MAPPING WETLANDS USING EARTH OBSERVATION TECHNIQUES

Eleni Fitoka and Iphigenia Keramitsoglou editors

Nick J Riddiford scientific reviewer

**INVENTORY, ASSESSMENT
AND MONITORING OF MEDITERRANEAN WETLANDS**

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INTERREG IIIC

MedWet   EKBY   ICN**B**   TOUR DU VALAT   UNIVERSITY of TARTU

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PREAMBLE

In the last few decades there has been a greater awareness of wetland values and benefits to society. At the same time wetland areas are under increasing pressure from development. The Millennium Eco-system Assessment (2005) emphasized that loss of wetlands globally is more rapid than those of any other ecosystem (Agardy and Alder, 2005; Finlayson and D'Cruz, 2005). Therefore, contemporary information which documents the abundance, distribution and condition of wetlands is absolutely essential.

Recently there has been a dramatic advance in both spatial resolution and availability of Earth Observation (EO) data with the potential for wide application in the field of wetland monitoring and mapping. EO provides improved thematic and geographical accuracy, high revisiting capability and data consistency, all in a cost effective manner. To this end EO is nowadays increasingly used for wetland mapping, and consequently in assessment and monitoring activities. At the same time, advanced image processing techniques have been developed and tailored specifically for wetland and habitat mapping in order to process data from raw to higher levels producing added-value maps and to provide frequently updated baseline and trend information.

Wetland mapping has been promoted by the MedWet inventory methodology from the first stage of its development, including: the MedWet Habitat Description System (Farinha et al, 1996) which provides an hierarchical nomenclature for wetland habitats easily interpreted through remote sensing; the Photointerpretation and Cartographic Conventions (Zalidis et al, 1996) which provide conventions on the use of aerial photography and on the production of wetland habitat maps; and the criteria that define a wetland and its terrestrial boundaries on the basis of the presence or absence of essential hydrological, soil and vegetation attributes (Zalidis et al, 1996: in Costa et al, 2006).

Clearly, the new technological achievements derived from Earth Observation sources and techniques should be made known and be applied to advance the wetland mapping efforts. The present manual is a contribution to this end.

CONTENTS

ABOUT THIS MANUAL

The new MedWet series

The **Mapping Wetlands Using Earth Observation Techniques** is part of the new series *Inventory, assessment and monitoring of Mediterranean wetlands* published under the auspices of the "MedWet information and knowledge network for the sustainable development of wetland ecosystems (MedWet CODDE)" project. Undertaken between 2005-2007, the MedWet CODDE addresses the urgent need for policy-makers, wetland managers and researchers to have easy access to up-to-date and standardized data in order to assess and monitor the current status and trends of Mediterranean wetlands and their surroundings. The project was launched through the INTERREG IIIC programme.

The purpose of the new MedWet publication *Inventory, assessment and monitoring of Mediterranean wetlands* is to assist wetland managers and scientists to inventory their wetland resources, to facilitate the monitoring and assessment of these resources and to promote data harmonization and compatibility among various inventory efforts in the Mediterranean and beyond. It has its roots in the original MedWet wetland inventory work (Costa et al, 1996; Hecker et al, 1996; Farinha et al, 1996; Zalidis et al, 1996) developed during the MedWet 1 (ACNAT) project and presented in 1996 at the Conference on Mediterranean Wetlands in Venice as a standard inventory methodology for the countries of the Mediterranean region. The publication also draws on the outputs of the first upgrading effort done under the SUDOE project (INTERREG IIB).

Inventory, assessment and monitoring of Mediterranean wetlands introduces a Mediterranean-wide system which is based on: a web database, the MedWet Web Information System (MedWet/WIS) which provides the tool for the creation of a Mediterranean wetland databank; a data sharing protocol which supports data exchange and sharing between wetland stakeholders; and the use of Earth Observation techniques (EO) as enhanced means of mapping wetland features. *Inventory, assessment and monitoring of Mediterranean wetlands* guides the reader through the upgraded MedWet system incorporating the socioeconomic and cultural aspects of wetlands, the Water Framework Directive requirements, inventory based indicators, the Pan-Mediterranean Wetland Inventory and EO techniques. Most importantly, it provides a full description of and guidance through the new online MedWet/WIS - a system which offers an advanced and flexible way to provide or restrict access to data, supported by a relevant protocol.

Inventory, assessment and monitoring of Mediterranean wetlands, incorporates the following series of manuals:
- The Pan-Mediterranean Wetland Inventory Module
- The Catchment Module & The Site Module
- The Water Framework Directive Module
- The Surveillance Module
- The Indicators Module
- The MedWet Web Information System User's Manual
- The MedWet Inventory Data Sharing Protocol
- Mapping Wetlands Using Earth Observations Techniques

They set out to explain the background, the relevance and the benefits of the new MedWet system and to provide detailed guidance on how to apply it. Each manual can be used in two ways: as a stand-alone reference for its particular theme or subject; or as an integral part of a series of works which guide the reader through the entire process from the early pioneering work to joining, using and getting the best out of the system.

Purpose and aims of the manual

The overall purpose of the Mapping Wetlands Using Earth Observation Techniques manual is to advance the understanding of the capabilities that EO offers in mapping wetland features such as vegetation and habitat, biophysical parameters, water

constituents or sea bottom properties, in a variety of spatial and temporal scales. Furthermore, it looks to raise awareness of the need for a coordinated effort to map Mediterranean wetlands.

In particular this manual aims to:
- Acquaint users with the most recent projects and initiatives relevant to wetland mapping and assessment.
- Promote the need for a coordinated initiative on mapping Mediterranean wetlands.
- Familiarise users with the principles of monitoring the natural environment from Space.
- Promote the use of EO for wetland monitoring and mapping activities to potential end users and inform them about certain image processing techniques.
- Present selected application examples of these techniques with the corresponding added-value map products.

Structure of the manual

To achieve its purpose and aims, the manual is structured as follows:

Part 1, **Overview**, presents existing efforts in support of wetland mapping and outlines the need for a comprehensive mapping programme. Wetland scientists receive an overall picture of the significant initiatives and programmes for consideration in organizing coordinated wetland mapping activities in the Mediterranean region.

Part 2, **Background on Earth Observation**, provides the theoretical background on satellite remote sensing starting from basic principles and gradually focusing on wetland monitoring and mapping. An overview of the most widely used satellite sensors is presented together with basic and state of the art image processing methods.

Part 3, **Indicative Applications**, is complementary to Part 2 by translating theory into practice. It presents a selection of wetland mapping examples from national to local scale using a variety of the sensors and image processing techniques described in Part 2.

Who should use this manual

This manual is targeted towards wetland scientists and technical staff of local, regional and national authorities, research institutes and Non Governmental Organisations (NGOs) who work on wetland management and conservation and are responsible for planning wetland inventorie and implementing mapping activities.

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PART 1: OVERVIEW OF EXISTING EFFORTSSUPPORTING WETLAND MAPPING

Part I aims to promote the need for coordinated wetland mapping in the Mediterranean region. Such a development should consider existing initiatives, projects and programmes which are creating frameworks for activities relevant to wetland mapping or have provided valuable products and services. To this end, Part I presents:

A) **Current initiatives**, comprising: the Observatory of Mediterranean Wetlands led by the MedWet Initiative; the Global Monitoring and Environment Services (GMES), which is a Europeanled initiative for the implementation of information services dealing with environment and security; the ALOS Kyoto and Carbon Initiative, which is jointly coordinated by EORC (JAXA) and the European Commission Joint Research Centre with the goal of addressing information needs of international environmental conventions, carbon cycle science and environmental conservation; the Partnership on wetland mapping and inventory, which is mobilized by the Food and Agriculture Organization (FAO) of the United Nations through the Coastal Panel of the Global Terrestrial Observing System (C-GTOS) and the International Water Management Institute (IWMI); the Global Observation System of Systems (GEOSS), supported by the United Nations; the progress of Spatial Data Infrastructure Initiatives; and

B) **notable programmes and projects**, comprising: the Pan-Mediterranean Wetland Inventory, which has been recommended by the fourth meeting of the Mediterranean Wetlands Committee (MedWet/Com) in 2001; the Land and Ecosystem Accounting (LEAC) of the European Environmental Agency (EEA); indicative mapping projects in Africa based mainly on Earth Observation techniques; the GlobWetland project, launched in 2003 by the European Space Agency (ESA) in collaboration with the Ramsar Secretariat; and the TerraLook program led by NASA, which provides easy no-cost access to satellite images.

INTRODUCTION

Wetland mapping and assessment has been the target of several initiatives and programmes in Europe and in the Mediterranean region, usually in the context of policies and strategies for protected areas (eg the European Habitat Directive), water resources management (eg the European Water Framework Directive) or biodiversity assessment (the 2010 Biodiversity Target).

Also nowadays, innovative and powerful tools are available in the fields of Earth Observation (EO) and Spatial Data Infrastructures that could facilitate the adoption and implementation of a standardized, consistent methodology on wetland mapping and assessment. Subsequently, at global, European and regional level, there is an increased effort to promote data comparability in support of ecosystem and biodiversity assessments. Notable examples are: i) the Global Earth Observing System of Systems (GEOSS), supported by the United Nations; ii) the Land and Ecosystem Accounting (LEAC) of the European Environmental Agency (EEA); iii) the Mediterranean Wetland Observatory and the Pan-Mediterranean Wetland Inventory, which are initiated under the regional MedWet Initiative of the Ramsar Convention.

However, recent studies prove that in the Mediterranean region, and globally too, there still exist inconsistencies in mapping practices (eg wetland definitions and nomenclatures) and there are major gaps in data mining and accessibility (Finlayson et al, 2001; Finlayson & Spiers, 1999; Finlayson et al, 1999; Hecker & Tomàs-Vives, 1996). Even among the inventories carried out following the standard methodology proposed by the MedWet Initiative since 1996, there is some level of inconsistency (Tomàs-Vives et al, 2004). Also, random selection of wetlands in local assessment studies is the common practice, instead of having a coordinated evaluation system based on a network of pre-selected representative sites as is now proposed for the global monitoring of changes (Christian & Mora, 2005). Furthermore, although the MedWet standard methodology has been implemented in several mapping applications (eg in Portugal, Greece, Albania, Tunisia, Algeria, Spain and Italy), no integration of any of the above mapping outputs has ever been attempted and no effort has been made to apply it at regional level. All these factors inevitably minimize any possibility to achieve integration and to figure out the overall picture of the status and trends of the wetland ecosystems in the Mediterranean region.

Therefore, it is apparent that the promotion of coordinated wetland mapping in the Mediterranean region is essential. Such a development should take advantage of existing initiatives and of the knowledge produced in relevant projects and programmes. Seeking a better understanding of these, the most notable - covering the regional, European and global scales - are presented next. Concluding remarks are also presented, at the end of this chapter. These set out future priorities and steps.

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CURRENT INITIATIVES

The Observatory of Mediterranean Wetlands: A tool for the assessment of status and trends of Mediterranean wetlands

by *Pere Tomàs Vives*

Introduction and Background

Wetlands are considered as one of the most productive and diverse ecosystems on Earth; they play a key role in natural processes and have provided humankind with goods and services since early times. Despite this, wetlands in the Mediterranean region are among the most threatened ecosystems and are subject to many pressures in the name of wrongly understood "development". For a long time, wetlands were considered as "wastelands", and consequently were transformed, drained and desiccated.

In the last 40 years, and in particular since the adoption of the Ramsar Convention on Wetlands in 1971, there has been a growing awareness of the importance of these ecosystems. As an outcome of the Grado conference in 1991, the MedWet Initiative was launched with its main goal to contribute to the conservation and wise use of Mediterranean wetlands. In 1997, MedWet became the first regional initiative under the umbrella of the Ramsar Convention.

In 2001, the Convention on Biological Diversity adopted the *2010 target*: to "achieve by 2010 a significant reduction of the current rate of biodiversity loss at the global, regional and national level", and this was endorsed by the World Summit on Sustainable Development in 2002. At EU and pan-European scales the target is even more ambitious, being to "halt the biodiversity decline" by 2010. At both levels (global and European) there are initiatives and programmes for assessing and disseminating information about progress towards the 2010 targets using selected indicators. Examples are Countdown 2010, the 2010 Biodiversity Indicators Partnership and SEBI2010 (Streamlining European 2010 Biodiversity Indicators).

The analysis of wetland resources[1], their status, trends and priorities, and the dissemination of the results are fundamental for mobilising decision-makers into addressing the need to conserve, manage and use aquatic ecosystems in a sustainable way. This should be reflected through the adoption and implementation of national wetland policies and action plans. As well as conserving biodiversity, sustainable use of wetlands will contribute to preserving water resources, reducing impacts of climate change (carbon sink and reservoirs functions) and alleviating poverty.

At present there is no general overview about the status and trends of wetland resources and biodiversity in the Mediterranean region. Data exist for many countries, regions and individual sites or taxonomic groups, but often they are not easily accessible and occur in non compatible formats. Since 1993, the Scientific and Technical Team of the MedWet Initiative - formed by CEZH-ICNB (Portugal), EKBY (Greece), Tour du Valat (France), SEHUMED (Spain), ARPAT (Italy) and the MedWet Secretariat – has been working on and promoting a standard and systematic methodology for wetland inventory, which includes an information system for data management. This has led to the current completion and expansion of the MedWet inventory tools by the MedWet Scientific & Technical Team (through its Med-Wet/CODDE project) in order to be more applicable for monitoring and assessment purposes. In response to the mandate of the MedWet/Com 4, the MedWet Scientific

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[1] Wetland resources include physical characteristics – water, soil etc. – biodiversity, values and functions of wetlands, as well as their role in ecosystem functioning.

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& Technical Team has also worked towards a Pan-Mediterranean Wetland Inventory (PMWI). This is the first attempt to develop a Mediterranean-wide wetland inventory and database which will allow analyses of location and extent of wetlands to be produced, as well as preliminary assessments of their values and status.

The 8th meeting of the Mediterranean Wetlands Committee, MedWet/Com 8, tasked the Steering Group to prepare a proposal, with the support of the Scientific and Technical Team and the IOPs, for an *Observatory of Mediterranean Wetlands*, for consideration by MedWet/Com 9.

The Observatory of Mediterranean Wetlands is an assessment and monitoring scheme and should be an integral part of MedWet's strategic planning process. Such a scheme should provide the means for analysis of wetlands, their resources, status and trends, and dissemination of the results.

The Observatory is intended to achieve the following:

• Mobilise decision-makers towards wise use of wetlands.

• Set clear, quantified and localised objectives for the MW Strategy and Work Plan.

• Assess the impact of MedWet action.

Objectives

The general objectives of the Observatory are:

1. To assess the conservation status of wetlands in the Mediterranean and to identify the trends, by using selected indicators and methods.

2. To raise awareness among policy- and decision-makers and to influence public policies towards the conservation and sustainable use of Mediterranean wetlands.

Overall, the Observatory is to contribute to the 2010 target (CBD & EU), which is to: "*achieve a significant reduction of the current rate of biodiversity loss at the global, regional and national level by 2010 and beyond*".

The specific objectives of the Observatory are:

1. Knowledge: data collection, analysis and assessment

1.1. To identify, test and propose suitable indicators, methods and techniques for the assessment of the conservation status and trends of wetlands in the Mediterranean region.

1.2. To make regular assessments using existing data to:

– Identify the location and extent of wetlands and their physical, biodiversity and socioeconomic characteristics.

– Analyse the evolution of these parameters and to assess the trends.

– Identify wetlands which have recently disappeared but have a high potential for restoration, and propose priorities for restoration.

– Assess the conservation status of the wetlands and to define priorities for conservation, for restoration and for sustainable use.

– Identify the gaps in knowledge in relation to wetland status and resources.

1.3. To identify and quantify the changes in surface area and in quality of Mediterranean wetlands based on selected indicators and using inventory, monitoring and assessment methods.

1.4. To construct hypotheses for the identification of the causes and mechanisms responsible for the ecological changes, and test them by gathering and analysing adequate data.

2. Transfer, awareness and policies

2.1. To publish regular reports on the status and trends of Mediterranean wetlands.

2.2. To transfer know-how and develop capacity building in wetland inventory, monitoring and assessment through training programmes.

2.3. To increase awareness on the importance of wetlands, their conservation and sustainable use, among decision-makers and stakeholders/users by communicating the results to them and developing partnerships with organisational structures that can influence them.

2.4. To promote the development, adoption and implementation of wetland strategies and the integration of wetland conservation into sectoral policies.

These objectives should be achieved through a Consortium of partners who will be in charge of the design and the development of the Observatory.

Geographical Scope

The geographical scope is the Mediterranean region in its widest sphere, including all the countries who are members of MedWet/Com.

The Observatory will establish different working scales: Mediterranean, national and local. For each scale, suitable indicators and assessment methods will be applied. At the scale of the Mediterranean basin, it is important in a first phase to identify the relevant indicators concerning the obligations of Mediterranean countries that have ratified the main environmental treaties: Ramsar Convention, Convention on Biological Diversity, Barcelona Convention, Bern Convention etc. In addition, other indicators of the state of the ecosystems and the pressures they are subject to will be defined and analysed in order to establish an accurate and dynamic image of the effects of public policies, allowing these elements to be taken into account when decisions are formulated.

At national and subnational level, the Observatory should work closely with the agencies responsible for wetland management to develop common standard tools for evaluating the implementation of their wetland policies, strategies and action plans. At the same time, the Observatory should assist national authorities in monitoring the fulfilment of their obligations in relation to international conventions.

Target Audience

The potential clients and users of the results of the Observatoryare:
- Government departments and agencies dealing with matters that affect wetland conservation and wise use (environment, water, agriculture, tourism, infrastructures etc.), both at national and subnational scale (eg Regions).
- National and local stakeholders.

In most cases, these users will be addressed through structures that can influence them, either supranational organisations (European Commission, European Environment Agency, Ramsar and Barcelona conventions, MedWet initiative etc) or lobbying organisations (WWF, Bird-Life International, national NGO etc).

Expected Outcomes

The following main outcomes of the Observatory of Mediterranean Wetlands are expected:

1. Knowledge: data collection, analysis and assessment
- National wetland inventory programmes compatible with Mediterranean standards undertaken or launched in focal countries, including contribution to the Pan-Mediterranean Wetland Inventory (PMWI).
- Standard tools/methods proposed for monitoring and assessment of Mediterranean wetlands, applicable at regional, national and local level.
- Regular assessment reports of the conservation status and trends of wetlands and their resources at Mediterranean-wide scale (end of 2008 & every 2-3 years thereafter).

2. Transfer, awareness and policies
- A programme for training and capacity building on inventory, monitoring and assessment.
- National Wetland Policies, Strategies and Action Plans undertaken or initiated in focal countries, and wetland conservation integrated into sectoral policies.
- Tools for regularly communicating the results of the analysis and to propose actions to decision-makers.
- Increased awareness among decision-makers and stakeholders/users, leading to improved status of Mediterranean wetlands.

GMES evolution and benefits for a Mediterranean wetland inventory

by *Michael Bock*

GMES from concept to reality

As a key element of the European space policy and strategy, GMES is a Europeanled initiative for the implementation of information services dealing with environment and security, in which the European Space Agency (ESA) will implement the space component and the European Commission (EC) will manage actions for identifying and developing services (COM(2005)565).

The objective is to establish by 2008 a European capacity for global as well as regional monitoring to support EU objectives in a wide variety of policy areas. GMES will be based on observation data received from Earth Observation satellites and ground based information. The services provided by GMES can be classified in three major categories:

- Periodical mapping and monitoring of land cover, land use and natural resources.
- Support to Emergency management in case of natural hazards and particularly civil protection.
- Forecasting applied to marine zones, air quality or crop yields.

GMES will be built up gradually. It starts with a pilot phase which targets the availability of a first set of operational GMES services by 2008, followed by the development of an extended range of services which meet user requirements.

The launch of the GMES concept back in 1998 was followed by a Political mandate given to the EC at the June 2001 Gothenburg Summit. Building on this and the outcome of an initial exploratory period (2001-2003), the European Commission has outlined an action plan (COM(2004)65) for the period up to 2008 aimed at the delivery of operational user oriented GMES services. These services are culminating in three types of interlinked infrastructures (Figure 1.1):

– The space segmentthat provides the imagery based on ESA Sentinels 1 to 5 missions and national and 3rd party missions.
– Data integration and management including data acquisition, flight operation, processing, archiving, networks and distribution according to INSPIRE rules.
– In Situ Systems consisting of terrestrial, marine & atmospheric networks, airborne sensors and socioeconomic data operated by the EC or Member States (MS).
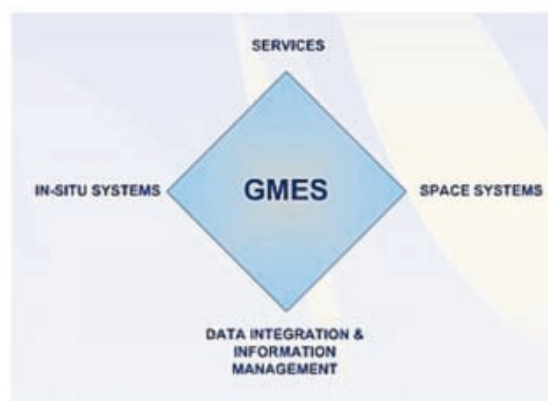
Figure 1.1. *GMES Elements.*

A further step on the road towards GMES services was made in 2005 with the Commission communication "GMES: from concept to reality" (COM(2005)565) in which three services (Land, Marine, Emergency) and two candidates (Atmosphere, Security) were identified for fast track introduction complete with the roadmap for their delivery.

In addition, the communication addressed the critical points for GMES sustainability: infrastructure (building on existing capabilities), keeping users at the forefront of GMES, a sustainable funding strategy and an adequate organisational structure. The two main management structures existing to date are the GMES Advisory Council (GAC) and the GMES Bureau. The GMES Advisory Council (GAC) brings together the EU Member States, the Commission, ESA and relevant other Agencies active in Earth Observation. It has the main role of maintaining and strengthening the "political ownership" of GMES. The GMES Bureau was founded by a decision of the EC dated 8th March 2006 (CEC, 2006). The task of the GMES Bureau is to properly identify the needs

and coordinate the activities of the GMES within the EC, and to contribute to the long term sustainability of GMES, including the preparation of proposals for GMES management structures (www.gmes.info).

Figure 1.2 gives an overview of the roadmap of GMES as it applies to the service and the space & ground segments. The development of services was and is partly funded and coordinated by the EC within the 6th and 7th European framework programme and by the ESA through the GMES Service Elements.
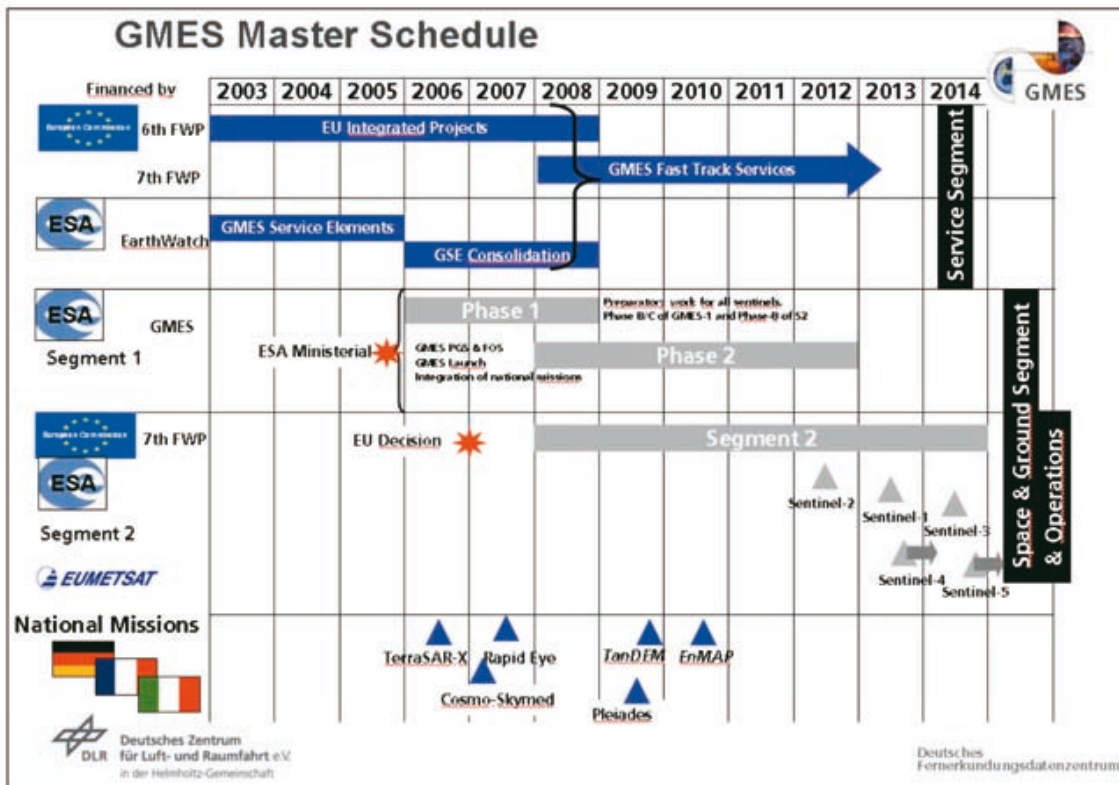
Figure 1.2. *The GMES Master Schedule (Layout by G. Schreier, DLR).*

The development of the Shared Environment Information System (SEIS) in compliance with the INSPIRE Directive will also facilitate the development, functioning and distribution of GMES services.

Evolution of the GMES Land Monitoring Core Service

The Strategic Implementation Plan for the Land Monitoring Core Service (LMCS)

The scope of the LMCS and the necessary steps towards its sustained operation from 2008 are mainly defined by the LMCS implementation group (IG), which was set up at a thematic workshop organized by the EC on 20-21 October 2005. The results of the LMCS IG are documented in the Strategic Implementation Plan for the Land Monitoring Core Service, whose final edition was published on 24 April 2007 (LMCS IG, 2007). The Strategic Implementation Plan identifies three dimensions to be taken into account (Figure 1.3):

• The geographical scale, which can be global, continental or local;
• The time scale, where a difference should be made between a) 'near real-time' (daily to monthly basis) information and b) periodical (annual to multi-annual) information;
• The level of elaboration of information, which can be categorised into a) 'basic' mapping products for broad generic use and for deriving more elaborated products (above all for downstream applications) and b) 'elaborate' information products which will address specific European policies.
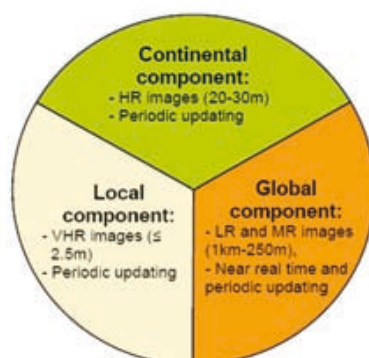
Figure 1.3. *Scale & EO data needs (LMCS IG).*

Based on their technical maturity, relevance for users and policy, the LMCS IG group selected the first initial GMES components: the "Fast Track Services". The fast track part focuses on "*a service providing, on a regular basis, core land cover/land use change data that can be used by a wide range of downstream services at European, national, regional and local level*". In the initial phase the Continental and the Local Component should be granted for a Fast track roll out while the further evolution of the service should include a Global Component as well.

- The objective of the Continental Component is to move from the current Corine Land Cover (25 ha MMU and 5 ha MMU for changes) to higher MMU (1 ha or less) with higher updating frequency (3-5 years). The target is to map all Europe with approximately 20 land cover classes. This has already started with two classes (Built-up areas and Forest) under the Fast Track precursor project.
- The Local Component will focus on the development of an Urban Atlas to complement the Urban Audit programme of DG REGIO.
- The Global Component of the LMCS includes near real-time monitoring

Figure 1.4. *The LMCS architecture (LMCS IG, 2007).*

systems such as, for instance, Land cover and forest change, Natural carbon flux, Crop production and food security as well as the production of Biogeophysical variables at continental to global scale.

In addition the GMES Land service portfolio comprises a set of thematic Downstream Services dedicated to the specific requirements of European and Member State policies, and which are not covered in the Core Land Cover mapping because the spatial and/or temporal resolution is not appropriate or because additional information is required. The strategy will be to define the service for each of the thematic elements (eg soil, water, biodiversity, agriculture, forestry etc), since they involve different communities of users with their own needs. The analysis of user requirements should involve the specific services of the Commission as well as Member States which play an important role in the implementation of these policies at national level. These elements will also be developed by building upon the heritage of current Research projects and existing applications

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The LMCS IG gives an overview of the various components of the GMES architecture and organisation in the current strategy paper. It is also planning to develop in more detail the role of the different actors at European and MS level. The current architectureproposed for the Land Fast Track (Figure 1.4) is built on existing systems, players and know-how based on a distributed architecture that takes account of existing building blocks. In order to mesh the individual components into a fully functioning service within a distributed architecture, two approaches, top-down and bottom-up, have to come together and a set of common rules agreed upon which addresses issues such as Standards & Specifications, Inter-operability, Coordination and compliance checking, and the interface with other components of the European and National Spatial data infrastructure (ESDI, NSDI).

A description of the LMCS's medium to long term needs for space data has been issued in Del. 4 of the IG (LMCSIG, 2007). The document comments on both ESA's proposals for sentinels 1, 2 and 3 and other existing or planned missions in MS or private ownership.

The in situ data have been identified as an equally important part of GMES as the space component and, where the MS have a central role to play. The architecture of this component has still to be defined by the IG in close collaboration with the MS.

From pre-operational to operational phase

The LMCS will not be developed from scratch. There are already a lot of applications in this field, some already operational, which will be integrated into it. In fact, the main building blocks for the implementation of the Fast Track parts of the LMCS are the GMES projects on "Land Cover & Vegetation". These are: i) DG ENTREPRISE´s Integrated Project "geoland" funded through the Framework Programme 6 - which has focused its activities on consolidating the flow from state of the art towards state of practice; ii) the ESA's GMES Service Elements "GSE Land, GSE Forest & GMFS" supplemented by the ESA funded Globcover which aim to demonstrate services and products. The "EEA GMES Land CLC/FTS project 2006-2008" offers the first GMES Fast track services funded by an operational budget line. Figure 1.5 gives an overview of the convergence of all these (pre-operational) precursor projects (both EC and ESA sponsored) and supplementary operations and national applications towards the establishment of an operational LMCS.
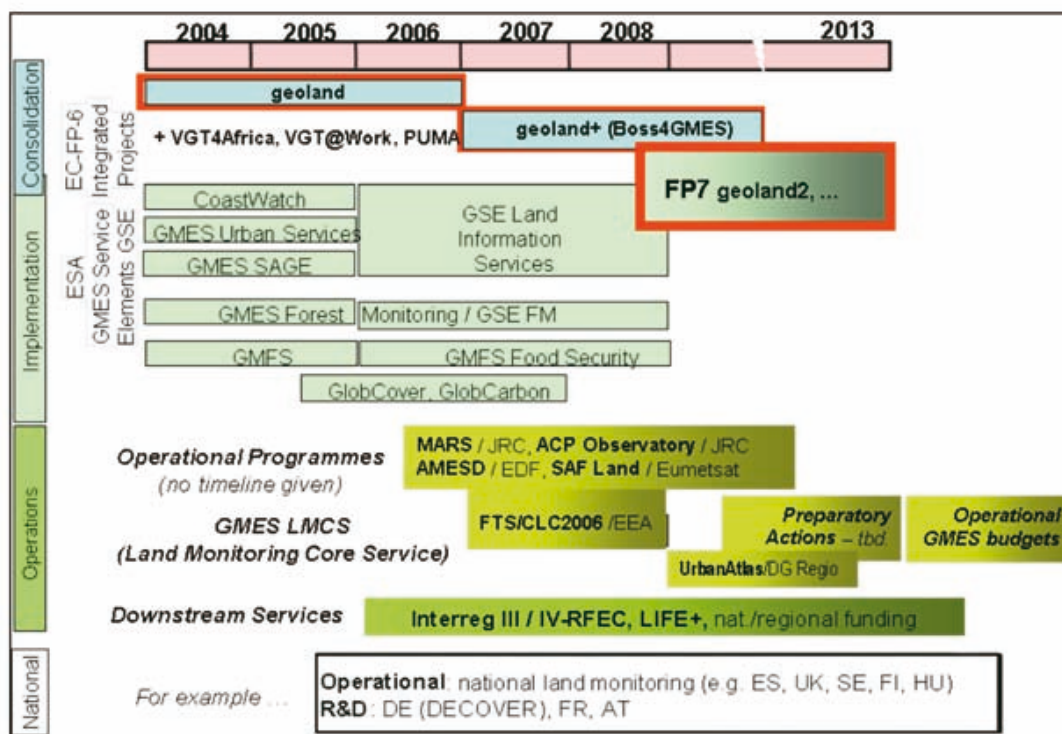
Figure 1.5. *The GMES Land service evolution (GMES Bureau, 2007).*

The GMES projects on "Land Cover & Vegetation" in implementation phase 2004–2008

The ESA GMES Service Element **GSE Land** Information Services (2004-2008) joins the three ESA GSE projects SAGE, GUS and Coastwatch which had already worked on land applications in the first GSE stage. The GSE Land Information Services portfolio has been structured into a common mapping services approach (common nomenclature used is shown in Figure 1.6) at three levels of scale; and a portfolio of geo-information services. The portfolio is the European Urban and the Water Quality (Diffuse Pollution) services, Land Take Trends and impact services, and the Irrigation services monitoring water consumption by agriculture in the Mediterranean. The evolution of the regional core mapping service was carried out in close cooperation with the geoland project.

Further project information, service prospectus and mapping guide lines are available at the GSE land website: http://www.gmes-gseland.info/.

GSELand M2.1 Regional Land Cover			
GSELand No. / CSL Code	Vectordata-code	Nomenclature	MinMU
	GSEL21_2006	M1 Mapping Units marked in orange	
1		Artificial surfaces	
1.1	11000	Urban fabric	1 ha
1.2	12000	Industrial, commercial and transport units	1 ha
1.3	13000	Mine, dump and construction sites	1 ha
1.4	14000	Artificial non-agricultural vegetated areas	1 ha
2		Agricultural areas	
2.1	21000	Arable land	5 ha
2.2	22000	Permanent crops	5 ha
2.3	23000	Pasture	5 ha
2.4	24000	Heterogeneous agricultural areas	5 ha
3		Forests and semi-natural areas	
16	31000	Forests	5 ha
3.2		Shrubs and / or herbaceous Vegetation	
3.2.1	32100	Natural Grassland	5 ha
3.2.2	32200	Moors and Heathland	5 ha
3.2.3	32300	Mediterranean Shrubs	5 ha
3.2.4	32400	Transitional woodland -shrub	5 ha
3.3		Permanently non-vegetated areas	
3.3.1	33100	Beaches, Dunes, Sands	5 ha
3.3.2	33200	Bare rocks	5 ha
3.3.3	33300	Sparsely vegetated areas	5 ha
3.3.4	33400	Burnt areas	5 ha
3.3.5	33500	Snow and ice	5 ha
4		Wetlands	
4.1	41000	Inland wetlands	5 ha
4.2	42000	Coastal wetlands	5 ha
5	50000	Water	5 ha

Figure 1.6. *The GSE land/geoland "LMCS" nomen-clature.*

The **geoland** project (2004–2006), an EC FP6 funded Integrated Project (IP), is organised as shown on the right (Figure 1.7). The Regional Observatories focus on implementation of newly established European directives and the Global Observatories address global change and sustainable development issues. The European and Global Core Services support the observatories with cross-cutting issues. The achievements and the complete product portfolio are documented in the geoland summary report (geoland, 2007). Detailed information and partners involved can be found on the geoland website www.gmes-geoland.info.

Figure 1.7. *The geoland architecture.*

The EC funded FP6 Integrated Project **BOSS4 GMES** is designed to promote the transition of GMES from a concept to an effective long term operational programme and enable the implementation of GMES Fast Track Services (FTS), and new Pilot Services, as soon as possible. By the time BOSS4 is completed in mid 2009 the project aims to:
- complete the design and testing of the three FTS, add new pilot services and synergies;
- develop data policies, identify future costs, define organization and governance for operational GMES services and show benefits for European citizens;
- communicate the GMES message and GMES standards for information delivery.

Details of the scope of the activities, and the partners involved, can be found on the project website www.boss4gmes.eu, which is also used to highlight news relevant to GMES and 'BOSS4'.

The EEA GMES Land FTS "operational project" 2006-2008

In June 2005 the EEA Management Board, in agreement with the DG environment, endorsed a proposal to update the Corine land cover data together with high resolution land cover data as part of the implementation of the GMES fast track service on land monitoring. In March 2006 EEA put forward a proposal to collaborate with the European Space Agency (ESA) and the European Commission (EC) on the implementation of a fast track service (FTS) on land monitoring 2006-2008.

The GMES FTS on Land Monitoring (EEA 2006) was launched as an operational service in order to provide by 2008 the following information:

• A set of multi-temporal orthocorrected satellite images for the reference year 2006.

• EA European mosaic based on orthorectified satellite imagery (referred to as IMAGE2006).

• Corine land cover changes 2000-2006.

• Corine land cover map 2006 (referred to as CLC2006).

• HR core LC data for built up areas: degree of soil sealing, 2006 (referred to as FTS sealing).

• HR core LC data for forest areas, including leaf type, 2006.

Due to the delayed start of some national CLC projects and the last mentioned task, the complete European CLC2006 coverage will not be available till the last quarter of 2009. The Image 2006 datasets are already available free of charge for non commercial usage by all from the EU member states (and their contractors) or can be obtained by tendering an ESA CAT-1 proposal for scientific usage (ESA image2006 information area)[2] .

Benefits of the GMES implementation phase for an Mediterranean wetland inventory

Figure 1.8. gives an overview of datasets from GMES EC/ESA funded projects, some national LMCS compatible mappings and the first EEA FTS-Sealing. Even though large areas are mapped with different types of demonstration services, most of these datasets are not directly supporting a Mediterranean wetland inventory.
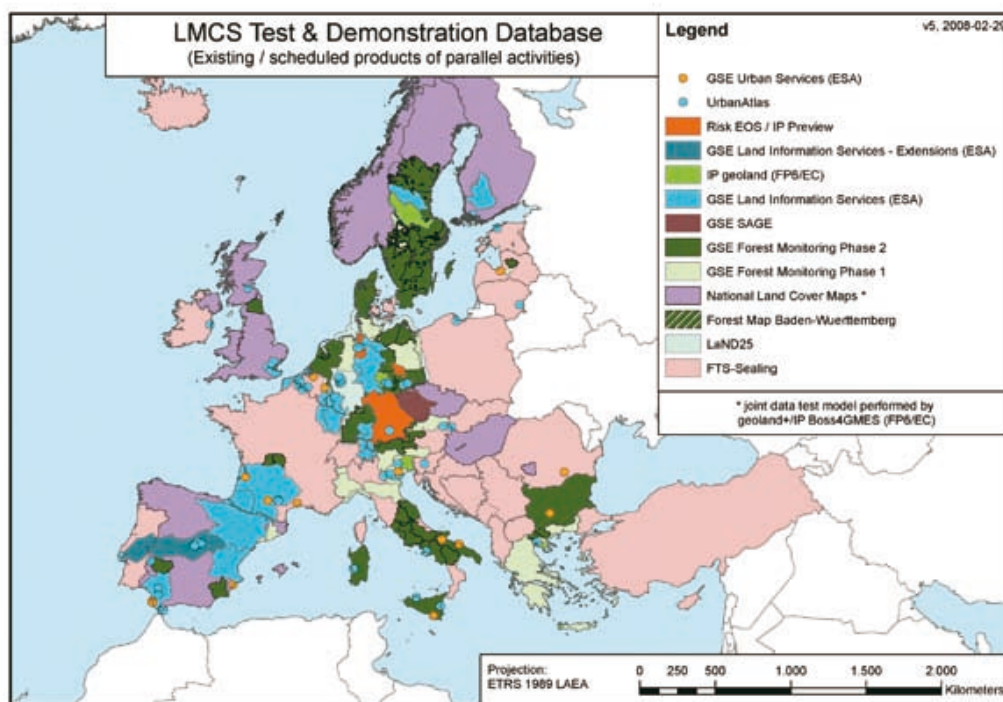
Figure 1.8. *LMCS Test and Demonstration Database.*

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Analysing the different product and service portfolios and specifications reveals the following:
- The Regional geoland and GSE land nomenclature includes the inland and coastal wetlands and water bodies in a minimum mapping unit of 5 ha, which is a major step forward in relation to the existing CLC mapping resolution of 25 ha.
- The geoland project comprises a "water observatory" and the GSE land provides inland water quality/contamination services.

In summary the provided core and downstream services and products are mainly twofold (geoland, 2007; GSE Land, 2007): (i) <u>Water quality</u> - water pollution map, source appointment maps, Nutrient input and surplus; and related input maps (such as specific agricultural land cover). (ii) <u>Irrigation</u> - irrigation volume, agricultural water consumption. GSE LAND validated products are accessible at http://www.geoway.de/infoportal/

The geoland observatory "nature protection" provides the prototype of the habitat interpretation database "HABID", a framework that could usefully be applied to harmonize the European-wide mapping of wetland habitats. Moreover, the observatory contributed by mapping the water bodies of Albania using a biophysical approach.

Regarding the global component, the global core service and observatories may provide some useful additional information for wetland ecosystems. A water bodies service is provided as well but in a spatial resolution of 1 km that is not sufficient for a Mediterranean wetland inventory.

The GMES Network of users GNU

GNU is the independent platform for users of environmental GMES products. It optimizes benefits from the socio-technological system GMES for national and regional level users. The GNU consortium is coordinated by the Austrian Environment Agency and consists of environment agencies and ministries, ETC LUSI, geological surveys, specialist agencies on air, forestry and land information, small and medium-sized enterprises for support work and research organizations; in total, 22 partners. GNU is funded via the 6th FP of the EC and is running from October 2007 to September 2010.

The objectives of GNU are to:
- defragment the environmental GMES user communities;
- enable independent and unfiltered user statements;
- be a mouthpiece for the needs of GMES users at the national/regional level;
- aggregate and differentiate users' appraisals of GMES products;
- link data-related and human aspects of the socio-technological system GMES.

GNU is not a closed consortium and target groups incorporate national and regional level stakeholders, including service providers, European and international stakeholders and other projects and networks. GNU will enter into discussion, and network with, other consortia to establish alliances and joint projects.

Useful documents for further reading (*can be accessed at: http://www.gmes.info/library/*)
- COM(2004)65 *Global Monitoring for Environment and Security (GMES): Establishing a GMES capacity by 2008* Action Plan (2004-2008.
- COM(2005)565 *Global Monitoring for Environment and Security (GMES): From Concept to Reality*.
- LMCS IG 2007. *GMES Fast Track Land Monitoring Core Service Strategic Implementation Plan, Final Version, 24/04/2007*.

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ALOS **Kyoto and Carbon Initiative: The Wetland Theme**

by *Laura L. Hess, Ake Rosenqvist and John Lowry*

ALOS Kyoto and Carbon Initiative

The ALOS Kyoto and Carbon (K&C) Initiative, created in 2000, is jointly coordinated by the Japanese Space Agency (JAXA) and the European Commission Joint Research Centre with the goal of addressing information needs of international environmental conventions, carbon cycle science and environmental conservation. As described in the Initiative's Science Plan (see http://www.eorc.jaxa.jp/ALOS/kyoto/kyoto_index.htm), this is achieved through provision of i) systematic global observations and consistent data archives and ii) derived and verified thematic products, organized thematically into Forest, Wetlands, Desert & Water, and Mosaic Products. During 2006-2008, products are being developed by K&C Science Team members and demonstrated for prototype areas, with successful products to be extended to larger regions during 2009-2010. ALOS PALSAR image mosaics and, when ready, derived thematic products are made available to the public for scientific purposes (see http://www.eorc.jaxa.jp/ALOS/kc_mosaic/kc_mosaic.htm).

ALOS Kyoto and Carbon Initiative Wetlands Products

For the Wetlands Theme, products have been grouped into three broad categories.

I) *Global wetland extent and properties*. These products will provide basic information on wetland extent and vegetation for regions that are currently poorly mapped, in support of Ramsar Convention information needs and global land cover mapping.

II) *Seasonal monitoring of major wetland regions*. Applications of these ScanSAR-based (wide swath, 100 m resolution) maps of inundation periodicity include estimation of methane emissions, hydrologic modelling, habitat mapping and assessment of ecosystem functioning.

III) *Mapping and monitoring of key wetland functional types*. These products focus on wetland types that are particularly significant for biodiversity and conservation (mangroves, tropical peat swamps) and the global carbon cycle (peat swamps, paddy rice, lake sediments). Products and prototype areas are shown in Table 1.1.

Products	Prototype Areas
I. Global wetland extent and properties	
Tropical wetland extent and vegetation type	Amazon, SE USA, North Australia
Boreal wetland extent and vegetation type	Alaska
II. Seasonal monitoring of major tropical/sub-tropical wetlands	
Seasonal monitoring of tropical floodplains	Amazon, Congo, Okavango
Greater Mekong basin inundation & vegetation change	Cambodia, Vietnam
Seasonal dynamics of Pantanal ecosystem	Brazilian Pantanal
Boreal wetlands open water and freeze-thaw state	Alaska, Canada, Finland, Siberia
III. Mapping and monitoring of key wetland functional types	
Mangrove extent and properties	N. Australia, Indonesia, Belize, French Guyana, Brazil, West Africa
Tropical peat swamp forests extent and hydrology	Sumatra, Kalimantan, Irian Jaya
Regional irrigated rice paddy monitoring	China, India, SE Asia, Philippines
Global lakes census	Canada, Pantanal, Zambezi basin

Table 1.1. *ALOS Kyoto & Carbon Initiative Wetlands Products.*

ALOS and Mediterranean wetlands

As described above, the Mediterranean is not a focus region in the ALOS systematic acquisi-tion plan, which emphasizes poorly mapped and cloud covered regions. Nevertheless, fine-beam data are acquired one to four times annually as part of a systematic global acquisition strategy and will be useful for particular sites. For areas with woody vegetation or certain ty-pes of herbaceous vegetation such as papyrus, the longer wavelength of PALSAR can provide information complementary to that of C-band sensors such as Envisat. Like Envisat and its predecessor ERS, PALSAR can be utilized in disaster monitoring for mapping of inundated areas. An example of ALOS Fine-Beam Dual-polarization data is shown in Figure 1.9 for the Camargue region in France.
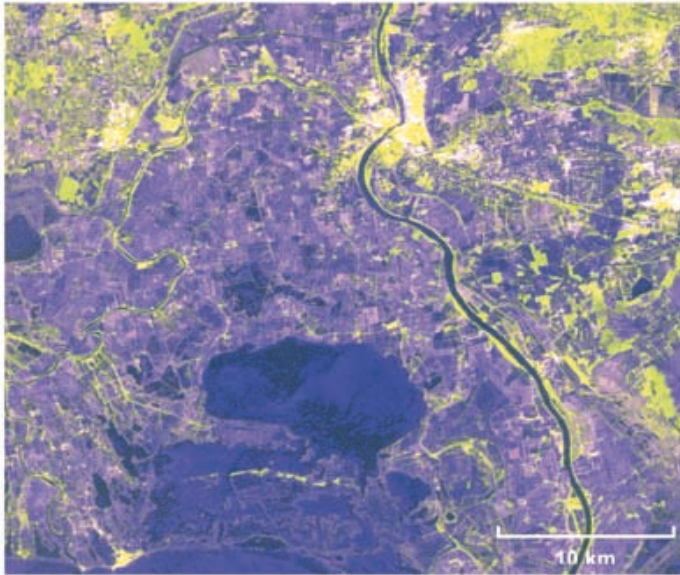
Figure 1.9. *ALOS PALSAR Fine Beam Dual-pol image of Camargue wetland (France); Red = HH, Green = HV, Blue = HH/HV. Woody vegetation, appearing here as green, is clearly distinguished from herbaceous and non-vegetated cover by strong cross-polarized returns. Rice fields, in shades of violet, occupy most of the scene. Natural marshlands at bottom and left of scene appear as bluish grey*

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A Partnership to promote, harmonize and support global and national scale mapping and inventory for assessment and monitoring of wetlands in support of the Ramsar Convention on Wetlands and other bio-diversity related conventions.

by *Lucilla Spini, Robert R Christian, Nick Davidson, Max Finlayson, John Latham and Robert Zomer*

The Conference of the Contracting Parties of the Ramsar Convention, at its 9th Meeting (Kampala, Uganda, 8–15 November 2005), through its adoption of a "Framework for wetland inventory, assessment and monitoring" (IF-WIAM; Resolution IX.1, Annex E) stressed the value of effective wetland inventory and affirmed its previous resolutions supporting national scale wetland inventory. Key issues that have afflicted much past wetland mapping and inventory include inadequate planning, lack of consistency and shortcomings in available methods and data. Some of these problems have been considered through published methods for Mediterranean and Asian wetlands. Further, more detailed methods have been developed and tested through organizations such as the Food and Agriculture Organization (FAO) of the United Nations and the International Water Management Institute (IWMI), working with local organizations in Asia and Africa in particular (Finlayson et al, 2002; Rebelo et al, 2007; Mazzilli & Christian, 2007).

The IF-WIAM, now also available as Ramsar Wise Use Handbook 11 (Ramsar Convention Secretariat, 2007) encourages multiple scalar analyses suitable for specified purposes and for informing regional management. FAO, IWMI and many other international organizations have programmes building in-country capacity for resource mapping and inventories in support of national, sub-national and local assessment and management needs throughout the developing world. At a regional and global level, these organizations play a key role in coordinating the integration and harmonization of datasets for use across a broad range of environmental change issues. They promote international standards, such as ISO TC 211 (eg Global Land Cover Network [GLCN], 2005), support the needs of conventions and global change assessments, and operationalize observing systems such as the Global Terrestrial Observing System (GTOS) and thereby GEOSS (FAO, 2005; GEO, 2006). Through planned and collective actions on wetland mapping and inventories, these programmes can also provide improved wetland-specific information and assessments at the multiple scales advocated by the Ramsar Convention. Acknowledging the identified shortcomings in existing inventory and the lack of an accurate and reliable global assessment, and recognizing the many ongoing efforts to address this issue at various scales, it has been proposed that a network of organizations and researchers active in wetland mapping and inventory be formed to harmonize these activities globally within the framework of the Ramsar Convention on Wetlands.

In this respect at the 13th Meeting of the Scientific and Technical Review Panel (STRP) of the Ramsar Convention on Wetlands (Gland, Switzerland, 30 May-2 June 2006), FAO, through the Coastal Panel of GTOS (C-GTOS), and IWMI, an International Organization Partner of the Ramsar Convention, called for a Type II Partnership. The partnership supports the Ramsar Convention on Wetlands and other Biodiversity-related Conventions (eg Convention on Biological Diversity [CBD], the Convention on Migratory Species [CMS]) with the objective to promote and improve wetland mapping inventories for assessment and monitoring at multiple scales through:

- development of a collaborative and distributed network of excellence to har-monize, support and undertake global wetland mapping, inventories and moni-toring;
- promotion of standards and methods for improved wetland-related data collec-tion and information access;
- encouragement of synergies among Conventions, observing systems and as-sessment initiatives on wetland-related issues; and
- establishment of capacity building initiatives at national and regional scales.

The Partnership's objectives are exemplified by highlighting the following three initial key result areas:

1) *Wetlands Mapping, Inventory, and Monitoring Core Network*: A core group of members with an active interest in wetlands mapping, inventory and assessment will form the Partnership. This core network will initiate a preliminary process whereby the bylaws and membership of the Partnership are established. In gen-eral, membership will be inclusive, with the intention of maximizing participation by organizations and researchers active in wetland mapping and inventory. In par-ticular, expertise will be sought on application of advanced techniques, such as satellite remote sensing and geospatial (GIS) analysis and modelling approaches, as well as cost effective methods such as rapid assessment techniques. This group of experts will be the basis for a knowledge sharing and transfer network and will guide the development of a knowledge resource for the support of local and na-tional mapping and inventory. In addition, wide participation by global, regional and national level bodies will be sought. Participation will be especially sought from national mapping agencies, national wetlands management focal points and other bodies with a mandate for wetlands mapping or inventory, utilizing existing networks of GTOS, the Global Land Cover Network (GLCN) and IWMI.

2) *Development of Wetlands Classification System Module in the Land Cover Classi-fication System (LCCS-WCSM)*: for incorporation into the FAO Land Cover Clas-sification System (LCCS) (Di Gregorio & Jansen, 2000). The WCSM will be de-veloped to provide a generic standardized approach to harmonizing existing clas-sification systems within a hierarchical taxonomy of wetland characteristics. The WCSM will provide a standard approach for a globally relevant wetlands classifi-cation system, applicable to a variety of scales and management needs. It is envis-aged that the Partnership will act as a technical resource and coordinating body for the development and dissemination of this approach and taxonomy.

3) *Wetlands Mapping and Inventory Information Network and Online Resources Centre*: The Partnership recognizes ongoing efforts by members of the Partnership and others, and the network of excellence to be created by the Partnership. It will facilitate and host information exchange and partner networking through internet based knowledge management and knowledge dissemination.

The Partnership was launched at the Globwetland Symposium (ESA Headquarters, Frascati, Italy, 20 October 2006) and is open to: countries which are Contracting Par-ties to the Ramsar Convention; biodiversity conservation-related MEAs and IGOs; NGOs and Networks; representatives of industry and scientific, academic and other organizations; and appropriate private business. Contact details for further informa-tion and/or application are available at http://csi.cgiar.org/wetland_partner/index.asp.

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The Global Observation System of Systems (GEOSS)

by *Robert R Christian*

Observing systems are designed to support the wise management of ecosystems and sustainable inter-relationships between humans and their environment. The observing systems recognize that both the natural environment and human interactions undergo change at multiple scales and are inter-related. Scales range from short term disturbances such as tsunamis, to intermediate scales such as overharvesting resources during a season, to large scale changes in the Earth's climate. Thus, the observations, products of synthesis and analysis, and communication to those who need the information must occur over multiple scales. Observing systems must be arranged hierarchically to address this hierarchy of scales. Thus, we have the Global Observation System of Systems (GEOSS).

GEOSS incorporates the efforts of many nations, organizations and individuals. The coordinating body of nations and international organizations is the Group on Earth Observations (GEO), which formed in 2002. This was initiated at the World Summit on Sustainable Development (Johannesburg Summit, 2002). Seventy-two Governments, the European Commission and 52 organizations are recorded as being members as of February 2008 (http://earthobservations.org/about_geo.shtml). The identification of issues for GEOSS is structured around "societal benefit areas." They are agriculture, biodiversity, climate, disasters, ecosystems, energy, health, weather and water. A 10 year implementation plan is used to determine how each of these issues will be addressed. Although many organizations and nations have had observing system programmes that pre-date GEO and GEOSS, much of their efforts are being channelled through GEOSS.

Much of the early efforts at global observations have been done through the United Nations (UN). The UN began supporting observing systems as a result of the United Nations Conference on Environment and Development in Rio de Janeiro in 1992. Three observing systems were formed. Observing systems focused on the global ocean (Global Ocean Observing System [GOOS]), climate (Global Climate Observing System [GCOS]) and terrestrial (Global Terrestrial Observing System [GTOS]).

The nature of observing systems has been discussed elsewhere (Clarke et al, 2001; Christian, 2005). Observing systems are "defined as operational and end to end systems designed to link, at appropriate time and space scales, environmental observations to scientifically sound management of ecosystems and natural resources. In this context, 'operational' means the routine, continuous provision of data and information of known quality. As 'end to end' systems, they coordinate and integrate long term monitoring with quality assurance and control, data assimilation and harmonization, information management, modelling and ultimately communication of information rich products to interested user groups. They are designed to build on ongoing monitoring and research programmes where possible and extend capabilities where needed. Thus, methods standardization and training are components of these systems."(Christian et al, 2006).

No one programme can be expected to do everything. Rather the various parts (by geography, issue of concern, and process of information transfer and transformation) are likely done by different organizations. GEOSS is the coordinating mechanism to promote cooperation, ensure quality and help support sustainability. These are major challenges, and quite frankly success will need to be measured in the future.

Observations can be characterized as being made remotely and in situ. Both have their advantages and limitations. Remote sensing is often done by aircraft or satellite and has the advantage that large areas can be covered. Limitations may occur with timing of observations, sustainability of measurements, resolution and ability to interpret signals. Generally, in situ observations are necessary both to provide ground truthing for remote sensing and provide information not available by remote sensing. These in situ observations are often of points in space and time, although continuous measurements over space and time are possible. Limitations to in situ observations include sustainability of measurements and ability to make observations temporally and spatially as appropriate. Measurements often require personnel, equipment and transportation logistics that are challenging. Further, access to locations for sampling may be restricted by ownership, terrain etc. These are problems in all nations, but are particularly obvious in developing countries.

The concept of sentinel ecosystems was promoted by Jassby (1998) and was further adopted for observing systems (Christian & de Mora, 2005; Christian & Mazzilli, 2007; Mazzilli & Christian, 2007). The approach is a mechanism to enhance the opportunity

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for in situ measurements by taking advantage of established networks of ecosystems. Sentinel ecosystems for observing systems represent a limited number of sites within international programmes (eg MedWet, Ramsar, Man and the Biosphere). It is reasoned that because the sites are part of larger programmes they are relatively wellunderstood with substantial datasets, society should value them so that management and protection are fostered, and there should be commitment for sustained observations – past, present and future. While good understanding and large datasets may not be available for all sites, both the likelihood and need for these is considered higher than for sites outside of such programmes. This approach has significance for MedWet and Ramsar. MedWet and Ramsar provide access to a wide variety of important wetlands that fit these criteria. The partner ecosystems reflect the conservation status and trends of a substantially larger number of wetlands.

Hierarchical observing systems work best when organizations at multiple layers benefit. There are several advantages to the sentinel ecosystem approach that contribute to the development and management of observing systems, as well as the individual sites themselves. The sentinel ecosystems are directly useful for long term observations of the particular location and represent a broader group of ecosystems for assessment. The work builds capacity for all steps in the observing system process in both the larger system and the individual site. This capacity improves quality-assured information for the development, validation and evaluation of large scale modelling and comparative change studies. The ability to make measurements at the sites and quality of work in general should be enhanced. Once the capacity is established, it can be extended; models can be transferred with greater confidence to other locations and adapted for use in regional and global studies. Finally, this approach bolsters existing networks of monitoring sites and their activities; it links networks with vested interests in sustained monitoring and supports current global and regional programme activities for monitoring and conservation of heritage areas. These are all necessary steps for regional and global change assessment.

The implementation of the sentinel ecosystem approach involves the balance of the scientific requirements for observing system products (eg sustained measurement of indicators) and the opportunities to meet those requirements. This may be illustrated in the following matrix. The goal of the approach is to identify those sites that would provide both the potential and practical access to the appropriate environmental information. This information in turn must be able to be made available to a broad spectrum of users. The matrix (Table 1.2) provides a simple classification system for identifying sentinel ecosystems, based on pairing conditions for both science and opportunity as high (H) and/or low (L) values.

Opportunity		Scientific Requirements	
		High	Low
	High	HH	HL
	Low	LH	LL

Table 1.2. *Matrix for identifying Sentinel Ecosystems.*

1. Scientific Requirements (prioritized such that a site would be considered in the following contexts):
   a. Diversity of ecosystem types (needs classification).
   b. Diversity of geographic locations (may be limited within larger region).
   c. Diversity of stressors.
   d. Diversity of condition of ecosystems.
   e. Diversity of management schemes.

2. Opportunity (prioritized with focus on a site being appropriate for cross-system analysis of indicators):
   a. Component of international network.
   b. Current description available.
   c. Willingness to make data free and accessible.
   d. Willingness to provide periodic synoptic descriptions.

    e. Historical data.

    f. Probability for continued monitoring.

    g. Probability of ability to modify future monitoring.

    h. Involvement in modelling efforts.

    i. Involvement in research.

In conclusion, GEOSS provides an opportunity and mechanism to coordinate and improve environmental observations. Further, the assimilation of data from various locations, times, organizations and sensor platforms can occur with resultant products that transcend what could be achieved by any component program. These products also will have the ability to reach the users and stakeholders with local to regional to global interests. MedWet can be an important contributor to GEOSS by providing observations from its partner wetlands through a sentinel ecosystem approach. The efforts will not only aid the global effort but also provide value to site managers and local and national policy makers.

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Spatial Data Infrastructure (SDI) Initiatives

by *Lena Hatziiordanou*

Wetland inventory, assessment and monitoring require different types of spatial data and multiscalar approaches at different geographical scales. Such data must not only exist, but it must be easy to identify where these are held and how they can be accessed and integrated with other data. The importance of geographic information to support decision-making and management of several national, regional and global issues was cited as critical at the 1992 Rio Summit and by a special session of the United Nations General Assembly assembled in 1997 to appraise the implementation of Agenda 21. In the mid 1990s, decision makers realized that natural disasters and environmental impacts have no political boundaries and began to recognize the benefit of using common standards and interoperable data and systems in an effort to share their spatial data, and to reduce costs and duplication of efforts in collecting, processing and archiving them. The term Spatial Data Infrastructure (SDI) encapsulates a framework of policies, institutional arrangements, technologies, data and people that enables spatial data sharing.

According to The SDI Cookbook Version 2.0 (Nebert, 2004), the *term "Spatial Data Infrastructure" (SDI) is often used to denote the relevant base collection of technolo-gies, policies and institutional arrangements that facilitate the availability of and ac-cess to spatial data … using a minimum set of standard practices, protocols, and specifications... [to provide]... a basis for spatial data discovery, evaluation and ap-plication for users and providers within all levels of government, the commercial sec-tor, the non-profit sector, academia and by citizens in general.*

A more detailed definition is given by the Global SDI (GSDI) Association: *Spatial Data Infrastructures (SDIs) support ready access to geographic information. This is achieved through the coordinated actions of nations and organisations that promote awareness and implementation of complementary policies, common standards and effective mechanisms for the development and availability of interoperable digital geographic data and technologies to support decision making at all scales for multiple purposes. These actions encompass the policies, organisational remits, data, technologies, standards, delivery mechanisms, and financial and human resources neces-sary to ensure that those working at the (national) and regional scale are not impeded in meeting their objectives.*

Spatial data infrastructures provide a basis for spatial data discovery, access, evalua-tion and application. The word infrastructure is used to promote the concept of a reliable, supporting environment that facilitates the access to geographic information us-ing a minimum set of standard practices, protocols and specifications.

A wide range of activities must be undertaken to ensure the effective implementation of an SDI. These include not only technical matters (data, technologies, standards etc), but also institutional matters related to organizational arrangements and national policies. The main objective of SDIs is to promote ready access to the geographic in-formation assets that are held by a wide range of stakeholders in both the public and the private sector with a view to maximising their overall usage and to support deci-sion-making. To ensure that this objective is attainable, there is a need for concerted action on the part of governments.

Based on the SDI initiative, many countries are developing SDIs at different levels ranging from local to national, regional and global level. The Global Spatial Data In-frastructure Association is a global non-profit organization that consists of members from more than 50 countries and promotes international cooperation and collaboration in support of local, national and global spatial data infrastructure developments by seeking, securing and sharing funds.

The INSPIRE Initiative for the creation of a European SDI (ESDI)

The development of SDIs has been studied extensively in Europe over the last eight years. The INfrastructure for SPatial InfoRmation in Europe (INSPIRE) initiative (http://inspire.jrc.it) was launched at the end of 2001 with the aim of making available relevant, harmonized and quality geographic information for the purpose of formulation, implementation, monitoring and evaluation of Community policy-making. To achieve its aim, INSPIRE has been addressing a broad set of issues including common reference data and metadata, architecture and standards, legal aspects and data policy, funding and implementation structures, and impact analysis.

After three years of preparatory work, and intensive collaboration with Member States' experts and stakeholder consultation, a proposal for an INSPIRE Directive was submitted on 23 July 2004 by the European Commission to the European

Parliament and the Council of Europe, to support the creation of a European Spatial Data Infrastructure (ESDI). INSPIRE was finally approved and published as *Directive 2007/2/EC of the European Parliament and of the Council of 14th of March 2007* in the Official Journal of the European Union on 25 April 2007, and entered into force on 15 May 2007.

INSPIRE lays down general rules for the establishment of a European Spatial Data Infrastructure for the purposes of environmental policies and policies or activities which may have a direct or indirect impact on the environment. The target users of the ESDI include policy-makers at European, national and local level and the general public. The directive will oblige EU Member States to improve the administration of their map services and other spatial data services according to common principles, the so-called Implementing Rules (IR). The IR are designed to control various aspects of the spatial data including: the creation of metadata; technical developments promoting interoperability; the use of data services; principles on access to data and related charges; and national coordination. The IR take into account relative standards adopted by European standardization bodies (CEN), as well as international standards (ISO, OGC). Implementing Rules will be adopted between 2008 and 2012 with compliance required between 2010 and 2019.

INSPIRE covers spatial data sets that are included in one or more of the themes listed in Annex I, II or III of the Directive (Table 1.3). The Directive requires Member States to ensure that metadata are created for the spatial data sets and services corresponding to the themes listed in the Annexes, and that those metadata are kept up-to-date. A metadata tool is already available online (http://www.inspire-geoportal.eu/inspireEditor.htm) for filling in metadata in compliance with the adopted INSPIRE Implementing Rules for Metadata. The Directive also requires Member States to operate a network of services (Discovery services, View services, Download services, Transformation services, Services allowing spatial data services to be invoked) available to the public for data sets for which metadata have been created (Figure 1.10).

Table 1.3. *Spatial Data Themes included in the Annexes of the INSPIRE Directive.*

SPATIAL DATA THEMES

ANNEX I
1. Coordinate reference systems
2. Geographical grid systems
3. Geographical names
4. Administrative units
5. Addresses
6. Cadastral parcels
7. Transport networks
8. Hydrography
9. Protected sites

ANNEX II
1. Elevation
2. Land cover
3. Orthoimagery
4. Geology

ANNEX III
1. Statistical units
2. Buildings
3. Soil
4. Land use
5. Human health and safety
6. Utility and governmental services
7. Environmental monitoring facilities
8. Production and industrial facilities
9. Agricultural and aquaculture facilities
10. Population distribution — demography
11. Area management/restriction/regulation zones and reporting units
12. Natural risk zones
13. Atmospheric conditions
14. Meteorological geographical features
15. Oceanographic geographical features
16. Sea regions
17. Bio-geographical regions
18. Habitats and biotopes
19. Species distribution
20. Energy resources
21. Mineral resources

Figure 1.10. *INSPIRE Technical Architecture Overview.*

INSPIRE should be based on the infrastructures for spatial information that will be created by the Member States based on the adopted Implementing Rules. In order to assist the integration of national or regional infrastructures into INSPIRE, they should provide access to these infrastructures through a Community geoportal (http://www.inspire-geoportal.eu/) operated by the Commission, as well as through any access points they decide to operate themselves. The INSPIRE Community Geoportal does not store or maintain the actual data. It acts as a gateway to geographic data and services, distributed from several European data servers, allowing users to search, view or - subject to access restrictions - download geographic data or use available services to derive information.

Once INSPIRE is transposed by the Member States into their national legislation (2007-2009) its measures will be implemented and monitored. It is expected that the infrastructure will be fully in place by 2019 and that it will enable European citizens to find useful environmental spatial information via the web, and the authorities to benefit more from information compiled by other official organizations.

The GEOSS Infrastructure

The Group on Earth Observations (GEO) is coordinating international efforts to build a Global Earth Observation System of Systems (GEOSS). GEOSS will provide decision-support tools to policy-makers, resource managers, science researchers and many other experts and decision-makers. GEOSS will be a global and flexible network of content providers allowing decision-makers to access an extraordinary range of information. This *system of systems* will proactively link together existing and planned global observing systems and will support the development of new systems where gaps are identified. It will promote common technical standards so that data from different sources and instruments can be combined into coherent data sets.

The Global Earth Observation System of Systems (GEOSS) is building upon and adding value to planned and existing Earth observation systems by connecting them to one another. This requires making these systems and components interoperable, so that any data they produce can be combined. GEOSS will become a system of systems by adopting appropriate standards for the interfaces through which the various GEOSS components will exchange data and information.

In common with Spatial Data Infrastructures and service-oriented information architectures, GEOSS system components are to be interfaced with each other through interoperability specifications based on open, international standards. A key consideration is that GEOSS will catalogue data and services with sufficient metadata information, so that users can find what they need and gain access as appropriate. The GEOSS Common Infrastructure allows the user of Earth observations to access, search and use the data, information, tools and services available through the Global Earth Observation System of Systems.

The infrastructure consists of four main elements:

- The *GEO Portal*, which provides a web-based interface for searching and accessing the data, information, imagery, services and applications available through GEOSS. It connects users to existing databases and portals.
- The *GEOSS Clearinghouse* is the engine that drives the entire system. It connects directly to the various GEOSS components and services, collects and searches their information and distributes data and services via the Geo Portal to the user.
- The *GEOSS Components and Services Registry* is similar to a library catalogue, providing a formal listing and description of all the Earth observation systems, datasets, models and other services and tools that together constitute GEOSS. These various components are being interlinked using standards and protocols that allow data and information from different sources to be integrated.
- The *GEOSS Standards and Interoperability Registry* enables contributors to GEOSS to configure their systems so that they can share information with other systems. This Registry provides information about standards and interoperability arrangements. GEOSS encourages the adoption of existing and new standards to support broader data and information usability.

The success of GEOSS will depend on data and information providers accepting and implementing the interoperability arrangements, including technical specifications for collecting, processing, storing and disseminating shared data, metadata and products.

The United Nations SDI (UNSDI)

During the Sixth United Nations Geographic Information Working Group (UNGIWG) Plenary Meeting held in Addis Ababa in October 2005, endorsement for a UN Spatial Data Infrastructure (UNSDI) to support coordinated efforts in the development and management of geospatial information was made. In 2006 the UNGIWG sponsored a number of strategic and technical papers on SDI. During the 7th UNGIWG Plenary meeting held in Santiago in November 2006, it was recognized that the development of a common vision and understanding on UNSDI was a priority.

The UNSDI vision is that of a comprehensive decentralized geospatial information framework that facilitates decision-making at various levels by enabling access, retrieval and dissemination of geospatial data and services in a rapid and secure way.

The UNSDI is a mechanism that enables interoperability between spatial data infrastructures developed for specific purposes that operate within UN agencies, among groups of UN agencies sharing common interests and between the UN, Member States and their regional and thematic groupings, and partners. To achieve this the UNSDI provides a base collection of technologies, datasets, human resources, policies, institutional arrangements and partnerships that facilitate the availability, exchange of, access to and use of geographically-related information using standard practices, protocols and specifications. Where SDIs do not yet exist it is in the UN's interest to foster their development as a means of encouraging improved ease of access and re-use of spatial data.

The UNSDI will contribute substantively to the mission of the United Nations by engaging member states, regional organizations and partners in building consensus, policy and governance mechanisms to ensure that geospatial data and information sharing practices are used widely in social, economic and environmental development. Access, retrieval and dissemination of geospatial data and services will be enabled in an easy and secure way by the UNSDI, avoiding duplication in data collection and management within the United Nations, and with and between its Member States and partners. By facilitating efficient global and local access, exchange and utilization of geospatial information to both developed and developing countries, the UNSDI will enhance decision-making on a global basis and at all levels of societies and thus contribute substantively to the achievement of the Millennium Development Goals (MDGs).

Interlinkages between the ESDI, the GEOSS Infrastructure, the UNSDI and other Legislations-Initiatives

At the European scale, the European Parliament successfully insisted that the INSPIRE Directive should not conflict with the provisions of other related legislation such as the *Aarhus Convention on access to environmental information* nor with Directive 2003/4/EC by which the Convention is implemented in the EU; and ensured that it would be without prejudice to Directive 2003/98/EC of the European Parliament and of the Council of 17 November 2003 on the re-use of public sector information (PSI), the objectives of which are complementary to those of this Directive. However, Member States will be able to restrict

public access to network consultation services displaying panoramic views where there is a risk to international relations, public security or national defence. Moreover, INSPIRE does not affect the existence or ownership of public authorities' intellectual property rights.

The INSPIRE Directive will also complement other EU initiatives that have the objective to collect and harmonize spatial environmental information (such as CORINE land cover, European Transport Policy Information System, WISE etc) by providing a framework that will enable them to become interoperable. As cited in the INSPIRE Directive, the establishment of INSPIRE will also have significant added value to (and will benefit from) other Community initiatives such as Council Regulation (EC) No 876/2002 of 21 May 2002 setting up the Galileo Joint Undertaking, and the Communication from the Commission to the European Parliament and the *Council Global Monitoring for Environment and Security (GMES): Establishing a GMES capacity by 2008 (Action Plan 2004-2008)*. It will also contribute to the implementation of the European Shared Environmental Information System (SEIS).

Nevertheless, it is important to recognize that INSPIRE will not directly address data of a non-spatial or non-numerical nature, will not by itself guarantee organizational consolidation within Member States, and will not lead directly to an improvement in the quality and comparability of data. The INSPIRE Directive is not actually setting the requirements for collecting new data, or for reporting such information to the Commission, since those matters are regulated by other legislation or initiatives related to the environment (eg. GMES, Galileo SEIS etc). Instead, it is designed to optimize the scope for exploiting the data that are already available by requiring the documentation of existing spatial data (metadata) and the implementation of services aimed at rendering the spatial data more accessible and interoperable, and by dealing with obstacles to the use of the spatial data. INSPIRE mostly focuses on infrastructure, harmonization and data sharing, in comparison with GMES and SEIS which focus on data collection and reporting.

At the global scale, the *UNSDI Strategy for developing and implementing a UNSDI in support of Humanitarian Response, Economic Development, Environmental Protection, Peace and Safety* emphasizes the need to forge interoperable links with national SDI initiatives and to develop strategic partnerships with regional programmes such as the INSPIRE initiative of the European Commission, the Heterogeneous Missions Accessibility (HMA) and the GEO portal, and with standardization bodies such as the Open Geospatial Consortium (OGC) and the International Organization for Standardization (ISO).

Moreover, the Group on Earth Observations, in its 10-year Implementation Plan Reference Document, cites that GEOSS will advocate further development of the Global Spatial Data Infrastructure and use of existing SDI components as institutional and technical precedents in areas such as geodetic reference frames, common geographic data and standard protocols. To the extent that GEOSS adopts identical or compatible standards, GEOSS and SDI components become interoperable with each other as well. This provides a powerful synergy as GEOSS addresses types of data and information that are not always geospatial, while SDIs address types of data and information that are not always Earth Observation.

INSPIRE is expected to contribute to GEOSS by:
- Making accessible interoperable spatial data and services operated by Member States in Europe and European Community institutions.
- Developing standards and specifications relevant to the GEO effort.
- Contributing with the INSPIRE Community geoportal and European components and services to the GEO Clearinghouse.

GEO contributes to the development of standards and specifications of relevance to INSPIRE. It also provides the opportunity for promoting interoperability between GEO and the ESDI and to the wider accessibility of interoperable earth observation data and services. To this end, the GEOSS INSPIRE and GMES an Action in Support (GIGAS)" Project (http://www.thegigasforum.eu) promotes the coherent and interoperable development of these initiatives through their concerted adoption of standards, protocols and open architectures.

SDI Benefits

The capacity to easily search for and integrate spatial data from different sources advances knowledge of the environment in a cost effective way. The implementation of local, national, regional or global SDIs brings a significant asset to the authorities

who maintain spatial data and to particular users (governmental agencies, academics, researchers, NGOs, general public) who can use these data for research or for policy-making, implementation and monitoring. The wider availability of interoperable datasets can also serve decision-making at all levels.

Recognising the recent trends, Resolution VIII.6 of the Ramsar COP8 (*A Ramsar Framework for Wetland Inventory*), paragraph 22, requested the Scientific and Technical Review Panel to work with Wetlands International, the Ramsar secretariat, remote sensing agencies and other interested organizations to review further the application of remote sensing data, low-cost Geographical Information Systems (GIS) and classification systems in wetland inventory. However, the situation on wetland spatial data in the Mediterranean region is still associated with lack of harmonization between datasets at different geographical scales, duplication of information collection, lack of metadata, difficulty of data discovery and access, and lack of common standards. These problems make it difficult to search, share and make practical use of the spatial data that is already available. It is therefore necessary to adopt a framework of policies, institutional arrangements, technologies, data and people that will enable the sharing and effective usage of geographic information for wetlands.

At a regional level, the MedWet Initiative - which has worked on the harmonization of inventories in the Mediterranean from its very start in 1991 - has already made significant developments relevant to the needs outlined above. Notable amongst them is the creation of a Pan-Mediterranean Wetland Inventory (PMWI) by 2010, which was agreed by the Mediterranean Wetlands Committee (MedWet/COM) in 2001 (for more see section "The Pan-Mediterranean Wetland Inventory (PMWI)" of the present manual), and the newly developed MedWet database The MedWet Web Information System [3] along with the MedWet Inventory Data Sharing Protocol (Fitoka et al, 2008) which provide advanced tools and services as well as the needed framework for maintaining a Mediterranean wetland databank accessible to various users (ie managers and stakeholders, policy makers, scientists).

To promote its work and set the basis for a future interoperability of its datasets and software tools, MedWet plans to play an active part in influencing the SDIs' final content by getting involved in the testing of the INSPIRE, GEO or UNSDI standards and providing useful feedback (ie metadata, data specifications, semantics etc) on Mediterranean wetlands.

A future interoperability of the MedWet datasets and tools with other GIS portals (European Community geoportal, GEO Portal etc) will have a significant added value to the MedWet community. It will enable wetland managers to share and search for good quality wetland geographic information as well as other thematic data (eg coast-lines, administrative units, hydrography, soil data, land cover, protected areas etc) and imagery from different data servers, and derive useful information for decision-making.

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[3] Access to the MedWet Web Information System is provided at www.wetlandwis.net. For more see The MedWet Web Information System User's Manual (Katsaros et al, 2008).

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NOTABLE PROJECTS AND PROGRAMMES

The Pan-Mediterranean Wetland Inventory (PMWI)

by *Pere Tomàs Vives*

The fourth meeting of the Mediterranean Wetlands Committee (MedWet/Com) in 2001 recommended the creation of a Pan-Mediterranean Wetland Inventory (PMWI) by 2010. This was the first attempt to develop a Mediterranean-wide wetland inventory and database which will allow analyses to be made of location and extent of wetlands, as well as preliminary assessments of their values and status.

The PMWI consists of a compilation of inventory data from Mediterranean countries in order to build a Mediterranean-wide wetland inventory; this will allow an overall picture to be built of the location of the wetlands in the Mediterranean and their extent. For this the PMWI aims to:
- Include as many wetlands as possible in each Mediterranean country.
- Include information useful for assessing the status of wetlands.
- Be easy and quick to compile (it is included in the overall MedWet inventory system).
- Facilitate data transfer, through the online database.
- Be accessible to contributors, through the online database.
- Allow dissemination of up-to-date information/results.
- Allow location maps to be produced of Mediterranean wetlands at different scales.

The first objective of the PMWI is to provide answers to some basic questions:
- How many wetlands are there in the Mediterranean countries and region?
- What is the area of these wetlands?
- Where are these wetlands located?

At the same time, it aims to identify *the geographic gaps in wetland inventory, the gaps regarding wetland type coverage, the age of each available dataset and the quality/completeness of each available dataset.*

Furthermore, the PMWI also aims to answer the following questions:
On the status of Mediterranean wetlands:
- What is their condition (degree of modification by human activities)?
- What is their protection status (legal designations)?
- What is the site tenure (public/private)?
- Which wetlands are affected by human activities and impacts?

On the values of Mediterranean wetlands:
- Where are the important habitats (MedWet types and/or Ramsar wetland types)?
- Where are the important species of flora and fauna?
- Which wetlands meet the Ramsar criteria?
- Which wetlands meet physical and biological functions?
- Which wetlands meet socioeconomic values?

The first attempt to compile existing inventory datasets for wetlands in the Mediterranean region took the form of a feasibility study, undertaken in 2004 (Tomàs Vives et al, 2004). This first exercise provided an analysis of the number and extent of wetlands in a number of countries/regions which held digital inventory datasets. The countries/regions involved are presented in Table 1.4. The study found that a total of 8,210 wetlands were covered by computerised wetland inventories in the seven countries included in this pre-PMWI and they covered a surface area of 764,351 ha (Table 1.4). Among the seven datasets, two of them alone (Slovenia and Spain) accounted for 73.6% of the total number of wetlands, while in terms of wetland area they amounted to 29% of the total area covered.

Table 1.4. *Number and Surface Area of Wetlands for Countries included in the PMWI Feasibility Study of 2004 (source: Tomàs Vives et al, 2004).*

Country	Number of wetlands	% wetlands	Wetland area (ha)	% wetland area
Albania	792	9.65%	101,132	13.23%
France: Bouches-du-Rhône, Gard	406	4.95%	213,668	27.95%
Greece	411	5.01%	216,032	28.26%
Italy: Tuscany	31	0.38%	11,909	1.56%
Portugal	527	6.42%	N/A	N/A
Slovenia	3,525	42.94%	35,344	4.62%
Spain	2,518	30.67%	186,266	24.37%
TOTAL	**8,210**	**100%**	**764,351**	**100%**

Table 1.5. *Current Status of the PMWI (unpublished study, source: MedWet/WIS)*

Country	Number of wetlands	% wetlands	Wetland area (ha)	% wetland area
Greece	410	4.00	216,032	5.19
Albania	792	7.73	101,132	2.43
France (3 regions)	525	5.13	227,839	5.47
Slovenia	3,525	34.41	35,345	0.85
Portugal	527	5.14	N/A	N/A
Croatia	3,624	35.38	N/A	N/A
Italy (Tuscany)	30	0.29	11,282	0.27
Cyprus	212	2.07	2,401	0.06
Serbia	499	4.87	22,168	0.53
Algeria	42	0.41	2,959,615	71.12
Morocco	24	0.23	272,010	6.54
Tunisia	33	0.32	313,646	7.54
TOTAL	**10,243**	**100%**	**4,161,470**	**100%**

Later, during the MedWet/CODDE project (INTEREG III C (2005-2007)) the earlier study was extended and additional electronic wetland archives from several Mediterranean countries were gathered and harmonized into the new MedWet database, the MedWet Web Information System (MedWet/WIS). Currently, the PMWI contains a total of 10,243 wetland sites covering some 4,161,470 hectares across twelve countries in the Mediterranean (Table 1.5).

The PMWI is one of the tools of the new MedWet system *Inventory, assessment and monitoring of Mediterranean wetlands* (under which title this current manual is published). More detailed information can be found in the publication "The Pan-Mediterranean Module (Tomàs Vives, 2008)".

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The Land and Ecosystem Accounting (LEAC) of the European Environmental Agency (EEA).

by *Françoise Breton and Jean-Louis Weber*

Why make an account?

Land, water and ecosystems are main parts of the resource system on which to build a sustainable living. The transformation of land cover and land use by human action can affect the integrity of the natural resource system and the output of ecosystem goods and services. Therefore each part of the system needs to be followed up, monitored and accounted.

The need for a system of economic-environmental accounting has been widely recognized by the international community. In the 1990s, Agenda 21 highlighted the need for reform of national systems of economic accounting. The intention was to ensure that the value of environmental services and resources as well as the impacts of economic activities are expressed clearly.

The building of an accounting framework

The accounting framework has been developed through a number of initiatives such as National accounting, the publication of the United Nations Handbook of National Accounting (SEEA, 2003) etc. This framework meets the needs of policy makers by showing how indicators and descriptive statistics can be used to monitor the interaction between the economy and the environment. For more details see http://reports.eea.europa.eu/eea report 2006 6/en/eea report 6 2006.pdf.

The construction of land cover accounts

Land accounts, like other types of environmental assets, seek to describe in a consistent and systematic way how resource stocks change over time. The form of land cover is not, however, simply an attribute or quality of the land, but a concrete set of natural and anthropogenic features that largely results from its use. A given land cover can be modified, degraded or destroyed (consumed) and a new type generated. As such, the consumption and formation of land cover is very similar to the transformation of capital goods in the economy. Since land cannot, in general terms, be created or destroyed (with exceptions such as coastal erosion and accretion), land cover change can generally be characterized in terms of different types of flows between land cover types. A key focus of land cover accounts is, then, the understanding of the way in which the stocks of different land covers and uses are transformed over time (Figure 1.11).

Figure 1.11. *Characterization of stock transformation over time.*

Figure 1.11 illustrates the conceptual model that underpins the asset accounts for land. If changes in land cover and use are monitored over time, they can be viewed as an opening balance which represents the stocks of land cover at time 1. These land cover elements are transformed by the process of land cover change to produce the closing balance at time 2. The gains

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and losses (flows) are the transfers of land area between the land use types. Each flow can be associated to a cause of change (driving force), such as afforestation, deforestation, farm abandonment, forest fires, urban sprawl etc.

The land cover map is extracted from satellite images following the procedure described in Figure 1.12.

Step 1: The raw image data are interpreted for a land cover map

Step 2: Interpreted CLC map for 1990 and 2000

Step 3: Superimposition of the 1 km x 1 km accounting grid

Step 4: Location of an individual record for the LEAC database

Step 5: The underlying 100 m raster used for stock calculation for the selected record

K1000 E3666

- Discontinuous urban fabric
- Industrial or commercial units
- Coniferous forest
- Schlerophyllous vegetation
- Water courses

Figure 1.12. *Example of steps to extract land cover changes from satellite images.*

The basic information on surfaces and changes is available by pixels of 1 hectare. For processing data at the European scale and combining land cover and other data with a different resolution (socioeconomic data, distribution of species etc), basic data are converted into the standard 1 km x 1 km grid. All these data are available for free at the EEA.

Exploring ecosystem accounts

The connection that asset accounts for land have with habitats and biodiversity is a particularly important one. Exploration of this interface can be achieved through the development of the so-called ecosystem accounts. As the work undertaken under the auspices of the Millennium Ecosystem Assessment has shown, many aspects of human well-being depend not on individual species or elements of the natural environment, but on the goods and services generated by whole ecosystems (Millennium Ecosystem Assessment, 2005). Thus an understanding of the ecosystem functions that give rise to these goods and services and the impact of human activities on the integrity of ecosystems are also fundamental parts of the planning for sustainable development.

LEAC and the Mediterranean wetlands
Context and objectives

LEAC methodology makes it possible to measure land cover changes in stocks and land use flows in all Europe. Different analytic units have been identified and mapped in such a way that LEAC data can be extracted for a regional sea, the coast, a river catchment or an administrative region. When invited to take part in the Observatory of Mediterranean Wetlands initiative of Tour du Valat supported by MEDWET, we began to consider how LEAC could be applied to the monitoring of land cover and land use changes in Mediterranean wetlands, and especially how it could monitor biodiversity losses and gains and the impacts of land uses on wetland ecosystem services.

Identifying wetland areas in the Mediterranean and the Black Sea

The construction of land and ecosystem accounts is in principle independent of any particular source of data. However, it is useful to demonstrate that an LEAC for Mediterranean wetlands can be derived from some specific applications.

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Firstly we have worked with one particular important dataset compiled over the period 1990-2000 and encompassing 24 European countries, the Corine Land Cover (CLC) dataset. CLC has been derived from the analysis of remotely sensed satellite imagery. With CLC it is possible to look at the different wetland classes, highlighting the different wetland sites. With the overlay of the RAMSAR shapefile on which the location of all RAMSAR sites is shown as a point, it is possible to see which have been identified by CLC (and provide a first mapping) and which have not (generally because they are smaller than 25 ha, the Minimum Mapping Unit of CLC, or because they are temporal wetlands). In addition wetlands not declared to RAMSAR can be identified and mapped.

In the absence of maps produced by conservation authorities, which is still the case for many wetlands, a methodology has been established to map the coastal wetlands and their socio-ecosystems from CLC. It shows interesting results which can be used as a first proxy for Mediterranean-wide assessment. The main limitation however is that it is not yet possible to cover the whole region with CLC data. We have started testing a variant of this methodology with the very first GlobCover data. It is still very imperfect but in a second phase, and taking advantage of the launch of GlobCover v.2 in July 2008, we expect to be able to map all the wetlands systems around the Mediterranean and Black Seas. In the future, these automatically detected areas will be substituted with the boundaries supplied by RAMSAR and various organizations involved in wetland protection and monitoring (eg MEDWET).

Accounting for land cover change in wetlands and their neighbourhood

This is the specific outcome of land cover accounts implemented for 35 European countries in Europe, for 1990, 2000 and now 2006 (available end 2008-early 2009). For the European coast, a 10 km strip is mapped for 1975 with the same methodology, which will give a useful 30 years perspective. GlobCover is expected to continue and deliver updates for all the Mediterranean in the future. Land cover change is important to monitor, even though in the case of protected wetlands change is under control and limited. The situation is often different in the neighbourhood of many wetlands, where urban sprawl and agriculture development carry with them future threats. Table 1.6 demonstrates the kind of information delivered by land covers accounts. They are aggregated tables for four case studies on which we are currently working to test ecosystem accounts.

LEAC: land cover consumption and formation 1990-2000 (Hectares)

SES	1 Artificial areas	2A Arable land & permanent crops	2B Pastures & mosaics	3A Forested land	3B Semi-natural vegetation	3C Open space/bare soils	4 Wetlands	5 Water bodies	Total consumption of 1990 land cover	LCF	1 Artificial areas	2A Arable land & permanent crops	2B Pastures & mosaics	3A Forested land	3B Semi-natural vegetation	3C Open space/bare soils	4 Wetlands	5 Water bodies	Total formation of 2000 land cover
Amvrakikos SES		4	44	23					71	LCF1 Urban land management	71								71
		7							7	LCF2 Urban residential sprawl	7								7
		4	79						83	LCF3 Sprawl of economic sites and infrastructures		83							83
										LCF4 Agriculture internal conversions									
			6						6	LCF5 Conversion from other land cover to agriculture				6					6
				373					373	LCF6 Withdrawal of farming				373					373
										LCF7 Forests creation and management									
										LCF8 Water bodies creation and management									
							2		2	LCF9 Changes due to natural and multiple causes				2					2
	2927	12643	13133	22273	2419	2317	165	96	55973	No Change	2927	12643	13133	22273	2419	2317	165	96	55973
	2927	12551	13269	22669	2419	2317	165	96	56515	Grand Total	3005	12726	13133	22654	2419	2317	165	96	56515
Camargue Delta SES	5								5	LCF1 Urban land management	5								5
		13							13	LCF2 Urban residential sprawl	13								13
		24	20						44	LCF3 Sprawl of economic sites and infrastructures	44								44
		145	21						166	LCF4 Agriculture internal conversions			21	145					166
										LCF5 Conversion from other land cover to agriculture									
										LCF6 Withdrawal of farming									
				362					362	LCF7 Forests creation and management				362					362
										LCF8 Water bodies creation and management									
										LCF9 Changes due to natural and multiple causes									
	1589	10844	5525	8996	150	1	177	126	27410	No Change	1589	10844	5525	8996	150	1	177	126	27410
	1594	11026	5566	9360	150	1	177	126	28000	Grand Total	1651	10865	5670	9360	150	1	177	126	28000
Danube Delta SES	302								302	LCF1 Urban land management	302								302
		187	94	6					287	LCF2 Urban residential sprawl	287								287
		192	97	180				40	509	LCF3 Sprawl of economic sites and infrastructures	509								509
		221	264						485	LCF4 Agriculture internal conversions		204	281						485
				7					7	LCF5 Conversion from other land cover to agriculture		7							7
		49							49	LCF6 Withdrawal of farming				49					49
				294	432				726	LCF7 Forests creation and management				726					726
		21	17						38	LCF8 Water bodies creation and management								38	38
	6								6	LCF9 Changes due to natural and multiple causes								6	6
	12213	76337	36329	30428	1612	239	442	2743	160343	No Change	12213	76337	36329	30428	1612	239	442	2743	160343
	12521	77007	36801	30915	2044	239	442	2783	162752	Grand Total	13311	76548	36610	31203	1612	239	442	2787	162752
Doñana Delta SES										LCF1 Urban land management									
		53							53	LCF2 Urban residential sprawl	53								53
		2							2	LCF3 Sprawl of economic sites and infrastructures	2								2
		50							50	LCF4 Agriculture internal conversions		50							50
										LCF5 Conversion from other land cover to agriculture									
			3						3	LCF6 Withdrawal of farming				3					3
				248	69				317	LCF7 Forests creation and management				317					317
										LCF8 Water bodies creation and management									
										LCF9 Changes due to natural and multiple causes									
	3700	17193	11383	11796	2297	1725	450	816	49360	No Change	3700	17193	11383	11796	2297	1725	450	816	49360
	3700	17296	11386	12044	2366	1725	450	816	49785	Grand Total	3755	17243	11383	12116	2297	1725	450	816	49785

Table 1.6. *Land Cover Consumption and Formation 1990-2000*

Documenting wetland ecosystem services (ES) in four sites

A nomenclature of ecosystem services for wetlands has been produced and agreed amongst the four sites (Camargue, Doñana, Amvrakikos and Danube Delta). A range of tables to be filled with local data have been produced and distributed with guidelines. GIS work is also underway to design different observation units for each wetland, units in which data such as statistics, questionnaire results, local monitoring etc can be collected. These units can be the CLC class with its derived land use statistics, the municipalities inside the wetlands, the protected area etc, depending on the information source.

The LEAC methodology stresses the importance of using geo-referenced or spatial data to construct land accounts. It is argued that information which can be linked to a geographical coordinate system is more flexible and versatile in its use because it can be aggregated in different ways to provide information about different observation and analytic units. CLC is a fully referenced dataset. A spatial grid system has also been created, starting from 100 x 100 metre CLC raster files which have then been assimilated statistically into successively larger grids at 1 km x 1 km, 5 km x 5 km and 10 km x 10 km resolution.

Such reference grids have, in fact, been widely used in GIS applications as a means of integrating different data sources and types. The grid developed for the purposes of the LEAC study was shaped by the recommendations of a workshop on European reference grids which was part of the INSPIRE initiative. It consists of approximately 4.5 million 1 km x 1 km cells, each of which can hold a data record in the LEAC database. Therefore, field data and socioeconomic statistics can be added in the appropriate cells, together with the land cover and land use statistics derived from CLC data. Accounting tables can then be used to evaluate the wetland's ecosystem services and their impacts in physical and monetary terms.

Conclusion

LEAC applied to Mediterranean wetlands would have five main advantages:

- Define wetlands core classes and produce the first map of wetlands for the whole Mediterranean area, which can be validated by MEDWET experts.
- Build a comprehensive picture of main wetland ecosystem services (ES), relating them to land uses and socioeconomic drivers.
- Construction of a framework to integrate diverse data sources on land cover and land use with other types of information such as population, economic activity, water balances, changes in species and fertilizer use etc, at local and Mediterranean scales and at different times.
- By delving deeply into ecosystem services, LEAC can also provide insights on the impacts of land use on ecosystem services and ecosystem functions as a diagnosis of the health of wetland ecosystems.
- Finally LEAC will produce accounting tables and a conceptual framework for valuation of wetland ecosystem services.

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Indicative examples of wetland mapping projects in Africa

by *Tobias Landmann*

In Africa, wetlands are characterized by highly seasonal variations in rainfall and thus a large variety of short and long term water regimes (Wittig, 2005; Howard, 1985). There are two main broad types of wetlands in Africa. The first comprises linear or streamlined regularly flooded (mostly wooded) wetlands, being mostly bordering rivers and exhibiting variable hydrological processes characterized by changing patterns of sedimentation and deposition. The second most common wetland type is characterized by floodplains formations found within 'sink' landscape topography and being mostly natural or semi natural regularly flooded herbaceous wetland habitats (RAMSAR, 2006; Landmann et al, 2006).

Due to the difficulty of entangling short term inundation regimes from long term variations in terms of contribution to wetland flooding regimes, the fact that wetland maps are often produ-ced from different data sources - in particular the variable spectral and spatial resolution of the remote sensing input data - and the highly fragmented and random nature of wetland mapping projects in Africa (Landmann et al, 2007), standardized, regular and contemporary wetland datasets are almost non existent in Africa. Furthermore, due to the lack of historic satellite and aerial photography and the lack of historic wetland inventory data, the re-construction or long term mapping of changes in wetlands, often occurring through subtle land use changes within or around the wetland area, becomes challenging. The above implies that even arbitrary mapped and outdated wetland inventory or mapping results should be used as proxy data throughout Africa, at least for similar and particular bioclimatic regions (Tayler et al, 1995).

The recently completed Ecotools project work to assess and perform a small scale inventory on shoreline wetlands along Lake Victoria in East Africa is an example of recent endeavours to assess the importance of tropical shoreline wetland systems in Africa (Loiselle, 2007). Variables from satellite imagery were used as input data to model and predict spatial and temporal variations in phytoplankton biomass, and also to map coastline characteristics - such as the presence of sludge or soil on the wetland perimeter - that may influence dissolved organic matter in the wetland. Given the availability of contemporary and high resolution satellite imagery, phytoplankton biomass can be modelled using a model developed as part of the Ecotools project. The project synthesis emphasizes the importance of improved wetland inventories. In particular they have a role in demonstrating the socioeconomic importance of wetlands for rural economies, in understanding nutrient flows and cycling and nitrogen retention potential, and in recording the water qualities characteristic of shoreline wetlands in Africa (Bikangaga et al, 2007; Bracchini et al, 2007; Kansiime et al, 2007; Van Dam et al, 2007).

Using high to moderate resolution 30-Landsat data, wetlands were mapped within the recently completed National Land Cover Project (NLC2000) in South Africa. The NLC method is based on indexing topographic variables such as valley bottom, valley, mid slope and scarp or crest with spectral classes from unsupervised classification results, using 30-meter NDVI (vegetation chlorophyll activity) and tasseled cap wetness (as an indicator for the presence of water). The NLC wetland mapping method is described in Tayler et al, 1995. The Landsat input datasets were from 2000 and 2001, and wetland predictions were only for the grassland and low shrubland biomes and restricted to the countries of South Africa, Lesotho and Swaziland.

Also for southern Africa, Tayler et al (1995) present an overview of wetland inventories in several southern African countries, comparing methods and sampling strategy based on the synergetic use of existing local scale inventories using primary high resolution satellite mapping and scaling the results to the regional scale using satellite imagery. Essentially, the assessment propagates the use of existing data and imagery, before new wetland inventories are commissioned.

Landmann et al (2006) recently mapped wetlands for the Volta catchment (400,000 km2) in Ghana and Burkina Faso, West Africa, using 250-meter MODIS satellite imagery at near to daily coverage, and 90-meter topographic variables from the Shuttle Radar Topographic Mission (SRTM) dataset. The satellite inferred wetland dataset was validated using local scale observations at three RAMSAR sites in Burkina Faso. Consequently, wetland vegetation abundance comprising morphology and species counts for wetland vegetation groupings were mapped for the whole Volta basin. The coding used for the Volta project data is compatible with the Land Cover Classification System (LCCS) coding system of the Food and Agricultural Organization (FAO).

The Volta basin wetland data are seen to be inter-operable between local scale wetland observations, satellite derived or from field work, and coarse resolution observations larger than 1 kilometre pixel size or 1 degree large grid cells.

Figure 1.13 below gives an example (subset) of the Volta basin wetland layer derived from 250-meter MODIS and 90-meter SRTM and superimposed on a 1-kilometre optical SPOT satellite image of an area in central Ghana north west of the Volta Lake, visible as a blue feature. The wetlands are visible as mostly bright 'green' linear features. The wetland mapping efforts are part of the German Government funded BIOdiversity Monitoring Transect Analysis in Africa (BIOTA) Africa project (www. biota-africa.org/).
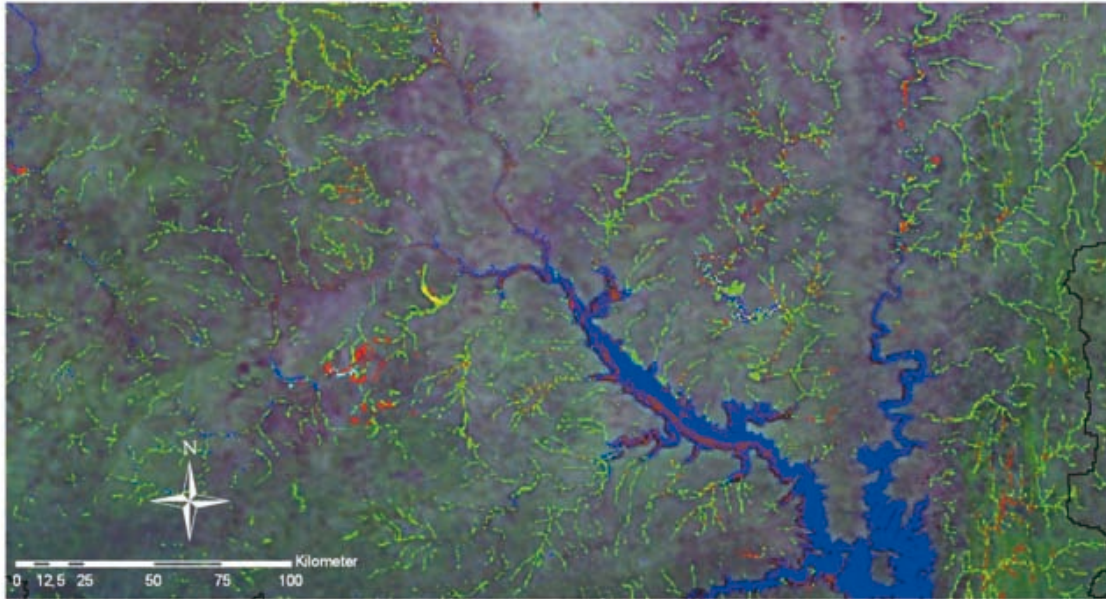
Figure 1.13. *Subset of the 250-meter MODIS wetland layer from the BIOTA Africa project in West Africa.The project area comprises Burkina Faso, Ghana and parts of Mali, Ivory Coast and Benin. The MODIS wetland data are derived from cloud corrected near and red waveband reflectance data from the year 2001 to 2006. Bright green linear features are mostly woody regular flooded wetlands with average to high numbers of semi aquatic and aquatic species. Yellow, blue and maroon illustrate wetlands with low species numbers. Red areas are areas where aquatic vegetation species per unit surface area are very high.*

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The GlobWetland project

by *Diego Fernández*

EO satellites, with increasing capabilities in terms of spatial, temporal and spectral resolution, allow a more efficient, reliable and affordable monitoring of the environment over time at global, regional and local scales. This renders EO technology a fundamental tool to support the Convention Parties and other related national and international bodies involved in the implementation of the Ramsar Convention. In 2003, in order to demonstrate at a large scale the above mentioned capabilities, the European Space Agency (ESA), in collaboration with the Ramsar Secretariat, launched the GlobWetland project (www. globwetland.org). The project aimed at developing and demonstrating an EO-based information service to support wetland managers and national authorities in responding to the requirements of the Ramsar Convention. The project, carried out from 2003 to 2007, involved 50 different wetlands dis-tributed in 21 countries worldwide and relied on the direct collaboration of several regional, national and local conservation authorities and wetland managers.

GlobWetland Information System Description

The GlobWetland geo-information products were designed in close consultation with the Ramsar community and the wetland managers participating in the project. The final objective was to develop a coherent dataset of geo-information that could be comparable worldwide, allowing not only local wet-land managers to rely on updated information describing wetland sites and their surrounding areas but also permitting the national and international conservation community to rely on an homogenous dataset that may provide a solid basis for developing a global wetland inventory within the context of the Ramsar Convention. The final set of products was divided into two main categories: Core and Spe-cific products. The former represents the basic set of common geo-information that was generated for all the 50 wetland areas selected for the project and includes three main layers of information: land use and land cover map, a long term change-analysis map and a water cycle map. The latter represent a number of site-specific maps generated in response to precise requests from wetland managers to better monitor and assess different local conditions. They incorporate a large range of geo-information prod-ucts including water quality parameters, topographic (coastal) dynamics and Digital Elevation Models (DEMs), among others. In all cases, the methods applied were validated using in situ data to ensure the products respect the accuracy required by the wetland managers. The lists of generated products are summarized below.

CORE PRODUCT: The following geo-information layers have been generated as a core dataset for all the sites under analysis.

Land Use and Land Cover Map, including wetland types. The Land Use Land Cover (LULC) map in-cludes a detailed classification of all land parcels within the area of interest at different scales depend-ing on the wetland size (1:25,000 or 1:50,000). The LULC maps include classes of interest defined by the end users, which are presented using a standardized classification scheme based on the Corine Land Cover system (EC, 1993), adapted to incorporate the Ramsar wetlands classification system in response to needs expressed by wetland managers.

Change Detection Map. The purpose of this product is to provide a historical comparison of the land use and the land cover in the wetland site and its surroundings between today and a reference date in the past. This may provide wetland managers with a synoptic view of the main changes occurring in the areas of interest in the last 20 years caused by natural and anthropogenic factors. It is worth noting the EO data archives include images acquired in the 1960s, thus providing a unique source of informa-tion to assess the historical evolution of wetlands worldwide. This type of information represents an optimum complement to the above LUCL map, as change-analysis provides wetland managers with a possibility to identify threats affecting the site and their impacts on the ecosystem over time.

Water Cycle Regime. The third layer of the core dataset complements the above two products by pro-viding an overview of the annual variations of the water table over the wetland site. In particular, this layer, provided at a scale of 1:50,000 or better,

shows the minimum and maximum above ground water extent, including open water bodies and inundated vegetation, during a hydrological year. This product, when generated over several years, provides wetland managers with a unique monitoring capacity to characterise the water cycle and identify variations that may affect the overall ecosystem.

These core products have been integrated into a Geographic Information System (GIS), along with geo-referenced information on additional features of interest such as basic cartography (eg roads, adminis-trative boundaries, facilities etc) and the corresponding in situ data collected during the ground valida-tion campaigns. The overall set of information, in addition to the usual capacities provided by GIS, provides wetland managers with a powerful tool to better design and apply management plans.

SPECIFIC PRODUCTS:In addition to the above core layers, in specific cases, additional geo-information products have been generated to complement the basic information provided over the 50 sites included in the project. These site-specific layers are listed below.

Wetland Identification and Delineation (Figure 1.14).The development of this specific product was motivated by a number of national agencies interested in exploring the possibilities to reduce costs as-sociated with national inventory exercises.
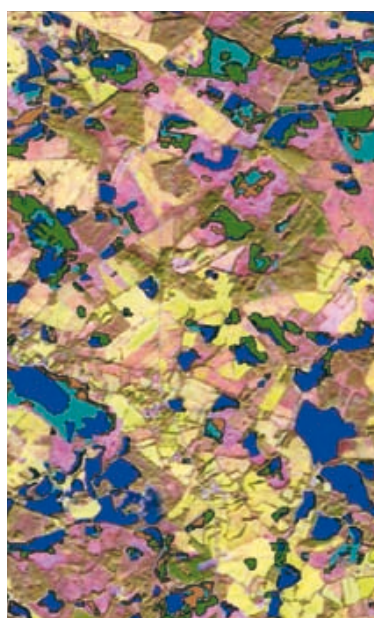
Two main approaches were explored with different implica-tions in terms of costs: i) The first provides national agencies with a number of areas (polygons) with a high potential to include wetlands. This represents a unique support tool to plan field visits in a cost effective manner, focusing resources only on the areas of interest. Precise delineation can them be completed in the field or with support of manual interpretation of aerial photography or high resolution EO data. ii) The second approach is more expensive but more accurate and provides wetland managers with a precise map of wetland areas. The production of such a map involves a significant human inter-vention and hence increases the cost. However, the result in comparison with that obtained with aerial photography is still cost effective for limited regions of interest, where a precise location of wetlands is required.

Figure 1.14. *Identification and delineation of wetlands, La Brenne, France. The blue polygons point out the wetlands identified. Polygons have been extracted using both SAR and SPOT-5 data.*

Topographic Dynamics in coastal wetlands. Coastal wetlands may be affected by currents, erosion and other factors that may impact the coastline. In addition, many coastal wetlands represent main sources for sand extraction and other mining activities that may affect the topography of the area. These changes are important indicators for the condition of the wetlands, as they may have significant im-pacts on the water cycle or may trigger salinization processes affecting ground water. In this context, a specific geo-information product was generated that merges two different types of information in a synergic manner: i) differences in the coastal line based on high resolution imagery and ii) subsidence mapping, outlining centimetre-level movements of the ground. The former component requires the comparison of both the coastal line extracted from an historical image and the present situation derived from a recent one. The latter component provides for each element in the image (with a ground resolu-tion of 25 m) an estimate of the ground displacement at centimetre level between two different dates. This last product is based on the capabilities of Synthetic Aperture Radar (SAR) data.

The Digital Elevation Models (DEM). The ability of EO sensors to generate DEMs covering large areas at relatively low cost is an important element for catchments characterisation. DEMs may provide sig-nificant information for a wetland site and can play a significant role in management supporting the delineation of the wetland catchment area, visualization of

wetlands information (ie 3D display), de-termination of areas affected by toxic point discharges, the location of recharge areas, vulnerability to contamination, flood modelling or estimation of runoff. DEM based on currently available SAR sen-sors allows elevation information to be extracted with errors close to 10 m. This type of DEM accuracy is not acceptable at site level, especially for hydrological modelling, where errors of only a few centi-metres are acceptable. However, it represents a cost effective manner to map and characterize large catchment areas, especially with a mountainous topography.

Water quality (Figure 1.15). The retrieval of water quality parameters over large lakes and wetland areas is one of the most interesting applications of EO technology to support wetlands management and conservation. Parameters such as turbidity, suspended solids and algae or chlorophyll concentration can be monitored from space with different resolutions (eg ranging from 30 m using Landsat data to 300 m using MERIS images). However, the extraction of such information in inland waters is still a complex technical process. For instance, it is worth noting that technical limitations associated with current available space-borne sensors, such as the spectral and spatial resolution, hinder the retrieval of such parameters over small water bodies. Also, shallow waters further complicate the information extraction process and may render the measurements unreliable. In addition, the extraction of absolute water qual-ity information from satellite imagery requires adequate in situ measurements for calibration purposes. The accuracy of the information extracted depends strongly on the concentrations of the different water constituents, available in situ data and the sensor used. In spite of these limits and the still experimental stage of the retrieval methods available, EO can provide today, under certain conditions, accurate in-formation on water quality.

(a)   (b)
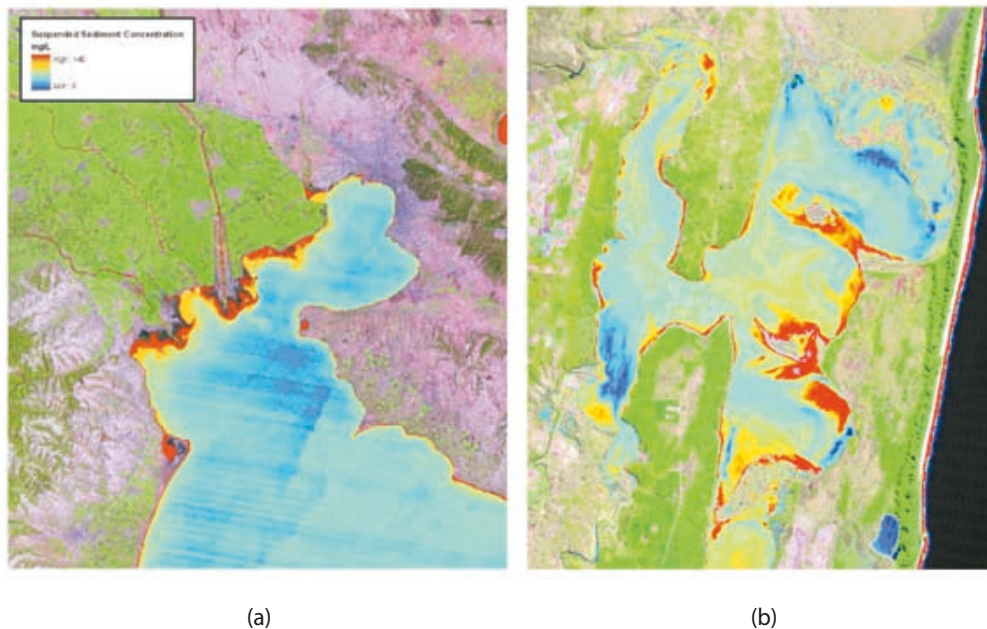
Figure 1.15. *Water quality parameters: (a) Absolute suspended sediments concentrations over the Axios delta, Greece. Values range from 0 mg/l (dark blue) to 40 mg/l (in red); (b) Chlorophyll-a relative concentration values, Saint Lucia, South Africa. The colour scale over the wetland ranges from the lower concentration values in dark blue to the maximum concentration values in red.*

Conclusions and final remarks

The GlobWetland project demonstrated the capacity and limits of EO technology to support national and local conservation authorities worldwide to undertake inventory, monitoring and assessment of wetlands and their ecological character. Clear benefits have been demonstrated, especially in develop-ing countries, and several users have already adopted this technology within their management prac-tices as a result of the project. However, the significant consultation process with wetland managers, national authorities and scientists carried out during the project lifetime has pointed out a significant gap between the EO and those implicated in wetland conservation management. Exercises such as the GlobWetland project have contributed to bridge that gap. Nevertheless, more efforts are still required in order to increase communication between the

EO and wetland groups in preparation for the next generation of satellites. In 2012 the European Space Agency will launch the first of a new set of EO missions, the sentinels, in the context of the European Global Monitoring for Environmental and Secu-rity (GMES) programme. This new generation of EO satellites will provide novel and advanced capa-bilities to monitor the environment worldwide on a regular basis at different scales, providing a unique capacity to monitor, and hence respond to, the environmental challenges affecting our planet. The suc-cess of such new technology within the Ramsar community will depend on the capability of both the space and the conservation sectors to work together in order to develop jointly cost effective applica-tions that respond directly to the information needs and requirements of national and local conservation authorities. ESA will continue supporting this effort with dedicated scientific and application activities.

TerraLook: Providing easy, no-cost access to satellite images for busy people and the technologically disinclined

by *Gary N Geller*

Access to satellite images has largely been limited to science communities with the necessary tools, expertise and funding, resulting in a great number of under served users and under utilization of the data. TerraLook addresses this problem by providing a time series of no-cost, geo-referenced images in standard JPEG format, and bundling these with open source desktop software for utilizing them. Formerly called the Protected Area Archive, TerraLook has evolved from interactions with the conservation community, but it is of use to all communities who can benefit from easy access to remote sensing data. There is no cost associated with the images or the tool, as cost was found to be a significant barrier to access.

TerraLook consists of three components: i) a website for users to find and order the images they need; ii) the collections of images that they download from the website; and iii) optional desktop software to help the user interact with the images. The website is operated by the US Geological Survey and uses their Global Visualization Viewer (GloVis), which is a standard tool for ordering many kinds of remote sensing data.

Images are available for four time periods: c1975, 1990, 2000 and also for 2000-present. The first three periods utilize Landsat data that have been pre-selected to provide a nearly cloud free, global image layer for each period, centred around the dates above. The last period provides images from the ASTER sensor. However, the entire contents of the ASTER archive are accessible (currently around 1.5 million scenes and increasing by about 500 scenes/day), so there are many images available for each location. After the user selects the scenes, the automated system creates a collection of geo-referenced JPEG images and makes it available for download. A collection can contain one, or hundreds of images. Image resolution varies with the period and sensor: 80 m pixels for 1975, 30 m pixels for 1990 and 2000, and 15 m pixels for the ASTER data from 2000 onwards.

The software is a no-cost, open source, image processing and GIS software package; Version 1.1 was released in March, 2008, and Version 2.0 - a major upgrade - is planned for the early of 2009. Major capabilities include:

- Image enhancement
- Image find, roam and zoom
- Distance and area measurement
- Display, edit and create overlays
- Image annotation (adding text, arrows etc)
- Image comparison using "flicker"
- Image mosaicking
- 3-D viewing capability (basic)
- Comparing old and new images

The main TerraLook website is http://terralook.cr.usgs.gov. That site explains how to create a new TerraLook collection using GloVis, and where to download the software package.

Satellite images are useful for many activities, including: detecting, mapping and managing land use change such as deforestation; classifying vegetation and land use; threat detection and management such as boundary encroachment; mapping burn scars; and simply understanding spatial relationships.

Traditional remote sensing approaches use full, multi-band datasets and specialized software to process the data into customized images that are designed to show the particular features of interest and allow quantitative analysis. This can provide excellent results but also requires considerable training, expensive tools and data, and tends to be time consuming. Yet many tasks do not require specially processed images or complicated quantitative analysis. Standard images such as those from TerraLook are fine for assessing the amount of a wetland that has been lost to a development, for example, or for

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communicating the threat of development or source of contamination. Such images can augment the ground knowledge that a wetland manager already has. For example, managers may know that the wetland they are managing is gradually being surrounded by development, but do not know exactly by how much. A simple image would allow managers to both determine what fraction of their wetland perimeter is now surrounded and to communicate this fact visually to policy makers. Figure 1.16 shows TerraLook images for the Camarque and Kerkini wetlands.

Figure 1.16. *TerraLook images of the Camarque (left, Landsat image from 21 July 2001) and Kerk-ini (right, ASTER image from 1 May 2008) wetlands.*

There are limitations, of course. For example, some care must be taken when using images, particularly when using them for change-analysis. Natural seasonal changes, in particular, can complicate the interpretation of images, especially since many seasonal changes do not occur on the same date each year. This means that local knowledge is critical to understanding what is happening in the images. Also, for the historical Landsat data, each period has only a single image at each location and unfortunately this sometimes means the available image does not coincide with the desired season. Nonetheless, simply making these images available has tremendous value.

Next Steps

Although TerraLook is now operational at USGS/EROS and Version 1.1 of the software is completed, there is still much to do. The software needs to be simplified so it is friendlier and more visually attractive, and several important capabilities must be added. Versions 2.0, 2.1, and 2.2 will address these. The other major area that will receive attention is outreach, so that the potential users in "non-traditional" groups are aware of TerraLook and encouraged to use it. The approach will be to engage regional and local organizations, such as MedWet, as liaisons between TerraLook and end users. Such liaisons can act as hubs to disseminate information, distribute collections, help users and foster education activities on use of images for conservation and development.

PART 1: CONCLUDING REMARKS

Certainly today, the state of the art in the sciences of wetland conservation and management and of information systems and the ability to use contemporary data at a variety of temporal and spatial scales, have boosted the initiation of regional, European and global ecosystem and biodiversity assessments.

The initiatives and projects described above outline a series of recent achievements already worthy of consideration in a coordinated mapping programme of the Mediterranean wetlands. Based on these experiences and with respect to the MedWet Initiative mission, the following priorities should be set for such a venture:

(i)   Promotion of a regional wetland mapping programme in the Mediterranean as a contribution to the European and Global Earth Observation, making use of the state of the art in the sciences of EO and information systems.

(ii)   Establishment of networking bodies who are responsible for wetland inventory and mapping and converging relevant acti-vities in the Mediterranean region. Reaching consensus about: nomenclatures and data specifications; data updating and assess-ments; data access and sharing.

(iii)   Further investigation (including launching of pilot projects) on the feasibility of implementing a Mediterranean wetland mapping programme in convergence with the PMWI priorities, the LEAC approach, the Mediterranean Wetland Observatory objectives, the GMES activities, the objectives and key result areas of the wetland mapping and inventory Partnership, the GEOSS implementation plan and the ALOS Kyoto and Carbon (K&C) Initiative Science Plan.

(iv)   Identification of a statistically robust representative sample of Mediterranean wetlands, upon which the assessment and monitoring of wetlands could be based. Spatial and traditional statistical methodologies and existing conceptual frameworks such as the sentinel ecosystem approach should be applied.

(v)   Creation of a Spatial Data Infrastructure for Mediterranean Wetlands, to allow access, retrieval and dissemination of ge-ospatial data and services in an easy and secure way, avoiding duplication in data collection and management. A future interope-rability of the MedWet datasets and tools with other GIS portals (European Community geoportal, GEO Portal etc) will have a significant added value to the MedWet community.

(vi)   Raise awareness of the importance of adopting standard mapping methodologies in consistency with existing priorities and initiatives and of supporting long term regional wetland assessments.

(vii)   Build capacities of the Mediterranean bodies active in the fields of wetland inventory, monitoring and assessment to apply widely used and recommended methods and tools (ie the MedWet tools for wetland inventory, monitoring and assessment) as well as innovative EO techniques (see contributions on this subject in Parts 2 and 3 of this manual).

PART 2: BACKGROUND ON EARTH OBSERVATION

Part 2 provides the theoretical background to using Earth Observation (EO) for Wetland monitoring and mapping. The material in this Part may be useful to people involved in wetland management who may or may not be acquainted with EO. People with no prior knowledge of remote sensing are recommended to start with the introduction on what is EO and its basic principles in terms of orbits, image characteristics and benefits for wetland applications. The most useful data for these applications follow, presented separately for passive and active sensors. The reader is then provided with an overview of the most popular web tools for image selection and ordering. However, after buying the images of interest the user has to apply specific corrections and these are explained in the text. The remaining chapters are targeted to users who have had some prior experience of remote sensing. They include the state-of-the-art methodologies for EO wetland mapping and monitoring such as classification of habitats, mapping of biophysical parameters and water constituent concentrations. A very interesting application is the extraction of sea bottom properties and bathymetry. Part 2 ends with methodologies for extracting information from active satellite sensors (such as SAR). Examples of applications for specific test sites are provided in Part 3 of the present Manual.

What is Earth Observation?

Earth Observation (EO) is the science of collecting measurements and information on the Earth's system from a distance. This information can be related to the physical properties and features of an object or class on the Earth, a phenomenon or an area of interest. It is accomplished primarily through distant measurement of the electromagnetic radiation that is reflected, emitted or scattered by the target by a sensor mounted on a satellite platform. Because of its nature, EO is also referred to as satellite "remote sensing".

A variety of ecological applications require data from broad spatial extents that are infeasible or too costly to be collected using field-based methods. Remote sensing data and techniques address these needs, which include identifying and detailing the biophysical characteristics of species' habitats, predicting the distribution of species and spatial variability in species richness, and detecting natural and human-caused change at scales ranging from individual landscapes to the entire world (Kerr & Ostrovsky, 2003).

System Elements. In a typical EO system, the process involves, broadly speaking, seven elements. An exemplified case of measuring the reflected radiation of the sun (CCRS, 2007) is shown in Figure 2.9. (A) is the Energy Source or Illumination. It is the first requirement for EO as it provides electromagnetic energy to the target of interest. In the case of our example, the energy source is the Sun. As the energy travels from the Sun to the target, it interacts with the atmosphere (B). This interaction takes place a second time as the energy travels from the target to the satellite sensor. Atmospheric contamination of the remote sensing signal can arise through interaction with ozone, water vapour, aerosols and other atmospheric constituents. Once the energy makes its way to the target (C) through the atmosphere, it interacts with the target depending on the properties of both the target and the radiation (in this case the radiation is reflected; in general it can be reflected, emitted or scattered). After the energy has interacted with the target, we require a satellite sensor (D) to collect and record the electromagnetic radiation. The energy recorded by the sensor has to be transmitted (E), often in electronic form, to a receiving and processing station (E) where the data are processed into an image. The processed image is interpreted, visually and/or digitally or electronically by experts, to extract information about the illuminated target (F). Finally, we use this information for particular applications. In the case of ecology and wetland monitoring, we apply specific methodologies to extract information on wetland classes, vegetation indices and biophysical properties (G). The resulting added-value products usually come in the form of images or maps.
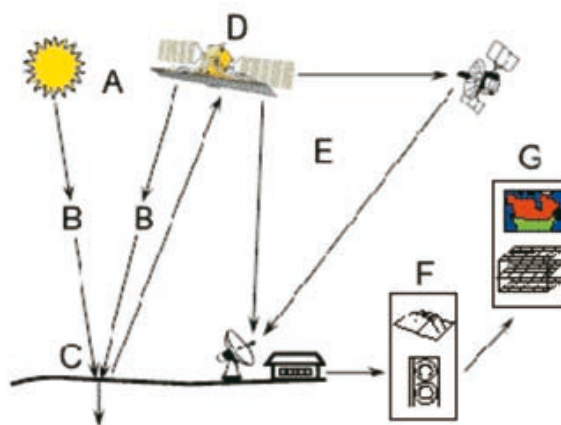
Figure 2.9. *Elements comprising an EO system. The case of measuring reflected solar radiation (Source: Canada Centre for Remote Sensing).*

Energy Source. The underlying basis for most EO methods and systems is simply that of measuring the varying energy levels of a single entity, the fundamental unit in the electromagnetic (EM) force field, known as the photon. Variations in photon energies are tied to the parameter *wavelength* [unit m] (or *frequency* [unit Hz]). The wavelength is the length of one wave cycle, which can be measured as the distance between successive wave crests. Wavelength is usually represented by the Greek letter lambda (λ). Wavelength is measured in metres (m) or some factor of the metric scale such as *nanometres* (nm, 10^{-9} metres), *micrometres* (μm, 10^{-6} metres) or *centimetres* (cm, 10^{-2} metres). Frequency refers to the number of wave cycles passing a fixed point per unit of time. Frequency is normally measured in *hertz* (Hz), equivalent to one cycle per second, and various multiples of hertz.

EM radiation, which varies from high to low energy levels, comprises the electromagnetic spectrum. When any target material is excited by internal processes or by interaction with incoming EM radiation, it will reflect, emit or scatter photons of varying wavelengths whose radiometric quantities differ at different wavelengths in a way diagnostic of the material (Short, 2006). The electromagnetic spectrum ranges from the shorter wavelengths (high frequencies - including gamma and x-rays) to the longer wavelengths (low frequencies - including microwaves). There are several regions of the electromagnetic spectrum which are useful for EO. For wetland monitoring and mapping our interest concentrates on three different regions, namely Visible, Infrared (IR) and Microwave, as shown in Figure 2.10. Each satellite sensor is tuned to measure radiation at one or more spectral bands, ie spectral regions centered at a specific wavelength and having a specific band width.
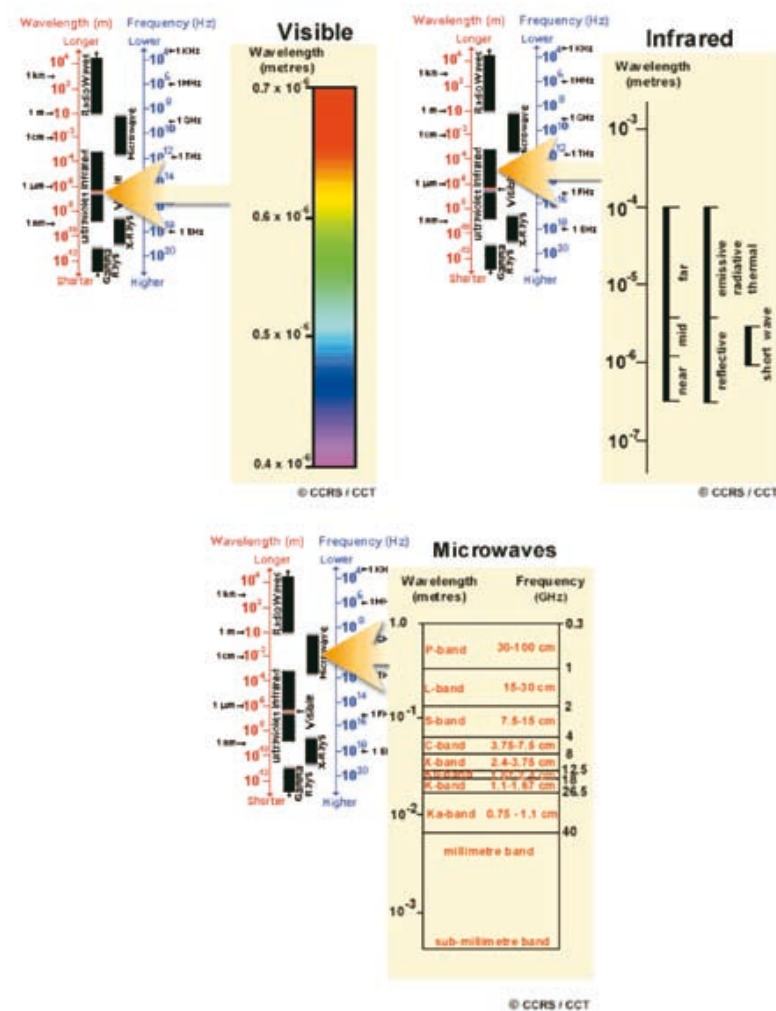
Figure 2.10. *Visible, Infrared and Microwave regions of the EM spectrum are useful for EO applica-tions regarding wetland monitoring and mapping (Source: Canada Centre for Remote Sensing).*

Any Restrictions? On a cloudy day, satellite sensors operating in the visible and IR see little but the tops of clouds. Shadows, particularly when they vary across the fields of view of sensors that see across broad areas [eg Advanced Very High Resolution Radiometer (AVHRR) or Vegetation (VGT) sensors], haze and scatter from terrestrial surfaces can severely reduce data consistency and such effects are very difficult to remove. Longwave (microwave) remote sensing systems (eg synthetic aperture radar) are much less affected by the vagaries of the weather. They are, however, subject to their own suite of shortcomings and optical remote sensing data are still used more widely for ecological applications.

Which are the orbit characteristics?

Satellites are objects which revolve around another object - in this case, the Earth. Man-made satellites include those platforms launched for EO, communication and telemetry (location and navigation) purposes. Because of their orbits, satellites permit repetitive coverage of the Earth's surface on a continuing basis. The vast majority of EO satellites are in either geostationary or near-polar orbit.

Geostationary Satellites. A geostationary satellite orbits the Earth in an equatorial orbit at an altitude where its orbital period is equal to that of the Earth's rotation (24 hours). The result is that the geostationary satellite turns with the Earth and remains over the *same fixed point* of the planet at all times, as shown in Figure 2.11. A geostationary orbit is usually circular with an inclination of 0º. In other words, the satellite will appear stationary with respect to the Earth surface. Satellites in geostationary orbit are located at a high altitude of 36,000 km.

Figure 2.11. *Satellites on a geostationary orbit allow frequent acquisition of images over a large area (Source: Canada Centre for Remote Sensing).*
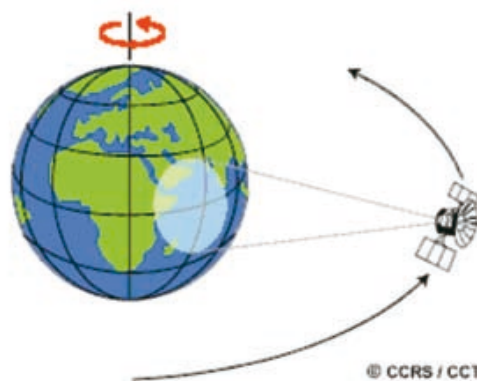
The fixed nature of geostationary satellites with respect to a given point on the Earth allows frequent acquisition of images which makes them very useful for meteorology. For example, the METEOSAT Second Generation satellite provides images every 15 minutes. One limitation of geostationary satellites is the low spatial resolution (ie the detail discernible; see Part 3 Section 3) of images, mainly due to the high altitude of the orbit. This results in a very low cost for these images (they are distributed practi-cally free). However, the limitation of low spatial resolution means that these satel-lites are not useful for wetland applications.

Polar orbiting satellites. While a true polar orbit has an inclination of 90º, many sat-ellites orbit the Earth with inclinations that are close to 90º. These form a class of sat-ellites known as polar orbiting satellites (Figure 2.12). These satellites orbit the Earth in an orbital plane that goes nearly from pole to pole. They are considered Low Earth Orbiters (LEO), as they orbit the Earth at an altitude of approximately 700 km.

Figure 2.12. *In near-polar orbit the orbital plane is inclined at a small angle with respect to the Earth's rotation axis. The satellite is able to cover nearly the whole Earth surface in a repeat cycle (Source: Canada Centre for Remote Sensing).*

As a polar orbiter circles the planet, and as the Earth rotates underneath, the satellite crosses a different strip of the Earth with each orbit. The effect is that a polar orbiting satellite can scan the Earth in strips, and over the course of several orbits, it can collect data over a significant portion of the planet. The lower altitude of the polar orbits can allow the sensors to study the Earth in greater detail (higher spatial resolution) than a higher altitude satellite (such as geostationary satellites), and it is far less expensive to build, launch and maintain than the latter.

Sun-synchronous orbits. Earth observation polar orbit satellites usually follow sun-synchronous orbits. A sun-synchronous orbit is a near-polar orbit whose altitude is such that the satellite always passes over a location at the same local solar time. This ensures that the same solar illumination conditions (except for seasonal variation) can be achieved for the images, an attribute especially valuable for change detection applications. Polar orbit is used extensively for environmental applications and monitoring. In the particular case of wetland applications this is the only kind of orbit used as it provides the detail required for such studies.

What characteristics do images have?

There are many applications of remote sensing, and each sensor is engineered for very specific purposes. The design and placement of a sensor is determined by the unique characteristics of the target that will be studied and the information that is required from the target. Each remote sensing application has specific demands on the amount of area to be covered, the frequency with which measurements will be made and the type of energy that will be detected. Thus, a sensor must provide the spatial, spectral and temporal resolution necessary to meet the needs of the application.

Spatial Resolution. The detail discernible in an image is dependent on the spatial resolution of the sensor; this refers to the size of the smallest possible feature that can be detected. Images where only large features are visible are said to have coarse or low resolution. In high or very high spatial resolution images, small objects can be detected. Military sensors, for example, are designed to view as much detail as possible and therefore have very fine resolution. Commercial satellites provide imagery with resolutions varying from 50 cm (Worldview-1 satellite launched in 2007) to several kilometres. Generally speaking, the finer the resolution, the higher the cost and the smaller the total ground area to be seen. Detailed mapping of habitat classes at local scale requires a much greater spatial resolution than observations of a catchment area. Figure 2.13 gives a schematic of different spatial resolutions when imaging a house. In 30 m pixel size the house is depicted as one pixel and the shape is not conserved. As the pixel size gets finer, an increasing number of pixels depict the house and its shape with increasing detail and accuracy. Figure 2.14 shows the different level of detail in high and very high spatial resolution images.
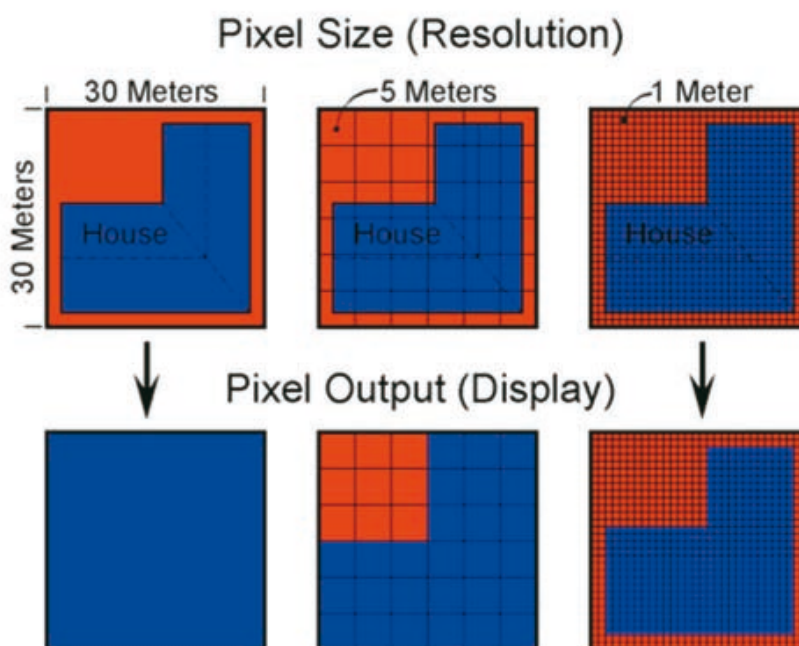
Figure 2.13. *Spatial resolution of 30 m, 5 m and 1 m and corresponding display on the screen (Source: Satellite Imaging Corporation).*

Figure 2.14. *The satellite images show the delta of River Strymon in Northern Greece. The image on the left is a Landsat ETM+ with spatial resolution of 30 m. On the right, there is a subset of the same area as acquired by QuickBird satellite with a spatial resolution of 60 cm (Source: QuickBird© Digital GlobeTM Longmont USA) .*

Spectral resolution. In the first instance, a sensor's spectral resolution specifies the number of spectral bands in which the sensor can collect radiation. But the number of bands is not the only important aspect of spectral resolution. The position of bands in the electromagnetic spectrum is important, too. Spectral resolution also refers to the width or range of each spectral band measured by a satellite sensor. Detection of some phenomena, such as vegetative stress, requires a sensor with sensitivity in a narrow spectral band so that differences in the spectral signatures at a specific wavelength can be detected. A panchromatic sensor, recording radiation over a wide range of visible wavelengths, would not be well suited to such a task. A narrow band sensor in the red portion of the spectrum would be better at detecting vegetative stress due to the chlorophyll absorption at this wavelength. Figure 2.15 shows the spectral resolution of ASTER and Landsat TM sensors (details of the sensors are given below in Part 2, Section 5).
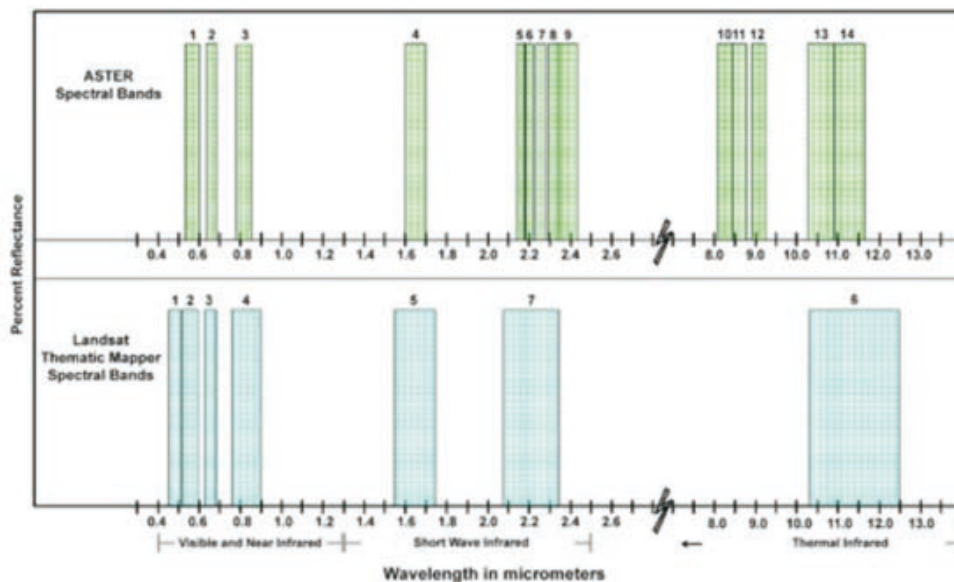
Figure 2.15. *Spectral resolution of ASTER (top) and Landsat TM (bottom) sensors. The x-axis de-picts wavelengths and the coloured columns are the spectral bands. The spectral reso-lution is defined by the number, the position and the width of these bands (Source: Sat-ellite Imaging Corporation).*

Temporal resolution. Temporal resolution refers to the time interval between image acquisitions over the same area. It is linked to the revisit period, which refers to the length of time it takes for a satellite to complete one entire orbit cycle. The revisit period of a satellite sensor is usually several days. Because of the overlap in the imaging swaths of adjacent orbits for most

satellites, some areas of the Earth are revisited more frequently. For some applications, such as monitoring the development of a severe thunderstorm, measurements are required at a frequency of a few minutes. Only geostationary satellites can acquire such information. Wetland mapping usually requires seasonal measurements.

Radiometric Resolution. The intensity of a pixel is digitised and recorded as a digital number. Due to the finite storage capacity, a digital number is stored with a finite number of bits (binary digits). The number of bits determines the radiometric resolution of the image. For example, an 8-bit digital number ranges from 0 to 255 (ie 28 - 1), while an 11-bit digital number ranges from 0 to 2047. The detected intensity value needs to be scaled and quantized to fit within this value range.

In terms of the **spatial resolution**, the satellite imaging systems can be classified into (Source: CRISP):
- Low resolution systems (approx. 1 km or more)
- Medium resolution systems (approx. 100 m to 1 km)
- High resolution systems (approx. 5 m to 100 m)
- Very high resolution systems (approx. 5 m or less)

In terms of the **spectral regions** used in data acquisition, the satellite imaging systems can be classified into:
- Optical imaging systems (include visible, near-infrared, and shortwave infrared systems)
- Thermal imaging systems
- Synthetic aperture radar (SAR) imaging systems

Optical/thermal imaging systems can be classified according to the **number of spectral bands** used:
- Panchromatic (single wavelength band, "black-and-white", grey-scale image) systems
- Multispectral (several spectral bands) systems
- Superspectral (tens of spectral bands) systems
- Hyperspectral (hundreds of spectral bands) systems

What are the benefits and drawbacks of using EO?

by *Iphigenia Keramitsoglou*

> *EO generates a remarkable array of ecologically valuable measurements, which includes the details of habitats (land cover classification) and their biophysical properties (integrated ecosystem measurements) as well as the capacity to detect natural and human-induced changes within and across landscapes (change detection).*

Remote sensing is indispensable for ecological and biological conservation applica-tions and will play an increasingly important role in the future. For many purposes, it provides the only means of measuring the characteristics of habitats across broad ar-eas and detecting environmental changes that occur as a result of human or natural processes (Kerr & Ostrovsky, 2003).

Benefits. Spaceborne remote sensing provides the following advantages:
- Satellites provide large area (global) coverage even for places not otherwise accessible.
- Ground features can be measured quantitatively using radiometrically calibrated sensors.
- The area of interest is frequently and repetitively covered.
- Comparison of different scenes is straightforward due to acquisition by the same sensor.
- Continuous acquisition of data is possible.
- Images acquired in the past are usually stored and may serve as a large archive of historical data.
- Satellites offer geometrically accurate data for information, analysis and simple integration into a Geographical Information System.
- It is possible to measure energy (such as ultra-violet, infrared, microwave etc) at wavelengths outside the span of human vision.
- There is a relatively lower cost per unit area of coverage when compared to conventional methods.

Drawbacks. Recently, ecological and conservation applications of satellite remote sensing data have increased. However, some of the limitations inherent to measurements frequently taken from >700 km above the surface of the Earth should be taken into consideration. Images as they are received by the ground stations (the so-called 'raw images') carry atmospheric and geometric distortions that need to be accounted for. Image correction (pre-processing) needs specific satellite image processing software and some degree of expert knowledge. In addition some sensors, as already mentioned, require cloud-free conditions over the area of interest. The quality of microwave images is independent of weather and sun conditions.

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Which are the most useful satellite data for wetland applications?

There are two kinds of remote sensing sensors. **Passive** sensors detect natural energy (radiation) that is emitted or reflected by the object or surrounding area being observed. Reflected sunlight is the most common source of radiation measured by passive sensors. **Active** sensors, on the other hand, provide their own energy source for illumination. The sensor emits radiation which is directed toward the target to be investigated. The radiation reflected from that target is detected and measured by the sensor.

Data from Passive sensors

by *Iphigenia Keramitsoglou*

(The sensors are ranked by decreasing spatial resolution)

QuickBird. QuickBird Satellite was set in orbit on 18th October 2001, at an altitude of only 450 km from the Earth's surface. The very low altitude results in a very high velocity of orbit (25,560 km/h), which means that, in its 98° sun-synchronous inclination (near-polar), it has an orbit period of 93.4 minutes. QuickBird is the first in a fleet of three spacecrafts scheduled to be in orbit by 2008. Equipped with great on-board storage capacity (128 gigabit) and high-technology sensors, it can collect images in four spectral channels (blue, green, red and near-infrared) with a spatial resolution of 2.44 m at nadir and 2.88 m at 72° angle (off-nadir) with a dynamic range of 11-bits. The panchromatic channel achieves submeter spatial resolutions of 0.61 m and 0.72 m respectively. With such a great resolution, it can be used for ecological studies at local scale. Detailed habitat mapping can be achieved.

Table 2.1. *Characteristics of the QuickBird spectral channels.*

Band	Spectral Range (μm)	Electromagnetic Spectrum	Spatial Resolution at Nadir (m)
1	0.45 – 0.52	Blue	2.4
2	0.52 – 0.60	Green	2.4
3	0.63 – 0.69	Red	2.4
4	0.76 – 0.90	Near-IR	2.4
Pan	0.45 – 0.90	Panchromatic	0.6

IKONOS. The IKONOS-2 satellite system which was launched in September 1999 became fully functional at the beginning of 2000. The spacecraft was set in a 98.1° sun-synchronous near-polar orbit at 681 km altitude. The velocity is 7.5 km per second, therefore it takes only 98 minutes for a complete revolution of the Earth. Before IKONOS-2, the IKONOS-1 satellite was launched but never functioned properly due to technical problems. The IKONOS satellite is equipped with two recording systems, one recording in the panchromatic with spectral resolution of 0.82 m at nadir, and a multispectral scanning radiometer with 3.2 m spectral resolution at four different spectral regions. Off-nadir, and more specifically at 26° degrees, it can provide 1 m

panchromatic resolution imagery, and 4 m for the multispectral. The image swath is 11.3 km at nadir and 13.8 km off-nadir. Finally, its radiometric resolution is equal to 11-bits, which indicates 2049 different grey levels. Both IKONOS-2 and Quickbird are extensively used for detailed habitat mapping.

Table 2.2. *Characteristics of the Ikonos spectral channels.*

Band	Spectral Range (µm)	Electromagnetic Spectrum	Spatial Resolution (m)
1	0.45 – 0.53	Blue	4 m
2	0.52 – 0.61	Green	4 m
3	0.64 – 0.72	Red	4 m
4	0.77 – 0.88	Near-IR	4 m
Pan	0.45 – 0.90	Panchromatic	1 m

FORMOSAT. The first remote sensing satellite developed by the National Space Organization (NSPO), FORMOSAT-2 was successfully launched on 21st May 2004 into a sun-synchronous orbit 891 kilometers above the ground. The main mission of FORMOSAT-2 is to conduct remote sensing imaging over Taiwan and on terrestrial and oceanic regions of the entire Earth. The images captured by FORMOSAT-2 during daytime can be used for land distribution, natural resources research, environmental protection, disaster prevention and rescue work etc. The image width (near vertical observation) is 24 km.

Table 2.3. *Characteristics of FORMOSAT-2 spectral channels.*

Band	Spectral Range (µm)	Electromagnetic Spectrum	Spatial Resolution (m)
1	0.45 – 0.52	Blue	8
2	0.52 – 0.60	Green	8
3	0.63 – 0.69	Red	8
4	0.76 – 0.90	Near-IR	8
Pan	0.45 – 0.90	Panchromatic	2

SPOT. The SPOT (*Satellite Pour l'Observation de la Terre*) programme consists of five multispectral satellites, four of which remain functional, and is operated by the French Space Agency, *Centre National d'Etudes Spatiales* (CNES). The most recent satellites, SPOT 4 and SPOT 5 launched on 24th March 1998 and 4th May 2002 respectively, are set in a sun-synchronous and phased orbit 832 km above the Earth at the Equator. Equipped with a high technology sensor called High Resolution Visible Infra Red Scanner (HRVIR), SPOT 4 is able to record the reflected radiation in 4 spectral channels with a spatial resolution of 20 meters. Furthermore, useful information about the vegetation at a global scale can be obtained from the integrated sensor called VEGETATION Instrument, with 1 km spatial resolution and 2250 km field of view. This is useful for wetland mapping at catchment level. Comparatively, the Geometric Resolution Sensor (HRG) included in SPOT 5 achieves a resolution of 10 meters in the visible and 5 meters in the two panchromatic bands, which can combine and provide 2.5 m resolution imagery. The second sensor on board is called High Resolution Stereoscopic (HRS) and includes the feature of acquiring simultaneously two images in order to form stereo pairs. This specific ability provides the opportunity to form 3D pictures and work in digital elevation models.

Table 2.4. *Characteristics of the SPOT 4 and SPOT 5 spectral bands.*

Band	Spectral Range (µm)	Electromagnetic Spectrum	Spatial Resolution (m)	
			SPOT 4	SPOT 5
1	0.50 – 0.59	Green	20	10
2	0.61 – 0.68	Red	20	10
3	0.63 – 0.69	Near-IR	20	10
4	0.78 – 0.89	Shortwave-IR	20	20
Mon	0.61 – 0.68	Visible	10	
Pan	1.48 – 1.71	Panchromatic		2.5 or 5

ASTER. The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), built by a consortium of Japanese government, industry and research groups, is one of five instruments aboard the Terra platform, launched in December 1999. The combination of wide spectral coverage and high spatial resolution allows ASTER to discriminate amongst a large variety of surface materials, ideal for geological studies, vegetation and ecosystem dynamics, and hazard monitoring. The Terra spacecraft operates in a circular, near-polar orbit at an altitude of 705 km. The orbit is sun-synchronous with equatorial crossing at a local time of 10:30 am. The local time depends on both latitude and off-nadir angle of an observation point. The Terra recurrent cycle is 16 days; there are 16 one-day path patterns respectively for both the daytime and the night time observations. The orbit parameters are the same as those of Landsat 7, except for the local equatorial crossing time.

Table 2.5. *Characteristics of ASTER spectral bands.*

Band	Central Wavelength	Electromagnetic Spectrum	Spatial Resolution (m)
1	0,556	Visible and Near-Infrared	15
2	0,659		
3N	0,807		
3B (aft-camera)	0,804		
4	1,657	Middle Infrared	30
5	2,169		
6	2,209		
7	2,263		
8	2,334		
9	2,4		
10	8,274	Thermal Infrared	90
11	8,626		
12	9,072		
13	10,654		

Landsat. The Landsat (Land Satellite) programme was established in 1972 in the U.S. with the launch of the first satellite of the whole constellation, which consists of 7 spacecrafts. For more than 30 years, the programme has offered high spatial resolution imagery of the Earth and ranks as the longest enterprise for remote sensing of our planet. The wide time range and the great archive of imagery for the last decades afford the possibility of studying, monitoring and researching in particular agriculture, the Earth's natural resources, forestry, population changes, urbanization and regional planning, wetlands and water resources, geology and natural disasters. The great quantity and array of high resolution images acquired from these satellites and the increased utility of the imagery for applications have attracted the interest of the scientific community, earned their respect and established the importance of the Landsat programme in the history of remote sensing. Landsat 5 was launched on 1st March 1984 to continue and enhance the Landsat programme with new features. At an inclination of 98.2°, it is set in a sun-synchronous near-polar orbit at an altitude of 705 km. Temporal resolution is 16 days, in keeping with the orbit characteristics of all Landsat satellites. This renders them unsuitable for applications where continuous monitoring is required. The first spacecrafts were equipped with two sensors, one called MSS and a second one called Thematic Mapper (TM). The main feature in TM is a channel able to measure radiation in the thermal infrared range with spatial resolution of 120 m. This band is included in a multispectral 7 band scanning, with 30 m spatial resolution for the other channels. The Landsat 5 satellite has exceeded its life expectancy and, despite some technical problems of the solar array drive in 2005, continues to provide imagery of the Earth complementary to the other Landsat satellites.

The most recent Landsat spacecraft is the Landsat 7 launched on April 15th 1999 into the same orbit and at the same altitude as the Landsat 5. It carries an advanced sensor, called Enhanced Thematic Mapper plus (ETM+), which incorporates an improved spatial resolution of the thermal band from 120 m to 60 m and an extra panchromatic channel at 15 m. The other bands correspond to the visible (3 channels), near and middle infrared. As well as the resolution of the new on-board instrument, Landsat 7 has a greater storage capacity (378 gigabits), allowing it to collect up to 532 images of size 183 km by 170 km per day. A hardware component failure in May 2003 caused problems in image acquisition for Landsat 7. Therefore, for images acquired after that date, an additional correction is required (for details please refer to http://landsat.gsfc.nasa.gov/-about/landsat7.html).

Table 2.6. *Landsat 7 ETM+ and Landsat TM spectral characteristics.*

Band	Spectral Range (μm)	Electromagnetic Spectrum	Spatial Resolution (m)	
			ETM+	TM
1	0.45 – 0.52	Blue	30	30
2	0.52 – 0.60	Green	30	30
3	0.63 – 0.69	Red	30	30
4	0.76 – 0.90	Near-IR	30	30
5	1.55 – 1.75	Middle-IR	30	30
6	10.40 – 12.50	Thermal-IR	60	120
7	2.08 – 2.35	Middle-IR	30	30
Pan	0.50 – 0.90	Panchromatic	15	-

MODIS. Moderate Resolution Imaging Spectroradiometer (MODIS) is a key instrument on board the Terra (EOS AM) and Aqua (EOS PM) satellites operated by NASA. Terra's orbit around the Earth at 705 km is timed to pass from north to south across the equator in the morning, while Aqua passes south to north over the equator in the afternoon. Terra MODIS

and Aqua MODIS view the entire Earth's surface every one to two days, acquiring data in 36 spectral bands ranging from visible to thermal infrared. Thus MODIS observations offer the possibility for frequent temporal coverage at moderate geometric resolution, ranging from 250 m for the visible and one near-IR band, to 1000 m for the thermal bands. These timely data observations improve our understanding of global processes occurring on land and on a regional scale (as well as the sea and the atmosphere), and can consequently be utilized in assisting policy makers in decision-making processes and/or sound environmental protection. Of special interest for wetland studies are the first two 250 m spectral bands, namely the Red and NIR bands, which are used to provide a number of biophysical measurements over time - for instance, chlorophyll activity in 'green' vegetation. Moreover, the 250 m MODIS data are free of charge and readily available to any user community.

Data from Active sensors

by *Annett Bartsch*

Introduction to active sensors. Radar signals are strongly dependent on hydrological conditions (soil moisture) in addition to surface roughness and vegetation structure, which is advantageous for wetland studies. Soil moisture changes, as well as inundation below vegetation, can be mapped. They are independent of cloud cover and daylight availability, in contrast to passive sensors working in the visible to infrared spectrum. A disadvantage is the comparatively coarse resolution, but this has been improved for the most recent sensors such as TerraSAR-X. The frequencies which are covered range from 0.3 to 300 GHz. This corresponds approximately to a 1 mm–1 m wavelength. The most commonly used for land cover applications are C-Band (~5.6 cm; ERS1/ERS2, ENVISAT ASAR), L-Band (~23.5 cm; ALOS PALSAR, JERS-1) and recently also X-Band (~3 cm; TerraSAR-X). Short wavelengths such as C-band are suitable for bare ground or sparse vegetation cover since they cannot penetrate vegetation or only partly so. Longer wavelengths, especially L-Band, do penetrate to the ground and are thus useful for the mapping of flooding in forests. Low values are characteristic for open calm water at all wavelengths (Figure 2.16b and Figure 2.16c). High backscatter (ie high signal scattered from the target back to the satellite) is observed for inundation below vegetation or high soil moisture content in the top soil layer (max. 5 cm; Figure 2.16a).

a)   b)   c)
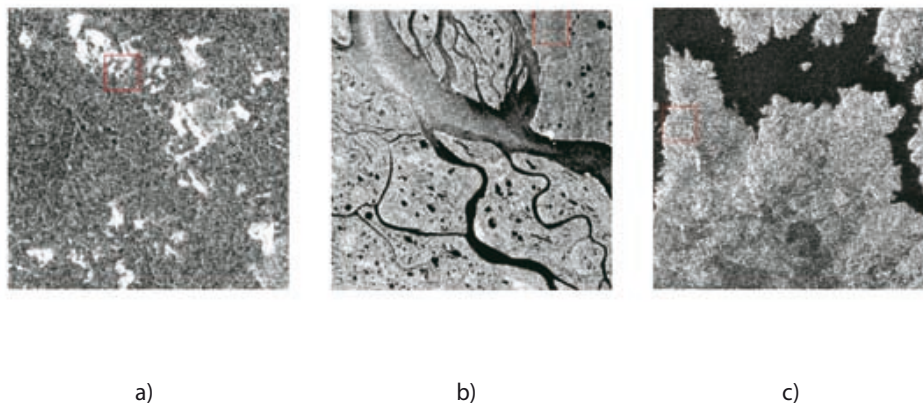
Figure 2.16. *Examples from ENVISAT ASAR Wide Swath (ScanSAR) in C-Band (75 m): a) Boreal peatlands – bright/high backscatter areas due to high soil moisture content; b) Tundra lakes and Yenisei River estuary – dark/low backscatter from open water surfaces; and c) ALOS PALSAR Fine Beam Mode in L-Band (12.5 m) – reservoir in Spain (JAXA level 1.5 product).*

Scatterometer and Synthetic Aperture Radar (SAR). Active microwave sensors (see also Part 2, Section 1 under "Energy Source") can be divided into two types: scatterometer and Synthetic Aperture Radar (SAR). They are not only distinguished by the way the backscatter is measured; they have also characteristic spatial and temporal resolution. Scatterometers can record data from one location several times per day whereas SARs have mostly monthly revisit intervals. The advantage of SAR is the spatial resolution and is thus preferred for land cover applications. It is in the range of tens of meters (<30 m) compared to the scatterometer which provides 25-50 km resolution. The sampling rate of SARs can be improved at the expense of spatial resolution if they are operated in scanning mode (ScanSAR, 150 m-1 km; Figure 2.17).
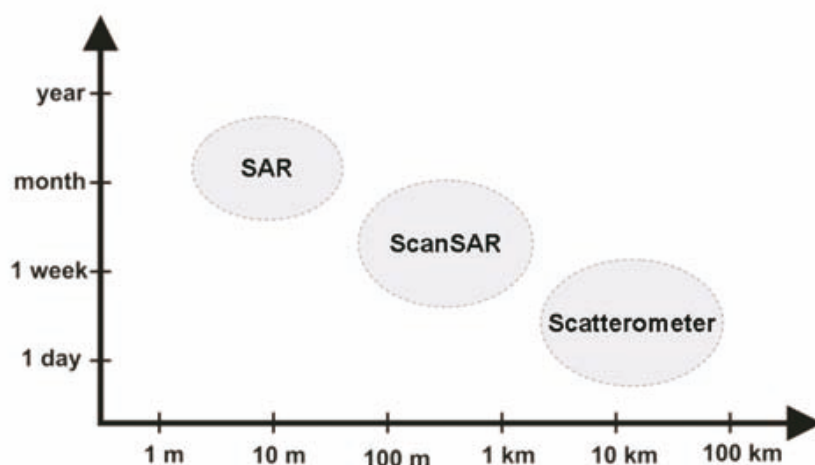
Figure 2.17. *Temporal and spatial resolution of spaceborne microwave sensors (adopted from: Wag-ner et al, 2007).*

Scatterometers have been developed for applications over oceans but are nowadays applied over land as well. The European ERS1, ERS2 and Metop ASCAT scatterometers operate in C-Band (5.6 cm). SARs are imaging radar instruments. If operated on satellites they usually cover an area of 100 km width. In ScanSAR mode, approximately 400 km can be covered. Such data are often delivered in stripes rather than as square scenes. Signals are emitted in a specific polarization, which influences backscatter characteristics on the Earth surface. The most common are linear polarization schemes. In equal polarization the signal is either transmitted and received vertically (VV) or horizontally (HH). With cross-polarization, only the amount of radiation whose polarization is changed due to specific interaction at the Earth surface is measured (HV or VH). Recent instruments can operate in several modes, allowing both acquisition in medium resolution at local scale and coarse resolution mapping at regional scale. A disadvantage is that these modes cannot be employed at the same time and availability depends on priority measures. For example ENVISAT ASAR Image and Wide Swath (WS, ScanSAR) mode are acquired on request. The Global Mode (GM, ScanSAR) serves as background mode if no other is specified. An example can be seen in Figure 2.18. Sensors on recently launched satellites feature multi-polarization capabilities. These are available for ENVISAT ASAR, ALOS PALSAR and TerraSAR-X. The SIR-C was flown on Shuttle Imaging Radar Missions in 1994 (Table 2.7).

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(a)   (b)
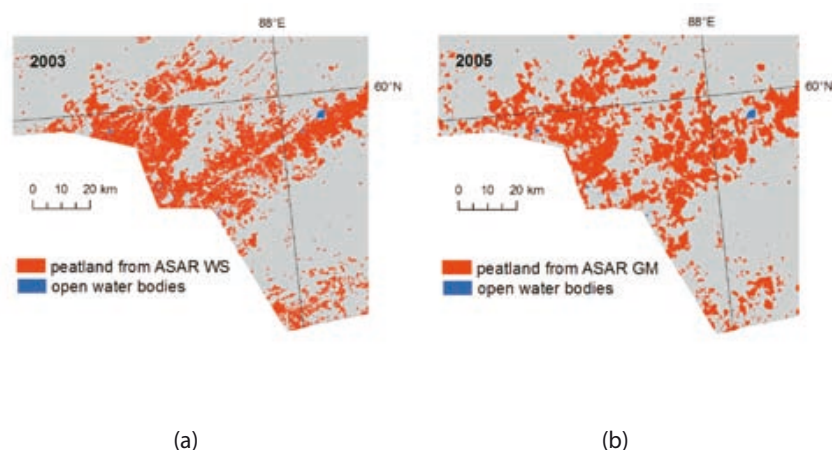
Figure 2.18. *Peatland map based on ENVISAT ASAR a) Wide Swath mode (75 m) and b) Global Mode (500 m) (Source: Bartsch et al, in press).*

Table 2.7. *Overview of spaceborne SAR systems.*

Sensor	Launch	Band	Pixel spacing
ERS1/2 (SAR)	1991	C	30 m
JERS	1992	L	18 m
SIR-C	1994	L, C, X	50 m
RADARSAT	1995	L	10-100 m
ENVISAT ASAR	2002	C	12.5 m – 500 m
ALOS PALSAR	2006	L	10-100 m
TerraSAR-X	2007	X	1-16 m

Coarse resolution data such as scatterometer data and ENVISAT ASAR Global Mode scenes are provided free of charge via rolling archives. Accepted Principal Investigator (PI) activities with the providing agencies (such as ESA http://eopi.esa.int, or JAXA https://auig.eoc.jaxa.jp/auigs/en/top/) allow finer spatial resolution SAR data for research purposes to be ordered free of charge. Data are in general held for a few days on the rolling archive after acquisition and then removed. This requires automatic download procedures. Fees should be expected if data are requested on disks or from the archives. For example one month's data from ENVISAT ASAR Global Mode costs €250 (September 2007). A fee of €25 is charged for single scenes from other modes. Although it is relatively straightforward to obtain the data, advanced processing capabilities are required.

ERS SAR. ERS 1 was launched by ESA (European Space Agency) in July 1991 and was followed by ERS 2 in April 1995. Both satellites operated in Tandem-Mode in 1996 (data acquired from the same place with an interval of approximately one day). ERS 1 stopped operating in March 2000. The SAR system provides data in C-Band (VV-Polarization) with a 100 km wide swath. Orbit parameters are similar to ENVISAT, which has been developed based on experience with the ERS satellites. Data are distributed by Eurimage for €400 per image (October 2007).

ENVISAT ASAR. ENVISAT was launched by the ESA (European Space Agency) in February 2002 into a sun-synchronous orbit at about 800 km altitude and an inclination of 98.55°. The ASAR (Advanced Synthetic Aperture Radar) instrument is one of the instruments installed aboard. ASAR provides radar data in several modes with varying spatial and temporal resolution and alternating polarizations in C-Band (~5.6 cm wavelength). The modes (Figure 2.19a) are Image, Wave and Alternating Polarization Mode (12.5 m), Wide Swath Mode (75 m) and Global Mode (500 m).
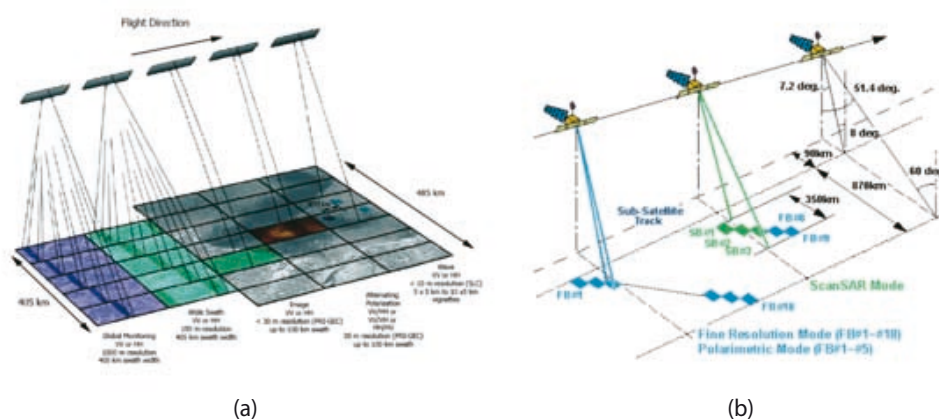

(a)   (b)

Figure 2.19. *Modes of recent SAR systems: a) ENVISAT ASAR Modes (source: ESA ASAR product Handbook), b) ALOS PALSAR Modes (Source: JAXA).*

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Image Mode products are split up into stripes between 57 km and 104 km width depending on the distance from the sensor. Wide Swath and Global Mode images have 405 km width. Image and Alternate Polarization Mode images can be ordered as geocoded products, but they are only corrected for the ellipsoid and may therefore still contain distortions in hilly terrain. Data are distributed by Eurimage for €400 per image (October 2007).

ALOS PALSAR, JERS, RADARSAT. The Advanced Land Observing Satellite (ALOS) is the largest satellite developed in Japan. It was launched in January 2006. The polarimetric Phased Array L-band Synthetic Aperture Radar (PALSAR) is one of the three instruments on board. The Fine Beam Mode provides data with 12.5 m pixel spacing (Figure 2.16c) and in ScanSAR 50 m (see Figure 2.19b). All SAR images can be ordered as readily geocoded products from the Japanese Space Agency (JAXA, http://www.palsar.ersdac.or.jp/e/gds/index.html). These are not corrected, however, for terrain effects. The cost per image is ¥ 20,000 (October 2007). ALOS PALSAR is the successor of the JERS (Japanese Earth Resources Satellite) launched in February 1992. JERS is an L-band SAR of the previous generation, like the Canadian RADARSAT which was launched in 1995. RADARSAT, however, already featured ScanSAR Modes. Single images are available for US$ 3,000 at varying processing levels (MDA Information products, October 2007).

TerraSAR-X. The German TerraSAR-X was launched in June 2007 and has successfully reached commissioning phase. TerraSAR-X carries an X-band radar system which is expected to produce images with a resolution of 1 m, the most detailed images available from a civil space radar. Once data become available they will be distributed by Infoterra GmbH.

How do I select and order images?

by *Iphigenia Keramitsoglou*

Five cataloguing/archiving tools are presented here, namely DESCW, EOLI-SA, EOLI-WEB, Einet and SIRIUS. ESA tools (DESCW, EOLI-SA, EOLI-WEB) handle data from a number of missions (satellite and sensors) whilst SIRIUS handles the catalogue of one mission. This list is only indicative of what exists online and is by no means exhaustive.

Introduction. When searching in the archive, all tools provide a graphical interface (map viewer) for navigating on a map and for selecting an area of interest. Einet and SIRIUS provide the option of uploading a shapefile comprising the area of interest. In addition, DESCW, EOLI-SA, Einet (QuickBird only) and SIRIUS permit the search for an area by name (country/city name). DESCW, EOLI-SA and SIRIUS allow the user to save the area of interest for future searches. Only DESCW allows searching for sparse (random) dates, whilst all provide a calendar and the ability to choose some usually requested time intervals, such as 'last week', 'last month' etc.

Additional information. The map layers available for searching the catalogues differ. However, most of the tools have country and city names and political borders and a satellite image as a standard background layer. All display the frame and track of a retrieved image. It has to be noted that Einet offers advanced graphical interface and searching options for QuickBird images but is very limited for Landsat, ERS 1 & 2 and Radarsat.

Ordering. Once the user finds one or more satellite scenes of interest, all tools except DESCW and EOLI-WEB provide online ordering. Checking order status online, however, is only possible through EOLI-SA.

DESCW. DESCW (Display Earth remote sensing Swath Coverage for Windows) (Figure 2.20) is a multimission software tool created to allow you to display Earth Observation satellites (ERS 1, ERS 2, LANDSAT 5, LANDSAT 7, JERS 1, TERRA/MODIS and, ENVISAT) coverage over the Earth Map. It has the ability of providing a baseline of repeat pass interferometry, selecting many missions with different date spans simultaneously, and it provides nice and useful interaction between the tabular data and its correspondence in the displayed map. It is capable of saving the selected multimission data and the area of interest. The searching can be performed using many parameters as query criteria.
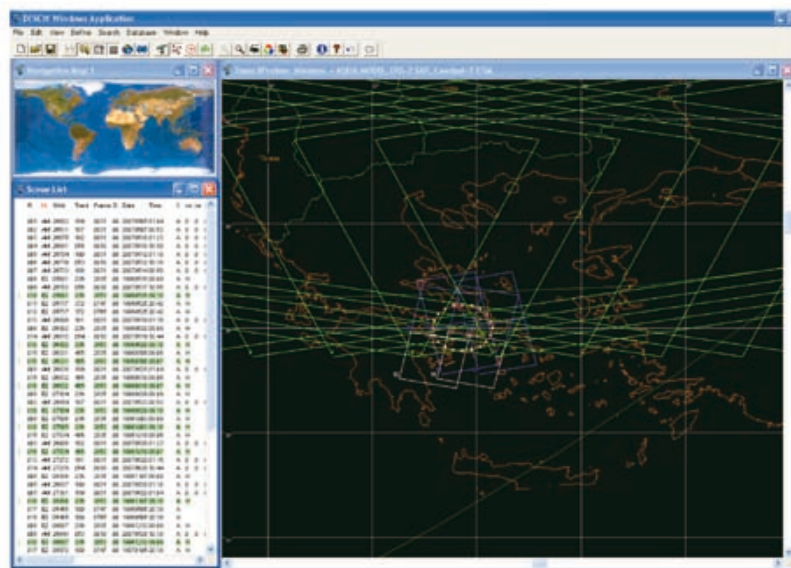
Web address: http://earth.esa.int/descw/

Figure 2.20. *View of DESCW user interface.*

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EOLI SA. EOLI-SA (Figure 2.21) is a free multi platform interactive tool that allows users to access the catalogues of ESA's Earth Observation data products, to order products and ultimately to Track the status of product orders. In addition, EOLI-SA provides a number of specialized features such as the SAR interferometric query and the possibility to access map layers from various OpenGIS compliant map servers. It gives access to and provides information on EO products of many data providers such as ESA, DLR and NASA. The user can search for EO products, get a brief description of their characteristics and see a "Quick Look" of many images. It is also possible to retrieve full details of a product, including information on how to order it. There is no limit on the number of collections which can be searched at a time.

Web address: http://earth.esa.int/object/index.cfm?fobjectid=5035
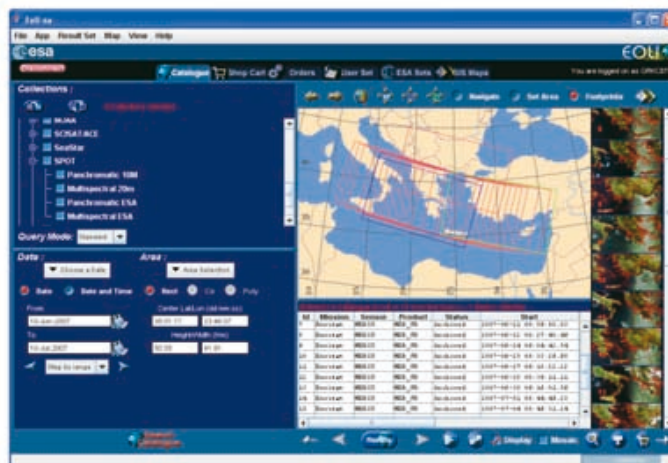
Figure 2.21. *View of EOLI SA user interface.*

EOLI-WEB. The eoPortal Catalogue Client (Figure 2.22) gives access and provides information on EO products of many data providers such as ESA, DLR and NASA. With the eoPortal Catalogue Client the user can search for EO products, get a brief description of their characteristics and see a Quick Look of many images. It is also possible to retrieve full details of a product, including information on how to order it. EOLI-WEB gives easy access to a large collection of EO data. However, the user can only search in three collections at a time.

Web address: http://catalogues.eoportal.org/eoli.html
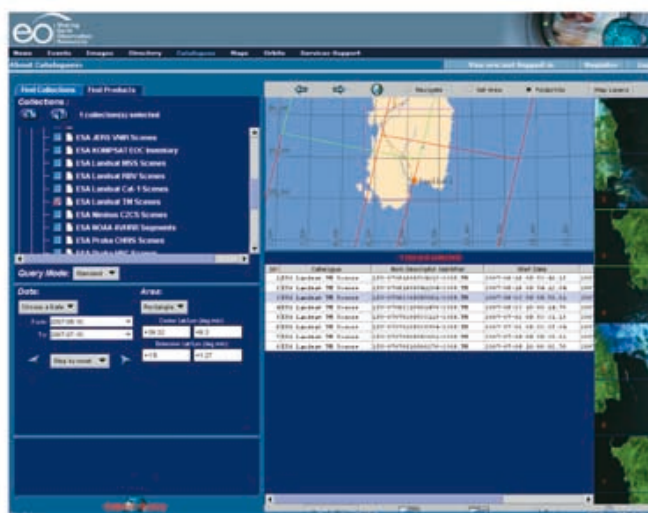
Figure 2.22. *View of EOLI-WEB user interface.*

EiNet. EiNet (Figure 2.23) is an online service that allows users to search for metadata and browse Quick Look images from satellite missions (QuickBird, ERS 1-2 and Landsat). The Client software can be any public domain World Wide Web client. The search area can be defined as a location from a list, a set of contiguous frames, or the user can manually enter the corner coordinates of a quadrilateral or draw a quadrilateral on a map viewer. It has advanced search options only for the QuickBird archive. For the latter, the user can also send an e-Book via email.

Web address: http://www.eurimage.com/einet_home.html

Figure 2.23. *View of EiNet user interface.*

SIRIUS (SPOT). The SIRIUS (Figure 2.24) Online catalogue contains an archive of satellite images acquired by the SPOT satellites since 1986. SIRIUS Online lets users instantaneously search and select images of an area of interest, using geographic, date and technical criteria (satellite, cloud cover, technical quality, spectral mode and angle of incidence). The user may choose from archived images or order a new acquisition. In addition an 'alert' function alerts the user of a new image acquisition for the designated area of interest.

Web address: http://sirius.spotimage.fr
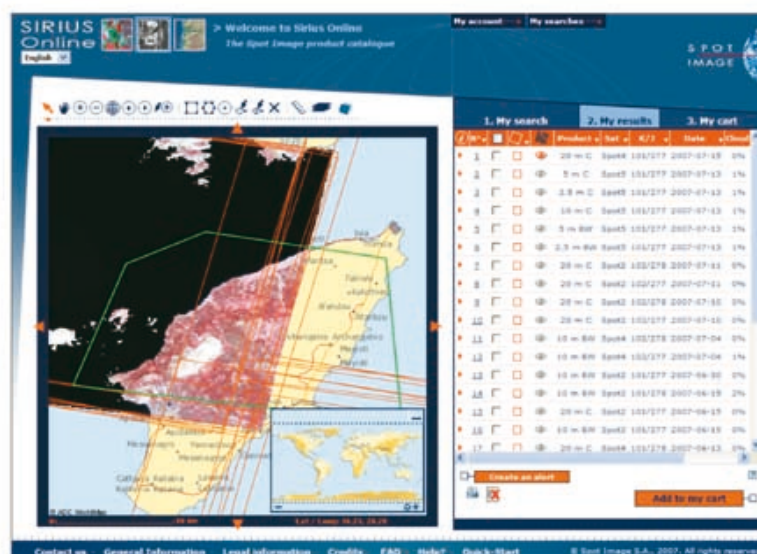
Figure 2.24. *View of SIRIUS user interface.*

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Do I need to apply corrections to the images I buy?

by *Iphigenia Keramitsoglou and Nicolaos Sifakis*

The data from satellite sensors are initially uncorrected for radiometric and geometric discrepancies; they are considered "raw" (some users prefer that status so that they can apply corrections to their own specifications). However, most users prefer to have errors and corrections made by the supplier (usually the organization that receives the data stream telemetry or, sometimes, the secondary distributor). The subject of correction is tied to the procedures called pre-processing or image restoration. The treatment of these modifications is extensive and will not be covered here other than to mention the principal actions normally made in adjusting the DN values (Love, 2006). The following discussion refers mainly to images from passive sensors.

Geometric Corrections. Geometric corrections aim at rectifying distortions - that is, errors between the actual image coordinates and the ideal image coordinates which would be projected theoretically with an ideal sensor and under ideal conditions. Geometric distortions are classified into: internal distortions, resulting from the geometry of the sensor; and external distortions, resulting from the altitude of the sensor/satellite or the shape of the object. Geometric correction is achieved by establishing the relationship between the image coordinate system and the geographic coordinate system using calibration data of the sensor, measured data of position and attitude, ground control points, atmospheric condition etc.

The main steps in carrying out a geometric correction are selection of method, deter-mination of parameters, accuracy check, interpolation and resampling (JARS, 1996). The technique of coordinate transformation is useful for geometric correction with ground control points (GCP). The key points are contained in i) the selection of trans-form formula, and ii) the selection of ground control points. The accuracy of geomet-ric correction is usually represented by the standard deviation (RMS). If the resultant RMS error is close to the pixel size then the correction is considered successful. In the majority of cases for wetland-related studies, the user has a raw image to be corrected and a reference image or a reference map. Therefore, he usually applies the so-called *image-to-image* or image-to-map registration. This involves the selection of a number of GCPs on both the uncorrected and the corrected data, making sure that the points are well distributed throughout the image. Most software packages dedicated for satel-lite image processing have extensive instructions on how to proceed with geometric corrections.

In the final stage of geometric correction a geocoded image will be produced by re-sampling, as shown in Figure 2.25. Resampling is the procedure of re-computing the pixel values of the corrected data, at their new locations. The spectral data should be interpolated by applying one of the following methods:

- Nearest neighbour, where the nearest point will be sampled. The geometric error will be a half pixel at maximum. It has the advantage of being easy and fast.
- Bi-linear is applied to the surrounding four points. The spectral data will be smoothed after the interpolation.
- Cubic convolution, where the spectral data will be interpolated by a cubic function using the surrounding sixteen points. The cubic convolution results in sharpening as well as smoothing, though the computation takes a longer time compared with the other methods.
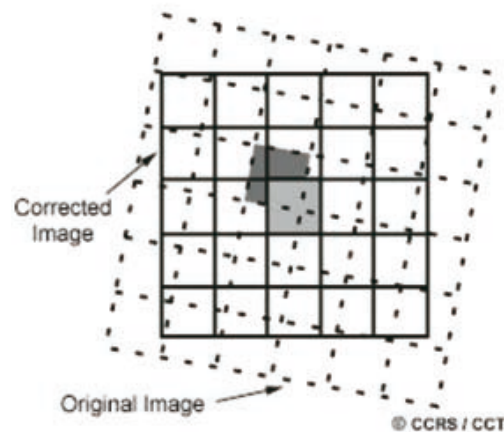
Figure 2.25. *Resampling of the distorted image is the final stage of image geometric correction. The user has to decide which rule to be applied (nearest neighbour, bi-linear or cubic convolution) (Source: Canada Centre for Remote Sensing).*

Finally, a map projection is used to project the rotated ellipse representing the Earth's shape to a two-dimensional plane. However, there will remain some distortions be-cause the curved surface of the Earth cannot be projected precisely on to a plane. Dis-tortions vary according to the type of map projection applied. Geometric correction and image registration to a map coordinating system is essential for integrating the image (and subsequently all its added-value products, such as maps) in a Geographi-cal Information System.

Radiometric Corrections. The emitted or reflected electromagnetic energy by an ob-ject does not coincide with the energy recorded by a remote sensing sensor. This is due to internal (sensors' sensitivity and response) and external factors (sun's azimuth and elevation, atmospheric conditions). In order to obtain the real irradiance or reflec-tance, these radiometric distortions must be corrected.

Firstly, radiometric correction should take into account the sensor's interspectral and intraspectral characteristics in order to convert the digital numbers (DNs) to spectral radiance values. Secondly, the sun angle (function of the time of day and season) and irradiance (function of the day in the year) is considered in order to convert spectral radiance to apparent spectral reflectance. Then, eventually, the area's topography can be taken into account to alleviate bi-directional reflectance effects.

The last stage of radiometric corrections are the atmospheric corrections, which at-tempt to remove the various atmospheric effects caused by absorption and scattering of the solar radiation by aerosols and molecules. At this stage, the apparent (or at-satellite or top-of-the-atmosphere) reflectance can be converted to real reflectance. Atmospheric corrections are based on the radiative transfer equation and may use ex-ternal data on the state of the atmosphere or ground truth data taken by radiometers.

How can I classify the habitats of a wetland?

by *Iphigenia Keramitsoglou*

Classification in remotely sensed data is used to assign labels to groups with similar spectral and/or textural characteristics. The label is called a class. Digital image classification uses the spectral information represented by the digital numbers in one or more spectral bands and attempts to classify each individual pixel-based on this spectral information. Therefore, the following discussion refers to images from passive sensors. The objective is to assign all pixels in the image to particular classes or themes (eg water, coniferous forest, deciduous forest, corn, wheat, artificial surfaces).

Introduction. Classification is executed on the basis of spectral or spectrally defined features, such as density, texture etc. Common classification procedures can be broken down into two broad subdivisions based on the method used: supervised classification and unsupervised classification. In a supervised classification, which is the most common type, the analyst identifies in the imagery homogeneous representative samples of the different surface cover types (information classes) of interest. These samples are referred to as training areas. The selection of appropriate training areas is based on the analyst's familiarity with the geographical area and knowledge of the actual surface cover types present in the image (this information may come from images of better spatial resolution, existing maps, field trips etc.). Thus, the analyst is "supervising" the categorization of a set of specific classes. In unsupervised classification spectral classes are grouped first, based solely on the numerical information in the data, and are then matched by the analyst to information classes (if possible).

Steps. For a successful classification the user is advised to adhere to the following steps.

- *Planning*. This is the first step and includes selection of the target thematic classes, based on the requirements of the end user and the information present in the image. There are predefined nomenclatures for the classification of wet-lands (such as MedWet's) and it is preferable that these are used for consis-tency and comparability of the results.

- *Training*. The second step is vital for the success of the classification. Based on the target classes, the user selects training samples from the image usually by means of polygons. The computer uses special algorithms to determine the numerical "signatures" for each training class and, in most cases, it determines the separability of the classes before the classification is performed.

- *Classification*. Once the training samples are determined with the correspond-ing signatures, each pixel in the original image is compared to these signatures and it is subsequently labelled as the class it most closely "resembles" digi-tally. This can be done with a number of different decision rules which, in turn, determines the classifier to be used (see below).

- *Post-classification processing*. In many cases, the result of a classification needs refinement due to possible errors or to match the required mapping scale. For that reason, filters can be used, the most common of which is the majority filter.

- *Accuracy assessment*. Accuracy assessment allows the evaluation of a classi-fied image file (thematic raster layer). The reference values should be based on ground truth data, previously tested maps, aerial photos or other data. The comparisons may be done by means of

  i confusion matrices, which compare the reference class values to the assigned class values in a c x c matrix, where c is the number of classes (including class 0); see also http://rst.gsfc.nasa.gov/Sect13/Sect13_3.html;

ii   Kappa statistics. The Kappa coefficient expresses the proportionate re-duction in error generated by a classification process compared with the error of a completely random classification. For example, a value of 0.82 implies that the classification process is avoiding 82 per cent of the errors that a completely random classification generates (Congalton, 1991);

iii   overall performance; and

iv   photo interpretation of results.

Classification algorithms. The most popular classification techniques, which can be found in the majority of satellite image processing software, are the following (based on CSTAR, 2005):

- *Multi-level slice classifier*: This technique (also known as parallelepiped clas-sifier) divides each axis of multispectral feature space. The decision region for each class is defined on the basis of a lowest and highest value on each axis. The accuracy of classification depends on the selection of the lowest and high-est values in consideration of the population statistics of each class. It is very important that the population distribution of each class is well understood. This classifier is simple and easy to understand schematically (Figure 2.26). The computing time will be at a minimum compared with other classifiers. However, pixels in the gaps between the parallelepipeds can not be classified as well as pixels in the region of overlapping parallelepipeds.
- *Minimum distance classifier*: A "centroid" for each class is determined from the data by calculating the mean value by band for each class. For each image pixel, the distance in n-dimensional distance to each of these centroids is cal-culated, and the closest centroid determines the class. It is mathematically simple and computationally efficient. However, it is insensitive to different degrees of variance in spectral response data.
- *Maximum likelihood classifier*: The assignment of each pixel ('classification') is made to that class whose probability of occurrence at that point in spectral space is highest ('most likely') - or to "Other" if the probability does not pass a pre-determined threshold. The method uses the class covariance matrix rep-resenting not only the first but also the second order statistics that often con-tain much of the information in RS data. Caution must be taken to split non-normally distributed classes into normally distributed subclasses.
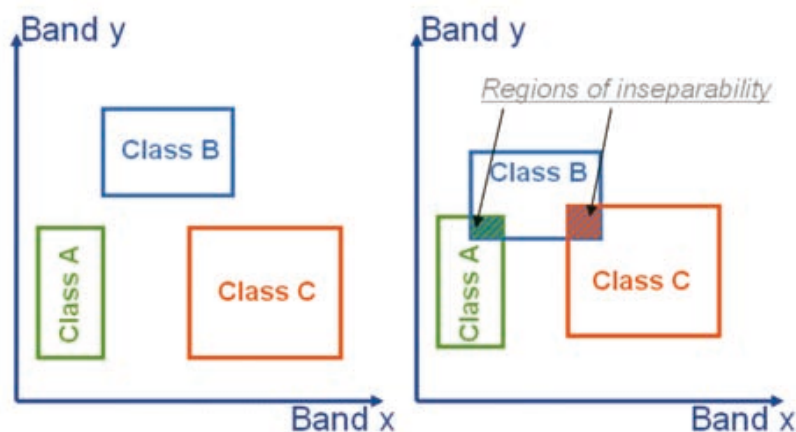

Figure 2.26. *The concept of Parallelepiped classifier. On the left, the ideal case of perfectly separable classes. On the right, the more realistic case where there exist regions of inseparability.*

Advanced classification algorithms. The remote sensing community's need for very high spatial resolution images (VHSR; ground sampling distance of sensor smaller than 5 m) has now been satisfied (QuickBird with a spatial resolution of 0.6 m was launched in 2001), yet there is a lack of image processing tools that can compensate for the inevitable problem present in land cover/land use classes including heterogeneous spectral classes. This is very often the case with habitat mapping, where small patch sizes and high land cover heterogeneity deteriorate the classification accuracies (Smith et al, 2002).

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In VHSR images the spectral responses of particular habitat classes are much more variable, being composed of the spectral responses of individual class elements (intraclass spectral variability). This results in the 'scene-noise' problem. Thus, it is needed to employ new techniques that take into account not only the spectral signature of an individual pixel but also the spatial features extracted from the vicinity of the pixel, within a specified pixel window (Zhang et al, 2003). Three different pixel window classifiers and the basic principles behind object-based classification are presented briefly next, specifically for habitat mapping:

- *Kernel-based re-classification*. This algorithm was first developed by Barnsely and Barr (1996). The kernel re-classification algorithm as specifically adapted for biotope mapping by the Institute for Space Applications and Remote Sensing (National Observatory of Athens) derives information on wetland classes in two stages. The first step is to transform the original multispectral image into a single channel image. This is usually achieved by pixel-based supervised or unsupervised clustering. The number of initial classes is not fixed and may vary from six to twelve. The kernel re-classifier is then applied to the transformed image and the pixel labels are grouped into discrete land cover (or habitat) classes on the basis of their frequency of occurrence and spatial arrangement within a specified pixel window (kernel). KRC examines labels of adjacent pixels within the square kernel and calculates the so-called adjacency event matrix, accounting for the spatial arrangement and frequency of the labels. The criterion for pixel re-labelling is the degree of matching between the adjacency event matrix and the Template Matrices produced during training. Thus, the algorithm accounts for texture and spectral components of the information classes (Keramitsoglou et al, 2005, 2006).

- *Radial basis function neural networks (RBF-NN)*. RBFs (Moody & Darken, 1989) constitute a special type of artificial neural networks which have certain advantages over other network types such as the Feedforward Neural Networks (FNNs), including simpler network configurations and faster training procedures. Neural networks have been utilized extensively in solving image classification problems (Abuelgasim et al, 1996; Chettri et al, 1992; Decatur, 1989; Hepner et al, 1990; Kanellopoulos et al, 1990). Surprisingly, the applications of the RBF architecture in solving these types of problem are very few. In a previous work (Keramitsoglou et al, 2005) the RBF-NN classifier has been compared with the maximum likelihood classifier (MLH). Overall, the neural network classifiers out performed the MLH classification by 10–17 per cent, reaching a maximum overall accuracy of 78 per cent. Analysis showed that the selection of input parameters is vital for the success of the classifiers (Keramitsoglou et al, 2005).

- *Support Vector Machines* (SVM) is the third classification method. It is a supervised learning technique rooted in the Statistical Learning Theory developed by Vladimir Vapnik and co-workers at AT and T Bell Laboratories (Vapnik, 1995, 1998) and is gaining popularity because of its many attractive features and promising empirical performance (Schölkopf & Smola, 2002). Originally the SVM method was worked out for linear two-class classification with margin, where margin means the minimal distance from the separating hyperplane to the closest data points. The SVM learning machine seeks an optimal separating hyperplane, where the margin is maximal. An important and unique feature of this approach is that the solution is based only on the marginal data points, called support vectors. The linear SVM can be extended to non-linear using a set of non-linear basis functions. Several successful applications of SVMs in image classification have been reported in the literature (Camps-Valls & Bruzzone, 2005; Foody & Mathur, 2004a, 2004b; Kim et al, 2002). The first results of the application of SVMs for wetland mapping are very promising, attaining an overall accuracy of over 70 per cent (Keramitsoglou et al, 2006; Figure 2.27).

- *Object oriented image analysis* employs the idea of image segmentation where an image is divided into a number of objects which represent meaningful geographic features such as evergreen and deciduous vegetation, water bodies etc. A number of different algorithms for image segmentation have been developed but the recently introduced multi scale segmentation (MSS), implemented in the software package eCognition (Definiens, 2004), represents a milestone in object oriented image analysis. The MSS technique offers the extraction of image objects at different resolutions to construct a hierarchical network of image objects in which each object knows its context, its neighbourhood and its sub-objects. In addition eCognition provides an extensive set of object features beyond spectral information, such as texture, shape and context which can be combined within the hierarchical semantic rule network for classification. EO data can be integrated with any other type of spatial data which either provide known object borders or add ancillary knowledge. Classification in eCognition is based on fuzzy membership functions or a fuzzy realisation of the standardized nearest

neighbour algorithm (NN). Fuzzy classification translates feature values of arbitrary range into standardized fuzzy values between 0 and 1, indicating the membership to a specific class. A class can be described by one-dimensional membership functions or by a combination of membership functions to cover a multidimensional feature space. Because the overlap in the feature space increases with the number of dimensions, a direct definition of the membership function using NN, trained by image samples, is advisable in high-dimensional space. In contrast, membership functions are more suitable for the definition of classes from a few features (Definiens, 2004).
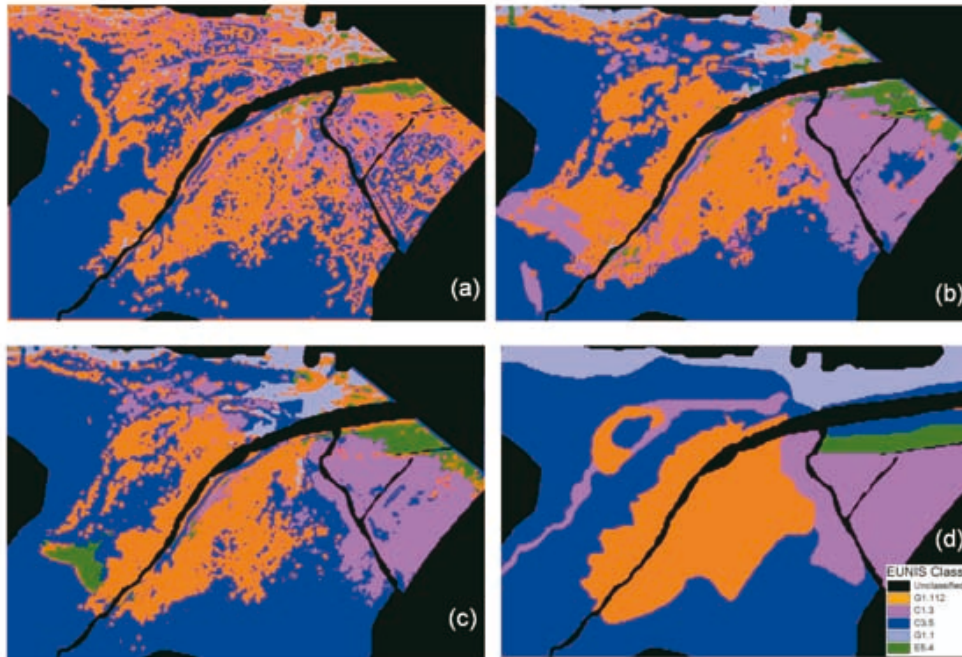
Figure 2.27. *Habitat mapping of Lake Kerkini using advanced classification techniques. (a) Kernel-based re-classification, (b) Radial basis function neural network, (c) Support vector machines. The reference map is displayed in (d) (Source: Keramitsoglou et al, 2006).*

How can I map the biophysical parameters of a wetland using satellites?

by *Tobias Landmann*

Rigorous large scale and near to daily satellite observations offer the opportunity of detecting biophysical parameters on a fine temporal scale. The biophysical parameters are measured from the daily reflectance data sets as spectral indices that are, for instance, sensitive to chlorophyll activity. Other biophysical parameters are inferred by using these reflectance observations in conjunction with reference data on land surface energy transfer properties to map energy flow processes such as land surface temperature. A biophysical parameter data set is sometimes called a remote sensing product. Since many of these products are available with known accuracies and at a fine temporal resolution, they offer much utility for wetland mapping, since wetlands are often fluctuating and dynamic regarding their water dynamics and thus their response to chlorophyll activity, surface temperature and flooding regimes.

Background. Wetlands are generally very dynamic systems that are sometimes highly chlorophyll-active (or 'green'), sometimes flooded or just wet soils and thus challenging to delineate and describe. The boundaries of wetlands are fuzzy, tending to merge with the surrounding area, and their dynamics have a unique 'hydrological signature' (changes in water level over time). Thus utilizing near to daily MODIS satellite imagery to describe the fuzzy wetland boundaries and endeavour to map water dynamics seems feasible. As such it may make sense to 'trace', over time or throughout a year, wetland flooding periods, 'greening up' phases (see Figure 2.28) and when only wet or dry soils make up a part of the wetland within a particular time or year. The time 'signature' of a wetland (Figure 2.28) can be an important surrogate for physical and chemical processes that are related to unique wetland habitats.

Recently at the University of Wuerzburg Remote Sensing Department, which is an entity of the German Aerospace Centre (DLR), a method was proposed and utilized that uses a MODIS 'greenness' biophysical variable (or the Normalized Differential Vegetation Index, NDVI, which is the complex ratio of reflectance in the red and near-infrared portions of the spectrum) in the dry period (Figure 2.29, left image), paired with the amount of water present, measured from the MODIS reflectance for the same area during the wet season (Figure 2.29, right image). The MODIS imagery from two different seasons can be basically combined to trace the annual flooding extent and 'greening up' rate, and discern different wetland spaces. The 'greening' or increased dry season NDVI within a wetland is usually due to increased soil moisture levels or (moisture residues) from regular flooding and consequently induces more vigorous vegetation growth within a wetland system.

The limitations of the method is that smaller fragmented wetlands cannot be mapped, since the MODIS pixel resolution used is 250 m; and the pairing only works well within an area that has a pronounced dry period and a pronounced wet or flooding period within one year (ie semi-arid savanna). Further, since the MODIS imagery is affected by cloud cover, especially in the wet period, there are some interpolation corrections to be performed on the MODIS imagery. The cloud or other 'noise' contaminated images can be corrected by statistical interpolation such as best fit harmonics. However, due to the fine temporal resolution of MODIS imagery, wetland flooding dynamics become more apparent in the MODIS satellite images than in higher resolution but 'once off' or 'snap shot' satellite imagery, and there is potential for good correspondence with field observed wetland spaces for bigger wetlands. Moreover, since the 250 m MODIS data are free of charge and readily available to any user community, mapping wetland dynamics with MODIS data can be deemed effective.

Method description. Figure 2.28 shows the development over time of MODIS 250 m NDVI (vegetation 'greenness') for a one year period, corrected for cloud and cloud shadow using harmonic best fit functions, for different wetland types in a semi-arid savanna system in West Africa.
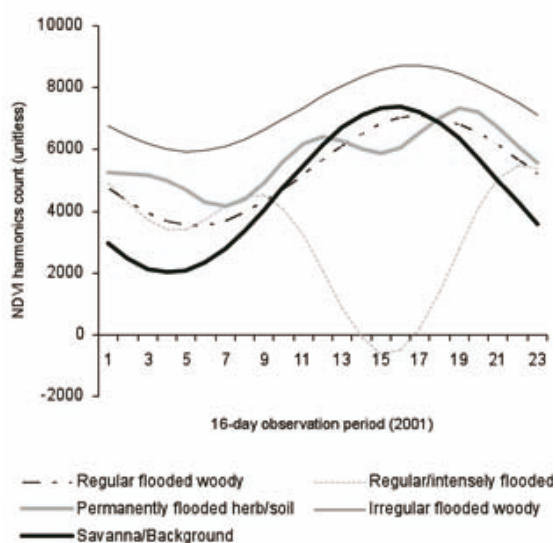

Figure 2.28. *MODIS satellite chlorophyll activity ('greenness') for one year using harmonics from 16-day satellite NDVI composite observations. The black solid curve shows the 'nor-mal' NDVI greenness development for a semi-arid savanna in the region around the wetland. As evident the peak growing period is in August/September (during the peak rainy season).*

Figure 2.29 (left) shows the MODIS NDVI imagery for the dry season - the NDVI 'greenness' is evident as bright and white areas; and the right picture in Figure 2.21 shows waterlogged wetland spaces for the same wetland and corresponding year, but for the wet season and using only the MODIS 250 m near-infrared (NIR) reflectance imagery. The wetland biophysical information from the wet and dry season (left and right image from Figure 2.29) are subsequently overlaid to discern wetland spaces, in Figure 2.30, which describe flooding and NDVI measured 'greening' concurrently. These spaces can be basically interpreted as either permanently flooded (the blue in Figure 2.30), regularly flooded but also 'green' in the dry season (yellow and orange in Figure 2.30) and/or always 'green' with close to no flooding (green in Figure 2.30). This information can then be used to make assumptions and give an overview of the structure of the whole wetland system, and effectively so since rigorous, free of charge MODIS imagery is being used.
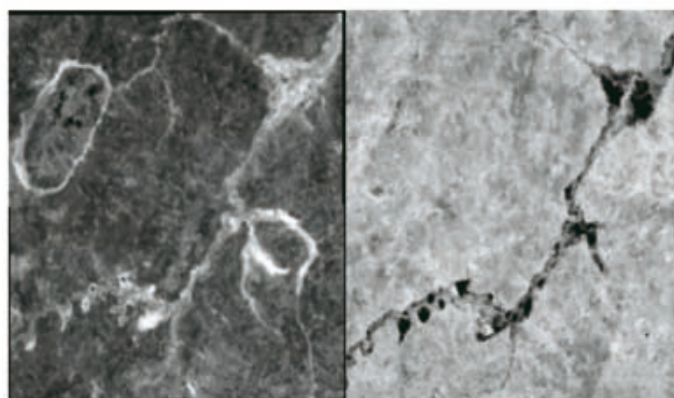

Figure 2.29. *Satellite image of a wetland system in a semi-arid savanna, showing high chlorophyll activity in the dry season on the left, using the 250 m MODIS chlorophyll index (NDVI); and flooding levels of the same wetland during the wet season using 250 m MODIS near–Infrared reflectance on the right.*
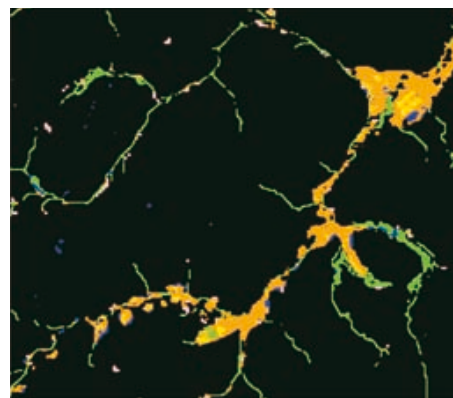

Figure 2.30. *MODIS satellite derived wetland spaces attributed to different flooding (wet season) and greening (dry season) levels. The blue areas are permanently flooded spaces, while the orange and yellow areas depict spaces of variable wet season flooding and correspond-ing dry season 'greening' levels. The green spaces depict areas that are irregularly flooded but very 'green' in the dry period.*

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How can I map water constituent concentrations?

by *Thomas Heege, Viacheslav Kiselev and Daniel Odermatt*

Several water constituents influence water colour and are therefore detectable by Earth observation sensors. Optically active water components include suspended matter, phytoplankton and their different absorbing pigments, detritus and dissolved coloured organic matter called Gelbstoff.

Principles. All the above mentioned components scatter and absorb light in a different spectral manner, which results in a non-linear relationship between their concentrations and the reflectance of water (Mobley, 1994). Water itself also has a specific optical behaviour. The strong increase in light absorption outside the visible range means that only optical sensors can directly detect water quality parameters from space. The key to determining water constituents is the use of the so-called specific inherent optical properties (SIOPs) of scattering and absorbing. The main characteristics are quite similar over most natural waters: suspended matter is the dominant scattering constituent, having a constant or slightly decreasing scattering behaviour with respect to wavelength. Phytoplankton pigments are identified by typical spectral absorption maxima in the blue and red regions. Gelbstoff and detritus are characterized by an exponential decrease in absorption with respect to wavelength. However, the magnitude and some spectral details of the SIOPs vary in different environments due to diverse biochemical compositions and particle distributions. Consideration of these regional specifics is important in order to achieve reliable, quantitative results.

Natural waters generally have a low reflectivity. Significant water constituent concentration changes may result in very slight water colour changes, often less than one percent reflectance, but they still need to be detected. Furthermore, the dominant part of the upwelling blue light measured at the satellite is scattered atmospheric light, even under clear sky conditions. Highly sensitive radiometric sensors and accurate atmospheric and water surface correction procedures are therefore necessary to quantitatively map water constituents. With spatially contrasting conditions, the correction of the so-called adjacency effect can be important. This occurs when a signal from a low-reflecting aquatic surface is appreciably influenced by highly reflective adjacent land surface properties, often due to scattering effects in the atmosphere (Santer & Schmechtig, 2000).

Statistical approaches. Despite the apparent complexity, the simplest way to map water constituents is to relate ground truth measurements with the sensor channel readings and carefully extrapolate the statistically derived relationship in space. This frequently works if the time and location of measurements and satellite readings are more or less concurrent. Nevertheless, due to the non-linear relationship between water colour and water constituents, this method is restricted in transferability and invalid extrapolations are hard to detect. A very successful application of this approach was demonstrated by Brezonik et al (2005). From an extensive set of ground truth observations, they used Landsat TM to monitor water quality in a variety of lakes in Minnesota. Potential users of RS data products usually do not have extensive in *situ* measurements available. They do, however, need comparable, quantitative water quality maps in an adequate temporal resolution, and standardized water quality products, even if different satellite sensors are used. In this case, physics-based data processing methods are required.

Physics-based algorithms. Physics-based approaches contain atmospheric and water surface correction algorithms and a water colour inversion to calculate the underlying water constituent concentrations. They transform the satellite-measured, radiometrically calibrated light intensity into water surface reflectance – a physical measure of water colour. The water

reflectance is then inverted into the concentrations of optically active water constituents, eg through an optimized fitting procedure with modelled sub-surface reflectance spectra.

In a first approximation, superimposed signals from atmosphere and water surface can be calculated using the near- and shortwave infrared channels to determine aerosol concentrations and water surface roughness. These two parameters are needed to correct for the atmospheric influence and sun glint in the channels of the visible spectral region, which are usually used to determine water constituent concentrations. In turbid waters, the infrared channels are affected by increased scattering from high particle concentrations in the water. This can be accounted for by iteratively coupling the retrieval of aerosols and suspended material. Near-infrared channels are therefore important for the retrieval of water constituent concentrations under very turbid conditions due to the increased scattering of light. As a practical result, only physics-based algorithms can account for these effects when dealing with different spectral resolutions supported by the different satellite sensors. These algorithms are based on sophisticated radiative transfer models, such as the FEM method (Kisselev & Bulgarelli, 2004), to calculate satellite-measured radiances as functions of water and atmospheric optical properties. The inversion of radiance or reflectance spectra back to water optical properties and water constituents is performed using non-linear optimization procedures (eg Miksa et al, 2006; Heege & Fischer, 2004), non-linear interpolation using Neural Networks (Schroeder et al, 2007; Doerffer & Schiller, 2007) or principal component inversion (Krawczyk & Hetscher, 1997).

EO derived maps of water constituents. End users seldom have the experience to run sophisticated data processing systems themselves. They rely instead on Earth observation service providers or research partners, or will apply their own extensive ground truth and statistics-based approaches, as described above. The professional Earth observation service providers pursue different supporting strategies:

- NASA focuses on global mapping of oceanic phytoplankton and productivity based on daily available MODIS data in 1 km resolution (http://oceancolor.gsfc.nasa.gov/).
- ESA mainly follows the same strategy of global services as NASA, but provides advanced algorithms for suspended matter and Gelbstoff retrieval in coastal zones with MERIS (http://eopi.esa.int/). The next generation of ESA satellites (Sentinel satellite series) is still focused on global coastal processes, but with higher spatial resolution. ESA also takes regional differences in algorithm requirements and availability under special consideration and supports professional users with suitable software tools, such as BEAM, to implement their own local algorithms for MERIS (http://earth.esa.int/resources/softwaretools/). In 2007, ESA started a lake algorithm development project for MERIS satellite data (ongoing).

Research. Mapping of water constituents in small scale wetland environments, such as lakes, rivers and near coastal shores, is still challenging research for the few groups specialized in remote sensing research of inland waters, such as CNR Milano (Giardino & Gomarasca, 2006), the Finnish Environment Institute and the University of Tartu (eg Kutser et al, 2005). EOMAP, a spin-off company of the German Aerospace Center Oberpfaffenhofen, is a specialized service provider in optical aquatic remote sensing and supports different organizations with the physics-based Modular Inversion and Processing System MIP (Univ. Zürich, Univ. Hohenheim, Murdoch Univ., Univ. Sevilla, Technical Univ. Munich, DLR). The system has been in operational use since 2007 to deliver daily water quality maps to industrial clients for the environmental monitoring of offshore construction sites using data from several Earth observation satellites at different temporal and spatial resolution. For complex inland water quality monitoring, the MIP system is at a pre-operational, automated stage in collaboration with the University of Zürich (Odermatt et al, 2008; Odermatt et al, 2007), and has been applied to a full spectrum of aquatic systems in Switzerland, Germany (eg Lake Constance), Armenia (Lake Sevan in the SEMIS project/University of Hohenheim), Vietnam (Mekong River monitoring project WISDOM/DLR), Indonesia and on the Western Australian coast.

How can I map littoral sea bottom properties and bathymetry?

by *Thomas Heege, Halina Kobryn and Matt Harvey*

Littoral sea bottom properties can be mapped from Earth observation sensors if the reflection of the sea bottom contributes a detectable part to the signal measured by the sensor. This sea bottom reflection must be separated from all other simultaneously measured portions of light for further mapping and classification procedures. Other contributors of light scattered to the sensor are atmospheric molecules and aerosols, the water surface reflection, and light scattered and absorbed due to particular properties of water constituents and the pure water itself.

Principles. The same optical processes as described in Part 2, Section 10 apply for sea floor applications and have to be solved, including the variable spectral sea bottom properties. The pure water itself also absorbs light in a spectrally specific manner and therefore leaves unique signatures in the signal while the light passes through the water column and returns after reflection at the sea bottom. This property is used to estimate water depth from optical remote sensing data (Figure 2.31). However, the many spectrally different sea bottom properties require that water depth and sea bottom reflectivity have to be retrieved in a combined or iterative procedure. In addition, if water constituents vary significantly over the image, then an adequate number and position of channels are needed to solve this further problem (Dekker et al, 2006). Due to this, hyperspectral sensors are useful for applications in shallow waters and able to deliver spatial resolutions that fit the scales of habitats to be mapped.
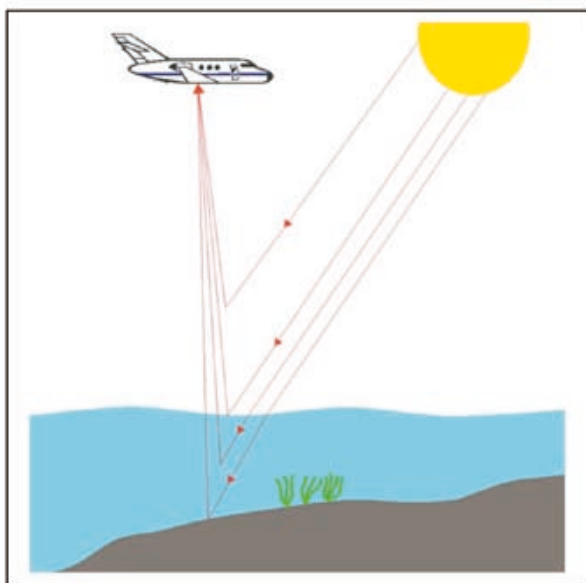
Figure 2.31. *The remote sensing signal combines contributions of sunlight scattered and reflected at different media.*

However, if atmospheric or sun glitter conditions and water constituent concentrations are assumed to be approximately constant over a specific area or image, even multispectral satellite sensors can be used to map sea bottom properties and water depth as demonstrated for the test site (see PART 3, Section 7 for test outcome). Pre-conditions are a suitable radiometric sensitivity and adequate calibration accuracy if a physics-based processing procedure is to be applied. In this case, water constituent concentrations and atmospheric properties can be estimated in adjacent deep water areas where bottom influence is not a factor. Values are then kept fixed in order to retrieve the shallow sea bottom properties.

Approach. Although aerial photographs have been used for decades to support littoral sea floor mapping tasks, digital processing techniques emerged only recently. This is due to the increased capacities of new processing techniques and the increased radiometric, spectral and spatial resolutions of new sensors which are needed for such mapping tasks.

In contrast to pure statistical approaches that do not account for the changing magnitude of the varying water depth and visibility of the sea floor, there are currently two main strategies to at least account for or calculate the water depth. Mishra et al (2006) applied a non-linear interpolation technique for manually selected areas of homogenous definition at different depth. Different applications demonstrate the usability of this method. Heege et al (2007) and Wettle et al (2004) used full physics-based retrieval techniques to determine both sea bottom coverage properties and bathymetry concurrently. A few of these approaches were even coupled with retrieval of water constituents (Wettle et al, 2004). The data processing for the latter study test site was performed using a fully physics-based processing system.

What information can I extract from active sensors images?

by *Annett Bartsch and Carsten Pathe*

Synthetic Aperture Radar (SAR) data require specific pre-processing. Depending on the terrain, orthorectification might be necessary. Wetlands, however, are usually found in regions with moderate or flat terrain and thus do not require advanced pre-processing. Geocoded images (not terrain corrected) can be ordered for ERS, ENVISAT ASAR and ALOS PALSAR and thus classified directly. Soil moisture changes as well as inundation can be mapped independent of cloud cover.

Pre-processing. For the pre-processing of SAR products from ESA (ERS and ENVISAT), the free software collection BEST (ESA) is suitable for small scale applications. Images can be radiometrically corrected, georeferenced and normalized. Normalization is necessary because of the varying viewing angle and distance from the sensor which causes backscatter differences. Some wetland types can, however, be distinguished from their specific backscatter behaviour at certain incidence angles with respect to polarization. If this method is applied, the normalization step is omitted. The radiometric calibration involves correction for the scattering area, the antenna gain pattern and the range spreading loss.

For large regions and long time series the Range–Doppler approach for performing a backward geocoding, achieved in most commercial software packages (eg PCI Geomatics, Sarmap SarScape, GAMMA MSP), is recommended. The Range-Doppler approach does not require tie points, if the sensor geometry is known precisely, which is the case for eg ENVISAT ASAR and ALOS PALSAR. The geometric accuracy of this geocoding approach mainly depends on the accuracy of the sensor position and velocity vectors, the measurement accuracy of the pulse delay time and the knowledge of the target height relative to the assumed Earth model given by a digital elevation model. In the case of ENVISAT ASAR, the orbit geometry files (DORIS files) become available within two weeks after acquisition.

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SAR data are provided in different processing levels for specific applications. The level 0 (single look complex) data serve as input for interferrometeric studies such as digital terrain model generation and land subsidence estimation with DInSAR (Differential Interferrometric SAR). Digital terrain models generated from short wavelengths represent forest height. They can be used for example to retrieve Mangrove heights. DInSAR, with longer wavelengths which better penetrate the forest canopy, provides relative water level changes.

Level 1 data (multi look data) are used for land cover classification. These data still require advanced georeferencing with respect to the Earth's curvature and terrain. Nearly global digital elevation data of suitable resolution for ScanSAR are only available free of charge below 60°N from the Shuttle Radar Topography Mission (SRTM, 100 m x 100 m). Since wetlands occupy mostly flat regions, a GTOPO30 (USGS; also available for high latitudes) based correction, however, is sufficient in many cases. Higher resolution terrain information is needed in the case of SAR data.

SAR images have a grainy appearance. This noise-like phenomenon is known as speckle. Each resolution cell of the system contains many scatterers. The phases of the return signals from these scatterers are randomly distributed and speckle is caused by the resulting interference. This effect is reduced by the multi look technique, which is a standard procedure for the conversion from level 0 to level 1 products. Additional speckle reduction can be achieved using special filters such as the adaptive Lee-, Gamma- or Frost-filter.

Classification. Basicclassification methods are the same as for passive sensors (Part 2, Section 8). Maximum likelihood approaches are the most common but simple hierarchical approaches are often sufficient for inundation or water bodies mapping. Since (for satellites) measurements are usually derived from only one frequency band at a certain point in time, classifications depend on time series and are thus change detection applications.

The actual classification approach depends on the wavelength used and the spatial and temporal resolution of the data. Long wavelengths (L-Band, ~23.5 cm) can penetrate vegetation cover. C-Band radiation (~5.6 cm) is mostly scattered back within the crown of a tree, compared to the shorter X-Band (~3 cm) which is very limited in penetration depth. Inundation in forested regions such as in the Amazon is therefore investigated using L-Band data. Double bounce is the characteristic scattering mechanism (Figure 2.24b). Radiation is reflected (away from the sensor) from the water surface underneath the trees and its direction diverted by tree trunks. A comparably large amount is thus scattered back to the sensor. The shorter C-Band is suitable for detection of open water surfaces and soil moisture changes (see Part 3, Section 2) in areas with limited vegetation coverage, which means in areas outside dense forests. Double bounce in C-Band occurs especially in inundated reed areas or other flooded elongated vegetation types with stem diameters smaller than the C-Band wavelength. Backscatter depends not only on geometrical but also the dielectric properties. The latter is largely influenced by water content in soils. The higher the near-surface soil moisture, the higher the backscatter. If the backscatter for dry and wet conditions is known for a specific location, a measure of relative soil moisture can be estimated for any acquisition.
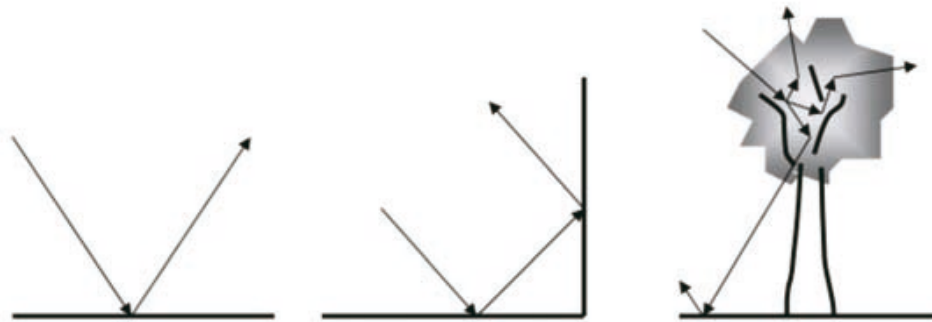

Figure 2.32. *Major scattering mechanisms: a) specular reflection, especially on open water surfaces; b) double bounce, in eg urban areas or reeds; c) volume scattering, here within a tree as characteristic for short wavelengths such as C- or Ku-band. L-band radiation may penetrate tree cover and is then reflected back to the sensor due to double bounce on standing water below and the trunks of trees.*

Open water surfaces can be identified using a simple threshold-based classification applied to the normalized image data. Specular reflection from calm water surfaces results in low backscatter (Figure 2.24a). This phenomenon enables a straightforward identification of inundation in areas with limited vegetation cover. Two types of inundation are usually considered: permanent inundation and seasonal inundation. The threshold for permanent inundation is determined from known permanent water surfaces. Seasonal inundation is then identified by change detection: low backscatter surfaces, which during the flooding period are above the set threshold in the reference data representing dry conditions, are only seasonally inundated. Low values similar to specular reflection from water can also occur in regions of radar shadow; high values can be the result of steep terrain, so-called foreshortening and layover effects. Both effects occur in terrain where no large wetland complexes are expected. Therefore, regions with high variation in elevation and steep slopes, respectively, may be derived from digital elevation data (SRTM and GTOPO30) and excluded from the analysis (masked).

Within regions of low human impact and flat to moderate terrain, a high backscatter signal in C-band is caused either by double bounce effect (Figure 2.24b) within vegetation standing in water, such as reeds, or by high soil moisture conditions. The latter backscatter behaviour is characteristic for open bogs, such as those found in the boreal forest biome. An example of an ENVISAT ASAR Global Mode peatland classification (from 2006; Bartsch et al, in press) over an area of 200,000 km² of the southern West Siberian lowlands is shown in Figure 2.25.

In summary, thresholds can be set to separate areas of low (water), medium (in general, forest or shrubs) and high backscatter (double bounce or high soil moisture). These values can be chosen independently from acquisition date or location. This may limit the detection of large water bodies such as reservoirs owing to wave action but enables efficient processing of large amounts of data.
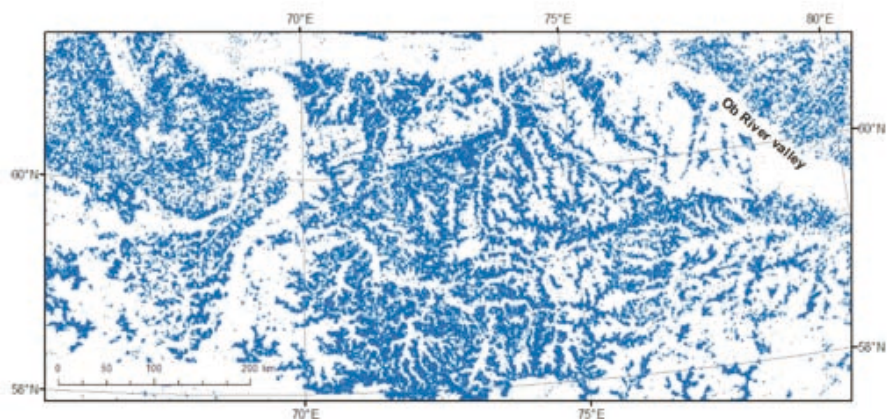

Figure 2.33. *ENVISAT ASAR Global Mode peatland classification (2006) over an area of 200,000 km² of the southern West Siberian lowlands (adapted from: Bartsch et al, in press).*

Although observed surface properties differ significantly from what can be detected with optical data, they are used for validation of SAR classifications in many cases due to the lack of ground data. The applicability of this validation approach is, however, limited to the detection of open water surfaces. For a complete assessment, measurements of surface roughness, soil moisture and vegetation structure would be necessary as the signal is a complex response to a combination of all these factors. Since such measurements are difficult to obtain over large areas, models may be used. The combination of higher resolution optical data with SAR data often delivers the desired results for land cover mapping. The capabilities of active sensors, however, range much further. Water level/extent and soil moisture changes are valuable additional parameters for wetland monitoring.

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PART 3: INDICATIVE APPLICATIONS

Part 3 provides a selection of applications based on the principles presented in Part 2. The applications are sorted by scale, from national to local. Part 3 starts by presenting a methodology for identification of wetland areas for the whole country of Albania based on Landsat ETM+ images. A regional application of monitoring Okavango Delta in Botswana (Africa) using ENVISAT ASAR data follows. Subsequently, the time series of chlorophyll-a and suspended matter concentrations of Lake Constance using 90 MERIS images is presented. Sections 4-6 are dedicated to object oriented classification applications. Three examples are presented using SPOT (Camargue and South Aral Sea Basin) and QuickBird images (Strymon), the last offering the highest spatial resolution available today in commercial satellites. Finally, an interesting application of mapping sea floor and bathymetry in Rottnest Island at one metre spatial resolution is described.

Wetland identification at National Level: AL

by *Antonis Apostolakis*

Specific Methodological Aspects

The generation of a national wetland inventory needs a lot of information to be collected, classified and processed. A major issue when collecting data for inventories is their reliability and current validity. Out-of-date or inaccurate information about a wetland can confuse and delay the inventory procedure while seriously affecting the reliability of the final result. Using EO data can effectively tackle the above-mentioned problems.

The Albanian Wetland Inventory was carried out with the use of remote sensed (RS) data as the primary source for spatial information and wetland identification. The basic principle that allows wetland identification from RS data is that high water concentration is a major physiographic characteristic for all wetlands and that, following appropriate processing, the areas with high water concentration can be extracted from the RS data allowing a list of possible wetland areas to be produced.

After the production of the list of possible wetland areas, a cross checking of this list is made with all the available information, such as topographic and thematic maps and official documents from local authorities. The participation of expert scientists for confirmation of the results is the final step for the determination of the actual wetland areas. Using the RS data, additional information (area, perimeter, geographic coordinates, mean altitude of the water surface) can be extracted for each wetland and stored in a GIS for further processing and map production.
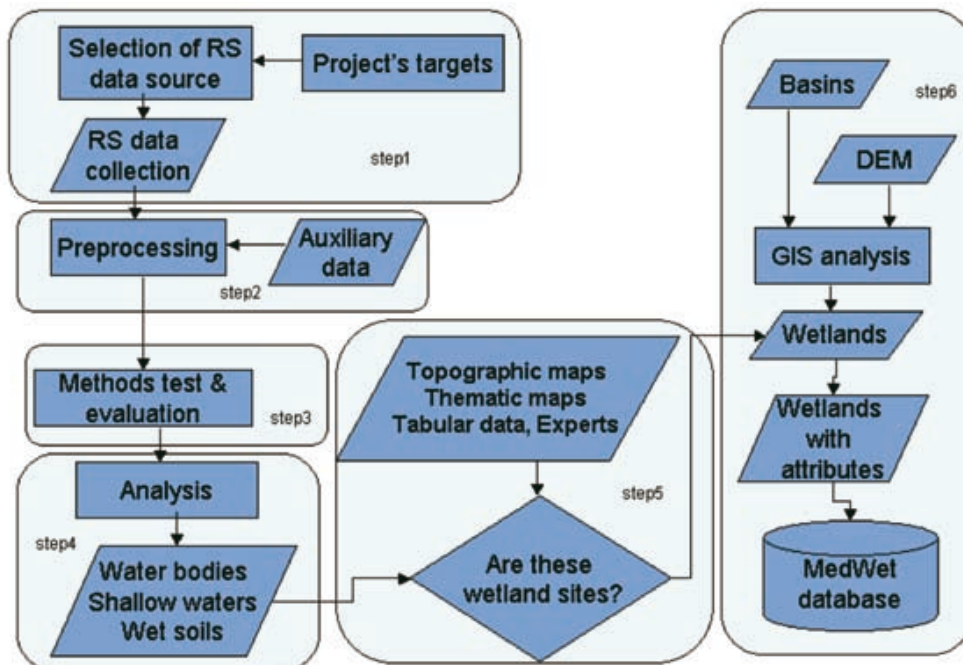

Figure 3.34. *Processing Chain for Identification of Wetland Areas.*

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The steps followed to conduct the identification of wetland sites in the Albanian Wetland Inven-tory are presented in a flow chart (
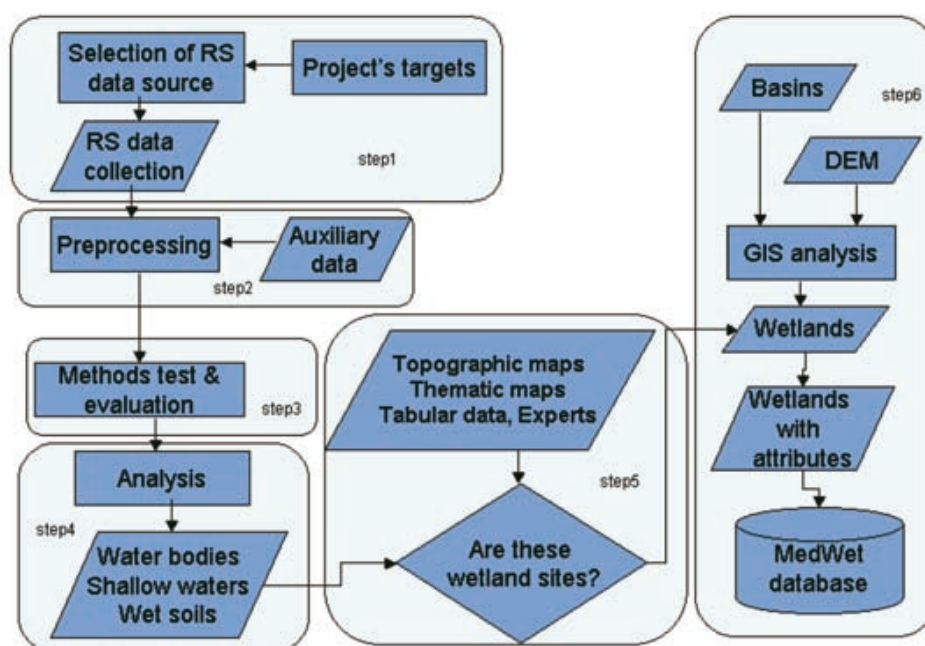

Figure 3.34) and described below:

Step 1. Selection of an appropriate RS data source.
The criteria for choosing the RS data source were:
- The images should contain the near-infrared band of the electromagnetic spectrum, which is strongly absorbed by water.
- The images should cover Albania in its entirety.
- The images should be taken during the spring season when wetlands in Albania have plenty of water.
- The minimum area for a wetland was taken as 2700 m^2, based on 3 pixels or 3 times the minimum resolution of the RS sensor – the Landsat pixel size being 30 x 30 m.
- The area should be covered with the minimum number of images to avoid extensive mosaicing or repetitious image by image analysis procedures.
- The total cost should not exceed the project's budget.

Following the above criteria, the RS data used were three full scene images from the Landsat 7 TM sensor from the spring of 2000 with 30 m spatial resolution covering 98.7% of Albania's area.

Step 2. Collection, preparation and organization of RS and auxiliary data.
The auxiliary data used were:
- Twenty eight topographic maps of 1:100,000 scale obtained by the Albanian authorities.
- One topographic map of 1:500,000 scale from the same source.
- Lists of lakes and reservoirs from the Albanian Ministry of Agriculture.

Both the 1:100,000 scale maps and the 1:500,000 scale map were colour-scanned at 300 dpi and georeferenced in the Gauss–Krugel projection system which is the official projection system for Albania. The three Landsat images were

georeferenced in the same coordinate system. The 1:100,000 scale maps were combined together to produce a detailed and unified background of the whole country.

In order to extract the parts of the satellite images which were outside the study area, the boundaries and shoreline of the country were digitized and the resulting polygon buffered for a distance of 5 km around it. The buffered polygon allowed the Landsat images to be clipped. The parts of the images which overlapped each other were also removed by discarding those parts containing clouds and snow. Areas covered by clouds were also clipped, together with cloud shadows and snow.

Step 3. Testing, evaluation and selection of a method to extract areas with high water concentration from the satellite images.

A test area of about 2,500 km^2 (circa 10% of the total area of Albania) containing both plains and mountainous areas was selected, and a total of 62 lakes and small reservoirs was identified and verified by experts as well known wetlands in the area (Figure 3.35). Four classification methods were tested and evaluated in the test area (Table 3.8).
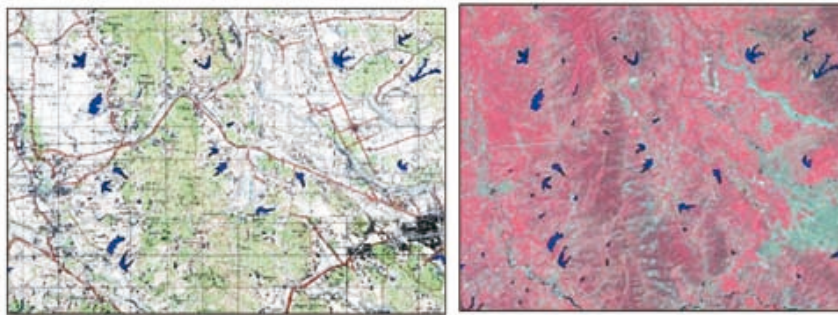

Figure 3.35. *The Test Area on a Topographic Map and on the Satellite Image.*

- *Unsupervised classification*: As a first step, unsupervised classification was applied in the area for various numbers of classes. After some fine-tuning and tests it was found that 12 classes (clusters) gave the best results, with 4 of the 12 classes representing areas with high water concentration. Only 49 of the 62 wetlands were identified by this method.

- *Supervised classification*: This method was repeated three times, collecting signatures from different groups of lakes and reservoirs. The method identified a maximum of 58 of the 62 wetlands.

- *Normalized Difference Vegetation Index (NDVI)*. The NDVI layer was calculated and then unsupervised classification was applied. Various numbers of classes were tested and the best results (61 of the 62 wetlands identified) occurred from a 32-classes unsupervised classification, where classes 1-6 represented areas with high water concentration.

- *Tasseled Cap transformation*. The Landsat TM image was enhanced using the Tasseled Cap transformation. The third layer of *Wetness* produced by the transformation was used in order to extract the areas with high water concentration (Crist et al, 1986). The other two layers of Tasseled Cap transformation (*Brightness* and *Greenness*) were not used. Unsupervised classification was applied to the wetness layer and different numbers of classes were tested. The best results occurred with a 40-classes unsupervised classification where all the 62 wetlands were identified. Further investigation, cross checking and verification of the classification results showed that, of the 40 classes, classes 1-9 represented deep waters, classes 10-14 shallow waters and classes 15-18 wet soils.

Step 4. Application of the Tasseled Cap transformation.

The application of the Tasseled Cap transformation in the test areas showed that the method identified areas around snow as "wet soils" (classes 15-18). Though this is a correct result (melting snow) these areas are not wetlands and so they need to

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be removed from the images, in the same way as the snow covered areas and clouds. The removal procedure was performed by manually checking the areas covered by snow one by one.

Table 3.8. *Classification Methods Tested.*

Method	Wetlands identified	Wetlands not identified	Accuracy (%)
Unsupervised classification	49	13	79.0
Supervised classification 1	53	9	85.5
Supervised classification 2	55	7	88.7
Supervised classification 3	58	4	93.6
Unsupervised classification of NDVI layer	61	1	98.4
Unsupervised classification of Tasseled Cap "Wetness" layer	62	0	100

After the above filtration, the Tasseled Cap transformation was applied to all TM images followed by a 40-classes unsupervised classification of the *Wetness* layer. Then, classes 1-18 were extracted to a separate layer and converted to a *labelled by class* polygon layer using raster to vector transformation. Area and perimeter were also calculated for each polygon. Finally, all polygons with area less than 3 pixels (2700 m²) were deleted.

Step 5. Wetland verification.

For each area identified as having a high water concentration, a preliminary code was inserted in the GIS database. These areas and their codes were plotted on twenty-eight 1:50,000 scale maps in order to magnify the details of the original 1:100,000 scale maps and to delineate smaller areas with high water concentration. These maps were checked one by one by expert scientists. For each wetland verified, two additional attributes were inserted in the GIS database: *wetland name* and *wetland type*. For areas found on maps which lacked additional information, field work was performed for identification and characterization to establish whether they were wetlands or not. After the verification process, all wetlands identified were collected in a single GIS polygon layer with attributes for area, perimeter, name and type for each wetland.

Step 6. Adding more spatial attributes for each wetland.

Using digitized hypsographic and hydrographic data, a Digital Elevation Model (DEM) was created with 100 m resolution. The wetland's polygons and the DEM were combined to calculate a mean altitude for the surface of each wetland. The additional attributes of catchment and sub-catchment were also calculated for each wetland using the corresponding digitized polygon layer. Polar and Cartesian coordinates for the centroid and the boundaries of each wetland were also calculated and added to the GIS database as additional attributes. Using the MedWet model for wetland coding, a code was generated for each wetland from the available attributes. Finally, using all the above spatial data, a shaded relief colour map was composed showing all the wetlands that were identified (Figure 3.36, Figure 3.37).

Result and Comments

The resultant inventory contained 784 wetlands. Forty-one of them were notdepicted on topographic maps even though they were listed in the archives of the Albanian authorities in tabular form. One wetland was neither depicted on topographic maps nor present in the lists provided by the Albanian authorities but was verified by experts after a field visit. One wetland, a

lake, was not identified because it had been drained. Twelve categories of wetlands were identified, namely marshes, reservoirs, river estuaries, lagoons, main rivers, lakes, glacier lakes, fresh water springs, fishponds, seasonally flooded agricultural lands, excavations and sea bays.

A major drawback of the method came from the spatial resolution of the EO data (30 m) which was not suitable for the identification of small rivers with a width of less than about 30 m. This drawback can be overcome using very high spatial resolution EO data. In this case the sensor should cover Landsat's TM bands and an adaptation of the Tasseled Cap transformation should be performed as this transformation was designed for Landsat TM EO data only.

Another problem was the areas covered by snow, which had to be removed. The method failed to identify 44 glacier lakes of the total 101 because they were covered in snow. A similar problem applied to the "wet soil" areas around melting snow which had to be extracted and could possibly have contained wetlands. This problem can be eliminated by using another set of RS data from the end of summer.

The availability of a suitable EO sensor is another serious issue. Although the first Landsat satellite was launched in the 1970s, TM sensors have a combination of characteristics that are very difficult to find in modern sensors:
- They cover large areas of the earth's surface. The whole country of Albania was covered by just 3 images.
- They offer a satisfactory balance between spatial resolution, availability, number of bands and cost.
- It is a well known and popular source of EO data, supported by a number of commercial software packages and users.

In addition, searching for alternative EO data sources with similar characteristics returned poor results. Despite the existence of a lot of sensors offering better spatial resolution, more bands and lower cost, there were major drawbacks due to the small area they covered per image and difficulties in data availability and data acquisition.

The major advantages of the method presented are:
- Reliable spatial information for each wetland as they were produced from EO data.
- A preliminary list of wetlands can be produced using only EO data. This list has to be checked and verified.
- Cost effectiveness. The cost for the Albanian wetland inventory was €4000 for EO data, six man-months to test and decide on the method to be applied, three man-months for data collection and preparation, three man-months to apply the method and two man-months to organize and publish the results.

Data sheet

The datasets used for the purposes of the present work are shown in the following table.

Case study: Identification of wetlands, Albania			
INPUT DATA			
Platform/Sensor	**Acq. date(s) / period**	**Spatial Resolution / scale**	
LANDSAT-ETM	22/03/2000	30 m 30 m 30 m	
LANDSAT-ETM	07/04/2000		
LANDSAT-ETM	09/05/2000		
ADDITIONAL GEODATA (GROUND TRUTH, TRAINING DATA)			
Type of data	**Acq. date(s) / period**	**Resolution / scale**	
28 topographic maps tabular data	1980-1984 1999-2000	1:100,000 -	
CLASSIFICATION RESULT			
Class. Nomenclature	**Reached no. of classes / Class hierarchy**	**Typical working scale**	**Method of accuracy assessment**
Custom	3/3	1:100,000	Confusion matrix

Map product

Figure 3.36. *Map of Albanian Wetlands (country level).*
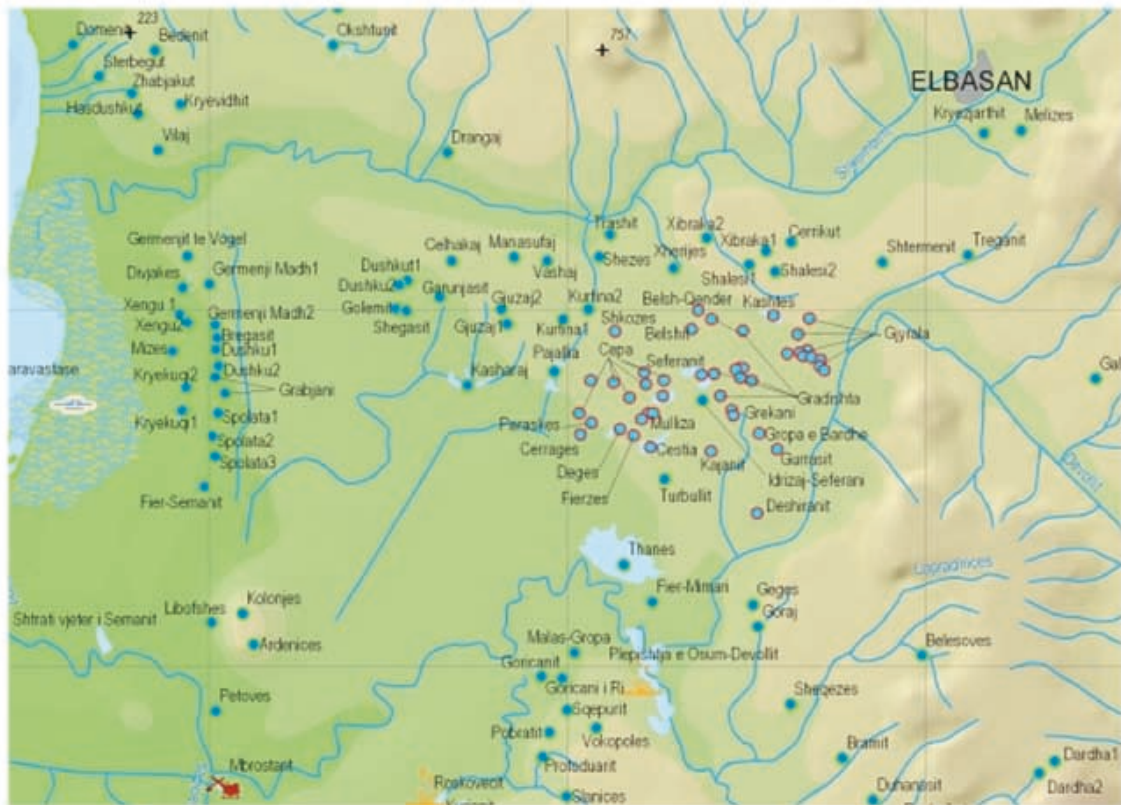
Figure 3.37. *Detail from the Final Map of Albanian Wetlands.*

Time series analyses with active microwave data:
Okavango Delta, BW

by *Annett Bartsch and Marcela Doubkova*

Specific Methodological Aspects

ScanSAR systems such as ENVISAT's ASAR Global Mode allow monitoring of dynamic processes at medium resolution. Hence they are especially useful for monitoring hydrological processes such as soil moisture and inundation dynamics. In the past SARs have been used mostly for inundation mapping. Recently, the system's abilities to detect saturated soil condition have been demonstrated.

ENVISAT was launched by ESA (European Space Agency) in February 2002 into a sun-synchronous orbit at about 800 km altitude and an inclination of 98.55°. The ASAR (Advanced Synthetic Aperture Radar) instrument is one of the instruments installed aboard. ASAR provides radar data in several modes with varying spatial and temporal resolution and alternating polarizations in C-Band (~5.6 cm wavelength).

The presented study of Okavango Delta utilizes ASAR data acquired in Global Mode (GM), which operates in HH polarization with pixel spacing of 500 m; this corresponds to an approximate spatial resolution of 1 km. Each swath covers an area of 405 km width (Desnos et al, 2000). GM data are available since December 2004. ENVISAT ASAR GM data are acquired as back-up if no other mode is requested. This setting alleviates data procurement considerably. Data can be downloaded directly from a rolling ESA FTP archive without planning and issuing specific data orders. The comparatively low data volume (40MB for a swath covering the entire African landmass) of the global mode makes access and data handling easier.

These data require georeferencing with respect to Earth curvature and terrain for further processing (Meier et al, 1993). The GTOPO30 digital elevation model (improved with SRTM data) provided by USGS is sufficient for geocoding of Global Mode data. Within a normalization step the effects on the backscatter due to varying incidence angle and distance from sensor (near and far range) are removed (Roth et al, 1993; van Zyl et al, 1993). To achieve sub-pixel accuracy DORIS orbit information is used for precise geocoding. For all pre-processing steps an in-house software (ESCAPE) was developed (Pathe & Wagner, 2004) which uses modules of the commercial software Sarscape (Sarmap). ESCAPE allows efficient operational ENVISAT ASAR data processing, which is essential for monitoring large regions such as the southern African subcontinent.

The Okavango Delta in Botswana is covered by ASAR GM approximately once a week. The acquisitions are, however, irregular and scenes often only partly cover the delta. On average, one image per month is available for complete wetland monitoring at this site. The HH polarization of GM is especially suitable for the Okavango study because of the enhanced penetration through vegetation to the ground compared to VV.

Two types of time series can be derived for the study area: i) collection of images with complete coverage of the delta during single acquisitions and ii) monthly means using all available images. In the first case, intervals are irregular, but approximately one image per month is available for the study area (Figure 3.38, Figure 3.42). Variations of coverage during each month need to be investigated to avoid disparities. The pre-processed images have been classified using a threshold typical for saturated soil conditions (Bartsch et al, 2007a) or double bounce in vegetated flooded areas. Figure 3.41 shows wetness frequency maps, containing the number of months when the surface is either wet or inundated. This is based on monthly mean values.

Data sheet

The datasets used for the purposes of the present work are shown in the following table.

Case study: Okavango Delta, Botswana			
INPUT DATA			
Platform/Sensor	**Acq. date(s) / period**	**Resolution / scale**	
ENVISAT ASAR Global Mode	01/01/2005- 31/12/2006	1 km x 1 km	
ADDITIONAL GEODATA (GROUND TRUTH, TRAINING DATA)			
Type of data	**Acq. date(s) / period**	**Resolution / scale**	
Digital Map	-	1:10,000	
CLASSIFICATION RESULT			
Class. Nomenclature	**Reached no. of classes / Class hierarchy**	**Typical working scale**	**Method of accuracy assessment**
Wetness frequency	12 (0-12 months)	1 km x 1 km resolution	Soil moisture probe River runoff measurements

Map product

The region of the Okavango delta (Figure 3.38) is semi-arid with evaporation four times higher than rainfall (Ringrose et al, 2005). The wetland area varies at decadal, multi decadal and millennial time scales, in response to variations in regional climate. Periods when conditions were drier and wetter than now were present in the last 7000 years. The dynamics within the delta, especially the extent of flooding, depends on internal as well as external factors (Gumbricht et al, 2004; Wolski & Savenjie, 2006). Recharge of the Okavango tributaries takes place in Angola during the rainy season. There are water management plans for water abstraction in Namibia shortly before the Okavango River reaches the floodplain in Botswana. Deposition processes cause changes in the distribution of inundations within the Delta. The western part of the system has dried progressively in the last 150 years (eg Gumare flats).
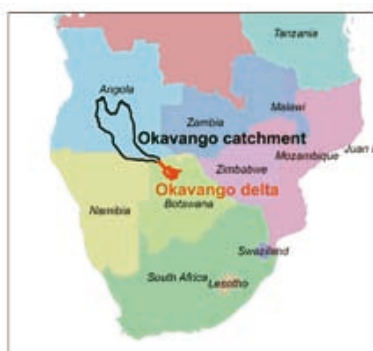
Figure 3.38. *The Location of the Study Area in Southern Africa including Overlay of the Okavango Delta and Okavango River Catchment.*

The 2005 flood at its maximum extent covered areas corresponding roughly to the regularly inundated zone. The largest expansion of the flood (the difference between annual maximum and annual minimum inundation extent) was observed in the SW part of the system, while in the NE part the flood expansion was smaller. Such behaviour corresponds to the known differences in inundation dynamics between these parts of the Delta. The year 2005 was characterized by below average rainfall and inflow. Soil moisture data from the upper Okavango catchment reflect these conditions (Figure 3.39). The length of the period with high soil moisture (above 50%) in 2005 is clearly shorter than in 2006. The maximum wet area (excluding 300 km² of the upper pan handle) was, however, 6500 km² (Figure 3.40, Figure 3.41). This is larger than the 1985-2004 mean maximum inundation area (6280 km²). This reflects the influence of preceding conditions on flooding in the Okavango Delta; the flood of the preceding year, 2004, was very large, attaining 10,000 km² (Bartsch et al, 2007b).
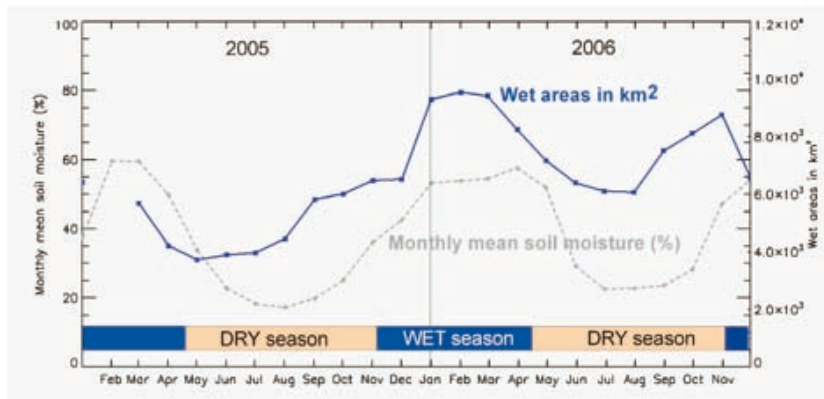

Figure 3.39. *Wet Area Extent in km² (in blue) derived from Monthly Mean composites of the Nor-malized Backscatter over the Okavango Delta and Monthly Mean Soil Moisture in the Upper Okavango Catchment (in grey). Note: monthly acquisitions were unequal.*

The year 2006 was characterized by heavy rainfall in most of southern Africa. The maximum extent of the wet areas reached 9500 km² compared with 6500 km² in 2005. The increase in the extent of the wet areas in January 2006 was caused by an increase in local precipitation. The second peak in September 2006 was a response to the increased inflow from the upper Okavango catchment (approximately three months after the end of the rainy season). The regular process of wetland expansion and contraction can be captured with the ENVISAT ASAR GM data, as shown for 2005 in Figure 3.40. Compare the conditions at the end of the rainy season (March) with the minimal extent during the dry season (May) and maximal extent of the wet areas in September.
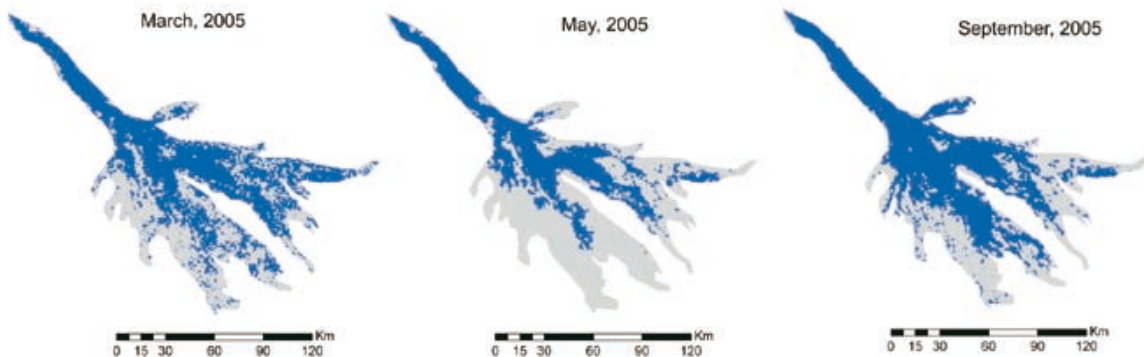

Figure 3.40. *2005 Wet Areas (blue) at the end of Rain Season (March), first half of the Dry Season (May) and time of Maximum Inundation (September); grey represents the Extent of the Delta.*

Figure 3.41 displays the number of months with wet surface conditions in 2005 and in 2006. Orange hues correspond to areas with low frequency of inundation (1-5 months) while blue hues correspond to frequently inundated areas (7-12 months). The difference in rainfall performance in 2005 compared with 2006 is clearly reflected by the difference in wetness frequency.
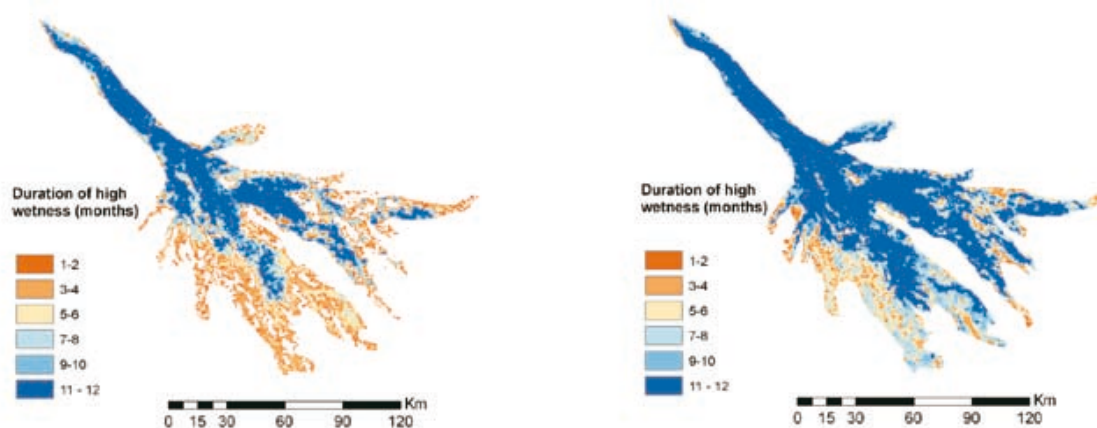

Figure 3.41. *Wetland Frequency Map in 2005 (left panel) and 2006 (right panel).*

Result and Comments

The performance of the classifier is difficult to access since no other data sources exist which provide soil moisture measurements for such a large area. Inundation can be mapped with high resolution optical data, but this is only one part of the detectable wet area. Surface soil moisture conditions can be modelled and then compared to the satellite images (Vischel et al, 2007; Rüdiger et al, 2007).

The derivation of relative soil moisture itself is an advanced application of the ENVISAT ASAR GM time series. The original approach has been developed for coarse resolution (25 km x 25 km) scatterometer data. These datasets are available globally. The approach allows the assessment of wetness stage at each location for all acquisitions. Such analyses should be split up into internal and external changes if appropriate. The Okavango Delta depends largely on external factors. The inflow into the wetland is directly related to the mean relative soil moisture in the upstream area (Bartsch et al, 2007c). Best correlation can be observed for a 3 months offset. This allows for prediction of the wetland extent.

A disadvantage of ENVISAT ASAR GM is the medium resolution (1 x 1 km – 500 m pixel spacing). But this is compensated by the high number of available acquisitions. Large areas can be investigated. Due to the simplicity of the approach it can be transferred easily to other sites. The only limitation is the irregular availability due to higher priority of other ASAR acquisition modes. Figure 3.42 shows the average annual global coverage. Regions with Mediterranean climate and good coverage are for example Australia, southern and parts of northern Africa. Europe is usually mapped in ASAR WS mode, which provides 150 m resolution data. They can be used especially for the detection of open water surfaces

(Bartsch et al, 2007a) and also for peatland mapping. This, however, requires higher resolution digital elevation data for orthorectification and each single acquisition needs to be requested from the ESA.
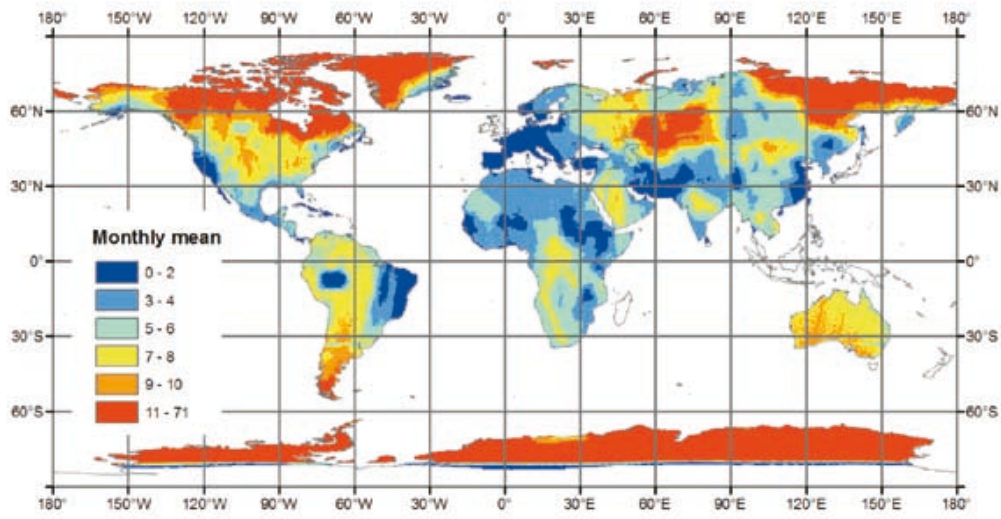

Figure 3.42. *ENVISAT ASAR GM Mean Monthly Coverage December 2004 – October 2006.*

MIP Inland Water Processor: Lake Constance, AT-DE-CH

by *Thomas Heege and Daniel Odermatt*

Specific Methodological Aspects

The algorithm used in this work consists of two MIP (Modular Inversion and Processing Scheme) modules in a processing chain for MERIS level 1B FR data (Heege & Fischer, 2004). The first MIP module performs image based aerosol retrieval and atmospheric correction on sensor radiance data, the second module retrieves water constituent concentrations. In order to obtain a fully automatic inland water processor, we applied IDL based pre- and post-processing routines for MERIS data to the algorithm. A simplified parameterization was optimized to the atmospheric and limnologic conditions in 90 MERIS scenes of Lake Constance during 2003 to 2005 (Odermatt et al, 2008; Odermatt et al, 2007). The atmospheric correction is based on a Look-Up Table (LUT), which was created for a coupled, plane-parallel atmosphere-water model by use of the Finite Element Method, FEM (Kisselev & Bulgarelli, 2004). A downhill simplex algorithm is then used for the inversion of the atmospherically corrected MERIS data to a biooptical model, which makes use of the lake's Specific Inherent Optical Properties (SIOP).

The processor handles MERIS 1B data of the original N1 file type, both in scene or imagette format. Internal pre-processing includes the conversion to BIL image format, the extraction of the pre-defined lake area from image data and corresponding metadata, such as geolocation, observation and illumination angles or pixel quality flags. Geometric correction is not performed.
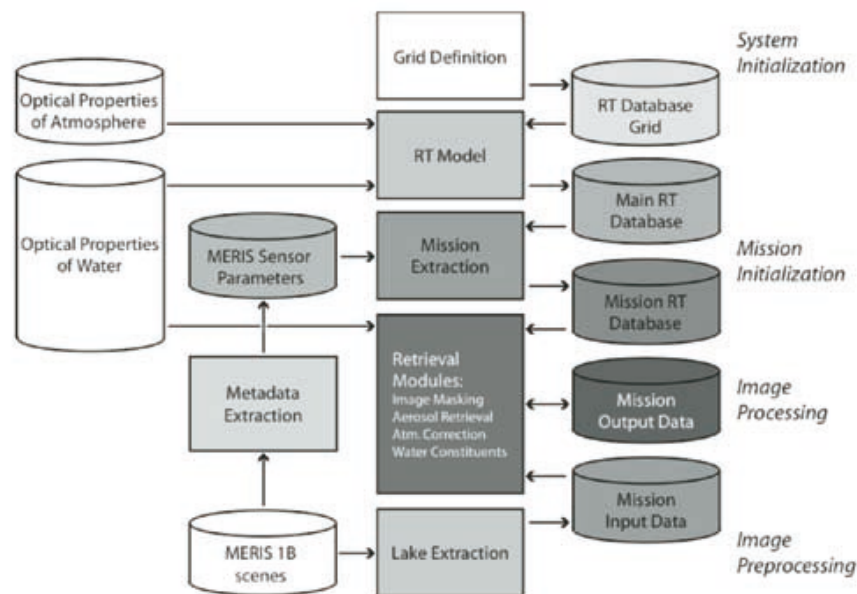
Figure 3.43. *Schematic Diagram of MIP Inland Water Processor.*

Data sheet

The datasets used for the purposes of the present work are shown in the following table.

Case study:MIP Inland Water Processor, Lake Constance, Austria/Germany/Switzerland			
INPUT DATA			
Platform/Sensor	**Acq. date(s) / period**	**Spatial Resolution / scale**	
MERIS (prospective MODIS)	2003 ongoing, more than 90 scenes	300 m / global	
ADDITIONAL GEODATA (GROUND TRUTH, TRAINING DATA)			
Type of data	**Acq. date(s) / period**	**Resolution / scale**	
IGKB (International Commission for the Protection of Lake Constance) water quality monitoring data for training and validation: Chl-a (20 m depth composite, HPCL) Secchi Depth	2003-2005	In-situ data (2 off-shore sites)	
CLASSIFICATION RESULT			
Class. Nomenclature	**Reached no. of classes / Class hierarchy**	**Typical working scale**	**Method of accuracy assessment**
Chlorophyll-a (Chl-a) Suspended Matter (SM)	2: quantitative values of Chl-a and SM	1 km	IGKB in situ data, Model/data fit residuals

Map products

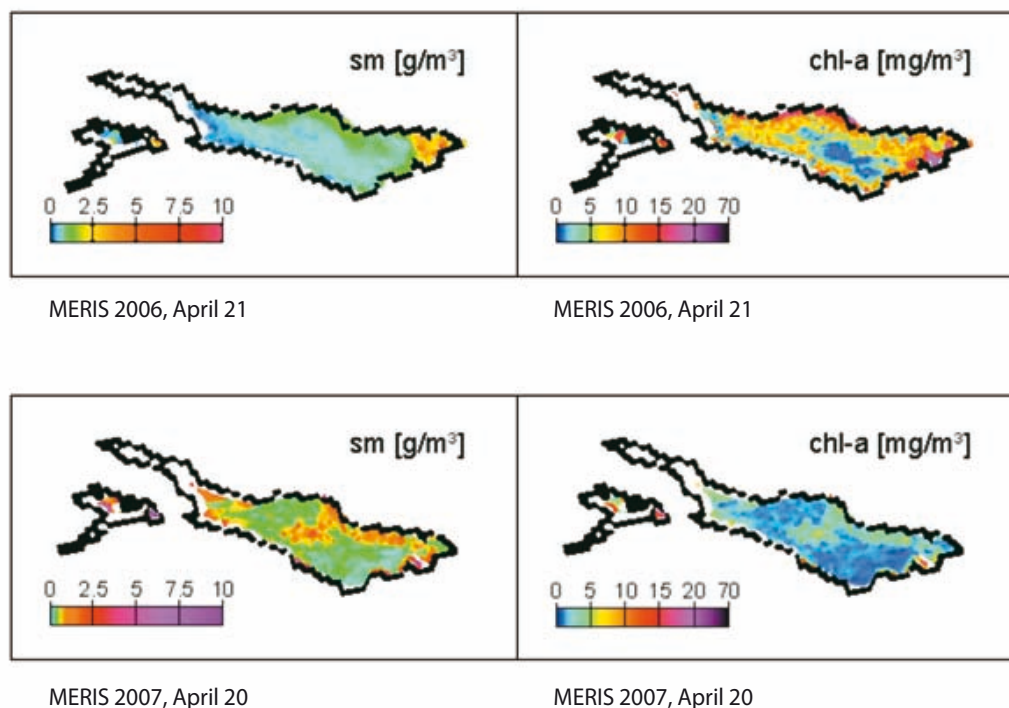**Figure 3.44.** *Map Products for Suspended Matter (sm) and Chlorophyll-a (chl-a).*

Result and Comments

The processor outputs coloured concentration maps of chlorophyll-a and suspended matter concentrations, with the lake's perimeter and cloud coverage from the MERIS metadata depicted. A Gelbstoff concentration map is also available, but a reliable separation of Gelbstoff and chlorophyll is currently not possible due to sensor noise in channels 1 and 2, which are essential for their discrimination. Additional output is a tabular time series of all data, with average concentration estimates for the entire lake, reliability assessment parameters and the accordant results for a well estimated pixel located in a 3 x 3 pixel vicinity around the IGKB sampling sites. The remote sensing method measures integrated values of chlorophyll and suspended matter in the upper 1.5-7 m, the actual depth limits depending on water transparency conditions in Lake Constance. Typically the signal depth was about 2-3 m. The IGKB data were measured as integrated samples of the first 20 m. In spite of this significant difference in depth and the difference of up to 24 hours between in situ sampling and satellite measurement, we still retrieved a regression coefficient of 0.8 and a standard deviation of 1.3 μg/l between both data sets for Chlorophyll-a. In order to correct at least the mean statistical effect of the vertical differences between the measurements, we applied a correction factor that is based on independent measured vertical chlorophyll profiles at the University of Constance.

The main advantage of this alignment of MIP is a maximum degree of automation, with no manipulation or supervision required in the entire processing. A certain variation in the quality of the results is thereby inevitable, and the assessment of processing quality parameters is indispensable. Furthermore, quality parameters can be used in a filtering procedure, which replaces badly retrieved pixel values with averaged concentrations of more adequate estimates in the immediate neighbourhood.

On the other hand, the simplifications we introduced lead to limitations in the reliability of the algorithm, especially for atmospheric conditions that are not accounted for in the radiative transfer model, such as thin cirrus clouds. Such effects could be corrected in manual operation to compensate for the effect on subsurface reflectance outputs. For 25 of the 90 scenes in our training data, an inadequate output of the atmospheric correction module caused bad estimates or land/water masking errors in the water constituent modules. One reason for the bad results is presumably the presence of cirrus clouds, and their occurrence is coincident with strong adjacency effects. Anyhow, since the same MIP modules were successfully used in many other aquatic environments (Germany, Finland, Italy, Armenia, Vietnam, Australia), we generally assume a very good transferability and will extend our research to other pre-alpine lakes of similar size in the future.

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Object Oriented Classification: Camargue, FR

by *Panteleimon Xofis*

Specific Methodological Aspects

Object Oriented Classification was employed for the classification of the Camargue study area, using the eCognition 4 platform (Definiens, 2006). Object oriented image analysis employs the idea of image segmentation where an image is divided into a number of objects which represent meaningful geographic features such as evergreen and deciduous vegetation, water bodies etc. A number of different algorithms for image segmentation have been developed but the recently introduced Multi Scale Segmentation (MSS), implemented in the software package eCognition (Definiens, 2006), represents a milestone in object oriented image analysis. The MSS technique offers the extraction of image objects at different resolutions to construct a hierarchical network of image objects, in which each object knows its context, its neighbourhood and its sub-objects. In addition eCognition provides an extensive set of object features beyond spectral information, such as texture, shape and context, which can be combined within the hierarchical semantic rule network for classification. EO data can be integrated with any other type of spatial data which provide either known object borders or add ancillary knowledge.

In this case, time series data were available. The images used were three SPOT 5 images at a spatial resolution of 10 m acquired in September 2005, January 2006 and June 2006 respectively. The three images were re-projected to a common projection and coordinate system and co-registered using a polynomial geometric model and approximately 15 points distributed evenly across the images.

Apart from the spectral information provided by the SPOT images, some additional indices were calculated for all scenes that were found useful for wetland classification (Ozemi & Beuer, 2002), including NDVI values and *Greenness* index calculated using the same formula as NDVI but using the Green band instead of NIR, NIR/RED ratio, Leaf Area Index and the first two Principal Components. All the available data layers were integrated (stacked) into a 30-layers image for use in the classification.

The training set was selected from a thematic habitat map provided by the local expert after converting the classification system of the thematic map to the MedWet classification system. Once the training set was selected, two different Object Oriented Classification approaches were employed for the classification of the Camargue study area. The first classification was done using the fuzzy Standard Nearest Neighbour classifier of eCognition.

The second Object Oriented Classification approach applied to the Camargue study site was based on the use of individual fuzzy membership functions for the description of each class. In this approach, each class is described through a series of membership functions which separate the class from the rest. A membership function is based on a single feature and assigns a membership value for the described class to each object to be classified. The membership value varies between 0 and 1 but because in this particular case only crisp rules were applied, the object takes either 0 or 1 as a membership value for the described class. This method performs better than Nearest Neighbour classifier when the various classes can be defined using a small number of features.

A thematic evaluation of the two classification products was performed using the thematic map provided by the local experts and some conclusions were drawn based on that evaluation.

Data sheet

The datasets used for the purposes of the present work are shown in the following table.

Case study: Object Oriented Classification, Camargue, France			
INPUT DATA			
Platform/Sensor	**Acq. date(s) / period**	**Spatial Resolution / scale**	
SPOT 5	9/2005, 1/2006, 6/2006	10 m	
ADDITIONAL GEODATA (GROUND TRUTH, TRAINING DATA)			
Type of data	**Acq. date(s) / period**	**Resolution / scale**	
CLASSIFICATION RESULT			
Class. Nomenclature	**Reached no. of classes / Class hierarchy**	**Typical working scale**	**Method of accuracy assessment**
MedWet	6	1:35,000	Error Matrix

Map product

Figure 2.45. *Classification result for the Camargue Study Area using the Standard Nearest Neighbour Classifier.*

Figure 2.46. *Classification result for the Camargue Study Area using Fuzzy Membership Functions for the Description of each Class.*

Result and Comments

The selection of a representative and complete training set is the first most important step for the successful completion of a classification project. The training set for the Camargue study area was selected from a complete and up-to-date thematic map of the area, ensuring its suitability for this classification project.

The thematic evaluation of the two classification products in relation to the original thematic map showed that the two classification approaches produced similar results which were close to the distribution of classes in the original thematic map. The various differences in the relative proportion of the various classes can be attributed to two facts. The original thematic

map included an area of approximately 8% which was unclassified while there was no unclassified area in the classification products. The second important parameter that may explain the differences between the classification products and the original thematic map is that the former referred only to the particular time period covered by the images used. The thematic map, on the other hand, was the result of a 10 year in situ inventory of the study area. Given that wetlands are ecosystems of a very dynamic nature, a variation in the land mosaic is very likely from year to year. A wet spring, for instance, would generate a different mosaic than a dry spring and summer.

A comparison of the two classification methods suggests that Nearest Neighbour classifier is a much more automated method, faster and less labour intensive than the membership functions based classification method. If the independent accuracy assessment performed by the local expert indicates that Nearest Neighbour is as accurate as the second method then it would undoubtedly be the recommended method for classification projects of a similar nature.

Regarding some general thoughts on the suitability of satellite data and state of the art methods for wetland classification, it could be said that VHSR images, at a spatial resolution of 10 m or less, are an extremely useful dataset for both segmentation and classification, achieving good spatial accuracy and a desirable thematic accuracy for MedWet classification. Very high spatial resolution data such as SPOT images could also be combined with data of a better spectral resolution, such as Landsat or ASTER, to create a comprehensive time series dataset increasing the potential to produce highly accurate and cost effective land cover maps at site or even regional scale.

Further, the combined use of high and very high spatial resolution data covering the main seasons of the year would definitely form a very useful approach in large scale habitat mapping, eg at regional and national level. eCognition and the Object Oriented image Classification is undoubtedly a very useful, easy to use tool in the hands of the ecologist and land manager in the ongoing process of land cover mapping. It needs further testing at larger spatial scales, of course, for safe conclusions to be drawn.

Object Oriented wetland habitat detection: South Aral Sea Basin, UZ

by *Peter Navratil*

Specific Methodological Aspects

This study focuses on the application of high resolution remote sensing data for the detection of common reed *Phragmites australis* dominated wetland sites. These are the main habitats of the Asiatic Migratory Locust *Locusta migratoria migratoria*, one of the most harmful locust pests in Asia. The results of this study will contribute to an effective wetland monitoring plan which embraces the concept of bio-compatible pest control by minimizing the pesticide treated area and thereby the negative impact of insect control measures on the health of the local population and biodiversity in general.

Figure 3.47 illustrates the conceptual workflow of the data processing. High resolution SPOT-5 satellite images, acquired in July 2005, were pre-processed (atmospheric and geometric correction) and analysed together with field data (vegetation mapping, Ground Control Points) from the same year. Additional indices were calculated, such as NDVI (Normalized Difference Vegetation Index) and Tasseled Cap transformation (Richards, 1995). The data were then segmented into image objects by multi resolution segmentation (Benz et al, 2004) in the image analysis software Definiens Professional 5.0 (Definiens, 2006), and a land cover map was derived containing 11 Classes according to the FAO Land Cover Classification System (LCCS).
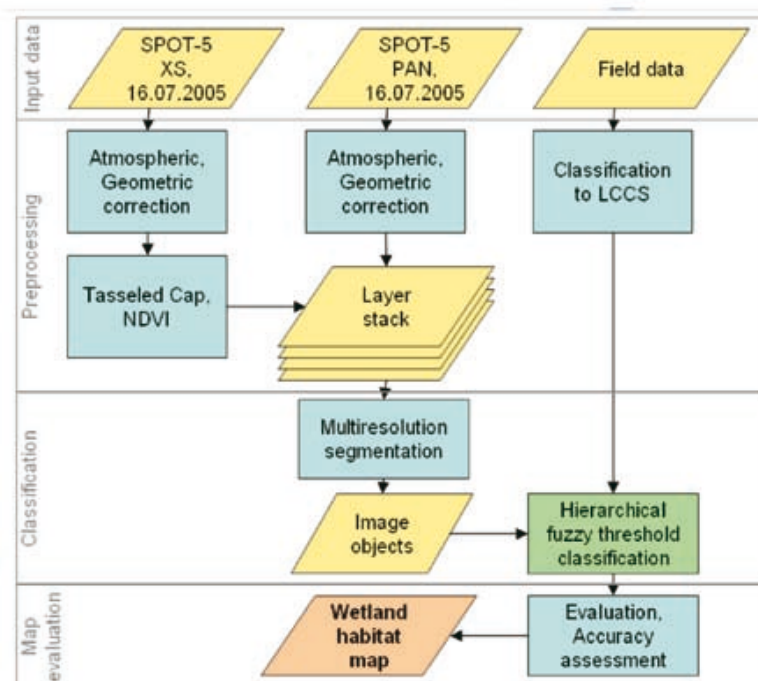
Figure 3.47. *Conceptual Workflow of the Data Processing for Object Based Wetland Habitat Detection.*

A user-defined Hierarchical Fuzzy Threshold (HFT) classification method was applied. The results have been analysed by visual quality assessment and statistical accuracy assessment (confusion matrix). In addition, the computational and labour time efforts were assessed. The objectives of this study were:

- Classification of high resolution SPOT-5 satellite images for the detection of wetland habitats in an arid environment.
- Delineation of different reed *Phragmites australis* habitats for locust control.

Data sheet

The datasets used for the purposes of the present work are shown in the following table.

| Case study: Object based wetland habitat detection, Southern Aral Sea basin, Uzbekistan			
INPUT DATA			
Platform/Sensor	**Acq. date(s) / period**	**Spatial Resolution / scale**	
SPOT-5 XS SPOT-5 PAN SPOT-5 XS	16/07/2005 16/07/2005 05/08/2006	10 m 2.5 m 10 m	
ADDITIONAL GEODATA (GROUND TRUTH, TRAINING DATA)			
Type of data	Acq. date(s) / period	Resolution / scale	
GPS Field Samples	07/2005 – 09/2005	GIS vector polygons	
CLASSIFICATION RESULT			
Class. Nomenclature	**Reached no. of classes / Class hierarchy**	**Typical working scale**	**Method of accuracy assessment**
FAO Land Cover Classification System (LCCS)	11	Universal	Confusion matrix Overall accuracy Kappa coefficient

Map product
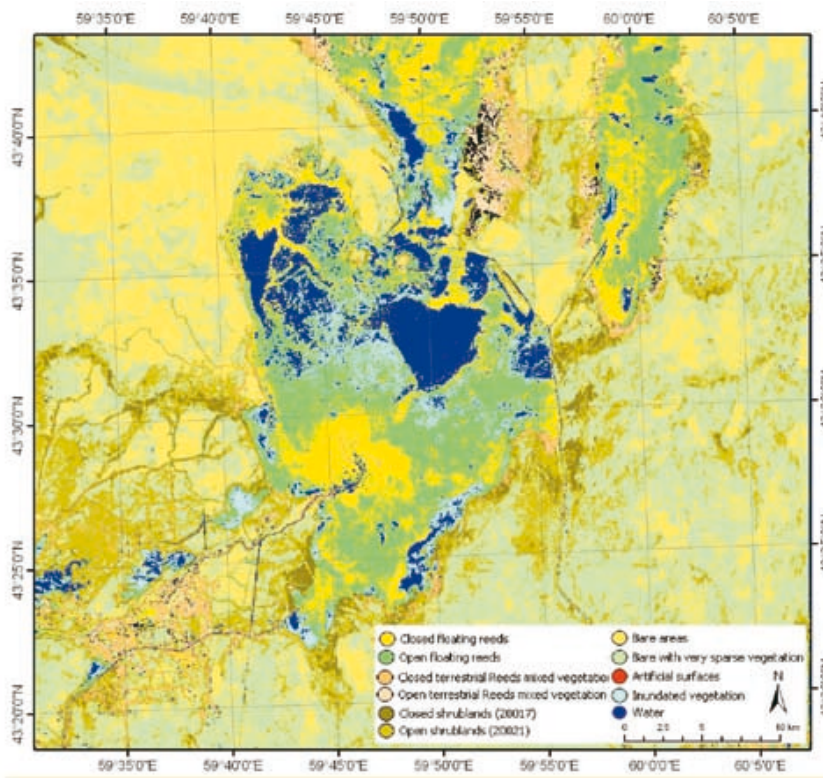
Figure 3.48. *Map Product of Southern Aral Sea basin, Uzbekistan.*

Result and Comments

Overall, the hierarchical fuzzy threshold (HFT) classification showed a good performance in terms of statistical accuracy (86.2% overall accuracy, 0.839 kappa coefficient) and map quality. Labour effort for the initial rule generation was considerably high. The interactive feature selection procedure and rule generation is time consuming, but in the end it leads to a robust classification scheme in terms of statistical and visual accuracy.

Class	Water	Closed floating reeds	Open floating reeds	Closed terrestrial reeds	Open terrestrial reeds	Closed shrublands	Open shrublands	Sparse vegetation	Inundated vegetation	Bare areas	Artificial surfaces	Total
Unclassified	0	0	0	0	0	0	0	0	0	0	0	0
Water	100	0	0	0	0	0	0	0	0	0	0	15,52
Closed floating reeds	0	100	0	0	0	0	0	0	0	0	0	6,9
Open floating reeds	0	0	100	0	0	0	0	0	0	0	0	6,9
Closed terrestrial reeds	0	0	0	85,71	16,67	0	0	0	0	0	0	12,07
Open terrestrial reeds	0	0	0	14,29	66,67	0	0	0	0	0	0	8,62
Closed shrublands	0	0	0	0	0	100	16,67	0	0	0	0	8,62
Open shrublands	0	0	0	0	16,67	0	66,67	0	0	0	0	8,62
Sparse vegetation	0	0	0	0	0	0	16,67	80	0	0	50	12,07
Inundated vegetation	0	0	0	0	0	0	0	0	100	0	0	8,62
Bare areas	0	0	0	0	0	0	0	20	0	100	0	8,62
Artificial surfaces	0	0	0	0	0	0	0	0	0	0	50	3,45
Total	100	100	100	100	100	100	100	100	100	100	100	100

Table 3.9. *Confusion Matrix representing the Class-wise accuracy of the HFT Classification* (rows: classification; columns: ground truth).

A look at the confusion matrix reveals the class-wise accuracy and the mis-classifications. The classes "Closed terrestrial reeds" are mis-classified with "Open terrestrial reeds (14.29%), while the "Open terrestrial reeds" class is confused with "Closed terrestrial reeds" (16.67%) and "Open shrublands" (16.67%). This indicates that the thresholds chosen for the discrimination of the two coverage classes of terrestrial reeds should be adjusted. The confusion of "Open reeds" and "Open shrublands" indicates that the soil signal disturbs the reflection of the vegetation which leads to difficulties in the differentiation of vegetation types. Furthermore, "Open shrublands" are mixed up with "Closed shrublands" (16.67%). This reflects one typical characteristic of the halophytic shrubs in the arid study area: even though the vegetation cover often exceeds 65% (FAO Land cover classification system [LCCS] classifier for closed coverage), the soil signal dominates in the surface reflection. This phenomenon has its origin in the leaf structure of the halophyte shrub species present. One, *Halostachys caspica*, is a succulent which has minimized leaf surface and orientates its leaves longitudinal to the direction of the sunlight in order to minimize water loss. The other, *Tamarix* sp, has relatively sparse needle-like leaves which also present a minimal surface area to the sun. In both cases, the result is that the typical spectral characteristics of vegetated surfaces are changed towards the underlying soil surface.

The good results for the wetland classes indicate that an operational use in habitat mapping is feasible. The LCCS classification structure is semantically meaningful and allowed an accurate classification. In the class descriptions, expert knowledge could be harnessed to generate a universally valid categorization making the class hierarchy easily transferable to other situations (temporal and geographic). Due to the transparent structure of the system, adoption in other study areas is possible with only minor adjustments (adjustments of threshold, inclusion of new classes). This makes the method directly applicable not only in Central Asia but also to wetland areas in arid and semi-arid environments in other parts of the world.

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Object Oriented Classification: Strymon, GR

by *Panteleimon Xofis*

Specific Methodological Aspects

For the classification of Strymon river study site a very high spatial resolution Quickbird image, acquired in May 2006, was used. The image was a pan-sharpened product of the merging between the multispectral and the panchromatic images resulting in a 0.6 m spatial resolution image. The image was geometrically corrected and re-projected to the Greek georeference system.

Apart from the four original spectral bands of the QuickBird image, a number of additional indices were calculated including NDVI, NIR/RED ratio, *Greenness* index and the first two Principal Components of a PCA which were stacked together producing a 9-band imagery.

Two different classifications were applied in the Strymon study site in two different segmentation levels where the first was generated using a low scale parameter and the second using a high scale parameter. This was done in order to identify the effect of the size of the generated objects in the classification result. This is an important parameter in Object Oriented Classification because of the scale parameter and as a result the number of generated objects affects dramatically the time required and the computer power needed for the classification.

The definition of classes was done using Nearest Neighbour while the best subset of features that define the multidimensional feature space where Nearest Neighbour is applied was found using the Feature Space Optimisation Analysis of eCognition. A post-classification processing was applied in order to further divide some classes which are spectrally similar and can only be separated based on the geographic location, eg Marine and Palustrine sand.

Data sheet

The datasets used for the purposes of the present work are shown in the following table.

| Case study: Object Oriented Classification, Strymon, Greece			
INPUT DATA			
Platform/Sensor	**Acq. date(s) / period**	**Spatial Resolution / scale**	
QuickBird	5/2007	0.6 m	
ADDITIONAL GEODATA (GROUND TRUTH, TRAINING DATA)			
Type of data	**Acq. date(s) / period**	**Resolution / scale**	
CORINE Land Classification System	2000	1:100,000	
CLASSIFICATION RESULT			
Class. Nomenclature	**Reached no. of classes / Class hierarchy**	**Typical working scale**	**Method of accuracy assessment**
MedWet	9	1:2,500	Error Matrix

Map product
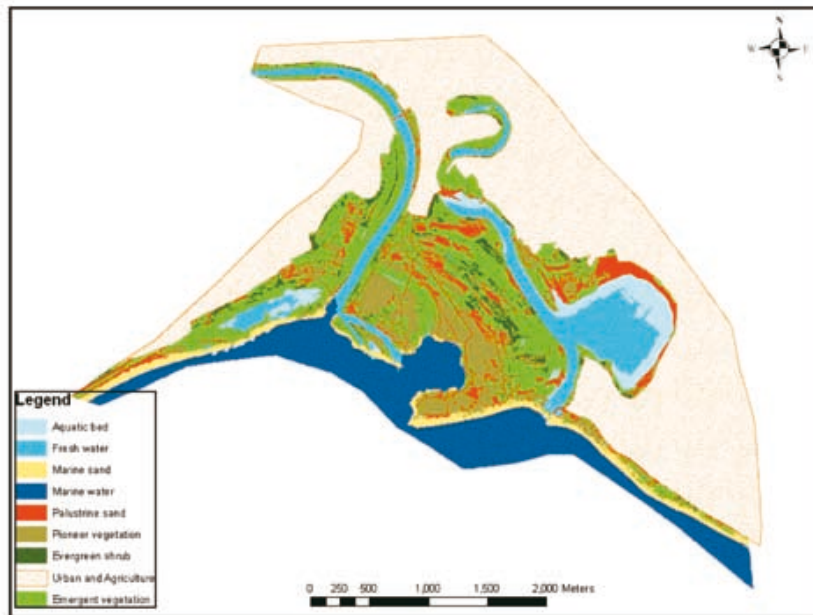
Figure 3.49. *Classification result for the Strymon Study Area using the Nearest Neighbour Classifier and 100 scale parameter.*

Figure 3.50. *Classification result for the Strymon Study Area using the Nearest Neighbour Classifier and 200 scale parameter.*

Result and Comments

The Strymon Delta study site is a rich mosaic of wetland habitats and agricultural land, and of a very dynamic nature. The landscape structure is strongly affected by each year's weather conditions and this forms a significant parameter in wetland classification approaches. In order to achieve a representative classification it is important to use time series data which can incorporate differences in weather patterns. The scope of this study, however, was to examine the effectiveness of Object Oriented Classification in classifying such a diverse landscape mosaic, rather than to detect the dynamics of the landscape.

Some of the habitats present in the study area were difficult to separate due to their very similar spectral characteristics, requiring a multidimensional feature space for their classification. The Nearest Neighbour classifier and the ability of eCognition to detect the most suitable features for the definition of the multidimensional feature space is an important advantage of the method employed. Although the final conclusions will be drawn after the independent accuracy assessment by the local expert, a preliminary accuracy assessment based on the training set showed some promising results. The training set was accurately reproduced in the classification despite the spectral similarities of some classes.

Another important advantage of the method is the ability to incorporate additional ancillary data which allows the classification of habitats based on geographic rather than the spectral features, such as different types of sand or water.

The ability to use different scale parameters in the segmentation allows for classification at various levels of detail. For instance, a fine segmentation could allow the separation of individual features within a homogenous matrix while a coarse segmentation leads to a broader classification ignoring some spatial details which may not be necessary for the demands of a given project. This is important because a coarser segmentation requires less processing time and reduces the cost of the classification.

An important parameter which was taken into account in the selection of the classification approach was the transferability of the method in different areas. All steps of the classification can be transferred, including both the classifier and the selection of the features that define the multidimensional feature space. Should time series data become available for this study area, they can be incorporated in the classification since the hierarchical scheme available in eCognition allows stepwise classification starting from broader land cover types - eg seasonally, regularly or permanently flooded areas - to finer habitats such as reedbeds, meadows etc.

Sea floor and bathymetry mapping: Rottnest Island, Western Australia, AU

by *Halina Kobryn, Matt Harvey and Thomas Heege*

Specific Methodological Aspects

Rottnest Island is a marine reserve lying 20 km offshore from Perth, Western Australia. It has a subtropical climate and, due to the south flowing, warm Leeuwin Current, many tropical as well as temperate marine species are found here. Many marine organisms are considered as isolated, at their southernmost extent. The marine reserve is mostly in shallow (less than 20 m depth) water and is made up of the following main habitat categories: sand, seagrass, mixed seagrass and reef, reef, intertidal platform and reef wash. The reef habitat (~ 45%) occupies the largest area, followed by seagrass (21%) and sand (20%) (Rottnest Island Management Plan 2003-2008). The island also has important coral communities, though not extensive in cover. Bathymetry of the waters surrounding Rottnest Island is quite varied, owing to the presence of many submerged limestone formations, favourite spots for divers and snorkellers.

QuickBird Rottnest Island data were processed using the Modular Inversion and Processing system MIP. The physical background of the multi- and hyperspectral, full transferable processing system incorporates the Finite Element Method for forward calculations of the radiative transfer in a multilayer atmosphere-ocean system (Kisselev & Bulgarelli, 2004). It is used for the atmospheric-, sun glitter-, water surface- and Q-factor- correction of the underwater light field as explained in Heege and Fischer (2004). The different programme modules support transferable algorithms. The adjustment of algorithms to sensor specifications and recording conditions is supported automatically in MIP. The inversion itself is based on a spectral matching technique.

Programme modules of MIP used for shallow water applications provide the retrieval of aerosols, pixel by pixel sun glitter correction (not needed for this scene), atmosphere and water surface corrections, retrieval of water constituents in optically deep waters, water column correction and the classification of substrates such as coral reef, seagrass, vegetation and bottom sediments (Pinnel, 2007; Heege et al, 2004). The processing system has been tested and validated in many surveys, using airborne and satellite sensors, over German inland waters and Australian coastal zones.

Aerosol concentrations are retrieved here over optical deep water areas in iteration with the water constituent retrieval. A bi-directional correction for the underwater light field is applied by use of the so-called Q- database (Heege & Fischer, 2004).

The transformation of subsurface reflectance to the bottom albedo was done here based on the equations published by Albert and Mobley (2003). The unknown input value of depth was calculated iteratively in combination with the spectral unmixing of the respective bottom reflectance. The unmixing procedure produced the sea floor coverage of three main bottom components and the residual error between the model bottom reflectance and the calculated reflectance. The final depth, bottom reflectance and bottom coverage were determined at the minimum value of the residual error. The final step of the thematic processing classifies the bottom reflectance due to the spectral signature of different bottom types and species using a Fuzzy Logic method and assignment of individual probability functions for each defined sea floor component.

Data sheet

The datasets used for the purposes of the present work are shown in the following table.

Case study: Sea floor and bathymetry mapping/ Rottnest Island, Western Australia			
INPUT DATA			
Platform/Sensor	**Acq. date(s) / period**	**Spatial Resolution / scale**	
QuickBird	17/07/2005	3 m	
ADDITIONAL GEODATA (GROUND TRUTH, TRAINING DATA)			
Type of data	**Acq. date(s) / period**	**Resolution / scale**	
Echo sounding data, provided by Western Australian Department for Planning and Infrastructure and processed by Murdoch University, Perth, Western Australia.	1985-2004	10 m	
CLASSIFICATION RESULT			
Class. Nomenclature	**Reached no. of classes / Class hierarchy**	**Typical working scale**	**Method of accuracy assessment**
A) Water depth [m], retrieved resolution up to 10 cm. B) Seafloor 7 habitat classes	A) Retrieved resolution for water depth: 10 cm. B) 5 spectral habitat classes	1 m	Direct comparison of validation points

Map products

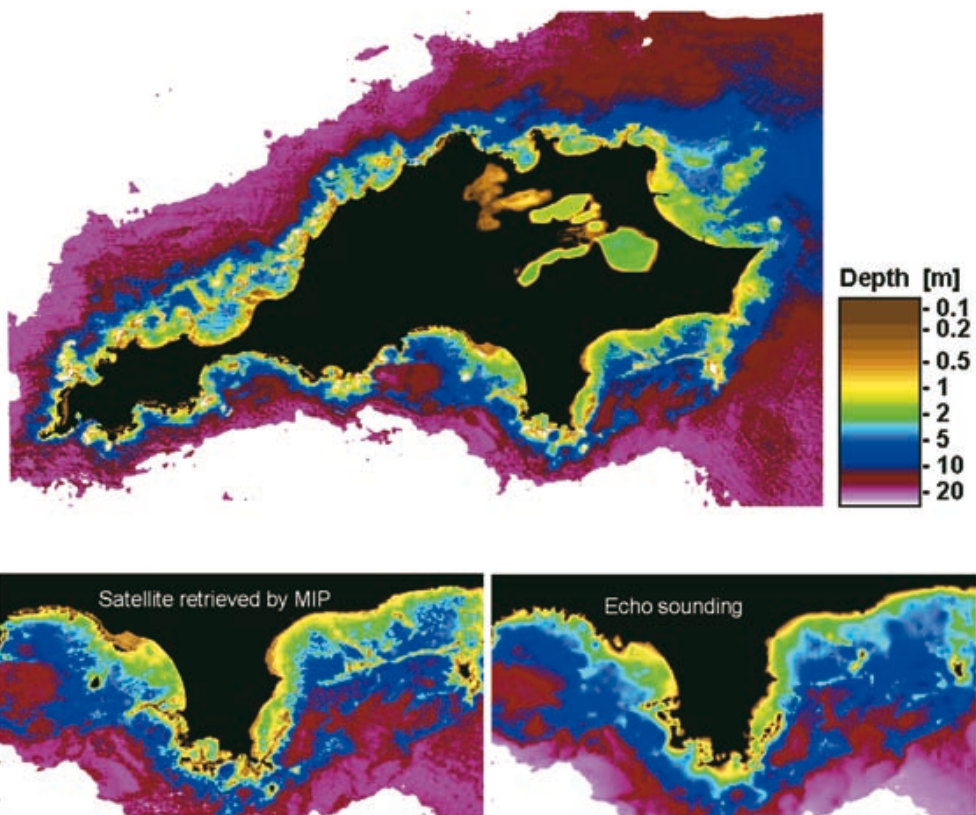**Figure 3.51.** *Rottnest Island, QuickBird, 17 July 2006.*

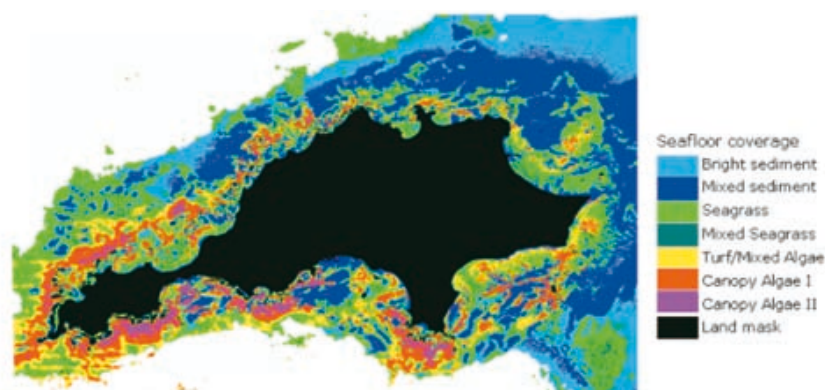**Figure 3.52.** *Depth retrieved from Satellite Data using MIP.*

Figure 3.53. *Preliminary Sea Floor Habitats retrieved from QuickBird Data.*

Result and Comments

QuickBird worked well for mapping ecologically diverse shallow reef areas. Bathymetry was determined with a relative error of 20% up to a depth of 22 m in comparison with echo sounding data (R=0.94, N=50400), but values had to be systematically re-scaled using echo sounding measurements. Other data products such as the sea floor coverage of the main benthic habitat components and the fuzzy logic-derived habitat classification gave promising results and compared well with the field-validated results from hyperspectral sensor, HYMAP (Harvey et al, 2007). All categories of algae, seagrass in water less than 15 m deep, sediments and mixed canopy algae cover compared very well with previously mapped habitats (Harvey et al, 2007). In areas deeper than 15 m, discrimination between seagrasses and macroalgae is currently not possible. Improvements may be achieved with either better sensors or additional data such as exposure and DEM-derived products.

The same processing procedure was applied successfully for multispectral QuickBird, Ikonos, Chris Proba satellite data and hyperspectral HYMAP airborne data in various aquatic systems. Applications covered inland waters - Lake Constance (Heege et al, 2004), Lake Starnberg (Pinnel, 2007), Lake Sevan (Armenia, SEMIS project) - coastal sites in the Mediterranean Sea (industrial mapping contract), Indonesia (bathymetry feasibility study for the German Aerospace Center DLR) and several sites in Australia (several research projects by Murdoch University, eg Harvey et al (2007) using a further hierarchal classification approach; and industrial mapping contracts).

REFERENCES FOR PART 3

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ACRONYMS

ALOS:	Advanced Land Observing Satellite
ANN:	Artificial Neural Networks
ASAR:	Advanced Synthetic Aperture Radar
ASAS:	Advanced Solid-State Array Spectroradiometer
ASCAT:	Advanced Scatterometer
ASTER:	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AVHRR:	Advanced Very High Resolution Radiometer
BEAM:	Basic ERS & Envisat (A)ATSR and MERIS Toolbox
BEST (ESA):	Basic Envisat SAR Toolbox
BIOTA:	Biodiversity Monitoring Transect Analysis (Africa Project)
CBD:	Convention on Biological Diversity
CCRS:	Canada Centre for Remote Sensing
CDOM:	Colored Dissolved Organic Matter
C-GTOS:	Coastal Panel of the Global Terrestrial Observing System
CLC:	Corine Land Cover
CMS:	Convention on Migratory Species
CNES:	Centre National d'Etudes Spatiales
CNR:	Consiglio Nazionale delle Ricerche (National Research Council of Italy)
CRISP:	Centre for Remote Imaging, Sensing and Processing
CSTARS:	Center for Spatial Technologies And Remote Sensing
DEM:	Digital Elevation Model
DESCW:	Display Earth remote sensing Swath Coverage for Windows
DInSAR:	Differential Interferrometric SAR
DLR:	German Remote Sensing Data Center
DNs:	Digital Numbers
DORIS:	Doppler Orbit Determination and Radiopositioning Integrated on Satellite
EC:	European Commission
EEA:	European Environmental Agency
EM:	ElectroMagnetic
ENVISAT:	ENVIronment SATellite

EO:	Earth Observation
EORC (JAXA):	JAXA's Earth Observation Research Center
EOS:	Earth Observing System
ERS:	European Research Satellite
ESA:	European Space Agency
ESDI:	European Spatial data infrastructure
ESRIN:	European Space Research Institute
ETC LUSI:	European Topic Centre on Land Use and Spatial Information
ETM+:	Enhanced Thematic Mapper plus
FAO:	Food and Agriculture Organization
FEM:	Finite Element Method
FNNs:	Feedforward Neural Networks
FORMOSAT:	FORMOsa SATellite
FTS:	Fast Track Services
GAC:	GMES Advisory Council
GAMMA MSP:	Modular SAR Processor developed by GAMMA Remote Sensing Research and Consulting AG
GCOS:	Global Climate Observing System
GCP:	Ground Control Points
GEO:	Group on Earth Observations
GEOSS:	Global Earth Observing System of Systems
GIS:	Geographic Information System
GLCN:	Global Land Cover Network
GloVis:	Global Visualization Viewer
GM:	Global Mode
GMES:	Global Monitoring and Environment Services
GNU:	GMES Network of Users
GOOS:	Global Ocean Observing System
GTOPO30:	Global Topographic Data (30-arc second resolution)
GTOS:	Global Terrestrial Observing System
HFT:	Hierarchical Fuzzy Threshold
HH:	Horizontal transmission - Horizontal reception (refers to polarisation)
HPCL:	High Performance Liquid Chromatography
HRG:	Geometric Resolution Sensor
HRS:	High Resolution Stereoscopic
HRVIR:	High Resolution Visible Infra Red Scanner

HYMAP:	Hyperspectral Mapper
Hz:	Hertz
IDL:	Interface Description Language
IEEE:	Institute of Electrical and Electronics Engineers, Inc
IF-WIAM:	Framework for wetland inventory, assessment and monitoring
IGKB:	International Commission for the Protection of Lake Constance
IGOs:	Inter-Governmental Organizations
IMAGE2006:	European mosaic based on ortho-rectified satellite imagery
IOPs:	International Organization Partners
IP:	Integrated Project
IR:	Infrared
ISPRS:	International Society for Photogrammetry and Remote Sensing
JAXA:	Japanese Space Agency
JERS:	Japanese Environmental Remote Sensing satellite
K&C:	ALOS Kyoto and Carbon Initiative
KRC:	Kernel re-classification
Landsat:	LAND SATellite
LCCS:	Land Cover Classification System (proposed by FAO)
LCCS-WCSM:	Wetlands Classification System Module in the Land Cover Classification System
LEAC:	Land and Ecosystem Accounting
LEO:	Low Earth Orbiters
LMCS:	Land Monitoring Core Service
LMCS (IG):	LMCS Implementation Group
LULC:	Land Use Land Cover
MEAs:	Multilateral Environmental Agreements
MedWet/Com:	Mediterranean Wetlands Committee
MedWet:	Mediterranean Wetland Initiative
MERIS:	MEdium Resolution Imaging Spectrometer
METEOSAT:	METEOrological SATellite
MIP scheme:	Modular Inversion and Processing Scheme
MLH:	Maximum Likelihood Classifier
MODIS:	Moderate Resolution Imaging Spectroradiometer
MS:	Member States
MSS:	MultiSpectral Scanner
NDVI:	Normalized Differential Vegetation Index

NIR:	Near-Infrared
NLC:	National Land Cover
NN:	Nearest Neighbour
NSDI:	National Spatial Data Infrastructure
NSPO:	National Space Organization
PALSAR:	Phased Array type L-band Synthetic Aperture Radar
PMWI:	Pan-Mediterranean Wetland Inventory
RADARSAT:	RADAR SATellite
RBF:	Radial Basis Function
RMS:	Root Mean Square
RS:	Remote Sensing
RSL:	Remote Sensing Laboratories
SAR:	Synthetic Aperture Radar
ScanSAR:	Scanning Synthetic Aperture Radar
SEEA-2003:	System of Environmental and Economic Accounting 2003
SEIS:	Shared Environment Information System
SEMIS:	Sub-regional Environmental Monitoring and Information System
SIOP:	Specific Inherent Optical Properties
SIR:	Shuttle Imaging Radar
SM:	Suspended Matter
SRTM:	Shuttle Radar Topography Mission
STRP:	Scientific and Technical Review Panel
SVM:	Support Vector Machines
TerraSAR-X:	German Earth observation satellite that uses an X-band SAR
TM:	Thematic Mapper
UN:	United Nations
USGS:	U.S. Geological Survey
VGT:	Vegetation
VHSR:	Very High Spatial Resolution
VV:	Vertical transmission - Vertical reception (refers to polarisation)
WISDOM:	Water-Informationsystem for the Mekong-Delta
WS:	Wide Swath