ha of new vegetation for Gavaraget in this year as compared to 35 ha in Tsovazard. On the other hand, Masrik lost about 380 ha of vegetation (Figure 32). In the last year, all the three regions of interest lost between 16 ha and 113ha of vegetation. However, apart from Gavaraget, the non-vegetated areas increased along the years with the sharpest occurring between 2006 and 2007 in Masrik (about 360 ha increment). For detailed results of Tsovazard and Masrik refer to Appendix 1.

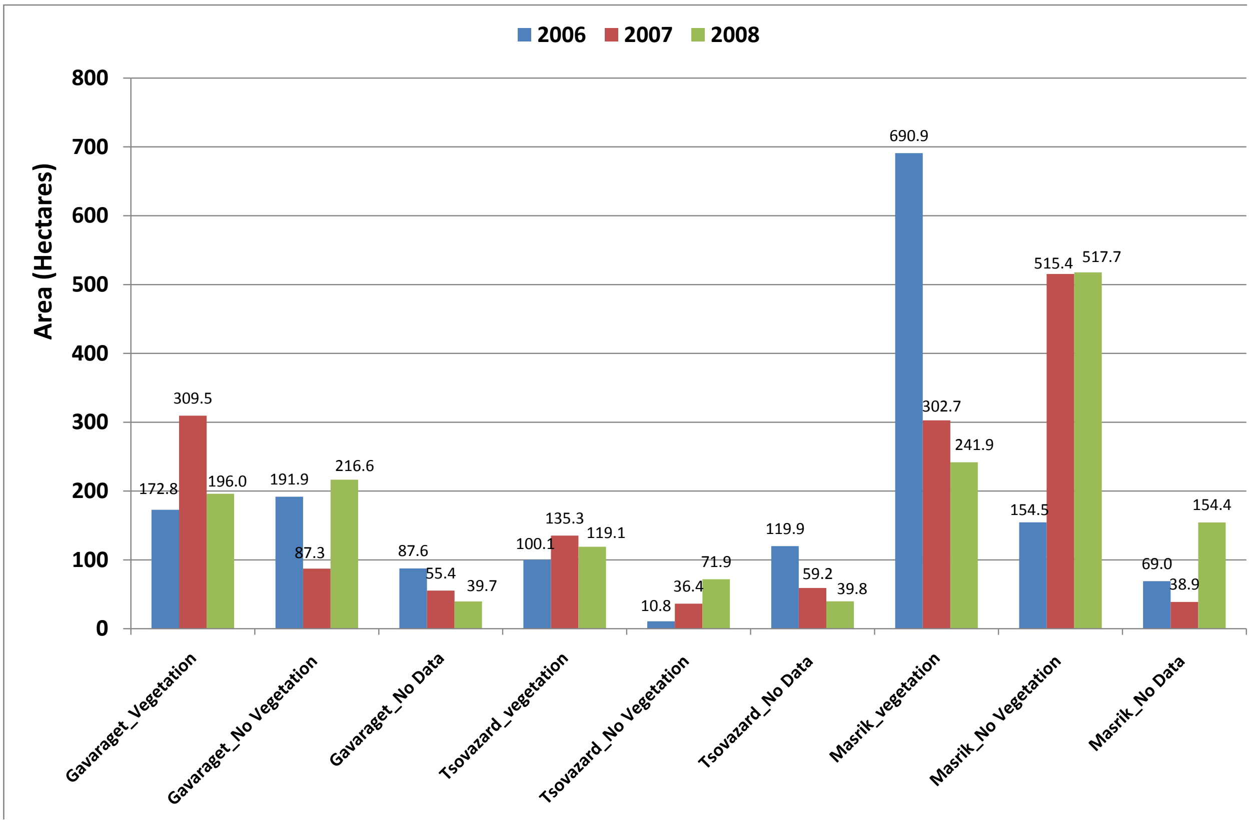

Figure 32: Comparison of vegetative and non-vegetative areas of submersed macrophytes among Gavaraget, Tsovazard and Masrik regions (2006-2008)

4.4.2 Emersed Macrophytes

4.4.2.1 Gavaraget

<u>Area Metrics</u>

Apart from Bushes, Broad-leaf Trees and No Data classes, there were decreases in the areal extent of all the other land cover types in 2007 (Figures 33-34, 36). Whereas Reeds and Grasses continued with their decline in 2008, Bushes and Broad-leaf Trees joined them. The rest (Dry Bushes, Conifers, No Vegetation and No Data) increased (Figures 35-36).

In 2006, Reeds (36.9%) followed by Conifers dominated the landscape (see PLAND in Table 19). However, the Broad-leaf Trees displaced Reeds as the dominant vegetation in 2007. In the last year, Conifers, Dry Bushes and Broad-leaf Trees co-dominated the landscape.

While the total landscape area decreased in subsequent years (Table 20).

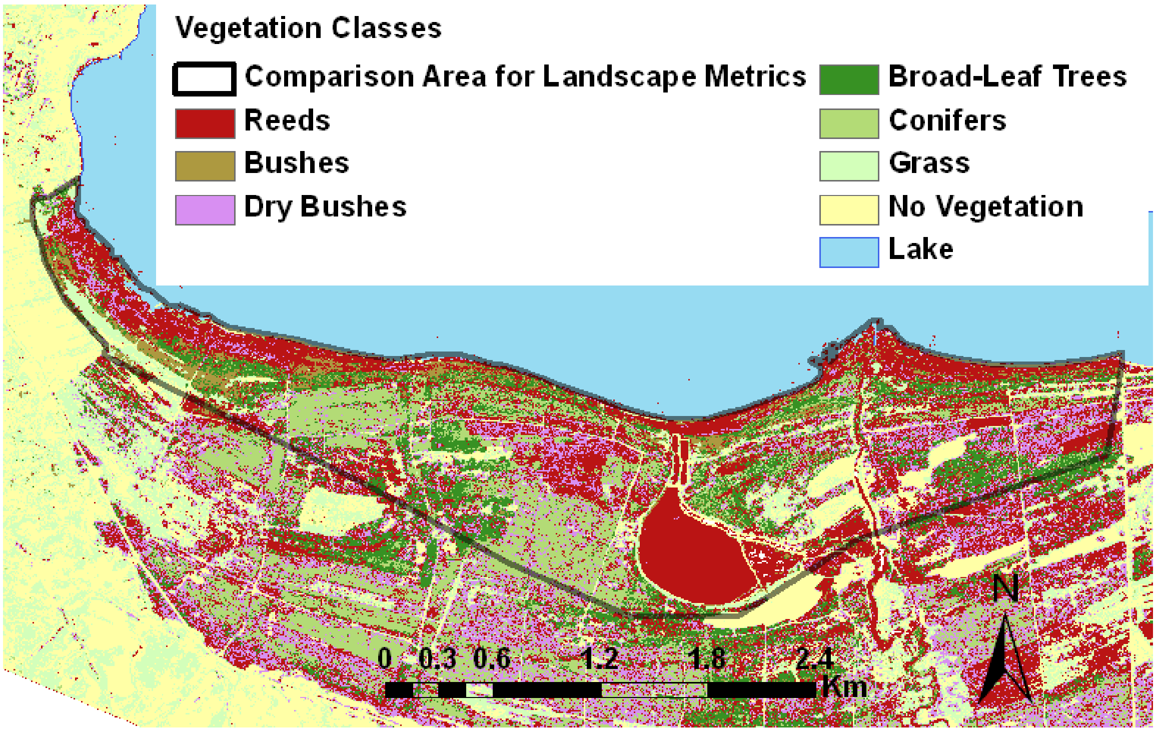

Figure 33: 2006 Supervised Landcover Classifications of Gavaraget
Source of Classifications: (Heblinski, 2008)

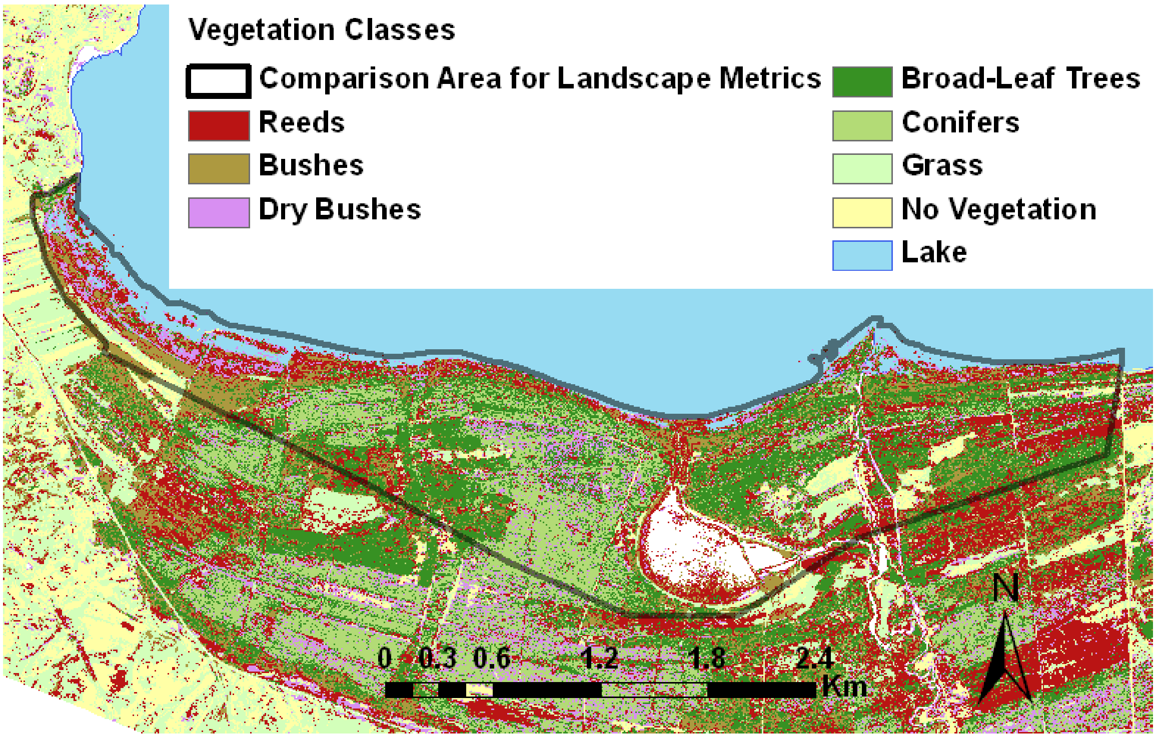

Figure 34: 2007 Supervised Landcover Classifications of Gavaraget
Source of Classifications: (Heblinski, 2008)

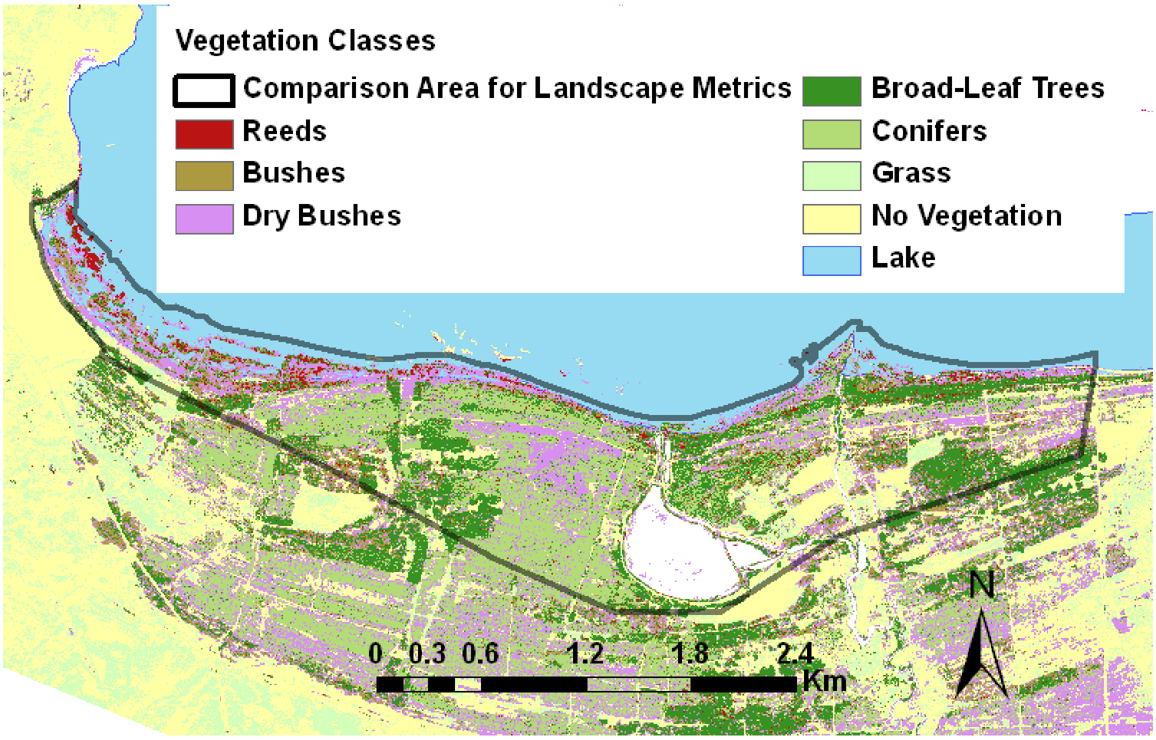

Figure 35: 2008 Supervised Landcover Classifications of Gavaraget
Source of Classifications: (Heblinski, 2008)

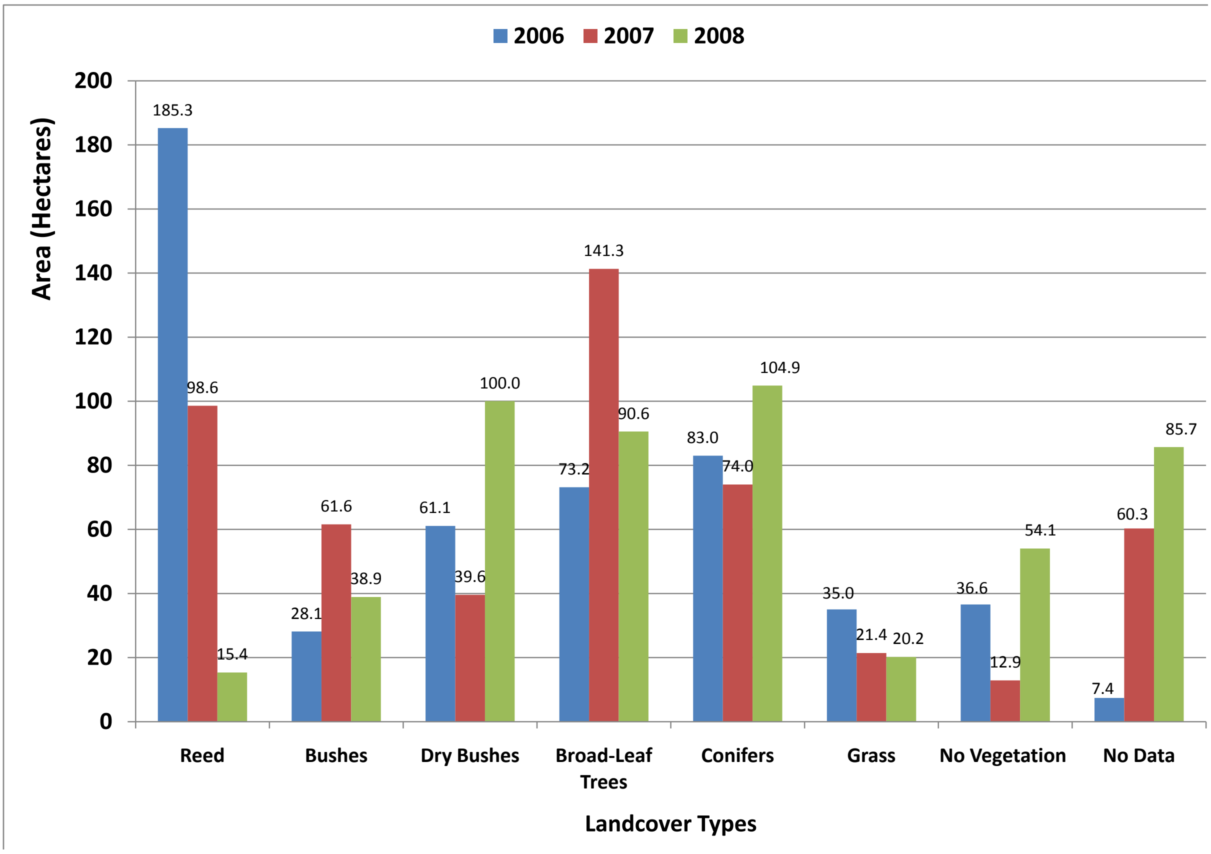

Figure 36: Gavaraget emersed macrophyte vegetation changes from 2006 to 2008

Patch Metrics (PD)

Patch density per 100 ha increased about 39% and 43% in 2007 and 2008 respectively (Table 20).

Diversity Metrics (SHDI)

The diversity of land cover types remained relatively the same in all the years in the landscape (Table 20).

Interspersion (IJI) and Contagion (CONTAG) Metrics

Reeds and Grasses were highly interspersed with other class patches in 2006 whereas Broad-leaf Trees and Conifers were well interspersed. The two bush classes and No Vegetation class had interspersions above average (Table 19). In 2007, Reeds, Grasses and Broad-leaf relatively maintained their interspersions. While Dry Bushes became more intermixed with other class patches, Bushes, Conifers and No Vegetation became less interspersed. In the last year, all the classes were well interspersed with each other.

The patches of classes were well interspersed in the landscape throughout the three years but a bit less in 2007. The patches of the classes in the landscape became more disaggregated over the years.

Table 19: Selected Landscape Metrics Percentage of Landscape, Interpersion and Juxtaposition Index) at the Class Level for Emersed Macrophytes in Gavaraget

Land Cover Types	Year	PLAND	IJI
Reeds	**2006**	36.88	81.22
	2007	21.94	77.76
	2008	3.62	71.39
Bushes	**2006**	5.60	61.26
	2007	13.70	53.65
	2008	9.18	78.23
Dry Bushes	**2006**	12.16	65.23
	2007	8.81	75.50
	2008	23.60	86.68
Broad-Leaf Trees	**2006**	14.57	78.70
	2007	31.45	74.80
	2008	21.36	83.98
Conifers	**2006**	16.53	77.07
	2007	16.47	49.07
	2008	24.74	69.88
Grasses	**2006**	6.98	88.49
	2007	4.77	86.91
	2008	4.76	65.33
No Vegetation	**2006**	7.28	57.72
	2007	2.87	42.94
	2008	12.75	66.21

Table 20: Selected Landscape Metrics (Total Landscape Area, Patch Density, Contagion, Interspersion and Juxtaposition Index, and Shannon Diversity Index) at the Landscape Level for Emersed Macrophytes in Gavaraget

Year	TA (ha)	PD /100 ha	CONTAG	IJI	SHDI
2006	502.30	6612.78	30.44	81.06	1.74
2007	449.41	9219.42	28.16	74.37	1.73
2008	424.00	13181.60	26.83	83.02	1.76
Mask	509.70				

4.4.2.2 Comparisons between Regions of Interest (ROI)

While the vegetated areas in Gavaraget decreased in 2007, those of Tsovazard and Masrik increased. Masrik gained more than 700 hectares of new vegetation (Reeds and Broad-Leaf Trees). However, there were decreases in all the regions for the non-vegetated areas. The areas covered by vegetation were reduced in all the regions in the last year. Masrik region lost more than 500 hectares of vegetation (Reeds, Broad-Leaf Trees and Grasses) in that year (Figure 37). No Data increased in their areal extent in all the regions for all the years except Masrik which had a reduction in 2007. Detailed results of Masrik and Tsovazard can be found in Appendix 2.

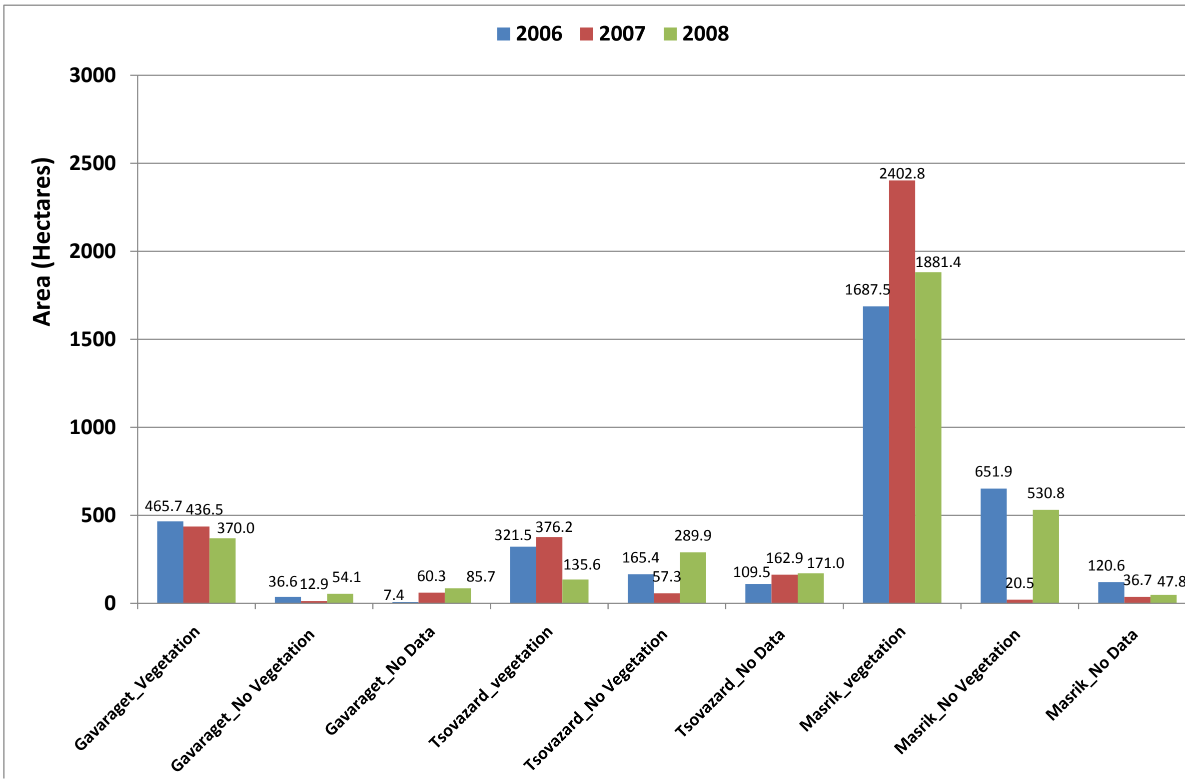

Figure 37: Comparison of vegetative and non-vegetative areas of emersed macrophytes among Gavaraget, Tsovazard and Masrik regions (2006-2008)

4.5 Habitat Modelling

4.5.1 Habitat Models of Crucian Carp (*Carassius* spp.)

4.5.1.1 Gavaraget

There was a total habitat area gain on the landside of about 146.3 ha in 2007 and a massive loss of 222.8 ha on the lakeside in 2008 in the landscape while the water level continued to rise.

Qualitatively there were general increases in covered areas of all the habitat suitability classes of 2007 over 2006 (Figures 38-39). This almost agrees with the quantitative results (Figure 41). The areas of Very Good (VG), Average (AV), and Poor (PR) classes increased about 57% (111.6 ha), 27% (13.9 ha), and 200% (29.5 ha) 56% respectively; while the

Good (GD) and Very Poor (VPR) classes decreased by 19% (11.3 ha) and 36% (2.6 ha). In 2008 (Figure 40), there was a severe reduction in the VG area resulting in a decrease of about 94% (290 ha) as compared to the decrease of PR of 21% (9.4 ha). However, there were 68% (43.8 ha) and 675% (31.9 ha) increases for AV and VPR classes respectively. The increase for GD class was very minimal (3.6 ha).

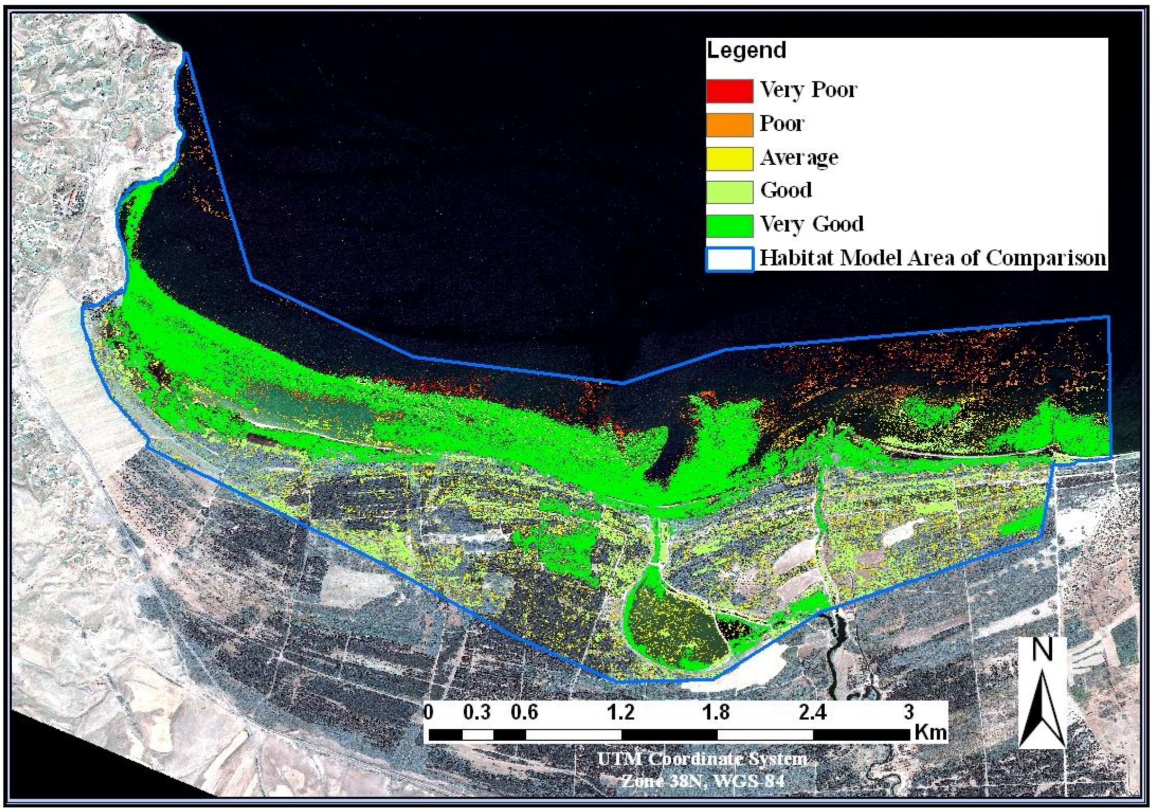

Figure 38: Potential Habitat Map of Crucian Carp (*Carassius* spp.) in Gavaraget for 2006. Five Habitat Classes ranging between Very Good and Very Poor were used

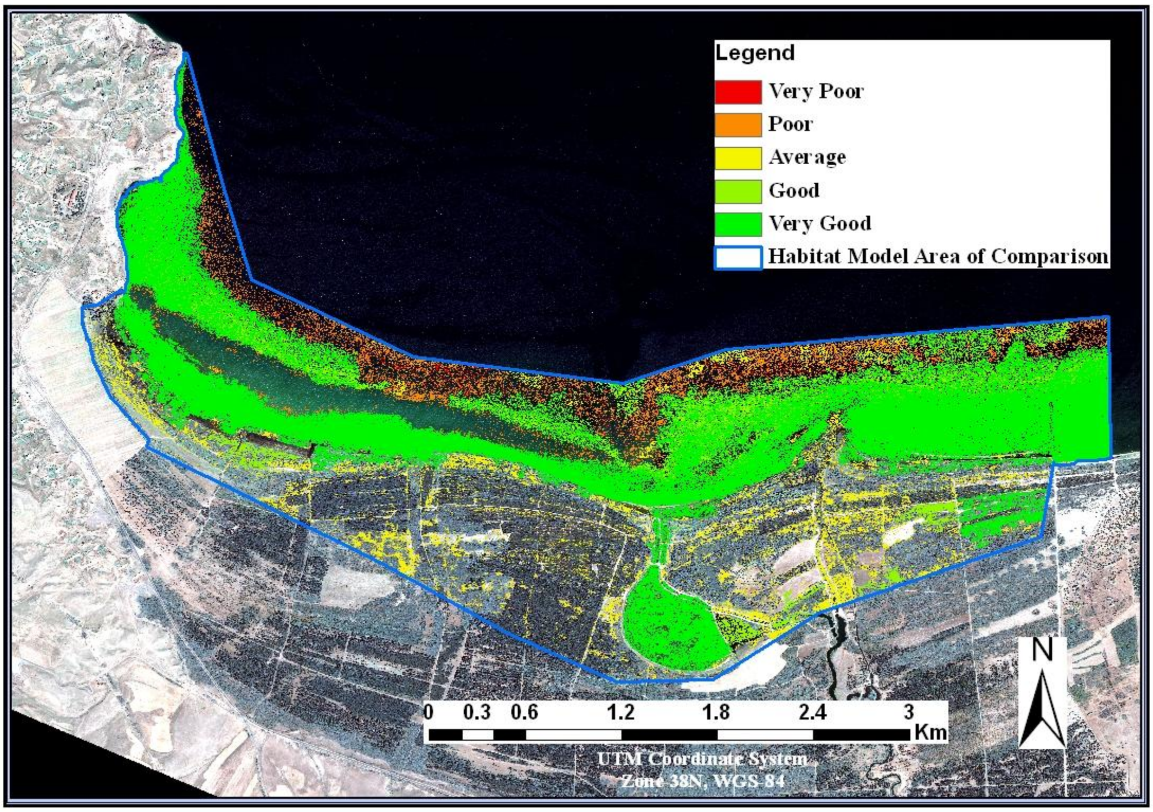

Figure 39: Potential Habitat Map of Crucian Carp (*Carassius* spp.) in Gavaraget for 2007. Five Habitat Classes ranging between Very Good and Very Poor were used

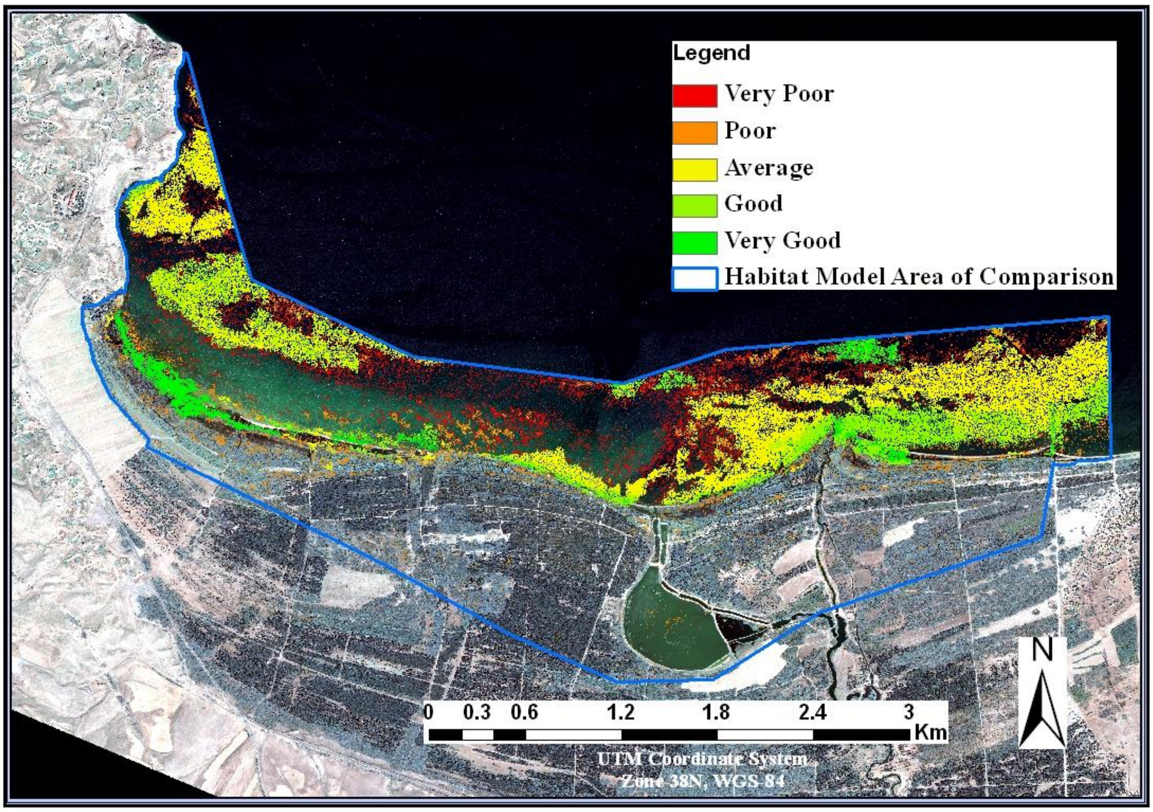

Figure 40: Potential Habitat Map of Crucian Carp (*Carassius* spp.) in Gavaraget for 2008. Five Habitat Classes ranging between Very Good and Very Poor were used.

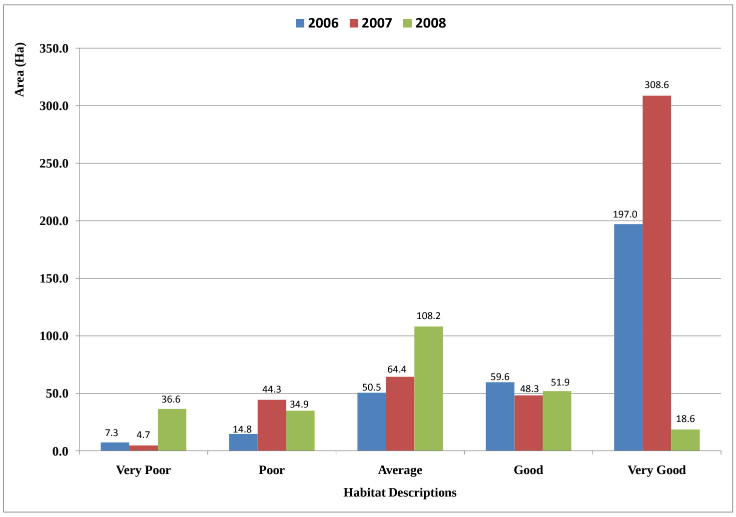

Figure 41: Fish Habitat Suitability Classes of Gavaraget and their Coverage Areas from 2006 to 2008

4.5.1.2 Summary of Fish Habitat Models in the ROI

There was a similar trend in habitat areas in all the landscapes in the Gavaraget, Tsovazard and Masrik regions. The habitat areas increased in 2007 and decreased in 2008. The increases in all the regions was the same (around 43%) while the highest reduction occurred in Gavaraget (47%) followed by Masrik (38%) and Tsovazard (25%) respectively (see Appendix 3). On the contrary, Masrik had the absolute area lost of about 542.5 ha followed by Gavaraget and Tsovazard with 220.2 ha and 51.5 ha respectively. Appendix 3 contains detailed fish habitat models for Masrik and Tsovazard.

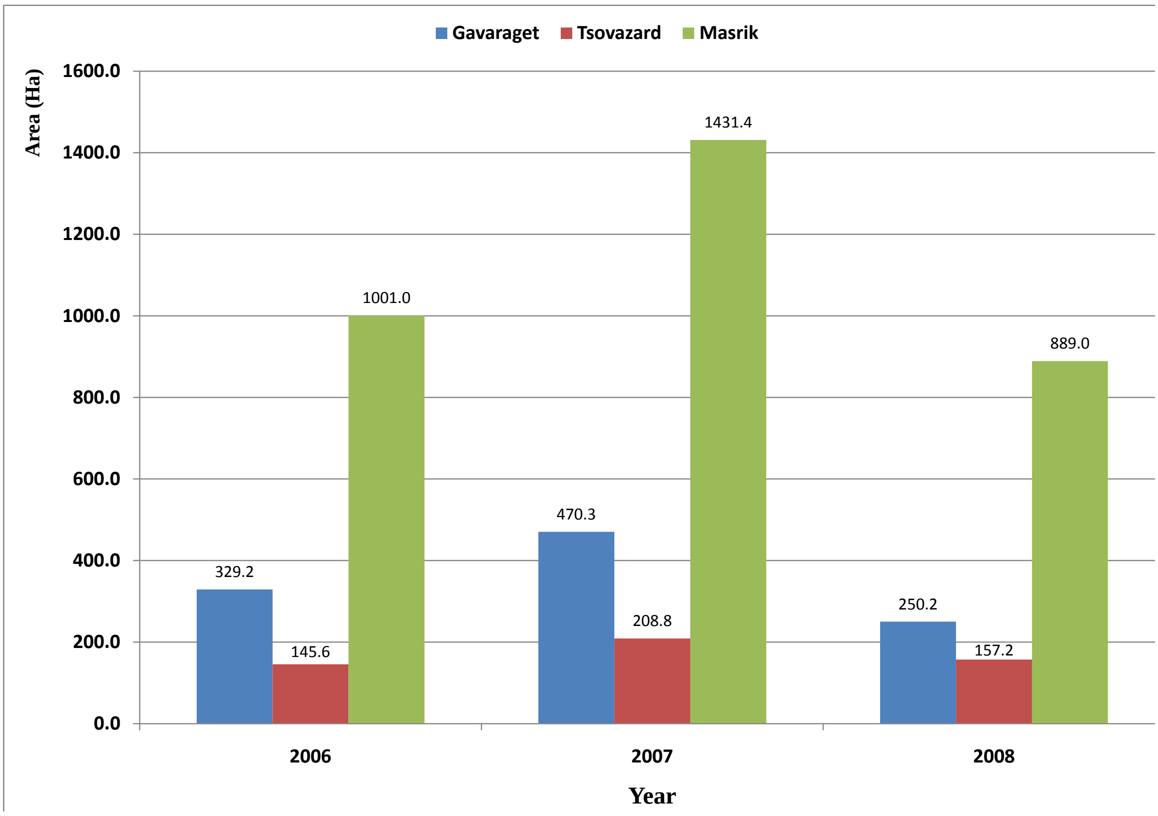

Figure 42: Summary of Fish Habitat Models showing the Areal Extent for each Year

4.5.2 Habitat Models of Common Coot (*Fulica atra*) and Great Crested Grebe (*Podiceps cristatus*)

4.5.2.1 Gavaraget

43.1 ha of the total habitat area on both the landside and the lakeside in 2006 were lost in 2007. This was further reduced by 83.3 ha in 2008 (Figure 46).

In 2007, apart from the VG class which increased slightly of about 3.6 ha (16%), all the other habitat classes reduced in coverage area when compared to the 2006 distributions (Figures 43-44, 46). The range of the reductions was between 21% (PR) and 74% (VPR). There were decreases in all the classes ranging from 45% (Moderate [MD]) and 99% (PR) in 2008 (Figures 45-46). While the highest absolute losers were VPR (19.9 ha) and MD (12.4 ha) in 2007, PR (29.5 ha) and VG (24.3 ha) became the highest and second highest in 2008 respectively.

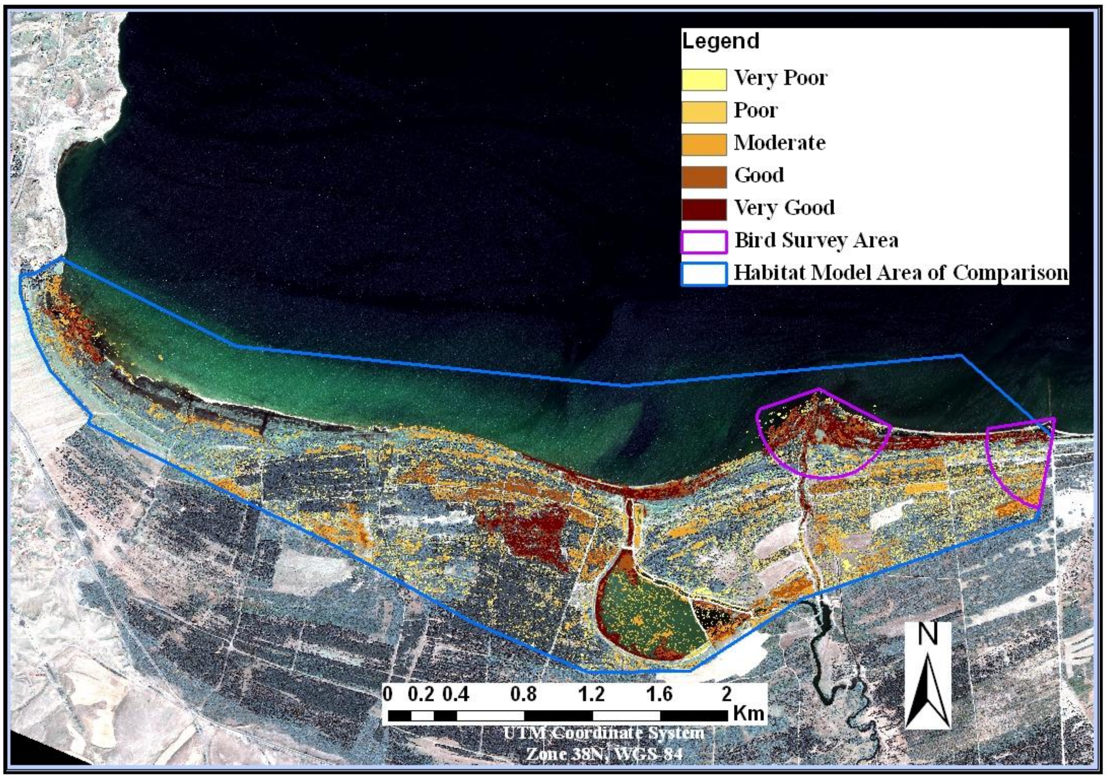

Figure 43: Potential Habitat Map of the Common Coot (*Fulica atra*) and the Great Crested Grebe (*Podiceps cristatus*) in Gavaraget for 2006. Five Habitat Classes ranging from Very Good to Very Poor were used

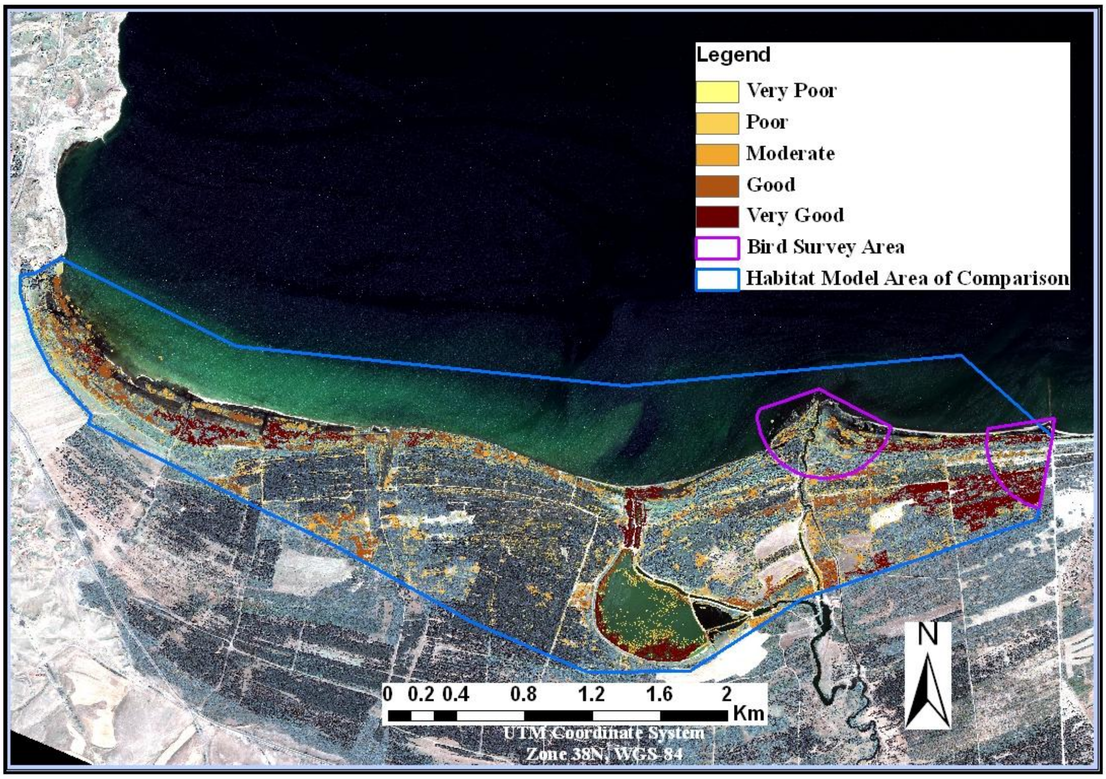

Figure 44: Potential Habitat Map of the Common Coot (*Fulica atra*) and the Great Crested Grebe (*Podiceps cristatus*) in Gavaraget for 2007. Five Habitat Classes ranging from Very Good to Very Poor were used

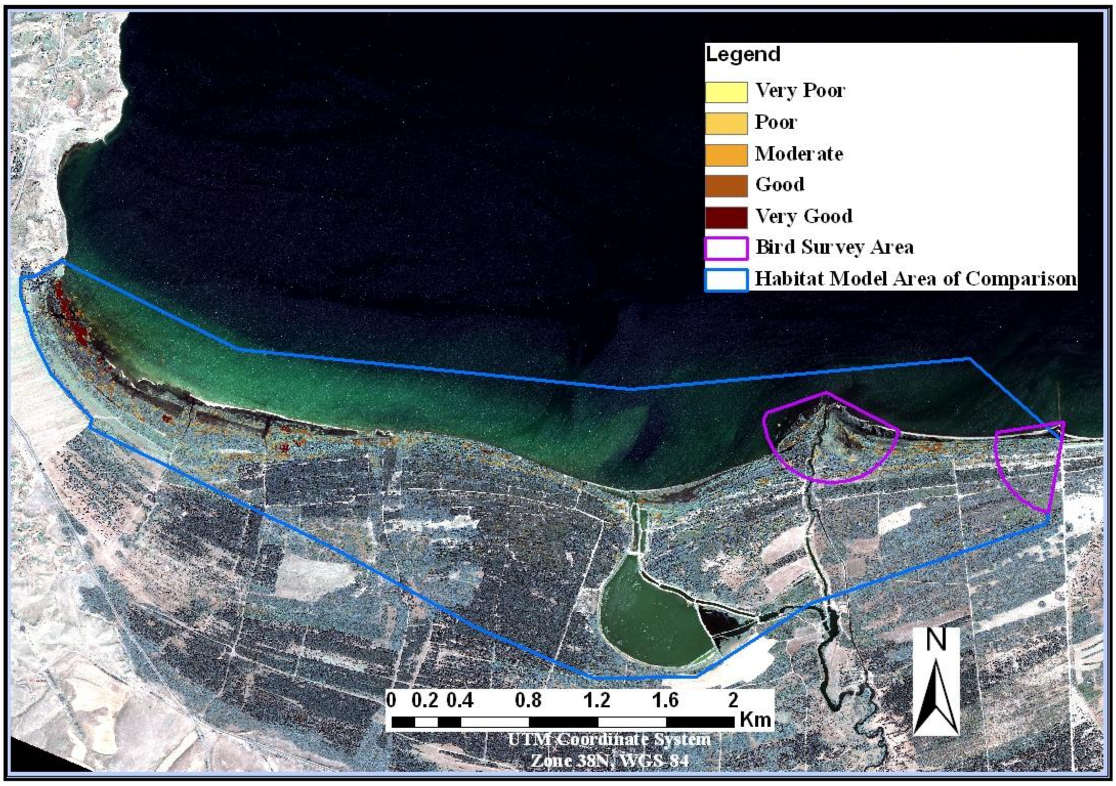

Figure 45: Potential Habitat Map of the Common Coot (*Fulica atra*) and the Great Crested Grebe (*Podiceps cristatus*) in Gavaraget for 2008. Five Habitat Classes ranging from Very Good to Very Poor were used

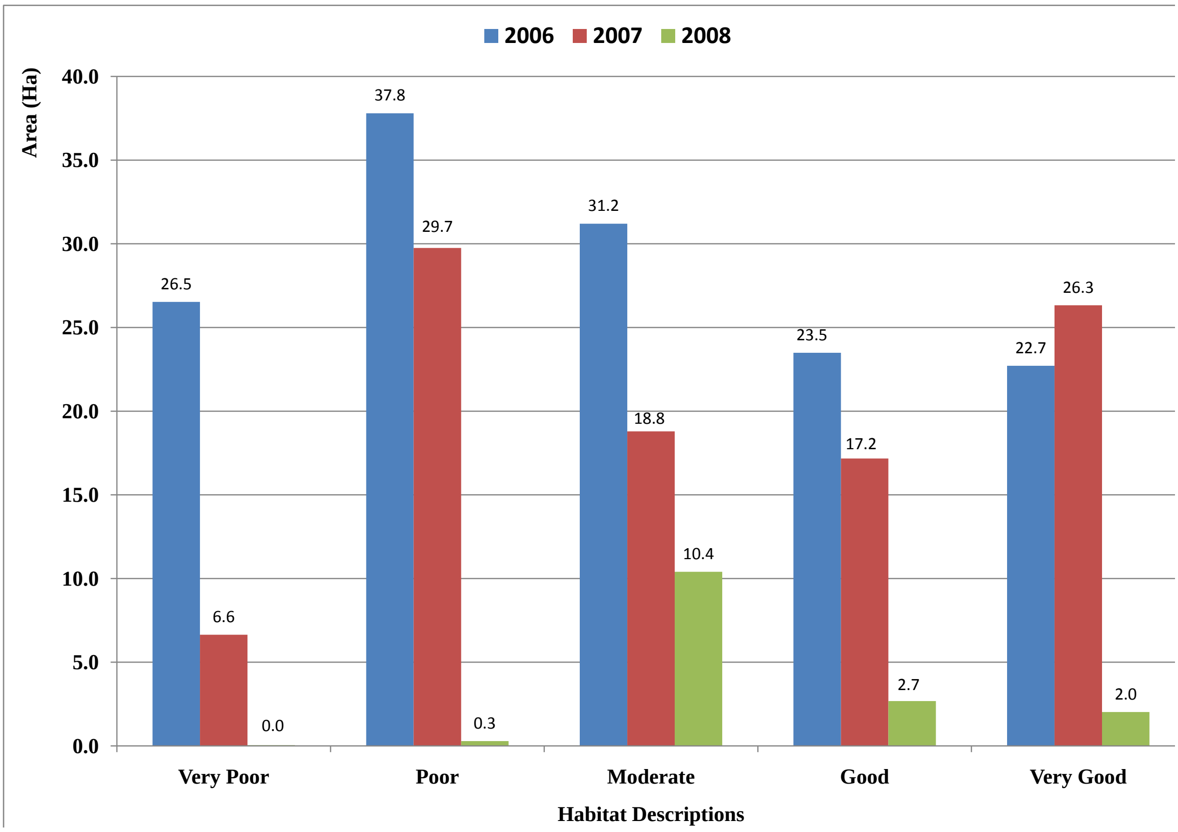

Figure 46: Bird Habitat Suitability Classes of Gavaraget and their Coverage Areas from 2006 to 2008

4.5.2.2 Summary of Bird Habitat Models in the ROI

Tsovazard and Masrik had a similar trend in habitat areas with an initial increase in 2007 followed by a decrease in 2008 (Figure 47). While the former had an increase of 42% (14.4 ha), the latter had a massive one of 255% (810.2 ha). However, Gavaraget had reductions in 2007 (43.1 ha) and 2008 (83.2 ha). The highest reduction occurred in Gavaraget (85%) followed by Tsovazard (78%) and Masrik (44%) respectively (Figure 47). Tsovazard and Masrik lost 38.1 ha and 492.4 ha respectively. For detailed bird habitat results for Tsovazard and Masrik, refer to Appendix 4.

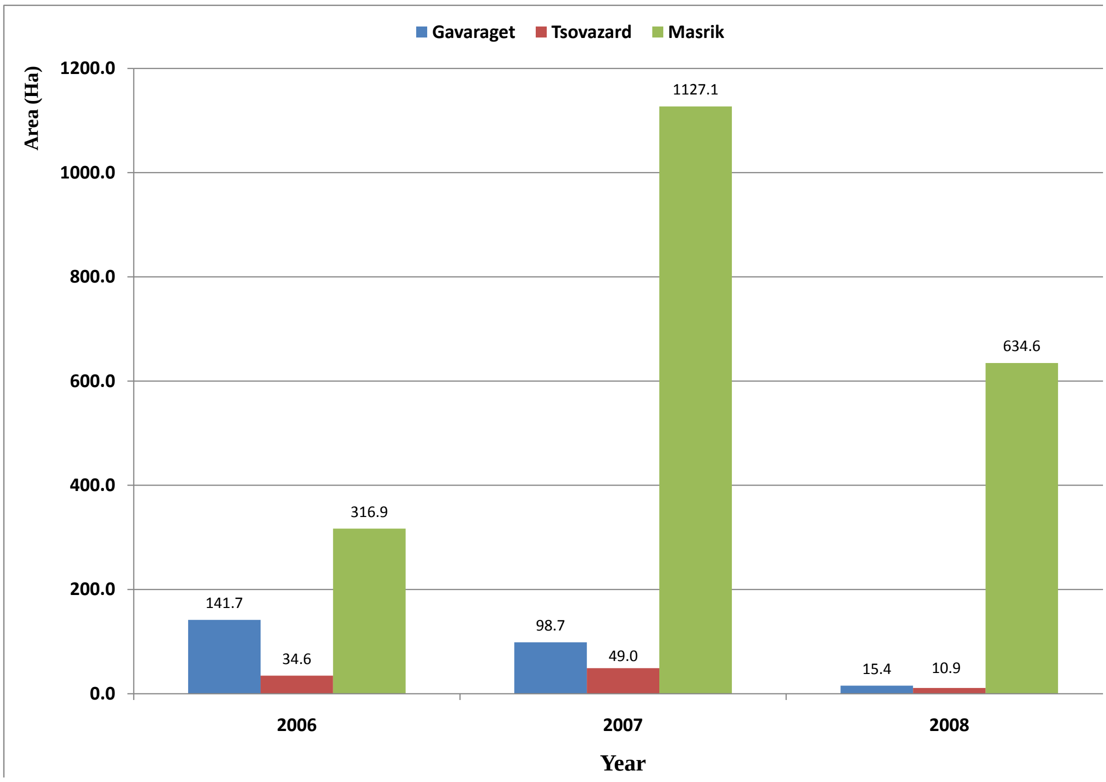

Figure 47: Summary of Bird Habitat Models showing the Areal Extent for each Year

4.5.2.3 Validation of Bird Habitat Models

The fewness of the survey data led to the combinations of the modelled HSI before the comparisons as shown in Table 21. In Masrik, the highest percentage area of 58% of the modelled habitat (Very Good to Good areas) among the three years falling in the bird survey area was obtained in 2007. This was followed by that of 2008 (46%) and 2006 (22%) (Table 21). For the Poor to Very Poor areas, the agreement between the modelled habitat and that of the bird survey areas was very high for all the three years (above 88%).

However, there was a yearly increase of agreement between the modelled habitat area and the bird survey area from 2006 (39%) to 2008 (86%) in Gavaraget (Table 21).

Table 21: Validation of the Bird Habitat Suitability Index maps from 2006 to 2008. The degree of reliability are shown in percentages

Survey Areas	**2006**	**2007**	**2008**	**Combined modelled HSI**
Gavaraget	39.38	45.27	86.39	1 - 3
Masrik	21.50	58.28	46.02	4 - 5
Masrik_KCB	88.80	96.29	100.00	1 - 3
Combined Average	**49.90**	**66.61**	**77.47**	

CHAPTER FIVE

5.0 DISCUSSIONS

5.1 Assessment of the Historical Development of Lake Surface Area

From 1933 to 1987, the surface area of Lake Sevan reduced drastically due to the draining of the lake for irrigation and electricity generation (Chilingaryan et al., 2002; Deheryan, 2005; Grigorian, 2005). The lowest area of the lake was found to be 1234.2 km^2 in 2001. The reason was that Armenia experienced energy crisis between 1991 and 2001 and therefore more lake water was used for hydro-power generation. About $6.1 x 10^9$ m^3 of water were drawn from the lake during those years and the outflow exceeded the inflow by $2.2 x 10^9$ m^3 (Deheryan, 2005; Armenia Hydro-Meteorological Institute (ArmHydromet), 2009).

The manipulations of the lake level had massive consequences in fluctuations of the lake surface area. In the years of the energy crisis, the water released for hydro-power generation amounted to about $1.0\ x10^9$ m^3 per annum, even reaching $1.5\ x10^9$ m^3 in some years (Papyan et al., 2002).

In 1996, the Government of the Republic of Armenia passed a decree to prohibit water releases from the Lake for energy purposes, but the implementation of it became possible only starting in 1999. Hence, in 2001, the Republic of Armenia 'Law on Lake Sevan' was approved and adopted by the National Assembly within the Complex Programme on Lake Sevan's Ecosystem Rehabilitation. The construction of the Vorotan-Arpa hydro-structure, which would transfer water from the River Vorotan via the Kechut Dam, and then, into Lake Sevan, was a fundamental action under the Programme. Therefore, since 2001, the lake surface area has been increasing due to the operation of the Vorotan-Arpa-Sevan tunnels. The Vorotan-Arpa would transfers about 165 million cubic meters of water per annum into the Lake, and another 250 million cubic meters come from the Arpa-Sevan (Papyan et al., 2002; Deheryan, 2005). But on the contrary, only about 217 million cubic meters of water per annum have been transferred into the lake by both tunnels (Armenia

Hydro-Meteorological Institute [ArmHydromet], 2009). Hence, between 2001 and 2009, the surface area of Sevan increased by 22 km^2.

Today, about hundreds of hectares of artificial forests have been submerged by the rising waters. But, if the programme to raise the water level by 6 m (Deheryan, 2005) is realized, then more hectares of land and forests would be submersed.

The surface area of lakes governs the distance over which the wind can blow which subsequently determines the wave height of both surface and internal waves, thereby determining in combination with maximum depth whether a particular lake will stratify or not (Kalff, 2002). In stratified lakes, lake surface area will largely determine the thickness of epilimnion which influences the light climate experienced by planktonic organisms (Kalff, 2002). The depth of epilimnion affected will depend on a number of factors including latitude, weather, water clarity and lake morphometry. Because most of the transport of heat to deeper levels of lakes is due to wind action, characteristics of the lake that may modify the wind effect will be important for the formation and depth of the thermocline. And as such, lake surface area in addition to lake mean depth, volume, exposure and fetch (the longest distance of the lake that the wind can act on uninterrupted by land) will affect how efficiently wind energy can transport heat to deeper strata (Brönmark and Hansson, 2005). Further, depending on the littoral area, the number of plants, fish, and invertebrate species rises with lake surface area, as does the length of the food chains (Wetzel, 2001; Kalff, 2002).

When compared with the surface area generated from traditional methods (Armenia Hydro-Meteorological Institute [ArmHydromet], 2009), the difference obtained by the GIS methods falls between 0.08% and 0.67%. These could be attributed to the differences between the average water level and the actual water level on the satellite acquisition day which ranged between 2 cm (2001) and 51 cm (1976). The comparable lake levels of 1976 & 1988 and 1996 & 2001 suggest similar lake surface areas, but they were not. Since the lake basin morphology remained constant during the research period, this can be attributed to the differences in the type of scanners and spatial resolutions used in the satellite images (MSS-80 m and ETM-30 m). Above all these, the results show the high accuracy of using GIS methods to monitor the surface area of Lakes in a fast, reliable and convenient way as compared to the traditional (cut & weigh, planimetry and grid) methods in order to sustainably manage the lake ecosystem.

5.2 Effects of Lake Sevan's Artificial Water Level Fluctuation on Its Littoral Zone

The year 2001 registered the lowest littoral zone area of about 105.45 km^2 between 1976 and 2005. Also, when compared to the base year of 1976, 2001 had the largest littoral zone loss of 7.44 %. This was due to the increased water discharge for hydro-power generation during the Armenian energy crisis between 1992 and 2001 (Deheryan, 2005; Armenia Hydro-Meteorological Institute [ArmHydromet], 2009). For instance, between 1989 and 2001, the water level reduced by 1.37m.

Since 2001, more than 170 million m^3 water has been added a year to the lake due to the operation of the Vorotan-Arpa tunnels (Garibyan, 2007; Armenia Hydro-Meteorological Institute [ArmHydromet], 2009). Also, the adaptation, approval and implementation of the 'Law on Lake Sevan' by the Armenian National Assembly, has helped in reducing the outflow of the lake. That is the more reason why the water level increased by 1.20m between 2001 and 2005. This resulted in an increase of about 18 km^2 of the Littoral Zone which is about 8% increase as compared to the base year of 1976.This is in agreement with the rehabilitation program which envisages raising the level of the lake by 6 meters within 30 years (Deheryan, 2005).

The calculations of littoral surface area were based on a constant base line of 10 m, derived from topographical maps at 1:50000 scale. In spite the fact that 10 m depth line and respectively the littoral zone shifts with varying water level, this should not change the results significantly. This base line is situated on the steep slope of the lake basin, so that for a drawdown of 1.2 m (water level changes from 1976 to 2005), the shift of the 10 m line on the steep slope affects the surface area much less than the shift on the landside due to the smooth slope. The comparable lake levels of 1976 and 2005 suggest similar littoral surface areas, but they were not. According to Hoyer and Canfield Jr. (1996), littoral zone of lakes are inversely related to basin slope, depth, and to the degree of regularity of the shoreline. Stating that the lake basin morphology remained constant during the investigated period, this can be attributed to the differences in the type of scanners and spatial resolutions used in the satellite images. Additionally, according to (United States Geological Survey

[USGS], 2009), an instrument malfunction occurred on May 31, 2003 and as a result, all Landsat 7 image data acquired from July 14, 2003 (20:32:40 GMT) to the present were collected in the Scan Line Corrector (SLC) off mode. This resulted in 20% loss of scene area therefore the underestimation of surface area of 2005. Furthermore, the applied depth model used to assess the effects of Lake Sevan's water level fluctuations on its littoral zone was not very accurate and this could have affected the results of the study. However, it was the only depth model available at that time and hence the above obtained results.

Concerning the linear regression between the littoral zone area and the surface area, approximately ninety percent of the variation in the former could be explained by the latter. The remaining ten percent could be explained by unknown, unobserved variables or inherent variability in the ecosystem. Therefore, shore areas with gentle slopes are expected to increase their littoral zone areas in the event of an increase in the surface area.

The littoral zone (including that of Lake Sevan), in addition to being a food source and a substrate for algae and invertebrates, provide refuge and spawning habitats for both young & old organisms especially fishes (Northcote and Atagi, 1997; Wetzel, 2001; Lake Access, 2007). The littoral zone (lake shore) represents a transitional habitat, an ecotone, because it provides habitats for both terrestrial and aquatic organisms and produces high biodiversity within a typical vertical zonation across small gradients, in contrast to the open water area which is much structured and which possess much less diversity in its biological community (Wetzel, 2001; Schmieder, 2004). Therefore, the sustainable management of lakes cannot be achieved without monitoring the development of the littoral zone.

Apart from the provision of habitat, the littoral biocoenosis of lakes serve as a buffer zone, self-purifier, erosion protector and recreation (which provides a major economic activity for the lake areas) (Schmieder, 2004). The high unnatural water-level fluctuations (as is the case of Lake Sevan) may lead to the loss of natural vegetation in the littoral zone, as well as to changes in the wave climate and subsequent erosion (Iseli, 1993; Wilcox, 1995; Fuller, 2002; Schmieder, 2004; Winfield, 2004). Hence, lake shore deterioration will create a substantial loss of economic benefits apart from the loss of ecological functions. This calls for the need to manage the lake responsibly which can be done on the base of sound assessment method and a continuous monitoring of the status of the lake shore or littoral areas (Schmieder, 2004).

5.3 Validation of Supervised Macrophyte Classification of QuickBird Satellite data

5.3.1 Submersed Macrophytes

5.3.1.1 Vegetation Type Level

With the advent of more advanced digital satellite remote sensing techniques and the complexity of digital classification, there is more of a need to assess the reliability of such results (Congalton, 1991) otherwise the classification would be assumed to be 100% correct which is not the case.

By applying the error matrix for the assessment of classification quality (Congalton, 1991; Stehman and Czaplewski, 1998), the high overall accuracies in submersed macrophyte classification in all the years indicating a high agreement between the classified remote sensing image and that of the groundtruth data, was as a result of high water clarity in those years. This enhanced good detection of submersed vegetation as shown in their high user accuracies. However, the very high overall accuracy in 2007 was because of its higher water clarity as compared to 2006 and 2008. On the other hand, the user accuracies of 'No Vegetation' class were low in 2006 and 2007 and very low in 2008 due to misclassifications. The rapid population increase of the blue-green algae that occurred on the lake during the field data collection and time of image acquisitions, contributed to these misclassifications as many areas without vegetation which were covered by these algae were recorded by the classification method as vegetated areas. The algal bloom was very severe in 2008 resulting in higher levels of misclassifications. Again, many submersed vegetation areas which were covered by algal blooms and clouds were masked out and classified as no vegetation therefore reducing the producer accuracies of the submersed macrophytes for all the three years.

The producer's accuracy indicated the probabilities that the groundtruth data will be correctly classified. Those samples which were not correctly classified into a particular class were omitted from that class. Therefore, if it is most important not to miss the presence of macrophytes or a type of macrophyte in the Sevan catchment area, then this type of accuracy should be the most important to the Sevan National Park authorities.

When samples are misclassified, they are not only omitted from the correct class but are also committed into another class. All samples that are classified as a particular class are actually not that particular class unless the classified image is 100 percent correct (Story and Congalton, 1986). Therefore, the user accuracy derived indicates the probability that a sample from the classified image actually represents that particular class on the ground. Hence, the Lake Sevan management board should take this user accuracy seriously for decisions associated with the macrophyte vegetation maps. If it is most important for managers not to overestimate a particular class or presence of macrophytes in general, then attention could be focused on this statistic.

The kappa coefficients ranging from 0.5 and 0.72 emphasize that these agreements are not coincidental or by chance. This promotes the fact that high resolution remote sensing data can be reliably applied in recording submersed macrophytes in lakes with sufficient transparencies as experienced in validation results obtained in Lake Constance (Woithon et al., 2004).

5.3.1.2 Growth Type Level

The 2007 classification had the best overall accuracy (70%) which means that the classified remote sensing data agreed moderately with the groundtruth data. The overall accuracies in 2006 and 2008 were average and below average respectively resulting in a fair agreement of classified data with the groundtruth data. Apart from 2006 (where data were transferred), high growing macrophytes were highly detectable resulting in high user accuracies (>92%). However, the ‘No Vegetation’ and ‘Low Growing’ classes were averagely and poorly detected in all the years. For 2006, this could have been caused by the inapplicable groundtruth data from 2007 and 2008, and substantial interannual changes in the vegetation structures. Additionally, for all the years, many submersed macrophytes designated as low growing (e.g. *Ceratophyllum* spp.) during the field observations reached or floated to the upper part of the water surface and hence could be detected as high growing by the remote sensing classification methods. Furthermore, some submersed macrophytes designated as high growing during the field observations could not reach the upper part of the water surface and therefore could not be detected as such by the remote sensing classification algorithms. (Haberäcker, 1991) explained that successful identification of vegetation patches requires that the patches are large and adequately dense and that the minimum dimension of the patches should be at least twice the length of the pixel diagonal. Therefore, for QuickBird images, with maximum resolution of 2.4 m, vegetation patches should be at least 6.8 m on a side. Otherwise, it would be very difficult for them to be detected correctly.

Again, in 2008, algal bloom, strong winds (generating high waves), cloud cover and shadow of clouds (Heblinski, 2008) inhibited the classification of ‘No Vegetation’ class in 2008 resulting in its average user accuracy. All areas which were covered by algal blooms and clouds were masked out and classified as no vegetation (Heblinski, 2008). Furthermore, the late data capture of macrophytes in October which was out of their growing season affected the detection of low growing macrophytes. This underscores the importance of getting groundtruth data close to the time of acquisition of the satellite imageries.

Also, where there was sparse vegetation with bright sand substratum, the reflectance of the sand was stronger than those of the submersed macrophytes therefore the patches were classified as no vegetation. Although the presence of algal bloom inhibited the detection of low growing macrophytes (Jenderedjian et al., 2005), the data could still be used for vertical structure assessment. In the validation of classified remote sensing data of submersed macrophytes of Lake Constance in 2004, similar accuracy values were obtained. An overall accuracy of 73% and a kappa coefficient of 0.51 were achieved (Woithon et al., 2004). Other sources of error which could affect the validation accuracy are GPS and georeferencing errors. The GPS used had an accuracy of 5-10 m. Furthermore, GIS analyses and the generalisation of vegetation patches could have resulted in some errors and uncertainties (Stoms, 1992; Goodchild, 1994). Also cloud cover, sun glitter, the variations in macrophyte spectral signatures and sediment suspensions could be added to the sources of error in the classification process (Heblinski et al., 2011) which in turn affected the validation process.

The application of remote sensing and GIS methods cannot replace field studies without the loss of information (Schmieder, 1997). This was realised when many submersed macrophytes could not be differentiated at the species level (Remillard and Welch, 1992). Although, this study was restricted to some selected sites, the results serve as baseline for spatial data build up of submersed macrophyte in Lake Sevan since there are no official digital geographic data of macrophytes available in Armenia. Nonetheless, building up the spatial data would involve immense manpower, lot of time and perseverance (Schmieder, 1997).

5.3.2 Emersed Macrophytes

While Reeds were highly detectable by the remote sensing methods in all the three years, the other landcover classes were poorly detected and mainly misclassified as Reeds. The detection of Bushes was very difficult because they had similar spectral reflectances and derived pixel values to the Reeds. A better differentiation was not possible with the remote sensing methods at that time (Heblinski, 2008). Grasses which were quite recognizable in 2007 were poorly identified in 2008 as result of cloudy skies (Heblinski, 2008), which also accounted for the low identification of Trees in the same year. The low user accuracy of Grasses could also have been due to similar spectral reflectance to Reeds and seasonal changes since the dry Grasses which were detected as No Vegetation by the classification methods, were labelled as Grasses by the groundtruth. That is why a lot of pixels of the No Vegetation class were misclassified as Grasses resulting in very low user accuracy for the No Vegetation class and low producer accuracy for Grasses. Therefore, more time should be invested in creating spectral signatures (reflectances) of species or plants to aid supervised classification of satellite images in the foreseeable future. Nevertheless, the high overall accuracy in 2007 (76%) is moderately supported by the Kappa coefficient (0.56).

Positional errors could have accounted for the low detectability of Trees in all the years since most of the Trees for the groundtruth were digitized on-screen from the unclassified remote sensing images. The above average overall accuracy of 2006 is strengthened by the moderate agreement between the classified remote sensing and the groundtruth data. In 2008, the satellite images were taken at the end of the growing season of the macrophytes and therefore the normal spectral signatures of Reeds were not detected properly. Hence, the need to acquire satellite images close to the field mapping time (if possible) should not be neglected. Therefore, it is understandable that the classified data slightly agreed with the groundtruth data in this year with a low overall accuracy.

Since the overall accuracy of the classified image represents the accuracy of the entire product and does not indicate the distribution of accuracy across the individual classes (which could and frequently show drastic differences in their accuracies), it is therefore always important to compute the individual class accuracies in order to completely assess the value of the classified image for a specific application (Story and Congalton, 1986). (Aronoff, 1982a) confirmed this by stating that the comparative analysis of error matrices may provide better methods of comparing land-use classification mapping methods than a simple comparison of overall estimated map accuracy. To use the classified images or map for decisions and policies regarding Lake Sevan, the authorities should focus on the user accuracies or ‘reliability’ of the various landcover types because they show how well the map represents what is actually on the ground (Congalton and Rekas, 1985; Story and Congalton, 1986).

The comparison of the classification results and the ground reference data consisted of spatial superimposition based on GIS. Both data sources could include certain positioning errors, so geometric inaccuracies may have caused some distortion in this pixel-based quality control. However, the accuracies for the classes could be increased by improving the algorithm of the remote sensing methods and using differential global positioning system (DGPS). Furthermore, the effectiveness of the classification algorithms and consequently the quality of the results and their use for further applications are limited by the low spectral resolution of the QuickBird satellite, as its sensors’ high bandwidths and their associated object characteristics can only detect at a general level (Sawaya et al., 2003). Nonetheless, (Sawaya et al., 2003) were able to obtain reliable results (about 80% accuracy) in mapping littoral vegetation from high-resolution IKONOS and QuickBird satellites. Since most applications in the lake littoral zones are based on airborne hyperspectral scanner data (Woithon and Schmieder, 2004; Schmieder et al., 2010), the usage of the commercially available operational satellite data with lower spectral resolution offer a practical and cost-effective alternative for the monitoring and ecological assessment in the lake littoral zone (Sawaya et al., 2003), especially in the inassessible areas.

On the other hand, landscape indices with meaningful ecological interpretations could be developed from these classified satellite images. Also, in addition to other data, habitat models of birds, fishes and other organisms could be developed from these classified macrophytes.

5.4 Landscape Metrics

5.4.1 Submersed Macrophytes

5.4.1.1 Area Metrics

The increase of the lake water level of 19 cm triggered the increases in the coverage areas of Vegetation classes 3 to 6 of Gavaraget in 2007 since new flooded areas were colonised as No Vegetation areas reduced. The additional water increase of 56 cm in the following year resulted in the decrease of the euphotic zone for the submersed macrophytes thereby affecting their photosynthesis and subsequent reductions. This is seen in the astronomical increases in the Vegetation 2 (which consists of low growing macrophytes and bright sediments) and No Vegetation classes.

The increases of the lake water level in the three years seem to have favoured the submersed macrophytes in Tsovazard since they all increased over the years except VEG 4 (2008) which decreased and VEG 5 (which disappeared in 2007 and 2008). This could have been due to the gentle slope at the littoral zone thereby making it easier to colonise newly flooded areas. No Vegetation increased at the expense of No Data throughout the years.

The increases of the lake water level in the three years did not favour the submersed macrophytes in Masrik region and brought about large shifts in the submersed macrophytes community (Coops et al., 2003). The increases of VEG 1 and VEG 6 in 2007 may have been due to the increases in the sediments and muddy components respectively in those vegetation classes. This is reflected in the astronomical values of NVC in the last two years.
These results agree with what (Coops et al., 2003) stated that even small changes of water level may result in a large shift in plant communities. It was further explained that high water levels in spring may limit submersed plant expansion inducing a shift to a sparsely vegetated state, whereas a substantial reduction in spring lake level may encourage expansion of submersed plants. Additionally, the algal blooms (especially in 2008) attenuated light in the lake which led to complete loss of growing areas in deeper parts of the littoral zone and this increased interspecies competition (Schmieder, 1997).

The choice of area masks for each region was based closely on the area masks used for supervised classifications in each region (Heblinski, 2008) so that falsely classified pixels could be avoided in the calculation of the metrics.

5.4.1.2 Patch Metrics (PD)

In Gavaraget, the increases of PD in 2007 and 2008 show that the landscape became more fragmented as the total area increased. It was expected that the increase of PD in 2008 would be affected by the lower grain size of 2.4 m as compared to 2.799 m in 2006 and 2007.

The landscape became more and more fragmented in Tsovazard over the years as depicted by the increases of PD and total landscape area as expected (Botequilha Leitão et al., 2006). These subdivisions could have been due to the creation of new patches or isolation of patches from their neighbours as explained by (Botequilha Leitão et al., 2006).

In 2007, there was more fragmentation in the landscape of Masrik than what existed in 2006 due to the increase in the total area. However, the decrease in total area resulted in less fragmentation in 2008 as shown by (Botequilha Leitão et al., 2006).

Movement of species and materials across the landscape is directly affected by fragmentation since more patches mean more boundaries between different classes, and new intervening classes that may pose barriers to movement (Botequilha Leitão et al., 2006). Since this index is a good reflection of the extent to which the landscape is fragmented, it therefore plays a fundamental part in the assessment of landscape structures and enables comparisons of units with different sizes (Eiden et al., 2009).

5.4.1.3 Diversity Metrics (SHDI)

The Shannon Diversity index (SHDI) in Gavaraget increased in 2007 due to decrease in variation of the proportional percentage of the area covered by each class since the number of classes remained constant. On the other hand, SHDI decreased in 2008 as a result in the decrease in the number of classes i.e. VEG 1, VEG 5 and VEG 6, as well as the increase in the variation of the proportional percentage area covered by each class as the water level increased.

In Tsovazard, the Shannon Diversity index (SHDI) decreased over the years as a result of the loss of VEG 5 and the increase in variation of the proportional percentage of the area covered by each class in 2007 and 2008 (Eiden et al., 2009).

The diversity of the landscape in Masrik remained the same in 2006 and 2007 but reduced in 2008 due to the increase in variation of the proportional percentage of the area covered by each class (Eiden et al., 2009).

Therefore, it can be concluded that SHDI increases as the number of different patch types (classes) increases and/or the proportional distribution of the area among patch types becomes more equitable (Eiden et al., 2009). This supports the statement that plant community shifts which result from water level fluctuations affect the species richness and diversity (Coops et al., 2003). This was also confirmed by Keddy and Reznicek (1986), Keddy (1990) and Schmieder (2004), that water-level fluctuations in particular contribute to and maintain plant species diversity in littoral ecotones.

5.4.1.4 Interspersion (IJI) and Contagion (CONTAG) Metrics

In 2006 and in Gavaraget, the patches of VEG 1 were a bit clumpy whiles those of VEG 4 and VEG 5 were less clumpy. However, patches of VEG 2 and VEG 3 were distributed proportionally within the landscape. In 2007, apart from VEG 3 which decreased in its proportional distribution in the landscape, all the other class became more equally adjacent to each other. In the last year, all the patches of the classes became a bit disproportionally distributed. At the landscape level, the patches of classes were equally adjacent to each other in 2007 than in 2006; but in 2008 this adjacency reduced to the lowest among the three years. Contagions in 2006 and 2008 indicated that the class patches were less clumped. The smaller contagion in 2007 showed that the class patches were generally characterize by many small and dispersed patches which were also well interspersed (McGarigal and Marks, 1995).

In Tsovazard, while patches of VEG 2, VEG 3 and VEG 5 were clumpy those NVC were distributed proportionally in the landscape in 2006. However, patches of VEG 1 and VEG 4 were less proportionally distributed. For 2007 and 2008, all the patches of the classes were equally adjacent to each other in the landscape. At the landscape level, the patches of classes were equally adjacent to each other in the years. But this adjacency increased over the years. The low and decreasing contagion over the years show that the class patches were less clumped or aggregated. Additionally, there were many small and dispersed patches which were well interspersed (McGarigal and Marks, 1995).

While the patches of VEG 3 in Masrik were heavily clumped, those of VEG 1 and NVC were averagely distributed within the landscape in 2006. However, patches of VEG 2 were highly equally adjacent to other patch types. Apart from patches of NVC (2007) and VEG 6 (2008) which were averagely clumped, all the other patches present were equally adjacent to each other in 2007and 2008. At the landscape level, the patches of classes were equally adjacent to each other throughout the years. That is, their interspersion remained almost constant within the landscape for the three years. The low and decreased contagion in 2007 showed that the class patches were less clumped or aggregated. Again, many small and dispersed patches which were well interspersed (McGarigal and Marks, 1995). In 2008, the patches of classes became averagely aggregated within the landscape.

Since the contagion index seems to be an effective summary of overall clumpiness on categorical maps, it has been frequently used in landscape ecology (Turner, 1989). These are emphasized by the PD and IJI values obtained.

5.4.1.5 Comparisons between Regions of Interest (ROI)

The increases in vegetated areas in Gavaraget and Tsovazard in 2007 and the decrease in Masrik could have been due to the differences in sediments and slope gradient. The sediments in Masrik were mostly sandy while those in Gavaraget and Tsovazard were mixture of sand, humus and earth. The decreases in all the regions accounted for the increases in the non-vegetated areas in 2008.

Water-level fluctuations may be a catastrophic disturbance for submersed plant communities since excessively high water-level in the growing season reduces light availability, while a low water-level may damage plants via ice and wave action during winter and desiccation during summer (Coops et al., 2003). One of the most important environmental factors affecting the abundance of aquatic macrophytes in lakes has been identified as light availability (Canfield et al., 1985; Hoyer and Canfield Jr., 1996). A study of the effects of very strong interannual water-level fluctuations in Turkey showed a shift in the dominance of submersed macrophytes in the landscape which further resulted in changes of the ecological and conservation values of the lakes i.e. species diversity (Coops et al., 2003) as seen in this research.

Therefore, to a certain extent, water-level management can serve as a useful tool for the restoration of lakes (Coops and Hosper, 2002; Coops et al., 2003) in conjunction with the use of submersed macrophytes as bioindicators. Consequently, the understanding of the lake water-level fluctuations in the ecosystem functioning has become more crucial especially with the current concerns about global climate change (Coops et al., 2003). The application of GIS allowed the analysis of syn- and autecological characteristics of the species and changes in their distribution patterns (Schmieder, 1997) that are not readily visible to the human eye nor easily detectable by a human analyst (Frohn, 1998), and how they reacted to high water-level fluctuations during the research period.

5.4.2 Emersed Macrophytes

5.4.2.1 Area Metrics

A comparison of Reeds and Grasses in Gavaraget in the different years revealed severe and slight reductions in the former and latter land cover types respectively. The reeds died-back since they could not propagate as fast as the high increases in the lake water level. This was confirmed by the field observations of large area of stumps of former reed stands. Schmieder (2004) re-affirmed this that the re-establishment of littoral communities is slower, since the local seed source had been affected. Similar effects had been proposed by Böcker et al. (2003) and Schmieder (2004) with reference to the regeneration of aquatic reeds of Lake Constance in 1999 after the extreme flood. Within the span of three years, an increase of the lake water level of about 1.13 m had been achieved (Armenia Hydro-Meteorological Institute [ArmHydromet], 2009). Bushes, Dry Bushes and No vegetation varied largely among the years due to phenological differences, i.e. flooded bushes become dry as they died slowly, and harvested dry grassland was classified mainly as no vegetation. The huge No Data values were as a result of large areas being masked out as deep water areas with the increasing water level. The variations of coverage of Broad-leaf Trees and Conifers over the years were due to misclassifications as it is not expected that the trees will increase in their areal extent of more than 40 ha within a year. This confirms what Schmieder (1997) stated, that the quality of geographical analyses depends on the quality of the data set.

Apart from Bushes and No Vegetation classes in Tsovazard, the water level favoured all the other classes thereby increasing their areal extents in 2007. The high disparities between

Grasses and No Vegetation classes were due to seasonal changes since very dried grasses were classified as No Vegetation in one year and as Grasses in another year. The seemingly increase of Conifers in 2008 was due to misclassifications. The increasing deep water areas resulted in high No Data class values. Again, Reeds died-back due to overwhelming water level increase. Similar die-backs of reeds occurred in Lake Constance-Untersee when high water levels in 1965-1967 created a loss of about 32 hectares. These die-backs of reed belts resulted from drowning and mechanical damage by waves and drifting matter (Ostendorp et al., 2003).

In Masrik, the increase in water level favoured the Reeds at first (2007) but the continuous rise of the water level was detrimental to them resulting in a massive die-back in 2008. The flooded bushes died and became drier resulting in its gradual increase over the years. The massive decrease of Bushes and astronomical increase of Broad-leaf Trees (which is not realistic) were due to misclassifications of the remote sensing data as a lot of Bushes were misclassified as Broad-leaf Trees. The high disparities between Grasses and No Vegetation classes were as a result of phenological changes since dry grasses were classified as No Vegetation in one year and as Grasses in another year.

5.4.2.2 Patch Metrics (PD)

The landscape of Gavaraget became more fragmented over the years against expectations as the total area decreased over the years (Botequilha Leitão et al., 2006). Therefore, the fast water level increase was creating a lot of subdivisions within the landscape.

In Tsovazard, it would have been expected that with the reduction of the total area over the years, the PD would have also reduced (Botequilha Leitão et al., 2006) but the opposite happened showing that the landscape became more fragmented as the years went by.

The PD of Masrik decreased in 2007 as expected since the total area decreased. The PD was expected to decrease in 2008 with the decrease in total area (Botequilha Leitão et al., 2006) but it rather increased indicating the highest fragmentation within the landscape among the three years.

5.4.2.3 Diversity Metrics (SHDI)

The Gavaraget diversity of landcover types remained relatively the same in all the years in the landscape since there were no loss of classes and little changes in the variation of the percentage proportion of the landcover types.

However, in Tsovazard, the gradual decrease in the diversity of patches of classes from 2006 to 2008 in landscape was due to the increase in the variation of the percentage proportional area of the class patches (Eiden et al., 2009).

The reduction of diversity of the class patches of Masrik in 2007 was due to the increase in variation of the proportional distribution of the area among patch types. This variation reduced in 2008 thereby increasing diversity in that year.

5.4.2.4 Interspersion (IJI) and Contagion (CONTAG) Metrics

In Gavaraget, Reeds and Grasses were distributed proportionally within the landscape in 2006 whereas the distributions of Broad-leaf Trees and Conifers were slightly lower than that of the Reeds and Grasses. The two bush classes and No Vegetation were slightly disaggregated. In 2007, Reeds, Grasses and Broad-leaf relatively maintained their distributions within the landscape. While Dry Bushes became more intermixed with other class patches, Bushes, Conifers and No Vegetation became less interspersed. In the last year, all the classes were well interspersed with each other. The patches of classes were well interspersed in the landscape throughout the three years but a bit less in 2007. The patches of the classes in the landscape became more disaggregated over the years.

On the other hand, in Tsovazard, Reeds patches were equally adjacent to patches of other class patches in 2006. Grasses and Conifers were above averagely distributed proportionally. Bushes had an average distribution. However, No Vegetation class patches were heavily clumped in 2006 and 2007. Aside Grasses which were well dispersed within the landscape in 2007; the rest had an above average dispersion. In 2008, Reeds and Bushes were highly disaggregated in the landscape. Grasses and Conifers were also dispersed well but No Vegetation was a bit clumped. The disaggregation of class patches in the landscape increased gradually over the years from average to a bit high. Furthermore, while the patches of the classes in the landscape were slightly clumped in the first two years, they became averagely distributed in the last year.

Reeds, Conifers and Grasses in Masrik were equally adjacent to other class patches in 2006 whereas Bushes and Broad-leaf Trees were above averagely distributed. Dry Bushes were proportionally distributed. However, No Vegetation class was evenly distributed within the landscape. In 2007, apart from Grasses which had equal adjacency with other class patches, Broad-leaf Trees and No Vegetation classes were clumped. Conifers and Dry Bushes were distributed more proportionally than Reeds and Bushes - which had an above average adjacency with other class patches. In 2008, it was only Bushes which had an above average adjacency; the rest were highly dispersed among other class patches. The class patches in the entire landscape were more equally distributed proportionally in 2006 and 2008 than in 2007. The patches of the classes in the landscape were many and dispersed in 2007 but more dispersed in 2006 and 2008.

The contagion shows promise for landscape planning because it provides a succinct description of landscape texture; specifically, the clumpiness or aggregation of land cover types. It can also be used to compare a landscape at different time periods as done in this research, to quantify how the degree of clumpiness has changed over time as urbanization or human interferences in the landscape progresses (Frohn, 1998; Botequilha Leitão et al., 2006).

5.4.2.5 Comparisons between Regions of Interest (ROI)

It was expected that the vegetated areas in all the regions would have decreased within the three years but that happened only in Gavaraget. The lower values of 2006 in Tsovazard and Masrik were as a result of phenological changes between Grasses and No Vegetation in which dried Grasses were classified as No Vegetation by the remote sensing methods. The increase in their area coverage of ‘No Data’ in all the regions for all the years except Masrik (which had a reduction in 2007), was due to the increasing area of deep water which were masked out.

The monitoring of the reed belts is very critical in the sustainable management of Lake Sevan since they protect the shoreline from bank erosion, retain nutrients from non-point sources and thereby act as buffer zones between the arable land and the open water, serve as a food resource for anthropods, birds and mammals, and provide typical habitat structure for many endangered species which are adapted to them in the lake catchment area (Ostendorp, 1993; Ostendorp et al., 2003). Since the recovering of reed belts take a very long time and even decades (Ostendorp et al., 2003), it is important that their reactions to the water-level fluctuations are monitored intensely by the Lake Sevan management committee. It is in this vain that Wilcox and Nichols (2008) and Petr (2000) explained that slowly and continuously increasing water levels will increase the chances of macrophytes adapting to changing conditions, thus maintaining their ecological functions. It is in this regard that GIS plays a very useful role in storing and analysing data, creating species distribution maps, analysing changes in their distributions for a particular time period and calculate summarising indices in the littoral zone (Schmieder, 1997). However, this does not mean that field studies should be neglected since GIS acts as a link between scientific research and landscape management (Schmieder, 1997).

5.5 Habitat Modelling

5.5.1 Habitat Models of Crucian Carp (*Carassius* spp.)

5.5.1.1 Gavaraget, Tsovazard and Masrik

In Gavaraget, the general increases of coverage areas of the habitat classes of 2007 over 2006 were due to high increase in submersed macrophytes. As a result of huge decreases in both submersed (128 ha) and emersed (66 ha) macrophytes, the VG class decreased about 94%, hence, reducing the habitat quality of the fishes. This is reflected in the increases in AV and VPR classes.

For Tsovazard, the massive increases in VG and GD in 2007 were as a result of increases in the coverage areas of submersed (35 ha) and emersed (55 ha) macrophytes. The increase of the PR class area by 27% indicates the reduction in quality in the fish habitat. A further decrease in submersed (16 ha) and emersed (240 ha) macrophytes reduced the coverage areas of the fish habitat classes in 2008.

The trend in Masrik is similar to the ones obtained in Gavaraget and Tsovazard. The massive increases in almost all the habitat classes in 2007 were due to the massive increase in the coverage area of emersed (715 ha) macrophytes. Even though there was 388 ha decrease in submersed macrophytes, it was not enough to change the effects of the emersed macrophytes. Decreases in both emersed (521 ha) and submersed (60 ha) macrophytes reduced further the coverage areas of the fish habitat classes in 2008.

Additionally, since water depth was an important factor in the fish habitat model, an increase of the water level by 54 cm (Armenia Hydro-Meteorological Institute [ArmHydromet], 2009) in 2008 also masked out some areas within the various habitat classes thereby reducing their coverage in all regions of interest.

5.5.1.2 Summary of Fish Habitat Models in the ROI

It can be seen that macrophytes and their distributions really affected the habitat suitability indices of the Crucian Carp. Net increases in macrophytes produced increases in the coverage areas of the habitat class areas and decreases resulted in decreases in the habitat areas. Schmieder (2004) and Heikinheimo-Schmid (1985) stated that the loss of submersed and emersed littoral vegetation reduces habitat for epiphyton and macroinvertebrates, which in turn affects the feeding conditions for littoral fish (Schmieder, 2004). Again, such loss threatens the spawning sites of fishes like Crucian Carp which lays or deposits its eggs on submersed part of the macrophytes (Rubenyan and Hayrapetyan, 2008). Crucian Carps are known to be extremely vulnerable to predation (Piironen and Holopainen, 1988) and therefore use vegetated inshore areas as refuge (Pettersson and Brönmark, 1993; Petr, 2000). A study of Crucian Carp in Finland by Paszkowski et al. (1996) found out that most of their catches (52%) were heavily concentrated in vegetated inshore areas confirming what Tonn et al. (1992) stated that Crucian Carps are primary inhabitants of vegetated littoral zones.

The magnitude of fish growth, abundance and population structure are generally in proportion to the abundance of aquatic macrophytes (Wiley et al., 1984; Canfield and Hoyer, 1992; Hoyer and Canfield Jr., 1996). Additionally, water depth played an important role in this model. Hence, water level management of Lake Sevan should be combined with habitat modelling of species to see the effects the water level fluctuations are having on the littoral zone. Moreover, these habitat suitability maps can be used as structural indicators in assessing the habitat and environmental qualities prevailing in the areas under consideration.

5.5.2 Habitat Models of Common Coot (*Fulica atra*) and Great Crested Grebe (*Podiceps cristatus*)

5.5.2.1 Gavaraget, Tsovazard and Masrik

The general decreases of coverage areas of the habitat suitability classes of Gavaraget in 2007 and 2008 were as a result of the decreases in emersed macrophytes. The Gavaraget bird habitat areas were almost lost in 2008 due to the die-back of the emersed macrophytes as a result of the increase of the lake water level by 54 cm (Armenia Hydro-Meteorological Institute [ArmHydromet], 2009). Therefore, this should serve as a wake-up call to the management of Lake Sevan if habitats of birds are to be managed sustainably.

In Tsovazard, although emersed macrophytes increased by 55 ha in 2007 resulting in increases in PR and VPR; VG and GD decreased, indicating reduction in habitat quality. Again, the die-back of 240 ha of emersed macrophytes in 2008 reduced the coverage areas of the bird habitat classes especially VG and GD. Again, an increase of the water level by 54 cm in 2008 was likely one of the causes of these die-backs. The suitable habitat areas were almost gone in 2008. Additionally, the massive decreases in 2008 could have been due to misclassifications of the reeds (emersed macrophytes) as bushes which resulted in a user accuracy of less than 49%.

For Masrik, the massive increases in almost all the habitat classes in 2007 were due to the astronomical increase of 715 ha in the coverage area of emersed macrophytes. The emersed macrophytes being on a higher ground as compared to Gavaraget and Tsovazard were able to withstand the initial water level increase of 19 cm in 2007 but not 54 cm (Armenia Hydro-Meteorological Institute [ArmHydromet], 2009) in 2008. Therefore, a decrease of 521 ha of the emersed macrophytes reduced further the coverage areas of the bird habitat suitability classes in 2008. However, the habitat suitability areas were better than those obtained in 2006.

5.5.2.2 Summary of Bird Habitat Models in the ROI

It can be confirmed that the macrophytes and their spatial distributions really affected the habitat suitability areas of the Common Coot and the Great Crested Grebe. Increases in emersed macrophytes produced increases in the coverage areas of the habitat areas and decreases resulted in decreases in the habitat areas. In the Netherlands, Ulenaers and Dhondt (1991) found out that food availability did not influence distribution, habitat choice nor breeding activities of the Great Crested Grebes, but habitat choice, distribution and hatchling survival were positively influenced by the presence of reeds.

Furthermore, the magnitudes of aquatic bird abundance and species composition are generally in proportion to the abundance of aquatic macrophytes (Hoyer and Canfield Jr., 1994; Hoyer and Canfield Jr., 1996). A study of the breeding ecology of the Great Crested Grebe in northern Slovenia by Vogrin (1999) revealed that the decrease of breeding pairs reduced with the loss of shore vegetation. Hoyer and Canfield Jr. (1994) concluded from their research on Florida lakes that bird species composition will change as aquatic macrophytes are removed from the lake system since birds that use aquatic macrophytes will be replaced by species that use open-water habitats. Hence, the management of aquatic macrophytes has the potential to affect bird populations.

Additionally, water level played a crucial role in the bird habitat model as well as the vitality of the reeds (Özesmi and Mitsch, 1997). Again, these habitat suitability maps can be used as indicators in assessing the ecological health or state of the littoral zone. They are useful for exploring the implications of planning objectives, assumptions and policy choices (Davis et al., 1997). Apart from GIS being used in the determination of spatial relationships between birds and their environments, it can also be used to rapidly analyze temporal changes in the spatial mosaic (Johnston and Naiman, 1990).

5.5.2.3 Validation of Bird Habitat Models

Generally, the agreement between the modelled areas and bird survey areas increased over the years due to the decreases in the quality of habitat areas and increases in poor habitat areas. The bird survey data used for the validations were very few, more data points could have yielded better results. During the 2008 bird survey, 51.5% and 45.4% of the 33 species found in the survery were located in Gavaraget and Masrik respectively (Aghababyan and Ananian, 2008). These statistics show that these regions play important role in the habitat of bird species in the Sevan catchment area. Therefore regular bird surveys accompanied by habitat suitability maps could be used to conserve and protect these organisms.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The results obtained for the assessment of development of Lake Sevan's surface area demonstrate that Landsat TM imagery analysed through a GIS can be used in monitoring long-term trends of lake surface areas. The expense of using topographic maps, the time and expertise for the traditional calculation of surface areas with the help of a planimeter or computer scanner, preclude their use as a routine, state-wide monitoring tool. TM imagery, despite its relatively coarse spatial resolution, is more routinely available than topographic maps and could be a more cost-effective method for monitoring water bodies distributed across large geographical areas. TM-imaging processes are subject to error. The TM images are limited by the 30-by-30-m ground resolution of the instrument. However, other satellite images aside Landsat, which have higher spatial resolution but are more expensive, could also be used.

The results obtained in the littoral zone area assessment demonstrate that in littoral zones with gentle slopes little or small water level changes affect markedly the littoral surface area and the respective ecological functions. Thus, it is crucial for lake management measures of Lake Sevan to focus particularly on the littoral zone development and observe changes due to lake level manipulations. Additionally, they show that remote sensing data analysed through GIS can be very useful in monitoring development trends of littoral zones. Again, since the water level of Lake Sevan keeps rising, it is very important that the littoral zones are monitored routinely together with other parameters.

Concerning the validation of the supervised classifications, the results for the submersed macrophytes and most of the emersed macrophytes confirm the remote sensing classification as having high quality and usefulness. Hence, the classified data can be relied upon to create land cover maps with high quality. This promotes the fact that high resolution remote sensing data can be reliably applied in recording submersed macrophytes and emersed vegetations. Validation of the shore vegetation classifications proved the applied methods as very successful instruments to monitor the changes in different littoral vegetation types and their spatial structures due to water level rise. The developed methods which produce high accuracies are cost-effective and time efficient as compared to the traditional methods of stereoscopic aerial picture analyses with its accompanying extensive littoral zone mapping and surveying. One of the most important coverages for lakeshore management and planning is its macrophyte vegetation. Therefore, highly reliable base resource maps developed from remotely sensed data are necessary for the public and resource managers to make effective decisions.

The landscape metrics provided an insight on how the artificial water level fluctuations are affecting the lakeshore vegetations, their spatial distributions and structural dynamics. Landscape indices in the various regions of interest (ROI) showed drastic reduction in emersed macrophytes and compositional changes in the submersed macrophytes over the years. Therefore the results could serve as guidelines of the lake water level manipulations for Lake Sevan authorities as to how fast the water level should be raised. Especially is the die-back of the emersed macrophytes a case for concern. The results showed that landscape metrics can reveal changes in the landscape's composition and configuration that can be observed, explained and interpreted comprehensively. Additionally, all analysis of landscape metrics heavily relies on the correct detection and classification of the remote sensing data. Therefore, the meaning and interpretations of these metrics are affected. Also, the spatial composition and configuration of landscape elements play a crucial role in the ecological functionality and biological diversity. There is no single metric which can be used to describe all the aspects of landscape structure, therefore multiple metrics should be calculated and interpreted to complement each other.

Since the Crucian Carp is an economically important fish species in Lake Sevan, a GIS-based analysis of its habitat could play an important role in the decision-making process with regards to measure planning and control. Additionally, they can serve as lead species indicators for the evaluation of the health or state of the aquatic macrophytes. The Common Coot and the Great Crested Grebe were found at all the regions of interest of Lake Sevan; therefore, they can be used as lead species indicators for the ecological soundness of the aquatic emersed macrophytes. Furthermore, habitat models for fishes and birds in all ROI showed reduction in habitat areas as well as habitat quality along the years. Since static maps poorly represent the complex dynamic phenomenon of species distribution, GIS has the potential of enhancing the visualization by combining several environmental factors of such a phenomenon. Furthermore, intensive field surveys cannot keep up with the rapid change of land cover in the large catchment area, therefore GIS with the support of remote sensing has the potential of mapping these land cover changes with its subsequent habitat changes at the regional scale. These habitat models generated in the GIS environment can be used for conservation and management decisions in the sensitive habitats in the lake catchment area.

The developed methodologies can be transferred and used in other geographically similar areas. The results produced so far can be used for large public and other organizations, the Internet, local mass media and other communication means to increase awareness creation and support.

Finally, monitoring the temporal and spatial dynamics of inland waters is crucial for the understanding of freshwater ecosystems. Remote sensing and GIS offer a good way to get, display, analyse, query and assess such information of physical and biological parameters. Therefore, spatially resolved information in interdisciplinary combination of different methods and scientific views can add to the understanding of the lake ecosystem.

The results show urgent the need for a modest water level rise to enable the future development of a diverse littoral biocenosis and to fulfil the important functions as habitat and in the balance of matter of the whole lake. In a nut shell, by applying remote sensing and GIS techniques, the project gave a deep insight in the strongly impaired ecosystem of Lake Sevan and provided instruments to assess and visualize the ecological state and to control the success of mandatory restoration measures.

6.2 RECOMMENDATIONS

From the results obtained and the experiences gained from this project, the following recommendations are proposed:

- ❖ Lake Sevan authorities should raise the Lake water level gradually and modestly i.e. about 15-20 cm annually to enable the littoral vegetation to adjust or adapt to the water rise since they cannot cope with the current speed of water level rise-
- ❖ Spectral data bank of species along the lakeshore should be created to aid supervised classifications of remote sensing data at the species level from which important vegetation maps could be developed to help in policy making and management decisions.

- ❖ The producer's accuracy indicated the probabilities that the groundtruth data will be correctly classified. Those samples which were not correctly classified into a particular class were omitted from that class. Therefore, if it is most important not to miss the presence of macrophytes or a type of macrophyte in the Sevan catchment area, then this type of accuracy should be the most important to the Sevan National Park authorities.
- ❖ When samples are misclassified, they are not only omitted from the correct class but are also committed into another class. All samples that are classified as a particular class are actually not that particular class unless the classified image is 100 percent correct. Therefore, the user accuracy derived indicates the probability that a sample from the classified image actually represents that particular class on the ground. Hence, the Sevan National Park authorities should take this user accuracy seriously for decisions associated with the vegetation maps. If it is most important for managers not to overestimate a particular class or presence of macrophytes in general, then attention could be focused on this statistic.
- ❖ Thorough fish and bird surveys should be conducted at many locations possible to validate the habitat models generated in this project.
- ❖ Lastly, there is the need to conduct shore vegetation mapping using these remote sensing and GIS techniques every 5 years for the sustainable management of the lake.

CHAPTER SEVEN

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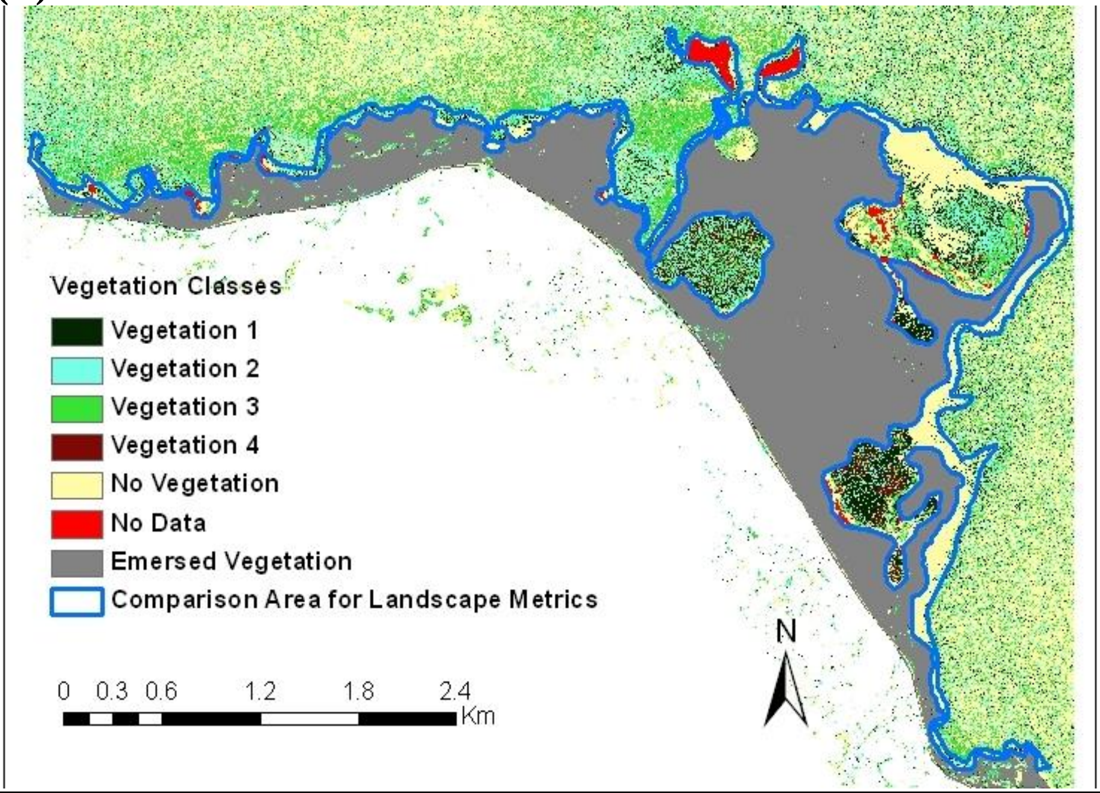
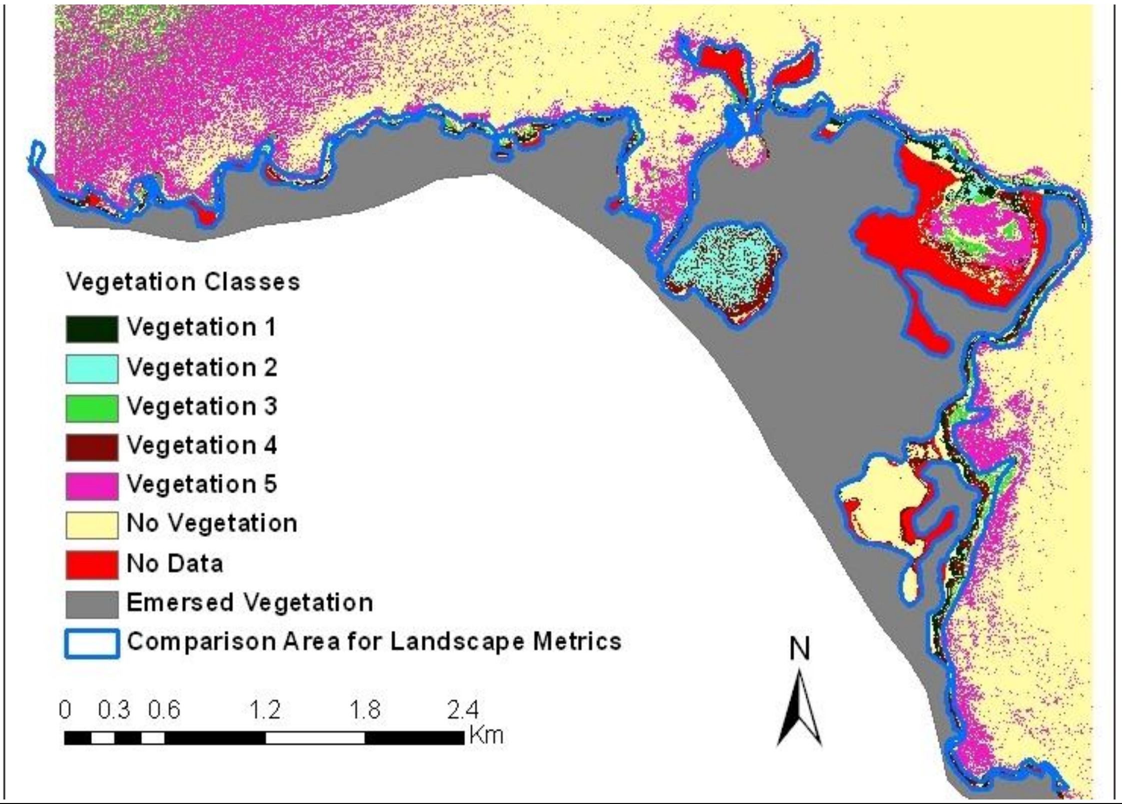
APPENDIX 1

(A)Tsovazard



2006 Supervised Classifications of Submersed Macrophytes in Tsovazard
Source of Classifications: (Heblinski, 2008)



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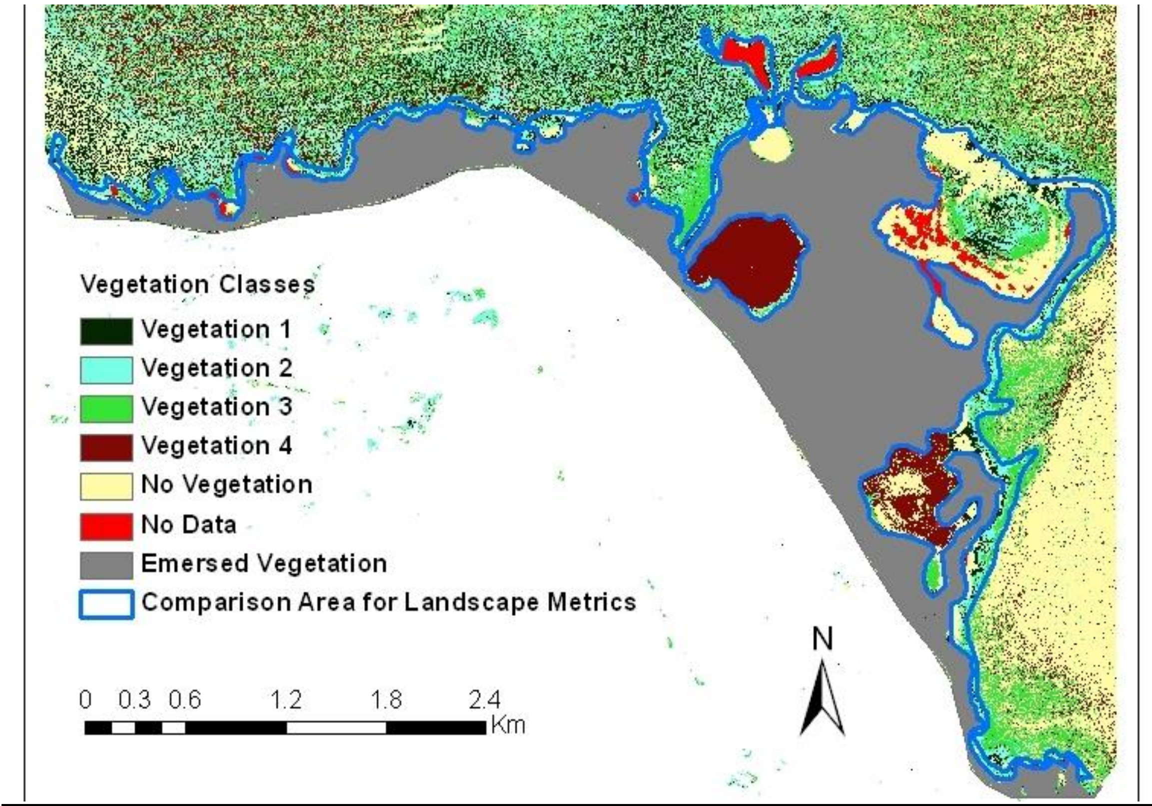
Source of Classifications: (Heblinski, 2008)



2008 Supervised Classifications of Submersed Macrophytes in Tsovazard
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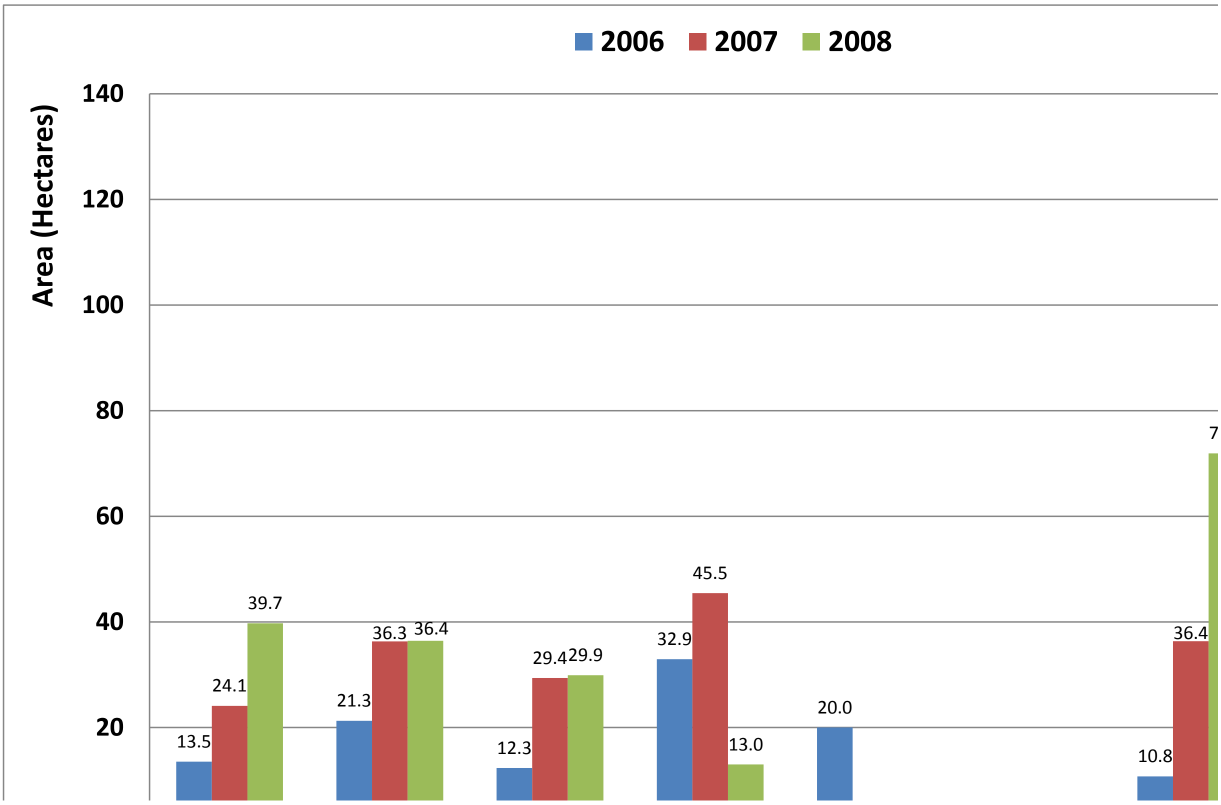


Tsovazard submersed macrophyte vegetation changes (2006-2008)

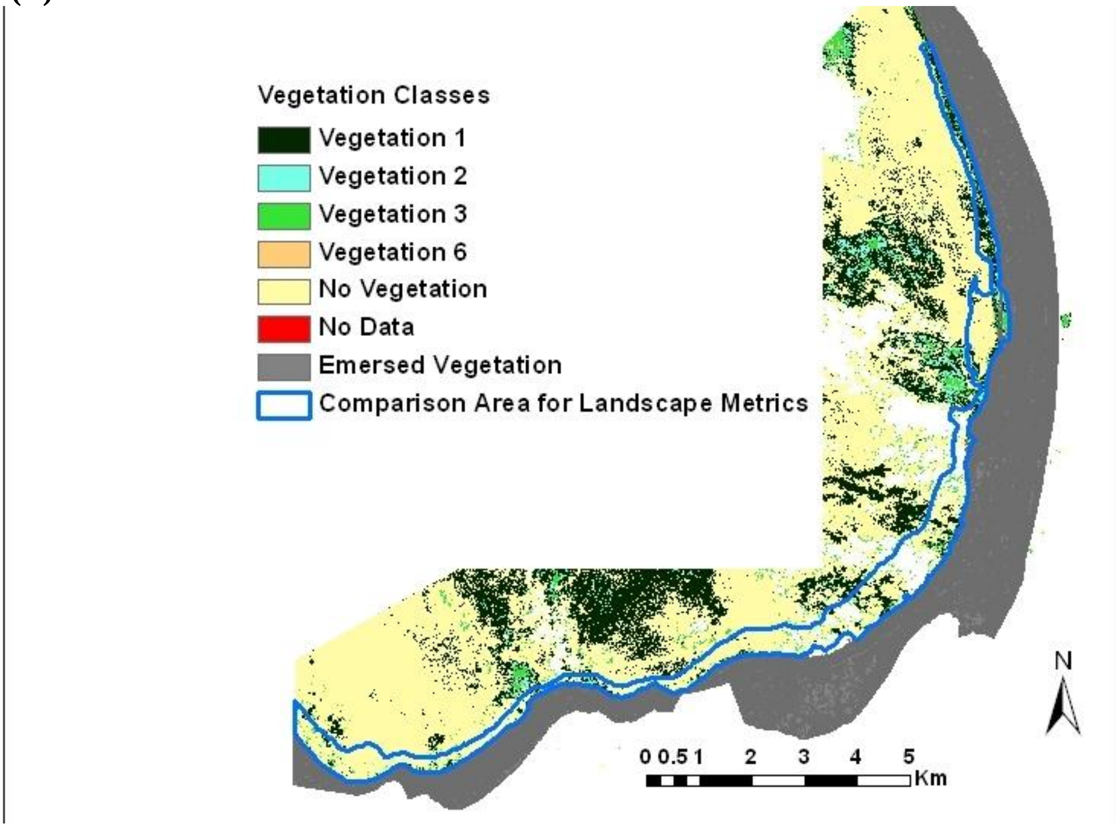
Selected Landscape Metrics at the Class Level for Submersed Macrophytes in Tsovazard

Land Cover Types	Year	PLAND	IJI
Vegetation 1	**2006**	8.87	71.35
	2007	11.88	81.31
	2008	18.67	91.70
Vegetation 2	**2006**	13.95	32.93
	2007	17.90	88.54
	2008	17.11	93.68
Vegetation 3	**2006**	8.09	39.12
	2007	14.48	86.11
	2008	14.05	95.58
Vegetation 4	**2006**	21.59	65.79
	2007	22.40	90.10
	2008	6.11	96.68
Vegetation 5	**2006**	13.11	30.76
	2007		
	2008		
No Vegetation	**2006**	34.39	85.97
	2007	33.34	98.99
	2008	44.06	89.26

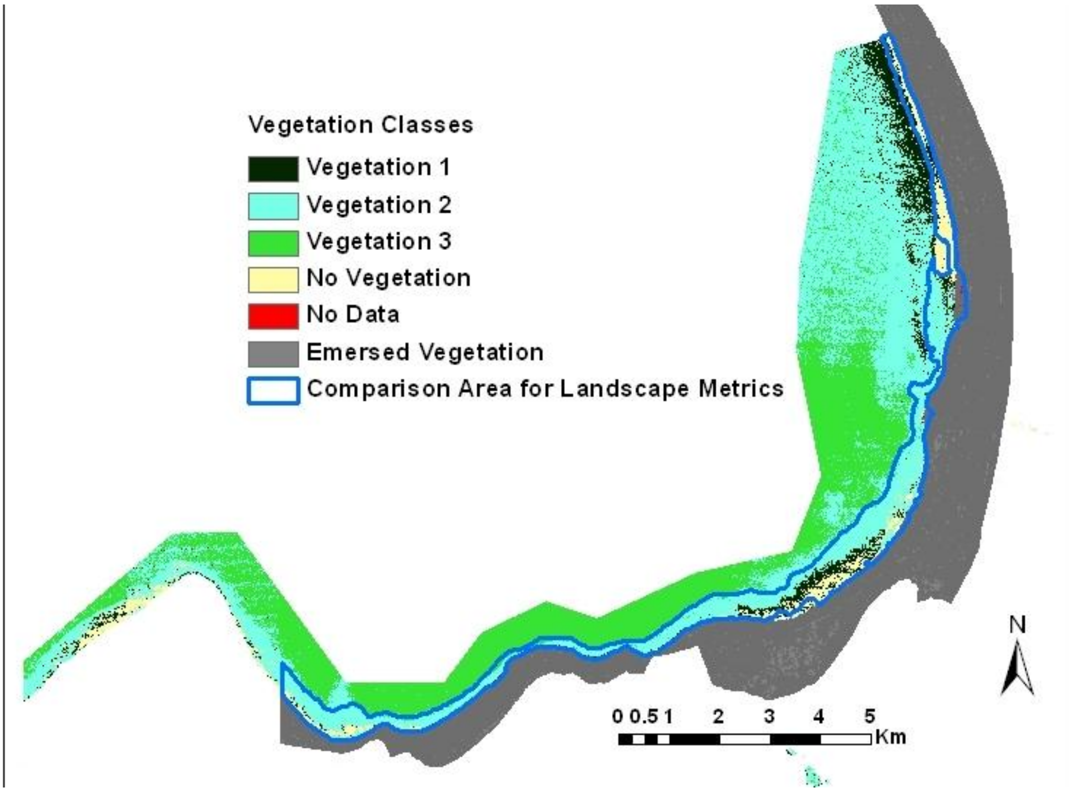
Selected Landscape Metrics at the Landscape Level for Submersed Macrophytes in Tsovazard

Year	TA (ha)	PD /100 ha	CONTAG	IJI	SHDI
2006	152.58	5215.67	31.72	71.87	1.66
2007	202.91	6493.60	27.34	91.00	1.54
2008	212.87	15602.82	23.70	93.87	1.42
Mask	230.78				

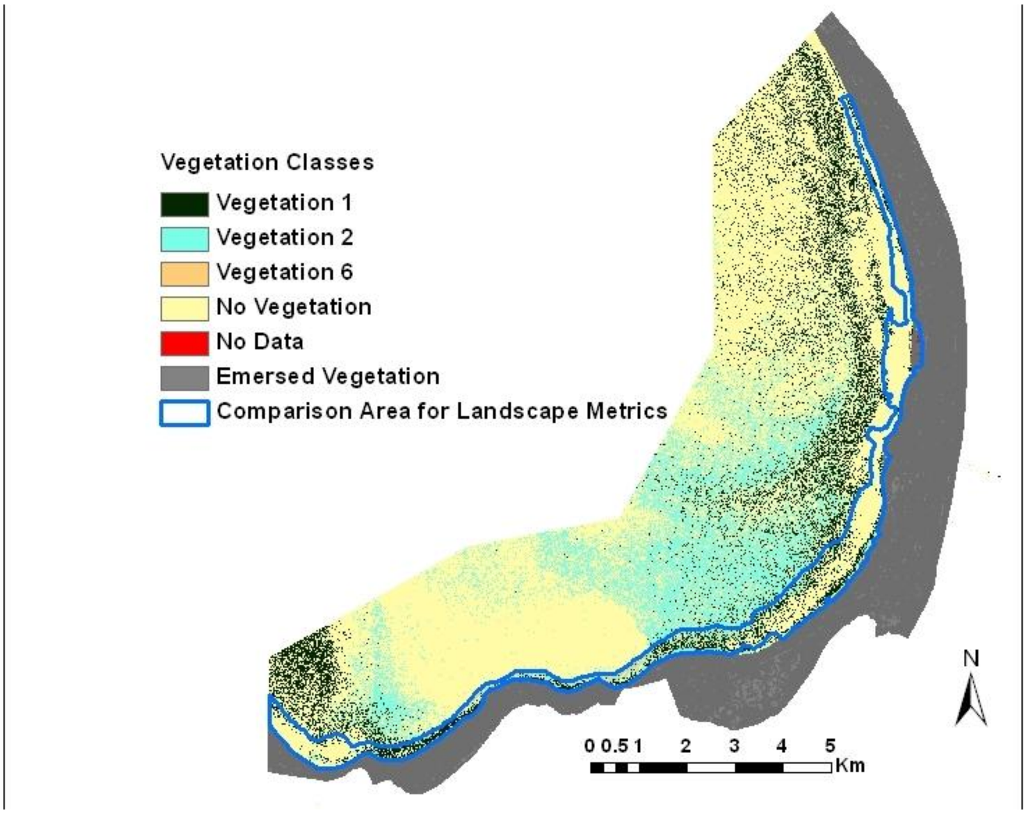
(B) Masrik



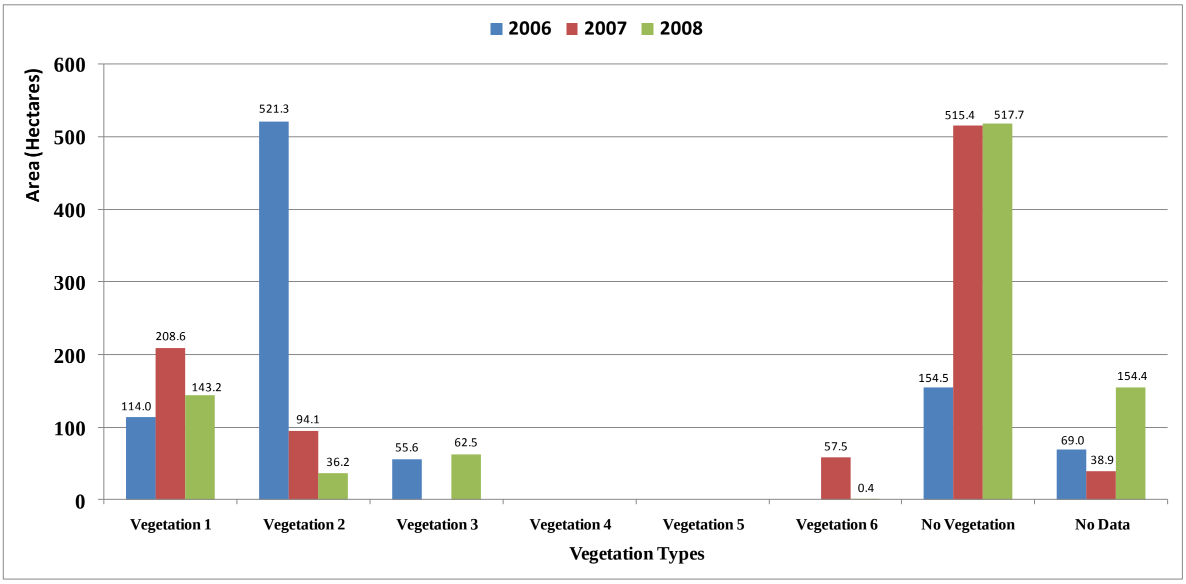
2006 Supervised Classifications of Submersed Macrophytes in Masrik
Source of Classifications: (Heblinski, 2008)



2007 Supervised Classifications of Submersed Macrophytes in Masrik
Source of Classifications: (Heblinski, 2008)



2008 Supervised Classifications of Submersed Macrophytes in Masrik
Source of Classifications: (Heblinski, 2008)



Masrik submersed macrophyte vegetation changes (2006-2008)

Selected Landscape Metrics at the Class Level for Submersed Macrophytes in Masrik

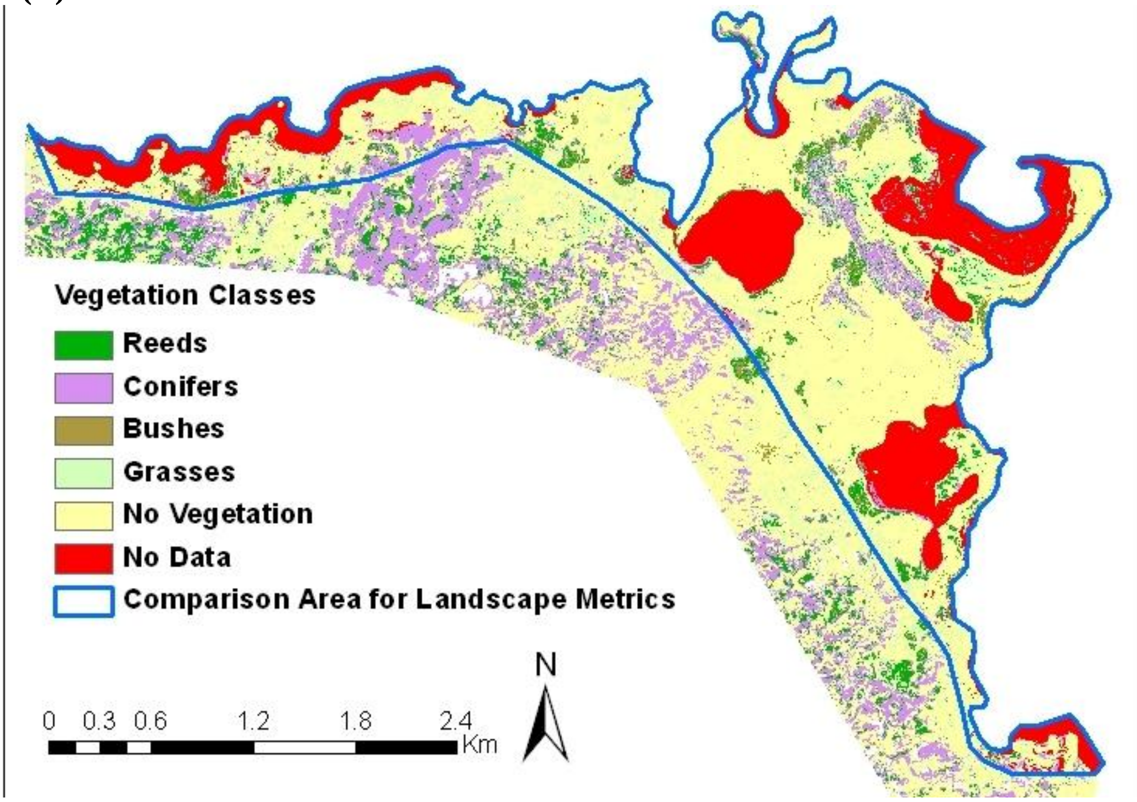
Land Cover Types	Year	PLAND	IJI
Vegetation 1	**2006**	13.49	61.47
	2007	23.82	71.57
	2008	18.84	75.20
Vegetation 2	**2006**	61.66	98.21
	2007	10.75	95.51
	2008	4.76	78.86
Vegetation 3	**2006**	6.58	1.32
	2007		
	2008	8.22	73.93
Vegetation 6	**2006**		
	2007	6.56	84.38
	2008	0.05	47.85
No Vegetation	**2006**	18.27	56.80
	2007	58.86	49.93
	2008	68.12	74.92

Selected Landscape Metrics at the Landscape Level for Submersed Macrophytes in Masrik

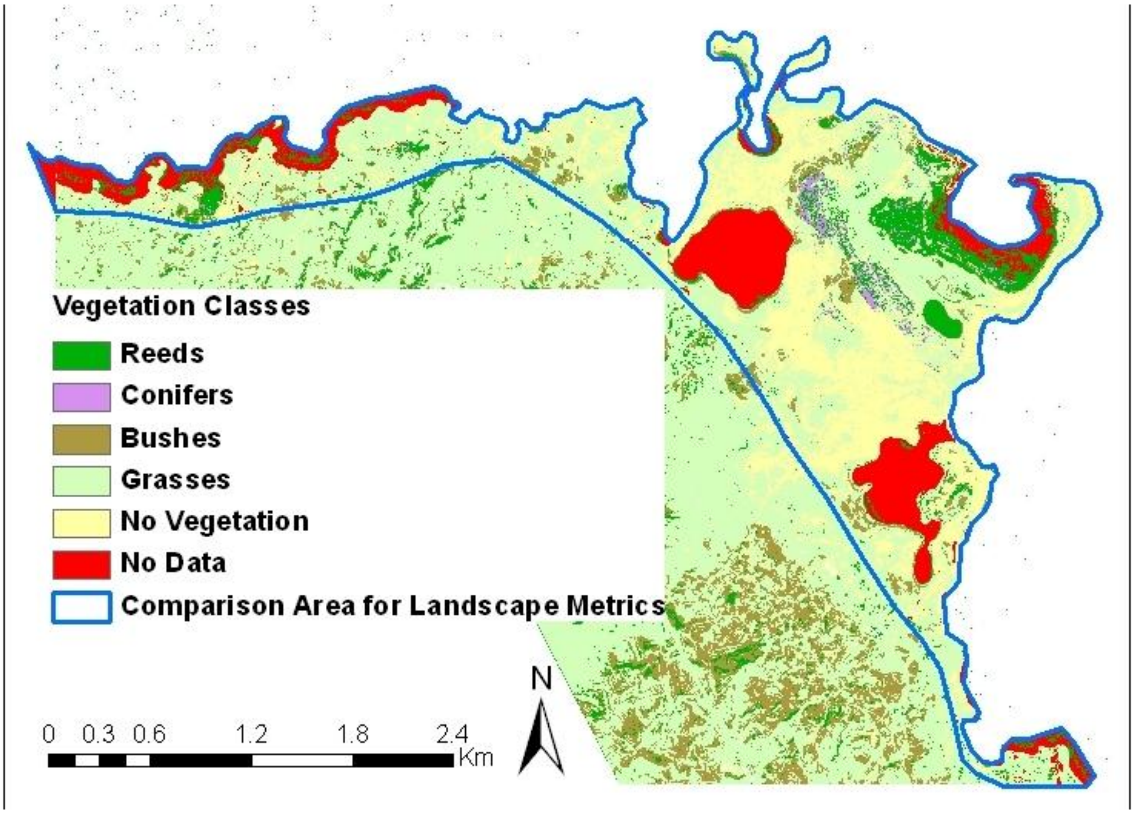
Year	TA (ha)	PD /100 ha	CONTAG	IJI	SHDI
2006	845.40	2805.31	46.58	74.24	1.06
2007	875.49	7754.64	33.52	75.79	1.07
2008	759.98	5939.33	54.53	74.45	0.93
Mask	914.40				

APPENDIX 2

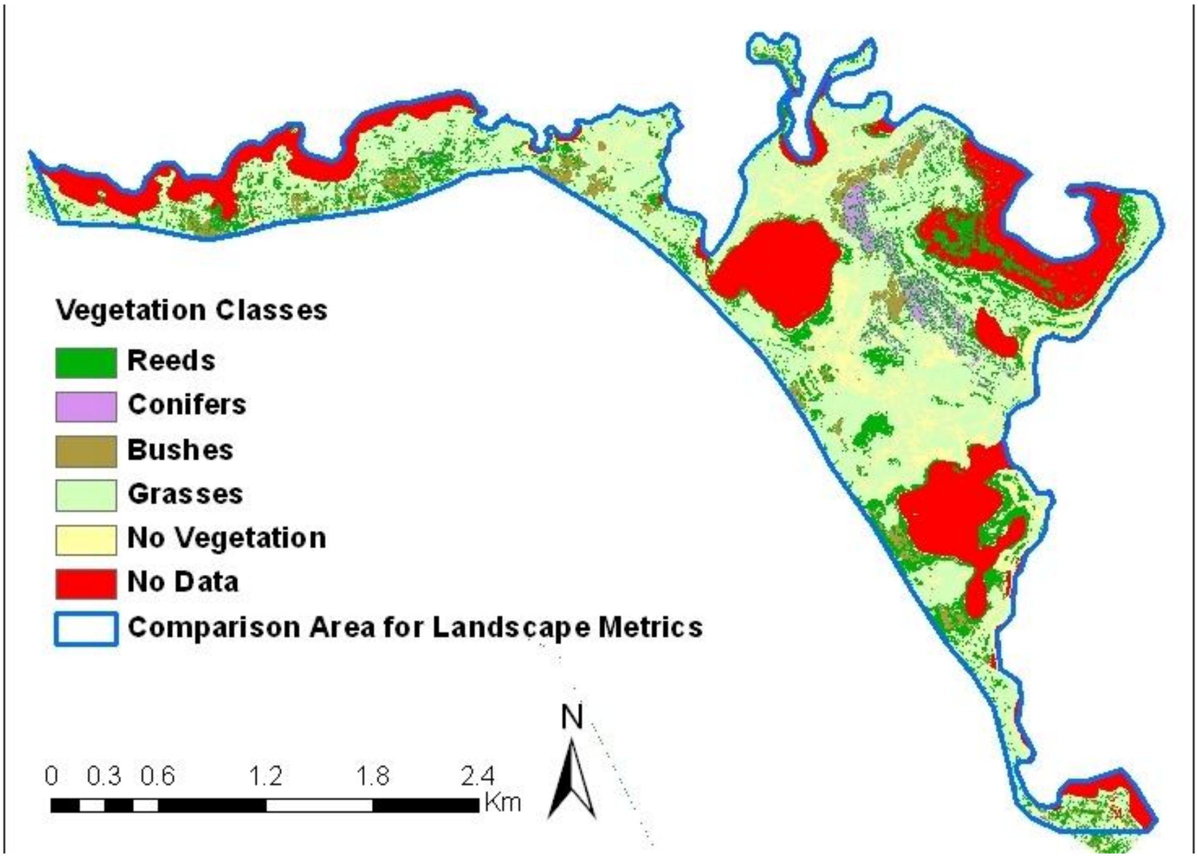
(A) Tsovazard



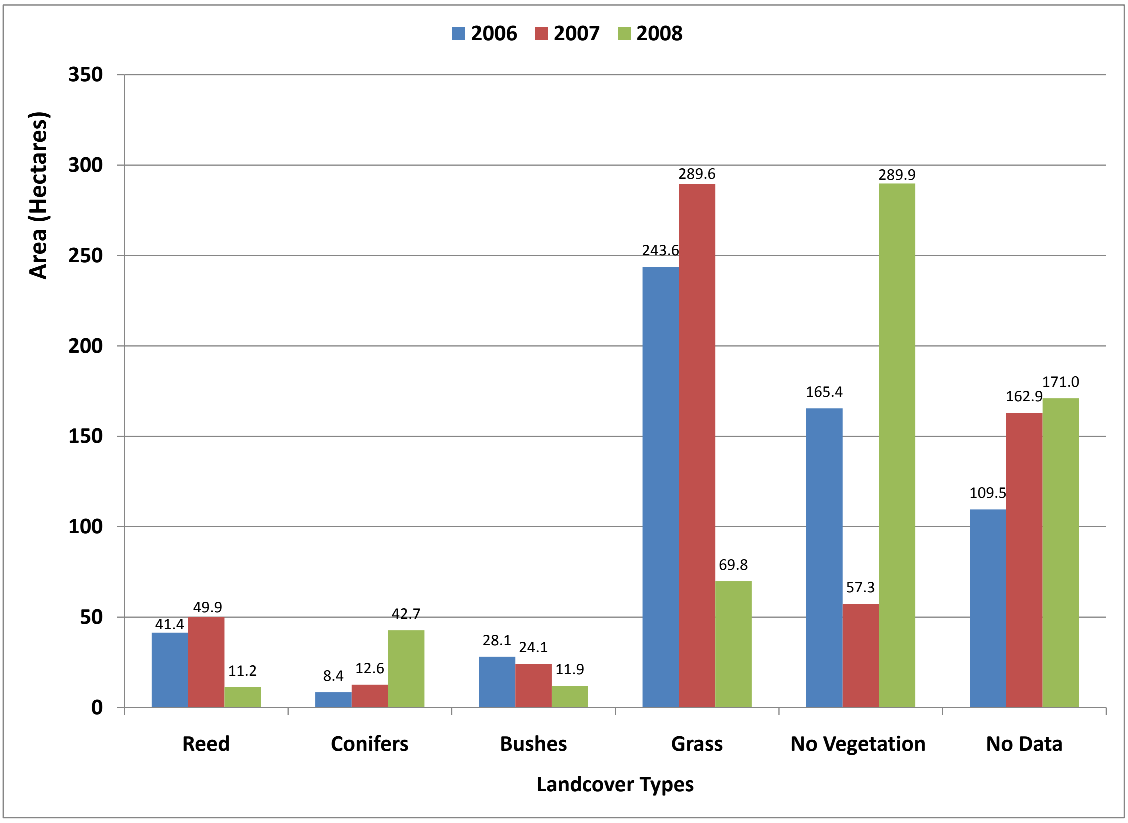
2006 Supervised Landcover Classifications of Tsovazard
Source of Classifications: (Heblinski, 2008)



2007 Supervised Landcover Classifications of Tsovazard
Source of Classifications: (Heblinski, 2008)



2008 Supervised Landcover Classifications of Tsovazard
Source of Classifications: (Heblinski, 2008)



Tsovazard Emersed Macrophytes changes from 2006 to 2008

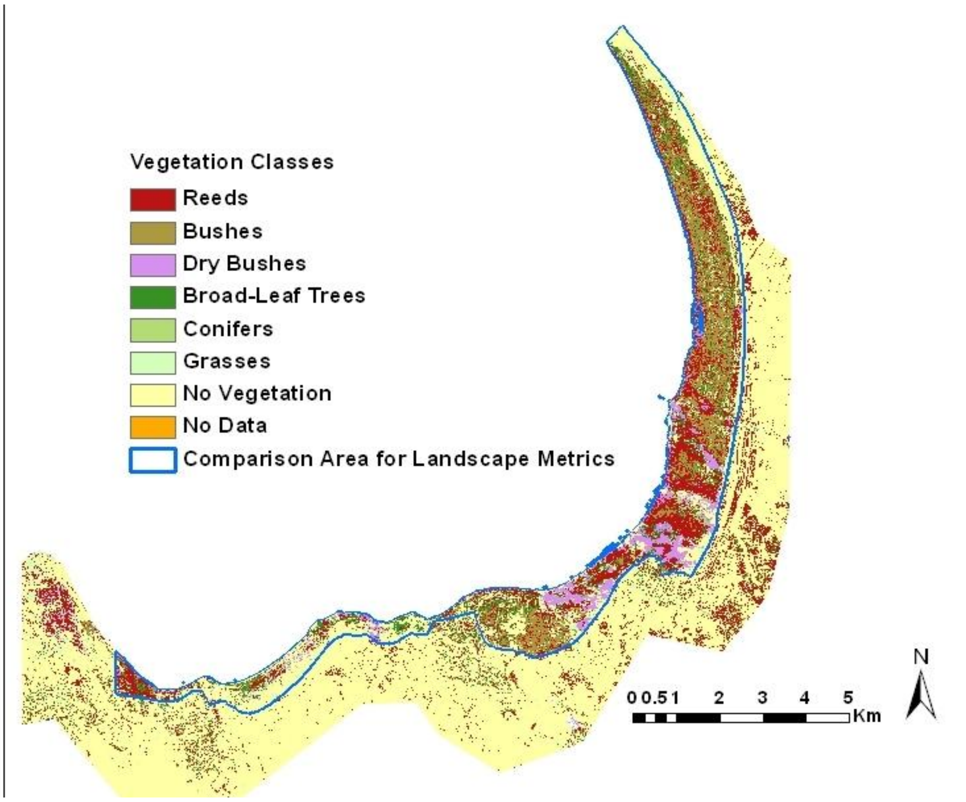
Selected Landscape Metrics at the Class Level for Emersed Macrophytes in Tsovazard

Land Cover Types	Year	PLAND	IJI
Reeds	2006	8.50	79.94
	2007	11.52	56.89
	2008	2.63	85.88
Conifers	2006	1.72	62.22
	2007	2.91	62.39
	2008	10.03	70.35
Bushes	2006	5.77	51.71
	2007	5.56	64.84
	2008	2.80	95.65
Grasses	2006	50.04	63.41
	2007	66.79	78.07
	2008	16.41	73.48
No Vegetation	2006	33.98	2.68
	2007	13.23	4.95
	2008	68.13	48.57

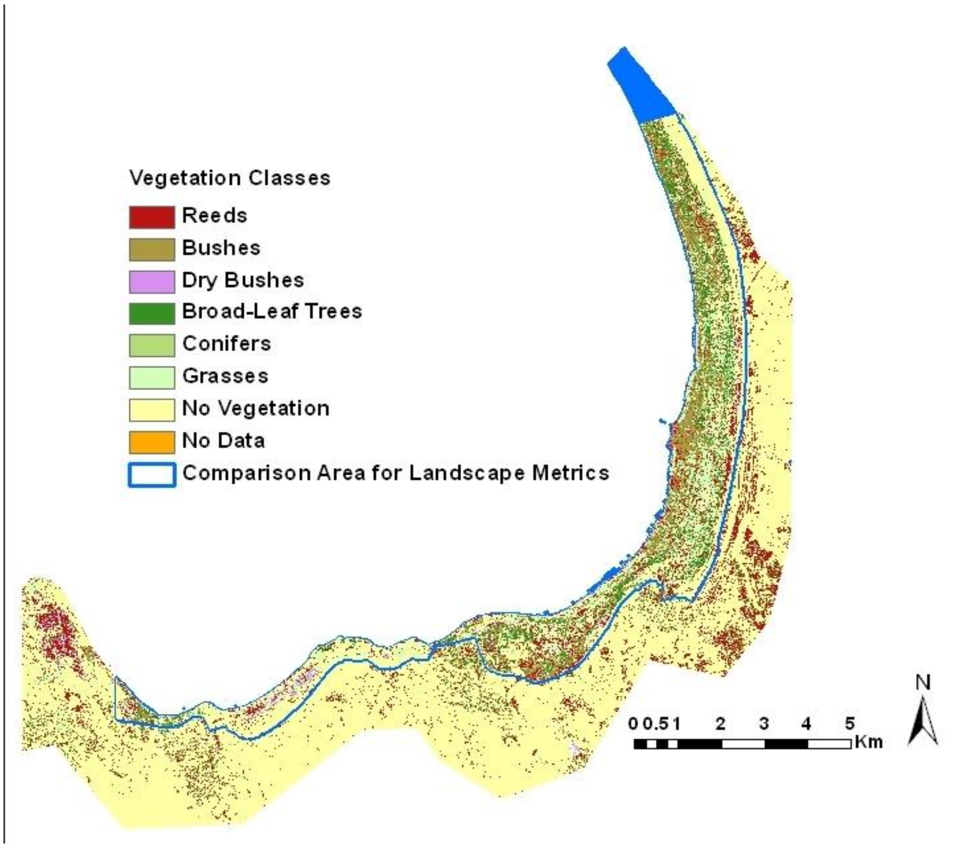
Selected Landscape Metrics at the Landscape Level for Emersed Macrophytes in Tsovazard

Year	TA (ha)	PD /100 ha	CONTAG	IJI	SHDI	SHEI
2006	486.92	2381.31	48.01	54.76	1.16	0.72
2007	433.55	3286.80	48.87	64.74	1.05	0.65
2008	425.46	5359.43	51.76	71.47	0.98	0.61
Mask	596.46					

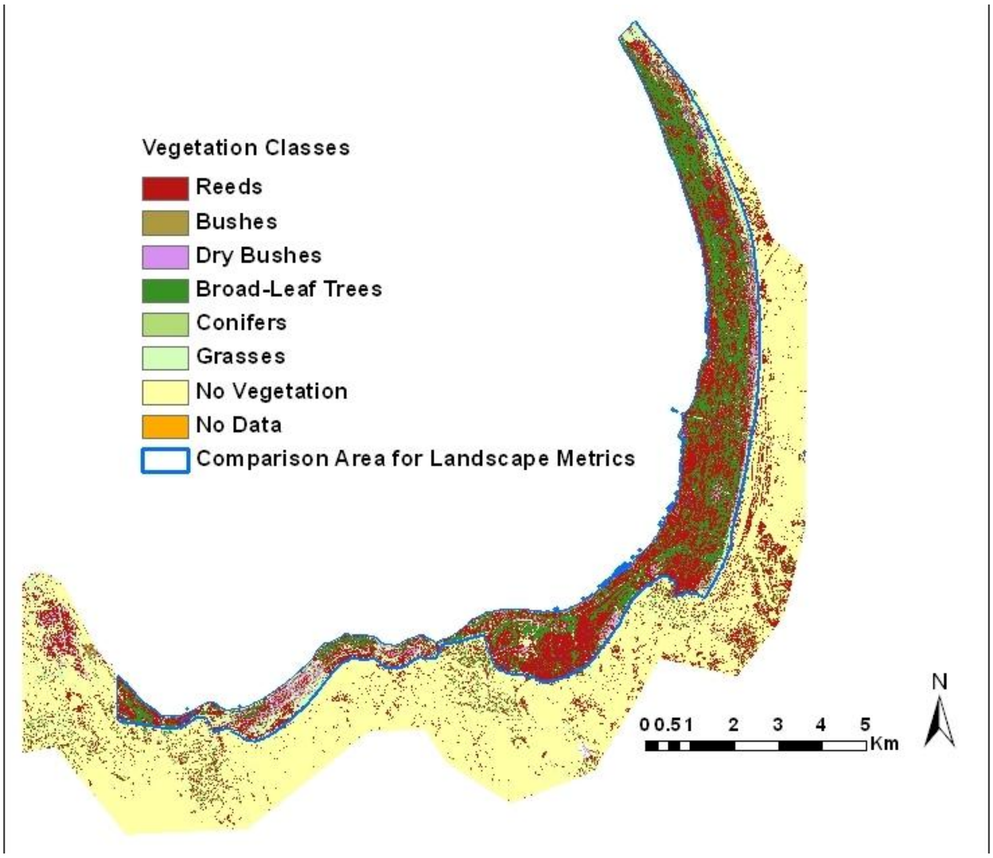
(B) Masrik



2006 Supervised Landcover Classifications of Masrik
Source of Classifications: (Heblinski, 2008)



2007 Supervised Landcover Classifications of Masrik
Source of Classifications: (Heblinski, 2008)



2008 Supervised Landcover Classifications of Masrik
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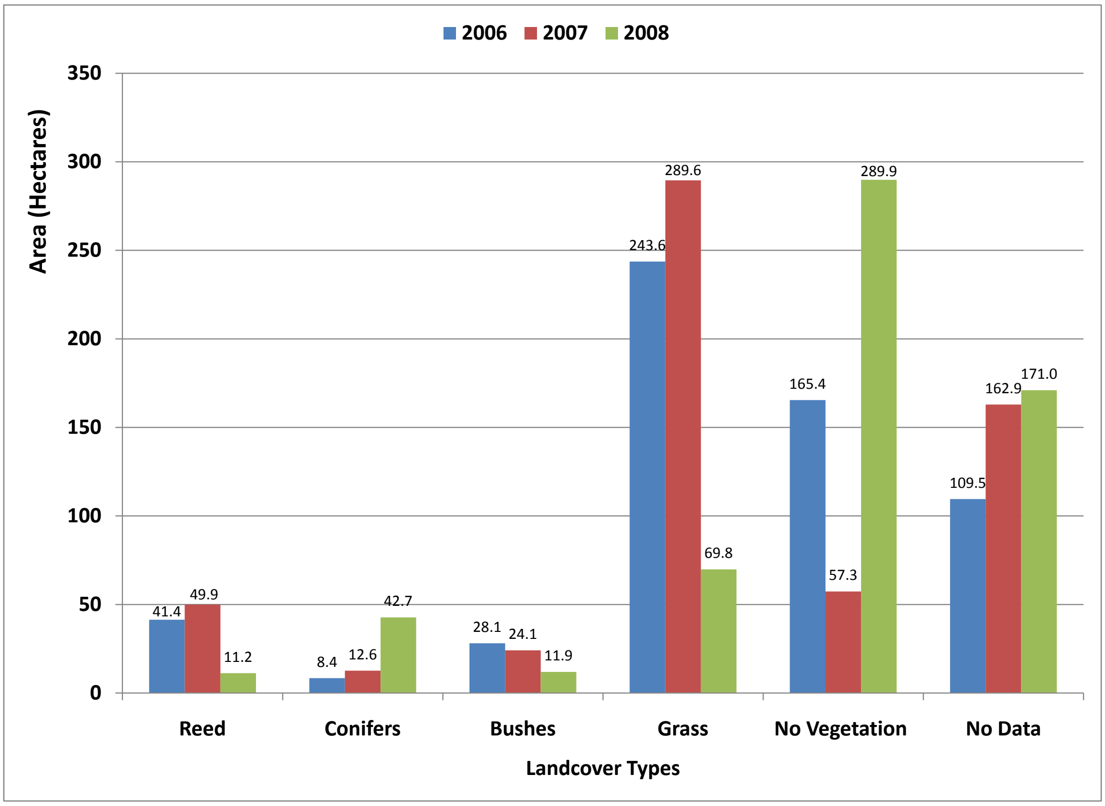


Masrik emersed macrophyte vegetation changes from 2006 to 2008

Selected Landscape Metrics at the Class Level for Emersed Macrophytes in Masrik

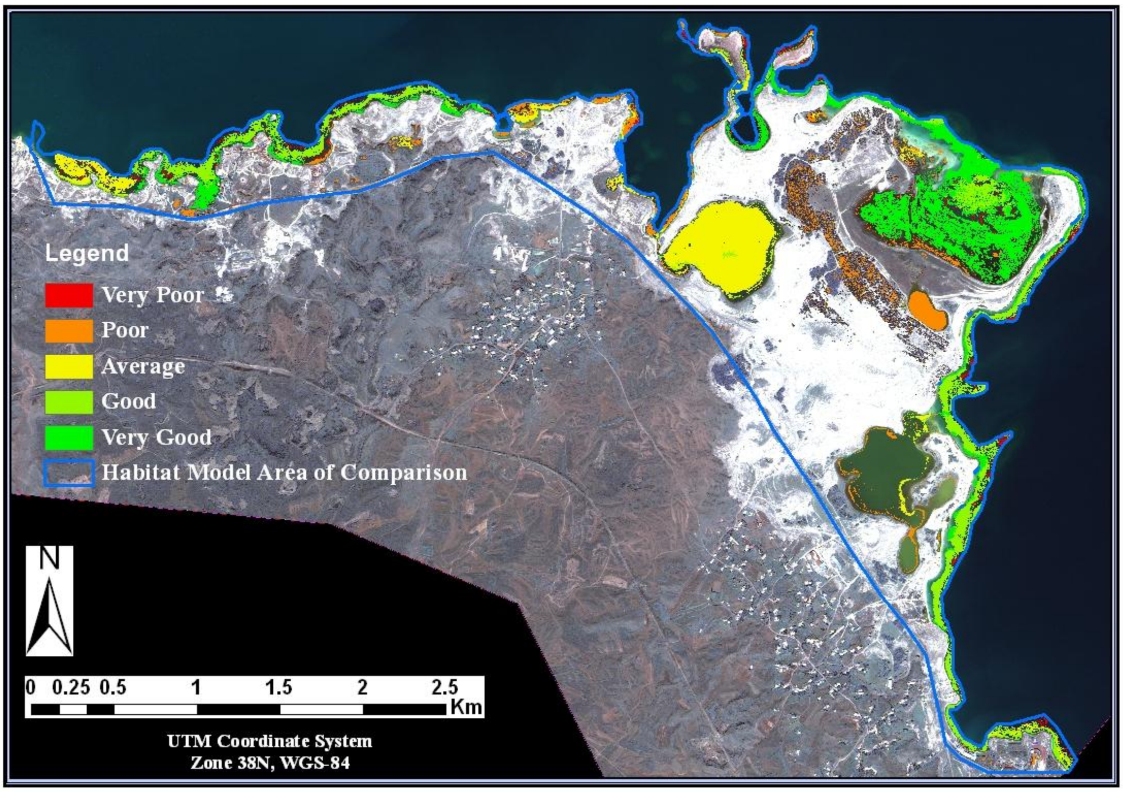
Land Cover Types	Year	PLAND	IJI
Reeds	**2006**	13.57	82.29
	2007	46.51	60.42
	2008	26.32	80.47
Bushes	**2006**	16.79	63.77
	2007	4.58	64.47
	2008	22.94	58.43
Dry Bushes	**2006**	1.95	76.10
	2007	4.89	70.93
	2008	9.19	86.04
Broad-Leaf Trees	**2006**	12.26	64.00
	2007	33.37	27.24
	2008	9.87	75.34
Conifers	**2006**	0.16	80.49
	2007	0.42	71.07
	2008	1.99	81.51
Grasses	**2006**	27.40	85.12
	2007	9.38	87.12
	2008	7.68	84.13
No Vegetation	**2006**	27.87	49.72
	2007	0.85	21.18
	2008	22.01	73.54

Selected Landscape Metrics at the Landscape Level for Emersed Macrophytes in Masrik

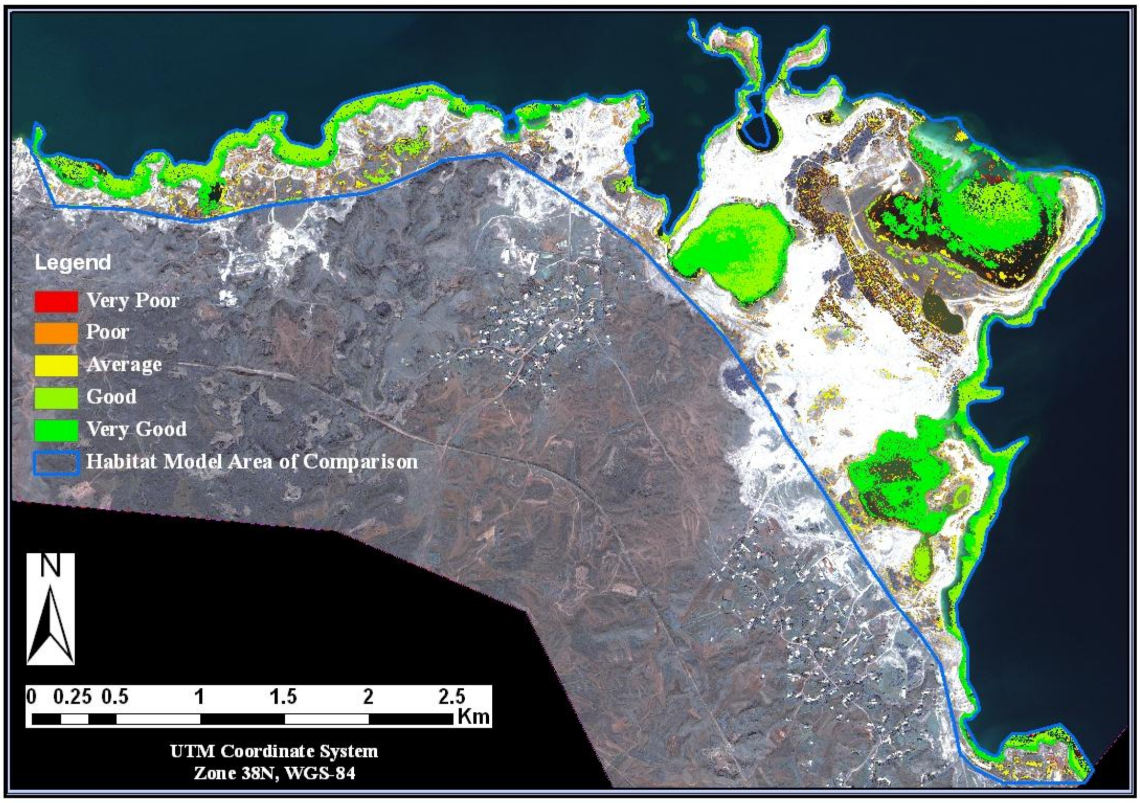
Year	TA (ha)	PD /100 ha	CONTAG	IJI	SHDI
2006	2339.39	5944.37	34.62	75.09	1.63
2007	2423.28	4511.57	47.03	58.58	1.30
2008	2412.21	6525.44	34.36	79.64	1.75
Mask	2460.00				

APPENDIX 3

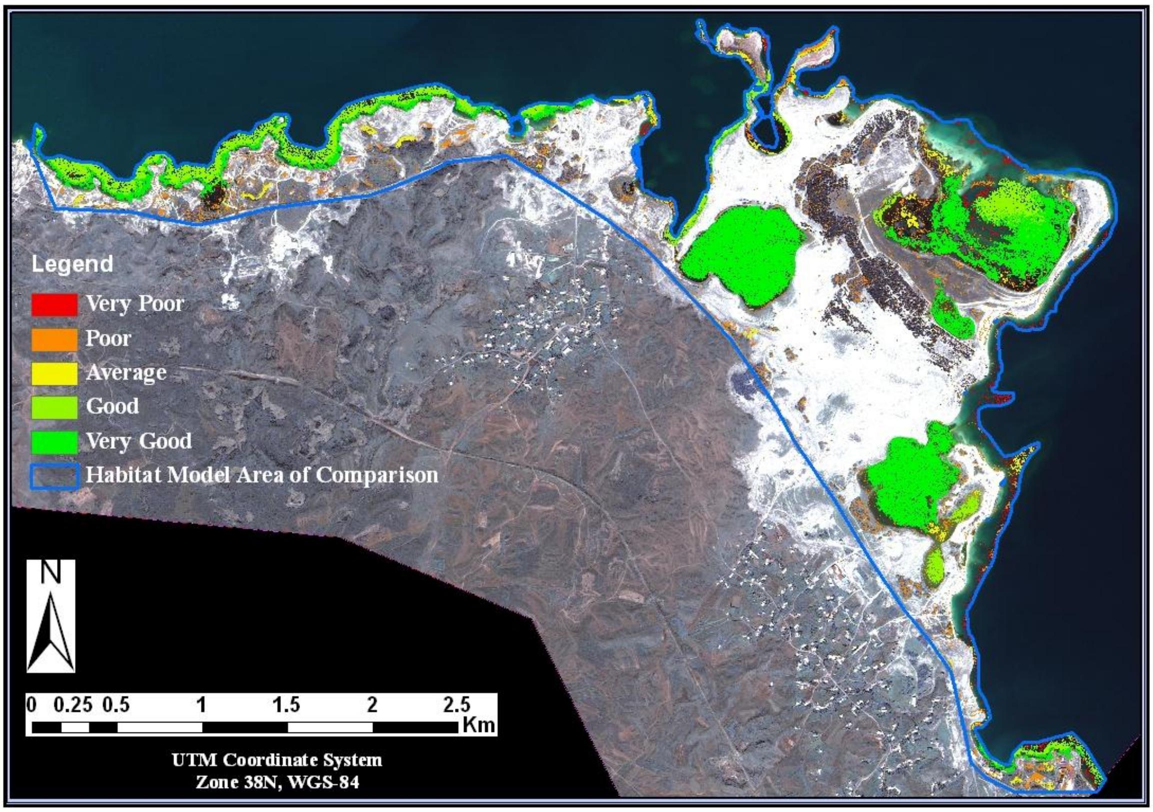
(A) Tsovazard



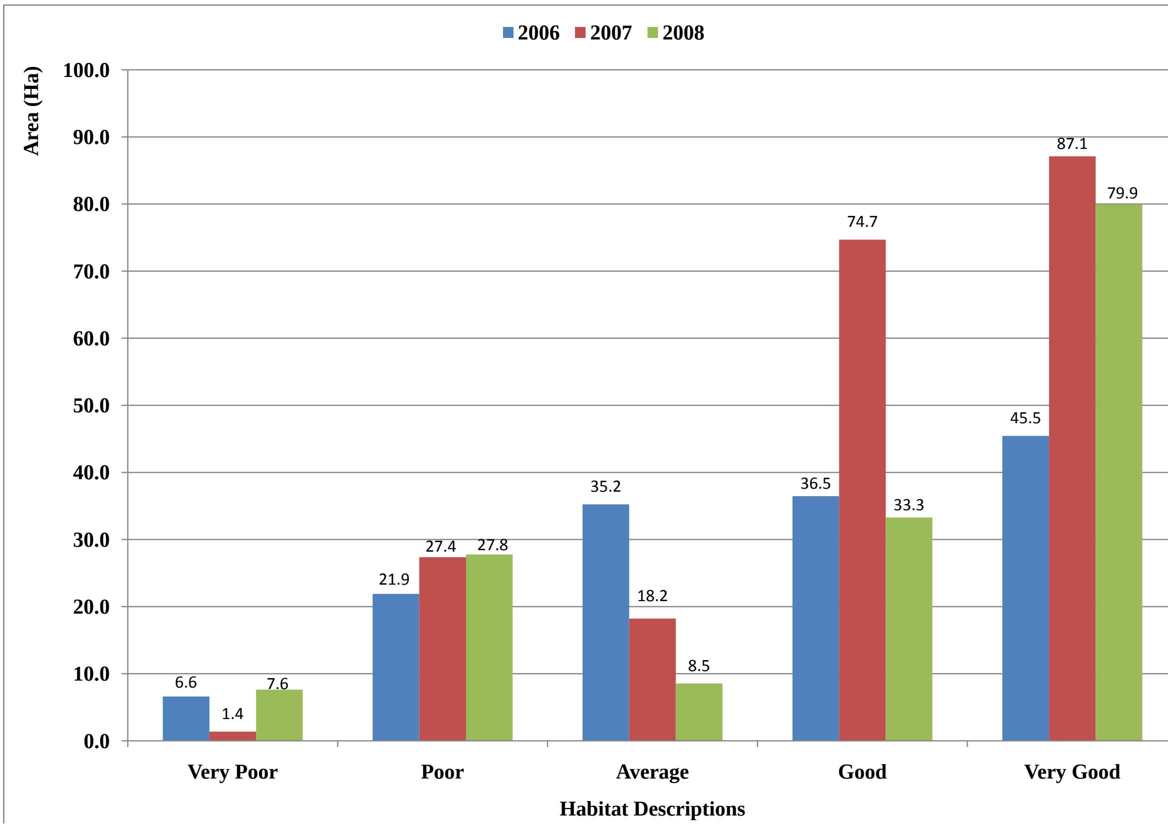
Potential Habitat Map of Crucian Carp (*Carassius* spp.) in Tsovazard for 2006



Potential Habitat Map of Crucian Carp (*Carassius* spp.) in Tsovazard for 2007

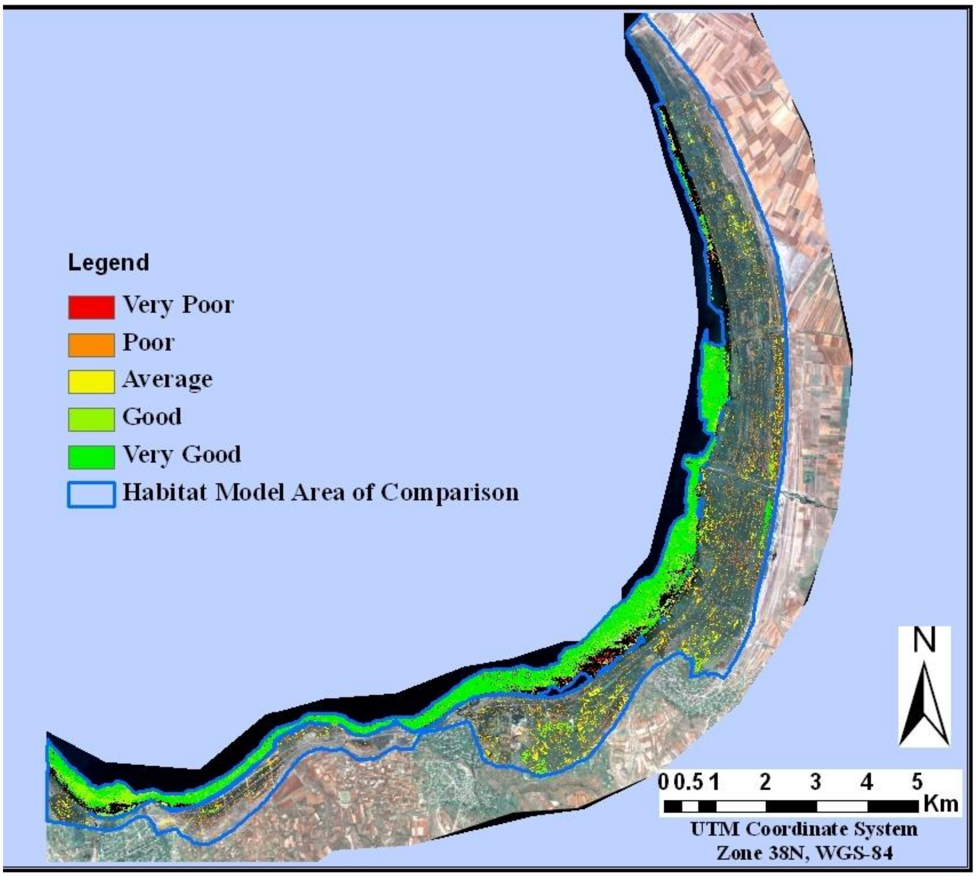


Potential Habitat Map of Crucian Carp (*Carassius* spp.) in Tsovazard for 2008

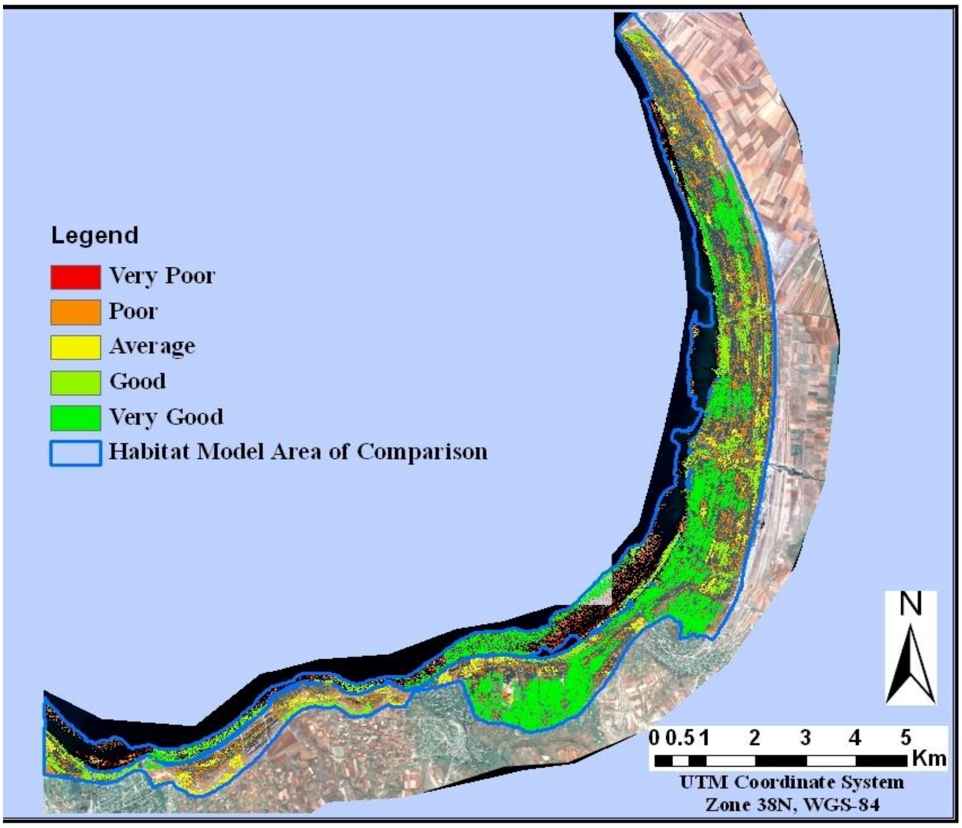


Fish Habitat Classes of Tsovazard and their Coverage Areas from 2006 to 2008

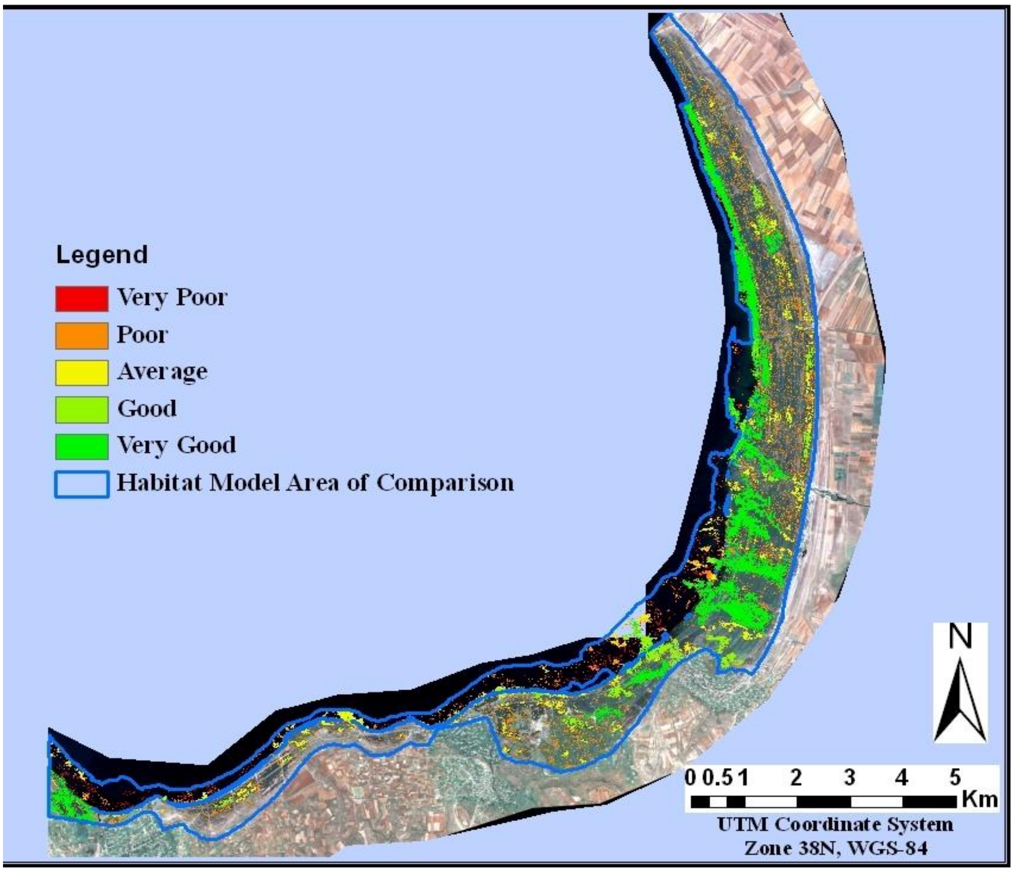
(B) Masrik



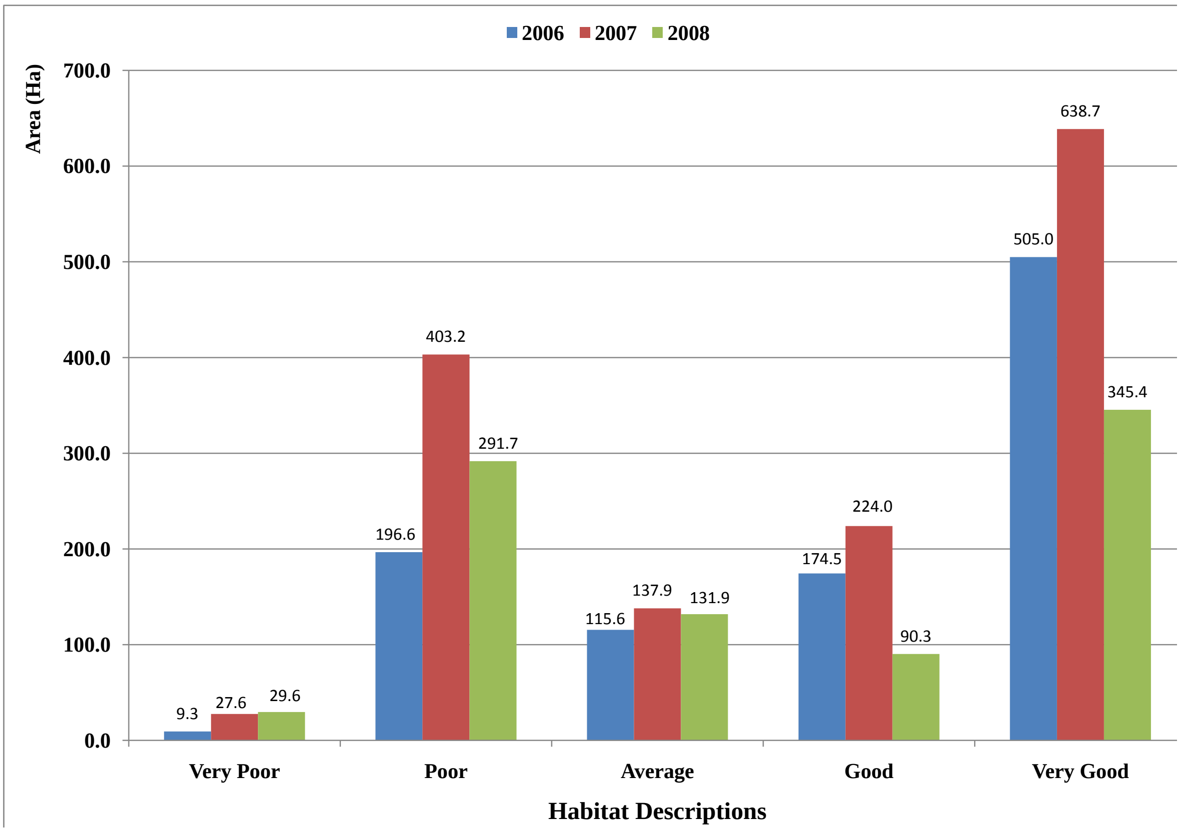
Potential Habitat Map of Crucian Carp (*Carassius* spp.) in Masrik for 2006



Potential Habitat Map of Crucian Carp (*Carassius* spp.) in Masrik for 2007



Potential Habitat Map of Crucian Carp (*Carassius* spp.) in Masrik for 2008



Fish Habitat Suitability Classes of Masrik and their Coverage Areas from 2006 to 2008

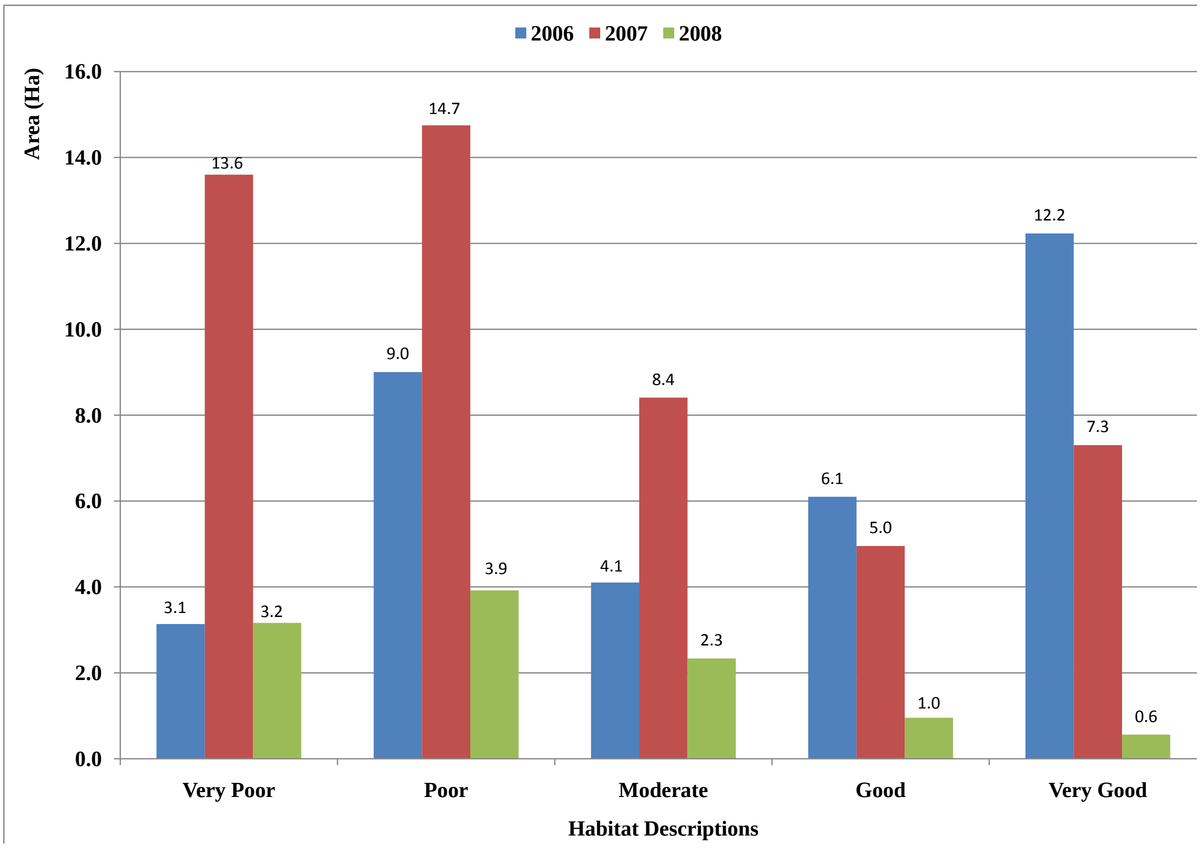
APPENDIX 4

(A) Tsovazard

Potential Habitat Map of the Common Coot (*Fulica atra*) and the Great Crested Grebe (*Podiceps cristatus*) in Tsovazard for 2006

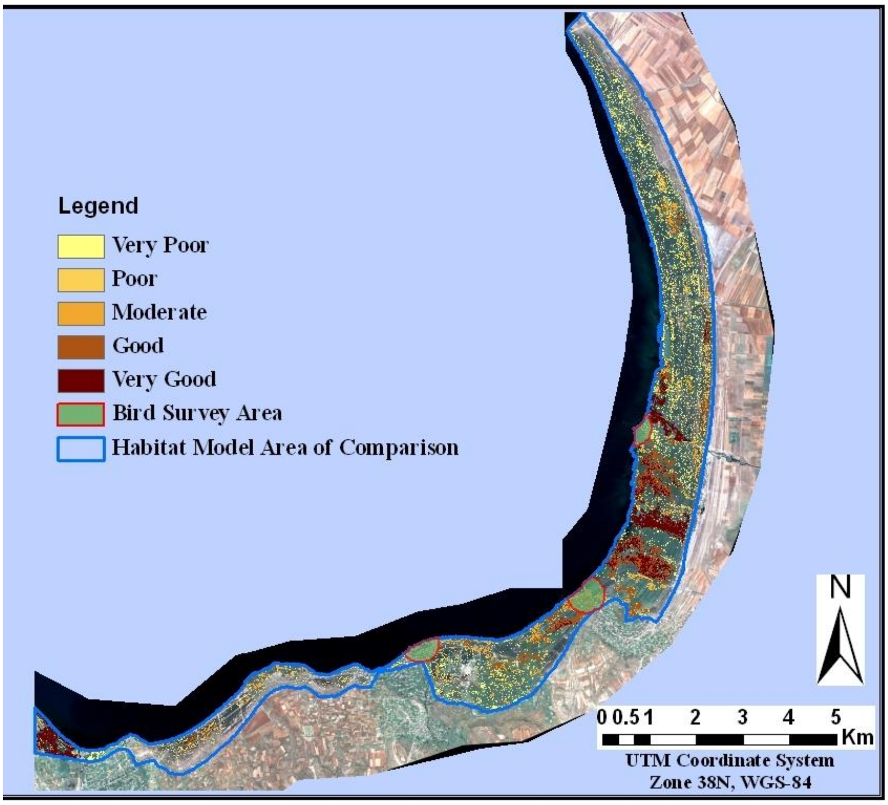
Potential Habitat Map of the Common Coot (*Fulica atra*) and the Great Crested Grebe (*Podiceps cristatus*) in Tsovazard for 2007

Potential Habitat Map of the Common Coot (*Fulica atra*) and the Great Crested Grebe (*Podiceps cristatus*) in Tsovazard for 2008

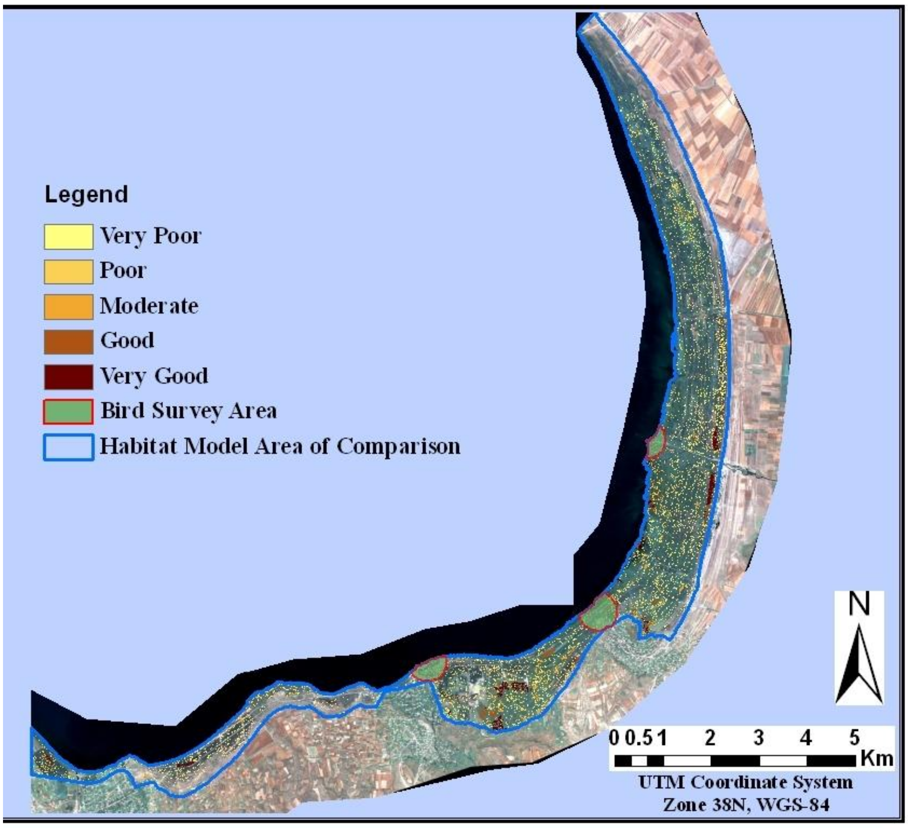


Bird Habitat Suitability Classes of Tsovazard and their Coverage Areas from 2006 to 2008

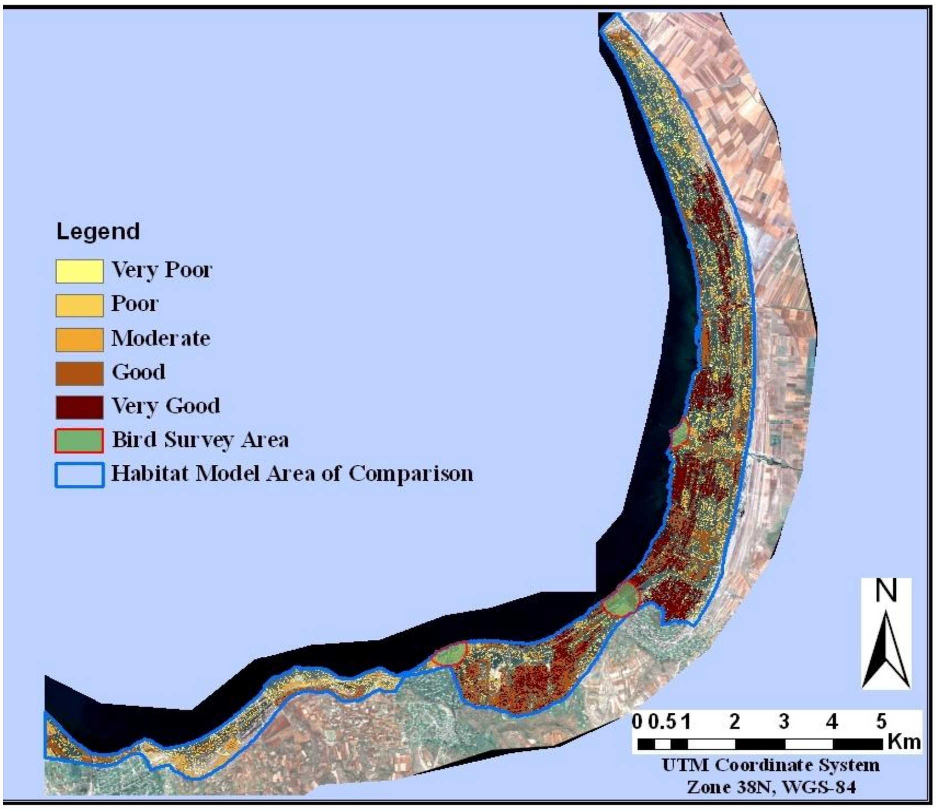
(B) Masrik



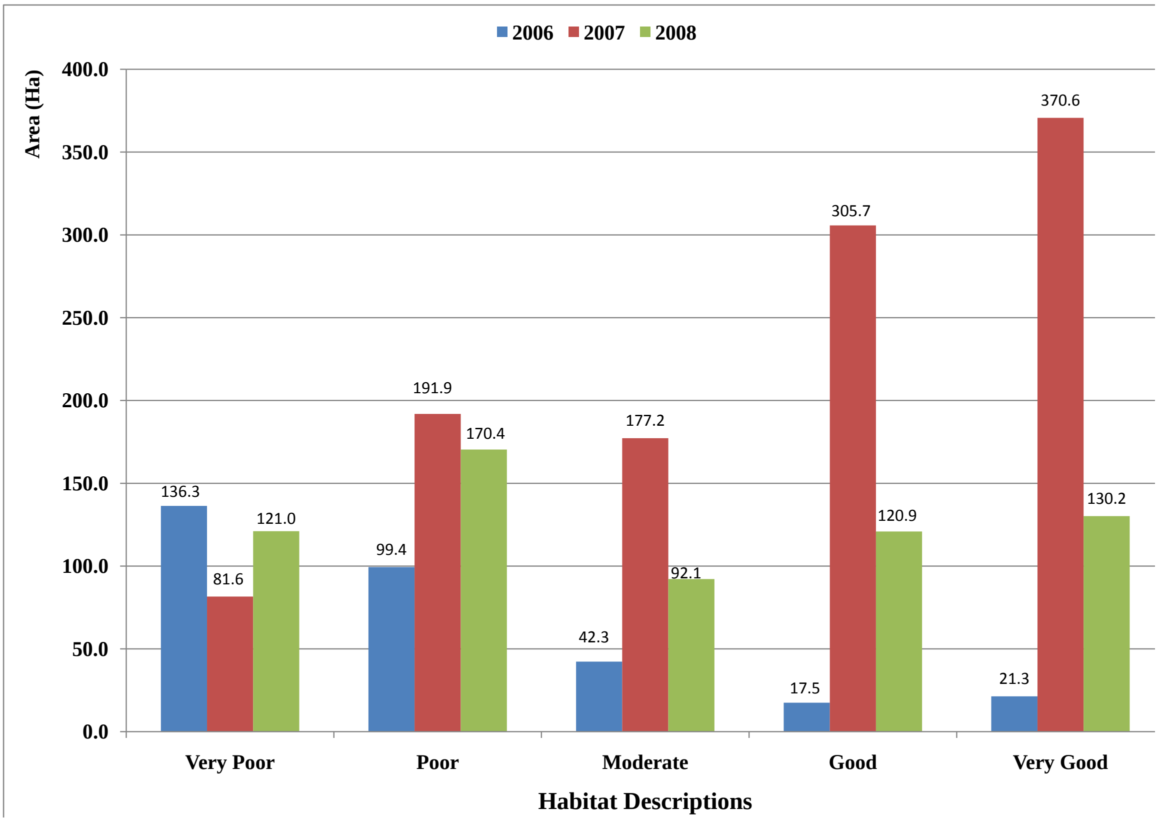
Potential Habitat Map of the Common Coot (*Fulica atra*) and the Great Crested Grebe (*Podiceps cristatus*) in Masrik for 2006



Potential Habitat Map of the Common Coot (*Fulica atra*) and the Great Crested Grebe (*Podiceps cristatus*) in Masrik for 2007



Potential Habitat Map of the Common Coot (*Fulica atra*) and the Great Crested Grebe (*Podiceps cristatus*) in Masrik for 2008



Bird Habitat Suitability Classes of Masrik and their Coverage Areas from 2006 to 2008