Convention on Wetlands

Ramsar

The use of Earth Observation for wetland inventory, assessment and monitoring

An information source for the Ramsar Convention on Wetlands

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The Ramsar Convention

The Convention on Wetlands, also known as the Ramsar Convention, is a global inter-governmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources. It is the only global treaty to focus on one single ecosystem.

Foreword

The use of Earth Observation (EO) provides Contracting Parties to the Ramsar Convention on Wetlands with new approaches to ensure the wise use and conservation of wetlands at the national and global levels. EO has many applications including the inventory, assessment and monitoring of wetlands. As technology advances, previous limitations of EO will be reduced, and it is anticipated that the use of EO in the management of wetlands will increase. This Ramsar Technical Report aims to provide practitioners with an overview and illustration, through case studies, on the use of EO for implementation of the Convention and the wise use of wetlands more broadly.

EO will be an increasingly important tool for the monitoring and reporting on implementation of the Ramsar Strategic Plan, indicators for the Sustainable Development Goals (SDGs), land-based Nationally Determined Contributions, under the Paris Agreement on climate change, and the Aichi Biodiversity Targets, under the Convention on Biological Diversity. Most importantly, the role of EO will be critical, as Parties fulfil their commitment to develop wetland inventories and report on wetland extent as part of their Ramsar Convention's National Reports. This is particularly relevant as these nationally validated data will be part of the reporting of Sustainable Development Goal Indicator 6.6.1 on the extent of water-related ecosystems, for which the Ramsar Convention and the UN Environment Programme are co-custodians. The case studies in this Report provide examples on how EO can be used to meet reporting requirements under the Convention (such as National Reports and the Ramsar Information Sheet (RIS)), as well as in global policy and targets.

However, effectively utilizing EO is not without challenges. Currently, available EO data is not suitable for some applications. Frequency, while improving, is still a constraint. Expertise with many wetlands practitioners in the validation, use of EO and managing data sets is lacking. The case studies illustrate how these limitations can be overcome.

The Scientific and Technical Review Panel (STRP) of the Convention has provided Contracting Parties with guidance and advice on EO over the years. As EO technologies evolve and the breadth and quality of applications increase, the Convention and the STRP stand ready to assist Parties in developing further guidance and tools to effectively use EO in implementation of the Convention and in ensuring the wise use and conservation of all wetlands.

Martha Rojas Urrego

Secretary General

Royal Gardner

STRP Chair

Summary

There is a growing awareness that data obtained from Earth Observation (EO) has the potential to provide the information needed for accurate wetland inventory, assessment and monitoring, and for updating a number of data fields in the Ramsar Sites Information Sheets (RIS). The latter includes: the physical features of the wetland, the presence and dominance of particular wetland types and factors affecting the ecological character of the wetland.

As with all current EO-based approaches, the identification of the location, extent and characteristics of any wetland may be limited by the availability of the specific data, including those related to the recognised limitations of optical imagery such as Landsat in cloud-covered tropical regions. Limitations to the use of EO for routinely deriving wetland information have included the cost of the technology, the technical capacity needed to use the data, the unsuitability of the available data for some basic applications (in particular in terms of the spatial and or temporal resolution of the data), the lack of clear, robust and efficient user-oriented methods, the absence of guidelines for using the technology, and a lack of case studies that are suitable for demonstrating how the technology can be applied in an operational manner. Other commonly reported limitations to the scaling-up and operational use of EO in wetland inventory, assessment and monitoring have included: restrictive data access policies; difficulties in discovering and accessing relevant datasets; a lack of standardisation in data analysis and applications; a lack of "fit for purpose" products; a frequency of observations insufficient to track wetlands changes at appropriate scales; the need for continuity of observations in the long-term; and insufficient training programmes for building EO capacities in the countries.

Although mapping of land cover and land uses are one of the most common uses of EO data, there are still challenges in assessing the current status and changes in wetlands over time. Monitoring historical trends and changing patterns of wetlands are complicated by the lack of medium to high-resolution data, in particular prior to 2000. While global thematic products are increasingly being made available, it should be noted that global datasets may not be able to provide the same high level of accuracy as a local scale map derived through ground surveys and the use of finer resolution (aerial, drones) geospatial data. A global area mapping exercise using consistent data and methods generally necessitates a trade-off in terms of local scale accuracy.

The advantages and limitations of EO approaches to the inventory, assessment and monitoring of wetlands in different environments is outlined through a series of case studies that address the following: i) tools and workflows, ii) global thematic datasets and iii) national scale replicable approaches available to the wetland community.

The case studies are presented as illustrative examples of the application of EO, but given a wide variance in local conditions and information needs they do not provide technical guidance for the specific application of any single approach. Such guidance is available through the agencies and organisations that are mentioned in the case studies, and through the specific references. This in itself reinforces the benefits that can accrue through a concerted and ongoing investment in local capacity and capability to apply EO in response to specific management needs. As global data sets become more readily available, the advantages of using EO for wetland inventory, assessment and monitoring are increasingly being realised, as shown through the case studies that have been presented, and it is anticipated that the usefulness of such approaches for reporting locally, nationally and internationally on the status and trends in wetlands will improve rapidly, including for reporting on wetland extent under the Sustainable Development Goals (SDGs).

Key messages

- The availability and accessibility of EO datasets suitable for addressing the information needs of the Ramsar Convention on Wetlands and wetland practitioners has increased dramatically. New capabilities in terms of spatial, temporal and spectral resolution of the data have enabled more efficient and reliable monitoring of the environment over time at global, regional and local scales. These developments provide a myriad of new opportunities for the monitoring and reporting on indicators for the Sustainable Development Goals (SDGs), Nationally Determined Contributions, under the Paris Agreement, and the UN Reducing emissions from deforestation and forest degradation scheme (REDD+), under the UN Framework Convention on Climate Change (UNFCCC).

- Previously expressed limitations in the use of Earth Observation (EO) for deriving wetland information have become less of a constraint, including: i) "the cost of the technology;" ii) lack of technical capabilities; iii) "the unsuitability of currently available EO data for some basic applications"; iv) "the lack of clear, robust and efficient user-oriented methodologies and guidelines for using this technology;" and v) "the lack of a solid track record of successful case studies that can form a basis for operational activities."
- The insufficient frequency of observations to track wetland changes at appropriate scales has been addressed through new sensors. In particular, the increasing availability of systematic and frequent satellite observations at high spatial resolution over all land surfaces and coastal areas enables better representation of seasonally and intermittently flooded areas and their changes, which are essential information sources for assessing the health of wetland ecosystems.
- The open and free data policies of government-funded satellite data, along with assurance of long-term continuity of observations, are important incentives for the Ramsar Convention's Contracting Parties and wetland practitioners to routinely integrate EO into their work.
- With the increasing availability of "analysis ready" datasets, the level of expertise required for basic wetland applications has decreased.
- Analysis ready datasets can be further analysed to derive wetland related information using freely available software toolboxes (often with open source licenses) produced through ongoing EO initiatives. In addition, an increasing number of thematic products are also being made available (at regional to global levels) which can be used to assess and monitor wetlands directly. The combination of these factors enables a shift in the use of EO for wetland inventory, assessment and monitoring away from experimental to operational.
- Data sets with improved temporal, spectral and spatial characteristics raise new challenges in handling large datasets, and in analysing long and dense time series which require new algorithms and processing chains. To face the technical challenges of accessing, processing and analysing such large EO datasets, a number of collaborative cloud computing platforms with big data analytics are currently being developed. These facilitate the discovery, access, processing, analysis and dissemination of EO data.
- While EO is an important input to wetland inventory, assessment and monitoring, knowledge of the local context and collection of in situ data remains critical for ensuring locally relevant outputs. With the development of EO methods and the sharing of information derived from global data sets, Contracting Parties to the Convention are better placed to develop inventories and to report on wetland extent, which is now part of the reporting for the SDGs.

Introduction

The Ramsar Convention on Wetlands has taken many steps to ensure the wise use and conservation of wetlands globally. This has included the development and promotion of guidance and tools for the inventory, assessment and monitoring of change in wetlands with a particular emphasis in recent years on the application of an increasing number of Earth Observation (EO) or satellite-based remote sensing approaches (Davidson & Finlayson, 2007; Mackay *et al.* 2009; Ramsar Convention Secretariat, 2010a). The role and use of these approaches described in this report are in response to a request from the Contracting Parties to the Convention for further information on tools that can be used for wetland inventory and the assessment and monitoring of change in wetlands, including those listed as Ramsar Sites (Wetlands of International Importance). This has become necessary as there is an increasing demand for information that can be readily used by wetland managers to understand and address the ongoing loss and degradation of wetlands, as well as information which can be used to address reporting requirements at the national and international scales, including reporting on the extent of wetlands as an input to the reporting on targets under the Sustainable Development Goals.

Many countries have undertaken or initiated wetland inventories using a variety of approaches (Finlayson *et al.* 2018), including making use of a range of satellite-based remote sensing tools. These include a second nationwide wetland resources survey in China, comprising general surveys of all wetlands and more specific surveys of 1,579 nationally or internationally important sites (SFA 2014); a national wetland inventory in Colombia (Instituto Humboldt, 2015) and a national freshwater ecosystem prioritisation project in South Africa (Nel *et al.* 2011). There has also been an increased level of mapping and analysis of wetlands and inundation using EO (See Papa *et al.* 2010; Niu *et al.* 2012; Reis *et al.* 2017) to provide a larger knowledge base for broader water and environmental management purposes. The availability of such data sets has increased the interest of natural resource managers in making use of the increasingly complex and data-rich EO approaches, and enabling Contracting Parties to the Convention to develop national inventories and report on wetland extent to measure SDG indicator 6.6.1.

As the purpose of this report is to provide an overview of the application of EO technologies that are currently being used to support implementation of the Convention, including contributing to its Fourth Strategic Plan (2016-2024), a number of current case studies are presented. It further draws on the Treaty Enforcement Services using Earth Observation (TESEO) project (Ramsar Convention, Secretariat, 2010a) analysis of how the information needs for the Convention could be met through the use of EO technologies. These included the needs for improved knowledge about wetlands, including a global inventory; support to ensure maintenance of ecological character; and information to enhance the implementation of the Convention. In addition to wetland inventory and baseline mapping, at the national level support is needed in the assessment of status and trends and for the implementation of management (e.g., rehabilitation) plans. Global reporting needs for wetlands have recently been extended to include those for the 2020 Aichi Targets for Biodiversity and for the Sustainable Development Goals (SDGs) (Ramsar Convention on Wetlands, 2018).

The term EO is increasingly being used to refer to the "gathering of information about ... [the] Earth's physical, chemical and biological systems," using a range of approaches and through different types of observations (e.g., ground-based, from airborne sensors, or from satellites) (Mayer, 2018). The term, however, is used in a more specific context in this report to refer to the acquisition of data through the use of satellite-based remote sensing. The term "remote sensing" refers to the acquisition of information about the surface of the Earth from a distance, a process which is typically achieved by aircraft or satellite-based sensors which record reflected or emitted energy, and the processing of these data into information and products for further use (Schowengerdt, 1997). Different types of remote sensing data are available, depending on the type and purpose of the sensor, and the portion of the electromagnetic spectrum in which it operates (The Ramsar Convention on Wetlands, 2002; Ramsar Convention Secretariat, 2010a). The utility of different remote sensing datasets for wetland inventory, assessment and monitoring is well established, in particular through the provision of site-based Land Use Land Cover (LULC) maps characterising a particular ecosystem, and the analysis of time series data (remote sensing datasets collected consistently over a particular time period) to determine Land Use and Land Cover Changes (LULCC) (Ramsar Convention Secretariat, 2010a).

This Briefing Note first provides general information on tropical peatlands and how to identify them with existing maps and data. It provides guidance on conducting inventories of tropical peatlands and possibly designating them as Ramsar Sites, taking into account their various characteristics. The accompanying *Guidelines for inventories of tropical peatlands to facilitate their designation as Ramsar Sites: Background notes* (see https://www.ramsar.org/bn9-background-notes-e) provides further details on:

The Ramsar Convention on Wetlands and EO-based approaches

Through a consistent and strategically developed set of recommendations, the Contracting Parties to the Convention have been provided with tools for maintaining and restoring the ecological character of wetlands. These have been presented within an Integrated Framework for Wetland Inventory, Assessment and Monitoring (IF-WIAM) (hereinafter the Framework), including reference to the potential use of satellite-based remote sensing technologies (Ramsar Convention Secretariat, 2010b), and to the specific application of data made available by the Japanese and the European Space Agencies (Finlayson *et al.* 2007; Fernández-Prieto & Finlayson, 2009). The role of EO technologies in supporting implementation of the Ramsar Convention on Wetlands has been investigated, but specific guidance that takes into account how advances in satellite-based remote sensing technologies can address the specific needs of the Convention has not been provided (See Mackay *et al.* 2009).

An assessment of information needs for wetland management at different levels and how EO could help fulfil them was undertaken. This included specific consideration of the requirements for mapping and delineating wetlands, undertaking wetland inventories and assessing the causes and outcomes of change as shown through ongoing monitoring and surveillance, whether at site or landscape levels, through the use of indicators that could support status and trends analyses as well as formal reporting under the Convention (Ramsar Convention Secretariat, 2018). The latter, included providing information for the Ramsar Information Sheet (RIS) for designating Ramsar sites, describing the ecological character of wetlands, and determining change in wetlands (See Mackay *et al.* 2009), including for the Aichi Biodiversity Targets and the SDGs.

The case studies presented in this report demonstrate the use of EO technologies for implementation of the Convention (Ramsar, 2002; Davidson & Finlayson, 2007; Mackay *et al.* 2009) and are placed within the conceptualisation of wetland inventory, assessment and monitoring that were incorporated into the Framework (Ramsar Convention Secretariat, 2010b). This included the following definitions:

Ecological character: is the combination of the ecosystem components, processes and benefits/services that characterise the wetland at a given point in time.

Wise use of wetlands: is the maintenance of their ecological character, achieved through the implementation of ecosystem approaches, within the context of sustainable development.

Wetland inventory: is the collection and/or collation of core information for wetland management, including the provision of an information base for specific assessment and monitoring activities.

Wetland assessment: is the identification of the status of, and threats to, wetlands as a basis for the collection of more specific information through monitoring activities.

Wetland monitoring: the collection of specific information for management purposes in response to hypotheses derived from assessment activities, and the use of these monitoring results for implementing management. The collection of time-series information that is not hypothesis-driven for wetland assessment is here termed ‘surveillance’ rather than monitoring.

Under these definitions, *wetland inventory* “provides the basis for guiding the development of appropriate assessment and monitoring”, and is used to “collect information to describe the ecological character of wetlands”, including that used to support the designation of Ramsar Sites, as recorded in the RIS (The Ramsar Convention on Wetlands, 2012). *Wetland assessment* “considers the pressures and associated risks of adverse change in ecological character”. *Wetland monitoring*, “which can include both survey and surveillance, provides information on the extent of any change” that occurs as a consequence of management actions. Wetland inventory, assessment and monitoring “are important and interactive data gathering exercises” and interlinked elements of the Framework. As there is overlap between such exercises, in particular given preferences for local and national approaches and terminology, the Framework is presented as a continuum, whereby data is gathered and used to assist wetland managers and practitioners to make decisions about their information needs, and priority management interventions to maintain the ecological character of a wetland within its wider landscape and waterscape contexts.

EO has come to be seen as a best practice tool for addressing the information gaps faced by wetland managers and practitioners. These information needs have been recognised by the Convention and its partner organisations and have covered the collection of long-term data on wetlands; the standardisation of techniques for data collection and the production of guidelines and manuals; capacity building and training; coordination of data and the effective use of networks and multiple sources of data (Davidson & Finlayson, 2007). There is

general agreement that the development of EO technologies needs to extend into operational implementation if its full potential benefits are to be realised for wetland management. In response to these needs and the rapid development of EO technologies, the usefulness of EO technologies for supporting wetland management both within the context of the Convention and more broadly has been explored (see Mackay *et al*. 2009 and Fernández-Prieto *et al*. 2006).

As advances in technologies have provided more options for gathering data and helped overcome many of the barriers that previously limited the use of these approaches (Ramsar Convention Secretariat, 2010a), there is increased interest in their application. In particular, the following previously expressed limitations have become less of a constraint: i) “cost of the technology;” ii) lack of technical capacity; iii) unsuitability of currently available data for basic applications; iv) “lack of clear, robust and efficient user-oriented methodologies and guidelines for using this technology;” and v) “lack of a solid track record of successful case studies that can form a basis for operational activities” (The Ramsar Convention on Wetlands, 2002). Further information on the advances that have been made is provided in this report through the use of case studies and practical examples, with explicit links to open access datasets and tools for replication of the approaches across different sites.

Information needs and relevant policy instruments

In addition to providing information that is applicable to the direct management of wetlands, EO can support reporting to the Convention through the triennial National Reports provided to the Convention by Contracting Parties. National Reports briefly report on activities undertaken by Contracting Parties to implement the Ramsar Strategic Plan 2016-2024. In particular, the use of EO information for wetland inventory, assessment and monitoring will support reporting on the following Goals:

Goal 2: “Effectively Conserving and Managing the Ramsar Site Network”;

Goal 3: “Wisely Using All Wetlands”; and

Goal 4: “Enhancing implementation”.

The Strategic Plan also shows the synergies that occur with the Ramsar Targets:

Target 4: “Invasive alien species and pathways of introduction and expansion are identified and prioritized, priority invasive alien species are controlled or eradicated, and management responses are prepared and implemented to prevent their introduction and establishment”;

Target 6: “There is a significant increase in area, numbers and ecological connectivity in the Ramsar Site network in particular under-represented types of wetlands including in under-represented ecoregions and transboundary sites”;

Target 8: “National wetland inventories have been initiated, completed or updated and disseminated and used for promoting the conservation and effective management of all wetlands”.

Similarly, some of the Convention on Biological Diversity’s Aichi Biodiversity Targets can be at least partly addressed through the use of EO information, specifically by informing decision-makers about progress:

Target 5: “By 2020 the rate of loss of all natural habitats … is at least halved and where feasible brought close to zero”;

Target 11: “By 2020 at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas … are conserved through … well connected systems of protected areas and other effective area-based conservation measures”;

Target 14: “By 2020, ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded”;

Target 15: “By 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks have been enhanced, through conservation and restoration”.

In this respect, the format of the Ramsar National Reports provides an opportunity to show how actions taken for the implementation of the Ramsar Convention on Wetlands also contribute to achievement of the Aichi Targets. More recently, the adoption of the 2030 Agenda for Sustainable Development by the UN in 2015 documents 17 Goals and 169 Targets

to monitor progress towards achieving sustainable development. SDGs address wetlands directly through: Target 15.1 for ensuring "the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services," Target 6.6 for the protection and restoration of water-related ecosystems and, in particular through indicator 6.6.1 which requires assessment of the "[c]hange in the extent of water-related ecosystems over time". From 2018, the Ramsar Convention is co-custodian with UN Environment of indicator 6.6.1, started reporting on wetland extent, drawing from national reports submitted by its Contracting Parties. Under the indicator, UNEP will be responsible for the internationally comparable methodology with national data (regional and global aggregations for indicator 6.6.1) and the Convention will conduct separate reporting from its National Reports. The two separate reporting lines to the SDG Global Data base for indicator 6.6.1 will have a clear delineation of the type of data in each stream. Each co-custodian will be responsible for its respective reporting line and will jointly contribute to the SDG target 6.6 storyline. A step-by-step monitoring method for the SDG indicators has been prepared and is made available from UN Water. Guidelines for Indicator 6.6.1, with a section on wetland extent, are under development.

Tools and datasets

The availability and accessibility of EO datasets suitable for addressing the information needs of the Ramsar Convention and wetland practitioners has increased significantly in the recent past. This has driven the development and implementation of various international initiatives, addressing gaps and information needs, as well as the development of tools for practitioners. This includes the GEO-Wetlands[1], a collaborative framework for international cooperation, co-designing of EO solutions and community engagement. The GEO-Wetlands initiative is part of the 2017-2019 Work Programme[2] of the Group on Earth Observations (GEO), fostering open and collaborative production and use of EO data in support of global decision making. Other initiatives are described in the case studies that are given below.

To further illustrate the application of EO technologies as a "best practice tool", a set of case studies contributing to the implementation of the Convention are presented, including information on identifying the associated data and tools available for implementation in different locations. These case studies are practical examples of how EO can support the maintenance and restoration of the ecological character of wetlands, in particular with regards to wetland inventory, assessment and monitoring. The case studies dodo not intend to provide an exhaustive list of options, but instead to demonstrate how existing EO datasets and tools can be used to address information gaps related to wetland extent and change. Each case study provides an example of either:

- freely available software and workflows designed for wetland assessments (case study 1 for site level analysis and case study 2 for regional scale analysis);
- a globally (and freely) available dataset relevant to wetlands (case studies 3 and 4); or
- a national level approach to wetland inventory, assessment and monitoring which is readily transferable to other locations (case studies 5 and 6).

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1 See http://geowetlands.org/.

2 The Work Programme can be viewed at: https://www.earthobservations.org/geoss_wp.php.

The potential for using EO products for completing information fields required for the RIS, which is used when designating wetlands as Ramsar Sites (Gardner & Davidson, 2011), are also identified where applicable within each case study. Table 1 explains the relevance of the case studies to the information needed for the designation of Ramsar Sites, based on the information fields in the RIS. The selection of specific examples was based on the information provided in each of the initiatives considered, regardless of the geographic location, in order to demonstrate the utility of current EO initiatives.

Table 1: **The relationship between different EO case studies and the information needed for the designation of Ramsar sites. The information needs are taken from the RIS.**

Information needed for RSIS Indicator	Case Study Example
Map of the site	All case studies
Geographic co-ordinates	All case studies
General location	All case studies
Wetland extent and area	Case study 1 - site scale Case study 2 - regional/national Case study 4 - global
Physical features of the site including: • seasonal water balance • water quality • fluctuations and permanence of surface water	Case study 1 Case study 3 Case study 1
Hydrological values	Case study 3
Presence and dominance of wetland types	Case study 1, 2, 4
General Ecological features Main habitats (including wetland and vegetation types): • zonation, seasonal variations, and long-term changes • current land and water use	Case study 1,3 Case study 1, 2, 3,4 Case study 1, 2
Threats to the ecological character	Case study 1

Case Study 1

Updating information on an existing Ramsar Site: the case of Lake Burullus, Egypt

In order to understand and mitigate the long and short-term adverse impacts associated with the destruction or modification of wetlands, the Ramsar Convention on Wetlands emphasises the importance of assessing the status, trends and threats to wetlands (Ramsar Convention Secretariat, 2010b). However, in many locations, lack of data is a serious constraint to the effective reporting on wetland status and trends. Conventional data are often lacking in time or space, are of poor quality, or are only available at locations that are not necessarily representative of the wetland ecosystem.

Lake Burullus in Egypt is used here as an example to illustrate the practical applications of EO for accurate wetlands assessment with a specific focus on using this information to update the RIS. The case study also identifies some of the challenges and limitations in using EO data for this purpose.

Context and ecological character

Lake Burullus is a shallow, saline lagoon along the Mediterranean coast comprising a number of "islands and islets connected with the sea by a narrow channel" (RSIS, Lake Burullus). It serves as critical wintering, staging and breeding habitat for birds, and was designated as a Ramsar site in 1988 and subsequently added to the Montreaux Record in 1990 (RSIS, Lake Burullus).

Pressures and threats

Major pressures on the wetland include reclamation for agriculture, aquaculture and urbanization. As a consequence, the site is subject to the inflow of large amounts of water contaminated with fertilizers and pesticides causing nutrient-enrichment and pollution (RIS, Lake Burullus; van Valkengoed, 2018). In addition, the freshwater inflow from the surrounding land may be declining as result of increasing demands for water for economic purposes, including the expansion of irrigated agriculture (Ibid.). This could affect the salinity and hence the ecological character of the wetland (Ibid.).

Information needs

Currently, there is no systematic way to characterize and monitor threats and impacts on Lake Burullus, and there was a critical need to update the RIS which was completed in 1992. The Ramsar Administrative Authority in Egypt, the Nature Conservation Sector under the Egyptian Environmental Affairs Agency, collaborated with the GlobWetland-II (2010-2014), SWOS (2015-2018) and GlobWetland Africa (2015-2018) projects to support the updating of the RIS and management plan for Lake Burullus with EO information about the status and trends of the wetland's ecological character (RSIS, Lake Burullus; van Valkengoed, 2018; GW-A c).

EO approach

Under GlobWetland Africa, the recent status of Lake Burullus was mapped from multi-date Sentinel-2 imagery acquired on the 1st May and 15th of July 2016 (GW-A c; van Valkengoed, 2018). Sample sites were identified through visual interpretation of very high-resolution imagery available from Google Earth, combined with a reference from the local land cover/ land use database. These datasets were used to train and calibrate a supervised classifier in order to produce a map of the spatial distribution of key wetland types and the surrounding land use (Figure 1 - top). The status mapping was complemented by an assessment of the long-term changes in Lake Burullus derived using images acquired by the Landsat mission during the 1990s and 2000s (Figure 1 - bottom).

The recent status map provides information about the presence and dominance of the main wetland types (online RIS section 4.2) while the change maps provide indications of the main threats to the sites ecological character (online RIS section 5.2). As an example, the changes within and around Lake Burullus include a sharp and steady increase in aquaculture over the period from 1990 to 2015 and 2016 (RSIS, Lake Burullus; van Valkengoed, 2018). Also, agriculture and artificial areas are showing increasing trends over the same period albeit at a more modest rate. These changes are at the expense of shoreline habitats as well as an overall decrease of salt marsh vegetation and eutrophication in the Lake due to the increased flow of wastewater (released by the large aquaculture area). Other changes include the extension of the road network and drainage channels in the vicinity of the lake.

Under GlobWetland Africa, EO data was also used to characterise the water regime (i.e., monitoring of the seasonal fluctuations and permanence of surface water inside and around a wetland site (online RIS section 4.4.4), which is an important part of the site's physical features (Figure 2).

Water quality is another physical feature which can be observed remotely. In the case of Lake Burullus, however, EO-based detection of water quality parameters is a challenge. The benthos in shallow waters, and a large extent of macro-algae, influence the signal received by the satellite sensor and can be misinterpreted as chlorophyll concentration in the water column if simplistic algorithms are used (GW-A c).

Resources for users

While many different types of EO data can be used to support land use mapping, high spatial resolution data are required for detailed wetland assessments. The examples in this case study all used data from the Sentinels and/or Landsat missions, because of the free and open data policies of the agencies responsible for their operation and product publication. EO-based land use and land cover classification and change (LULCC) mapping is supported by a wide range of open source and proprietary software. In particular, open source toolboxes such as the GeoClassifier and the GlobWetland Africa Toolbox have LULCC processing workflows designed specifically for wetland applications.

Figure 1

Example of a recent wetland status assessment of Lake Burullus in Egypt derived from multi-date Sentinel-2 imagery, acquired in 2015 to 2016, and a long-term change assessment, derived from Landsat imagery, acquired over the period from 1990 to 2010 *(Source: GlobWetland Africa (GW-A))*.

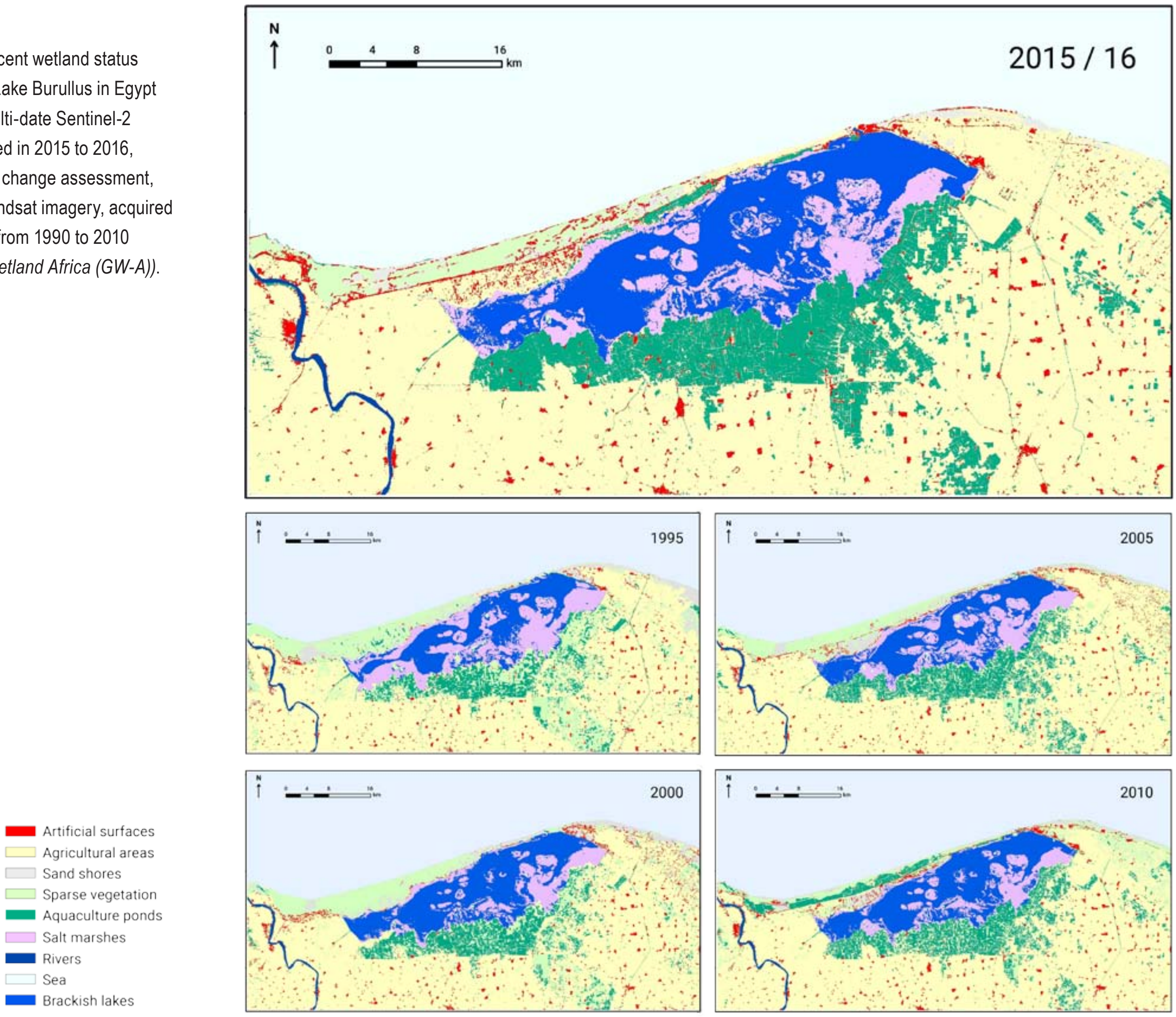
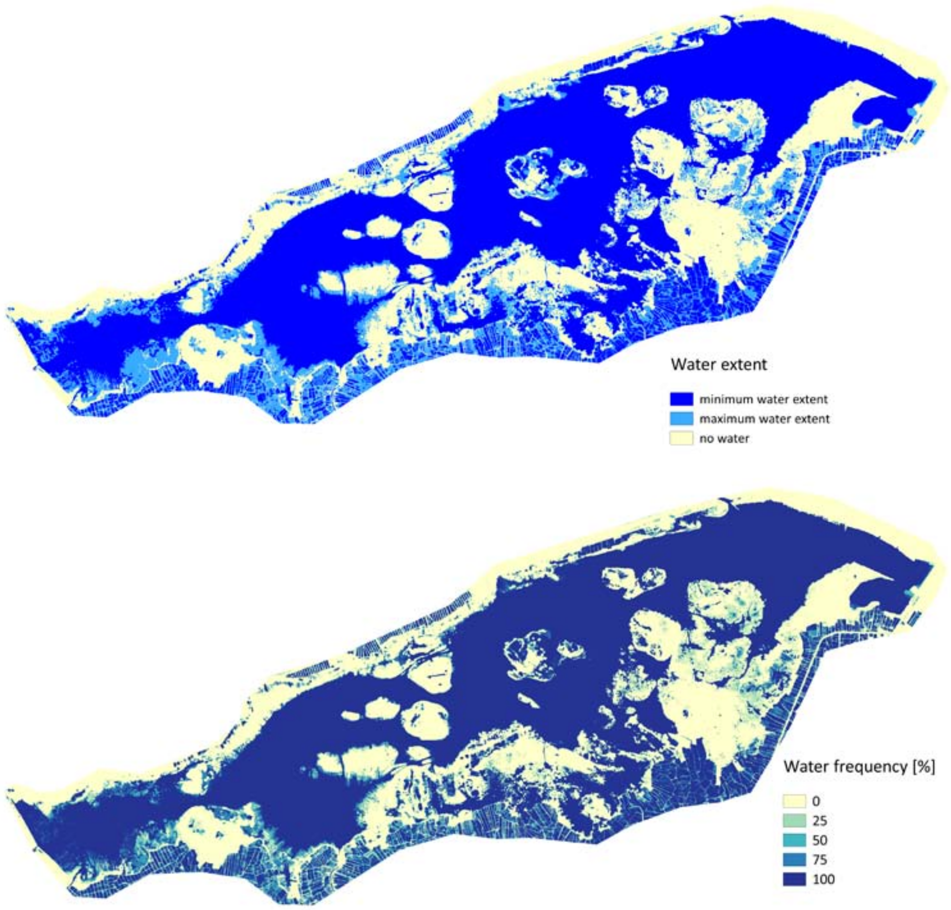


Figure 2

Minimum and maximum water extent (top) based on Sentinel-1/2 satellite imagery considering all data from January 2016 until June 2017. The illustration shows that temporary water mainly occurs in aquaculture and agricultural areas, and hence it is more strongly associated with man-made water control rather than natural seasonal fluctuations. The water frequency (bottom), based on monthly measurements, illustrates the water level change in more detail. *(Source: GW-A)*.



Benefits and Limitations

The case study from Lake Burullus serves to illustrate how EO can provide standardised and comparable geo-information products about the status and trends of a wetland's ecological character, facilitating the integration of remote sensing into the conservation and management of wetlands. All maps have been shared with the Nature Conservation Section of the government in Egypt for review with the intention of using the maps as the basis for updating the RSIS on Lake Burullus.

Although mapping LULCC and surface water are some of the most common uses of EO data, there are still challenges in assessing the current status and changes of wetlands over time. Monitoring the historical trends and changing patterns of wetlands is complicated by the lack of medium to high-resolution data, in particular prior to 2000. Historical optical data is available from Landsat and SPOT missions; however, persistent cloud cover in certain regions renders much of these data unusable. Distinguishing between permanent and temporary surface water and wetlands can therefore be difficult considering the available historical data. It is further noted that the authors recommend that for complex environments with different wetland types in situ data or local knowledge is critical to support the analysis of the EO data, and is sometimes the only way to obtain information on certain wetland types.

Case Study 2

EO for regional or national assessments: Mediterranean coastal wetlands

EO data has the unique advantage of enabling the study and assessment of a large number of wetlands, as well as the sampling of broad regions. It facilitates the assessment of multiple wetland sites in a consistent way, using the same methods. The example provided below illustrates practical applications of EO for wetland status and trends assessments at a regional scale (i.e., the Mediterranean). It addresses several data fields on the RIS including wetland extent and area (online RIS section 2.2.4), the presence and dominance of wetland types (online RIS section 4.2) and general ecological features (online RIS section field 4.1).

Context and Ecological character

The Mediterranean region includes the 28 countries of the MedWet regional initiative of the Ramsar convention (MedWet). The region has important delta wetlands, such as Doñana in Spain, the Camargue in France, and the Nile delta in Egypt, as well as large inland salt lakes (Chotts and Sebkhas in North Africa), oases, temporary ponds and marshes (MWO, 2012). The status and health of these areas depend on climate variability, which leads to large inter-annual fluctuations in ecosystem extent and functions.

Pressures and threats

The Mediterranean is one of the regions with the highest pressure on water resources globally (MWO, 2012; MWO 2018; United Nations, 2016), and thus on wetlands. This pressure is especially high in coastal areas, which attract most of the residential, tourism and infrastructure developments in MedWet countries (Plan Bleu, 2009). Agriculture and the destruction of wetlands to fight malaria (elimination of mosquito breeding sites) have also been historically key driving forces for wetland loss. As a consequence of these various and changing pressures, wetlands have been lost in the region for at least the past 2,000 years (Finlayson *et al.* 1992), and the trend continues today.

Information needs

Until recently, there was no means to document regional extent and trends of Mediterranean wetland status. In order to provide regional initiatives, such as MedWet, and treaties, such as the Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention), an overview of the current situation and information on recent trends (post-1975) was derived from EO data. In 2014, the Mediterranean Wetlands Observatory undertook, as part of the GlobWetland II project of the European Space Agency (ESA), an analysis of a sample of coastal Mediterranean wetlands in order to quantify their change in extent (See MWO, 2014). A similar analysis was undertaken in all metropolitan Ramsar Sites in France in 2015-2016, demonstrating that the approach is also possible at a national scale (Perennou *et al.*, 2016).

EO approach

The assessment of the status of 214 coastal Mediterranean wetlands, including Ramsar Sites, Important Bird Area (IBAs) and other important wetlands, was based on a series of Landsat images from 1975, 1990 and 2005. Field validation was carried out, either directly on the ground to validate the wetland types identified from EO data, or by checking with existing local, high resolution land-cover maps. A supervised classifier (i.e. a partly automatic, partly human-mediated process) was used for mapping the spatial distribution of key wetland types and land use within the 214 sites, which encompassed both wetland and dryland habitats. Figure 3 summarizes the results for wetland habitat surface areas in the 214 sites, overall, and Figure 4 provides an example the changes on one specific site.

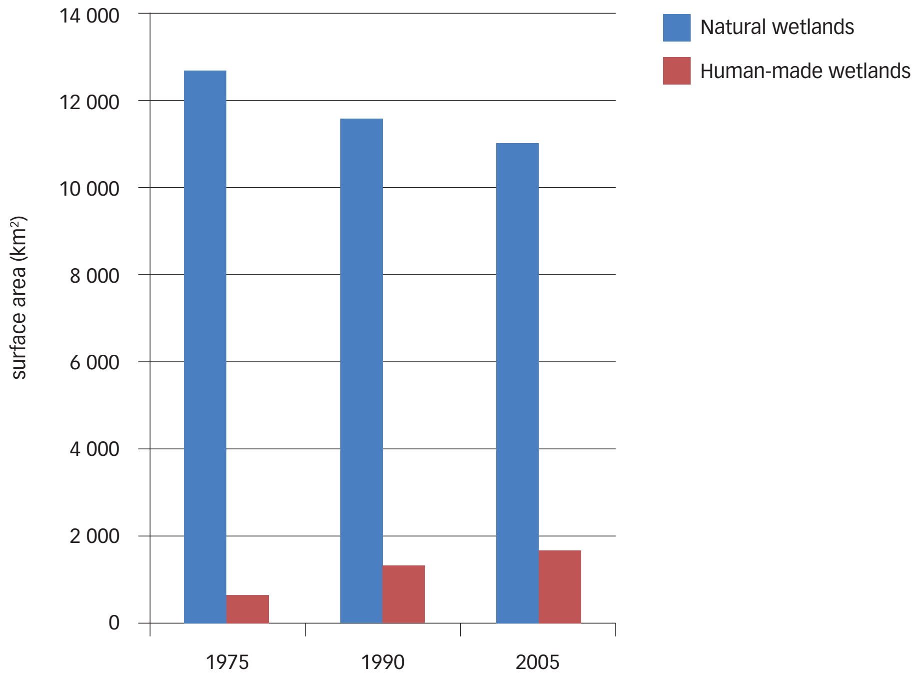


Figure 3
Evolution of natural and human-made wetland habitats within a sample of 214 coastal Mediterranean sites. Natural wetland habitats lost 13 percent of their surface area within 30 years (1624 km²). Human-made wetlands gained 157 percent (1039 km²). *Source: MWO ongoing work, adapted from MWO, 2014.*

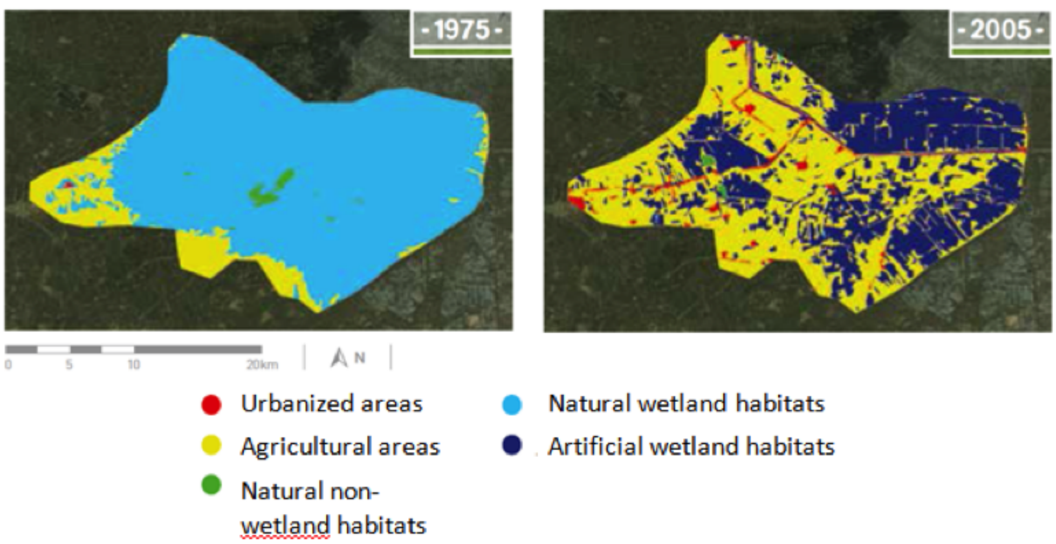


Figure 4
Change in land-cover in the Sinnéraé and San EIE-Hagar Site in the Nile Delta, Egypt. Natural wetland habitats have largely been converted to man-made ones, as well as to farmland, between 1975 and 2005. *Source: MWO, 2014.*

Resources for users

Many satellite data types can support land use mapping. For detailed wetland assessments, high spatial resolution (i.e., small pixel size, ideally 30 x 30 m or less) data is required (e.g., MWO, 2014). In this case study, Landsat data were used because of the free and open data policies and the availability of a historical archive (dating back to the 1970s). From 2015 onward, the Sentinel images are available (ESA). For both the Landsat and Sentinel data, specific processes to identify land-cover changes have been designed specifically for wetland applications, and embedded in the GlobWetland II Toolbox, currently being upgraded to the SWOS toolbox, which will be available in late 2018 (Osenga, 2016). The SWOS toolbox is a free-of-charge collection of 22 tools for analysis of optical satellite data. It is available as stand-alone software and as an ArcGIS toolbox (SWOSb). A QGIS version is being developed in the framework of the SWOS project. The tools range from pre-processing (geometric and radiometric correction), segmentation and classification of images, to change detection and labelling, as well as indicator calculation. The software is continuously being improved (SWOSb).

Benefits and Limitations

The limitations are essentially the same as those found at the single-wetland scale, and described in the Burullus case study (see above), with the addition that analysis of such a large area required dividing the work between different EO specialists which resulted in differences in the interpretation of results between sites. These were overcome, however, through a careful quality control of the overall site maps including, in some cases, through a full re-analysis of the images (Perennou *et al.*, 2018). Mapping land-cover changes eventually led to a regional overview which was considered acceptable given the images available.

The lack of enough exploitable images from any one particular year has been a problem mainly in developing assessments for the earlier period (1975). Specifically, lack of seasonal data makes it difficult to reliably separate habitats (e.g., rice fields), but it is a decreasing limitation now that satellite return time has greatly increased (Perennou *et al.*, 2018). However, it still hinders retrospective analysis, although a historical perspective based on comparisons with the 1970s to 1980s would be desirable in many cases.

These analyses have proved useful for MedWet countries. They demonstrated that wetland loss in the region continues, despite all countries being Contracting Parties to the Ramsar Convention. Therefore, a key recommendation based on the outcome of the analysis is that national policies on wetlands need to be consolidated, implemented and strengthened.

Case Study 3

EO for monitoring lakes and reservoirs - Lake Victoria and Lake Volta

This case study provides examples of how EO can contribute to the inventory, assessment and monitoring of a large transboundary lake and a reservoir, using Lake Victoria and Lake Volta as examples. With regards to the RIS, the EO methodologies described in this case study provide information for measuring water quality, and for showing the main habitats, zonation and seasonal changes.

Context and Ecological character

Lakes and reservoirs are water bodies that are often highly productive and biologically diverse ecosystems (Schindler, 1978). Lakes have played a crucial role in shaping culture and driving local and regional economies for centuries. Although reservoirs are essentially human-made lakes, they support different sets of processes and ecosystem services (Millennium Ecosystem Assessment, 2005). Both lakes and reservoirs are important for water regulation, freshwater supply, fisheries and navigation. In addition, reservoirs may provide hydropower, and both reservoirs and lakes enable irrigation. At the same time, reservoirs affect the river ecosystem by fragmenting it and changing the flood regime and nutrient cycle, impacting wetland ecosystems and societies downstream. (McCully, 2001; Richter *et al.*, 2010). In a Ramsar context, lakes and reservoirs are classified as one of the following inland wetland types: i) permanent freshwater lakes over 8 hectares (O), ii) seasonal/intermittent freshwater lakes (P), or pools below 8 hectares (Tp), or as human made wetlands: i) water storage areas (6) (The Ramsar Convention on Wetlands, 2012).

Lake Victoria, the second largest freshwater lake in the world, is a transboundary lake, with shores in Uganda, Kenya and Tanzania (Ledang & Odermatt, n.d.). It is part of the Nile basin. The Ramsar Convention has emphasized the obligation of Contracting Parties to cooperate in the management of wetlands that cross international boundaries, pursuant to Article 5 and Article 3.1 of the Convention (The Ramsar Convention on Wetlands, 1994). In this respect, EO can support information collection, inventory and assessment of wetland values and functions. Extensive wetlands and connected lakes can be found along the shores of Lake Victoria, five of which have been designated as wetlands of international importance (RSIS).

Lake Volta is a major reservoir located entirely in Ghana. It was completed in 1965 with the main aim of providing electricity to the country through hydropower. The lake is fed by three major tributaries: the Black Volta, Red Volta and White Volta rivers (AQUASTAT, 2005; ESAb).

Pressures and threats

A wide range of pressures threatens the ecological character of lakes, reservoirs and the basins they are part of. Examples include the over extraction of water, eutrophication, pollution, ill-advised water infrastructure, sedimentation, overfishing and invasive species.

Lake Victoria has suffered from land use change, particularly deforestation, as well as agricultural intensification in its catchment (Ledang & Odermatt, n.d.). This has led to increased siltation and eutrophication in parts of the lake, which in turn caused algal blooms, fish death events and the further spread of invasive species such as water hyacinth (Ibid.). Although less relevant to a remote sensing case study, the lake's very rich and unique biodiversity is also under pressure since the introduction of Nile perch and Nile tilapia, two species that were introduced in the late 1950s for commercial fisheries (Ibid.). Wetlands at the shores of the lake are under threat from land use change and drainage for agricultural purposes (Birdlife International, 2013).

Lake Volta suffers from decreased water availability through changed rainfall and runoff patterns upstream (Gyau-Boakye, 2001). Downstream, the changes in sedimentation and flooding patterns caused by the hydropower dam, have led to an invasion of aquatic weeds, lower fish catch, lower agricultural production on former floodplains, and higher prevalence of water-related diseases like Schistosomiasis (Gordon & Amatekpor, 1999).

Information needs

Good wetland management practices require up-to-date and high quality information. Both case studies require a wetland inventory, and EO can provide information with regards to the delineation, physical features of the site and catchment, as well as wetland types, wetland dominance and ecological features. Ecological character description for lakes and reservoirs will also require information on water dynamics, like water level, water extent, seasonality and water quality. Aspects of trends and changes in the ecological character of lakes and reservoirs that EO can measure include water dynamics trends, such as water levels, change in extent, and change in seasonality and water quality. To effectively manage a transboundary wetland like Lake Victoria, information, management practices and governance need to be harmonised between authorities.

EO approach

EO is a suitable technology to meet information needs with regards to water level, extent, seasonality, temperature and quality parameters, as well as temporal aspects like surface water dynamics and water quality changes. To delineate a lake or reservoir, open water extent can be mapped using different approaches, based on passive (Huang, 2018) or active (Bioresita, 2018) types of sensors. The combined use of optical and radar sensors facilitates monitoring the dynamics of aquatic ecosystems by exploiting the respective advantages of both types of sensors and by increasing the observation frequency for a particular location. Tools that jointly use radar and optical data to map the inundation regimes of wetlands are available on both the SWOS and GlobWetland Africa Toolboxes. Two global high-resolution datasets on water extent, change and seasonality are available from the European Union's Joint Research Centre and from Deltares.

Figure 5
Inter-annual water recurrence between 1984 and 2015 in the Black Volta tributary of Lake Volta with water recurrence ranging from never (bright orange) to annually (bright blue) *(EC JRC/Google, 2016).*

Spaceborne altimeters are a type of radar, used to measure ocean height variations, but can also be used to measure the height variation of any large water body (ESA, 2018). Jason-3 is a spaceborne altimeter mission used to derive maps of water body height to an accuracy of approximately 3 cm (Figure 5 and 6). Although altimetry data processing is a specialist task, for many large lakes and reservoirs there is water level variation data readily available through the NASA/USDA funded Global Reservoirs and Lake Monitor. ESA's new Sentinel-3 also has an altimetry sensor on board, which will deliver a wealth of information once operational due to its global coverage, as opposed to the narrow transect-like coverage of earlier altimeters.

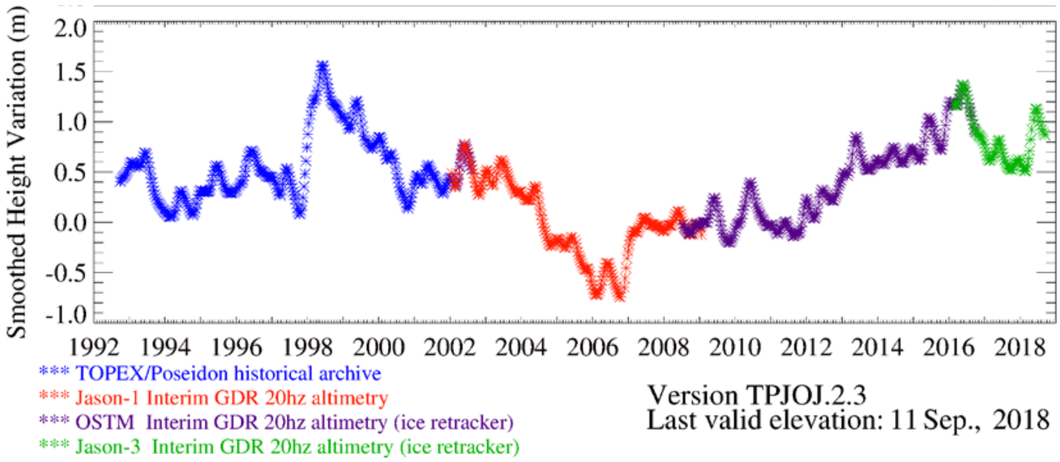


Figure 6
Long-term water level variation in Lake Victoria as measured by consecutive spaceborne altimeters *(USDA Global Reservoirs and Lakes Monitor (6))*.

Many water quality parameters are difficult to measure from space, but some key parameters for inland water quality that EO can measure, and which can be used to describe the ecological character and assess or monitor a wetland, include chlorophyll-α concentration (Figure 7), suspended matter concentration, dissolved organic matters, cyanobacteria blooms and surface water temperature (Gholizadeh *et al.* 2016). These parameters are proxies for eutrophication, disturbance and contamination. The method and tools are suitable for advanced users only and calibration using local data is crucial for good results.

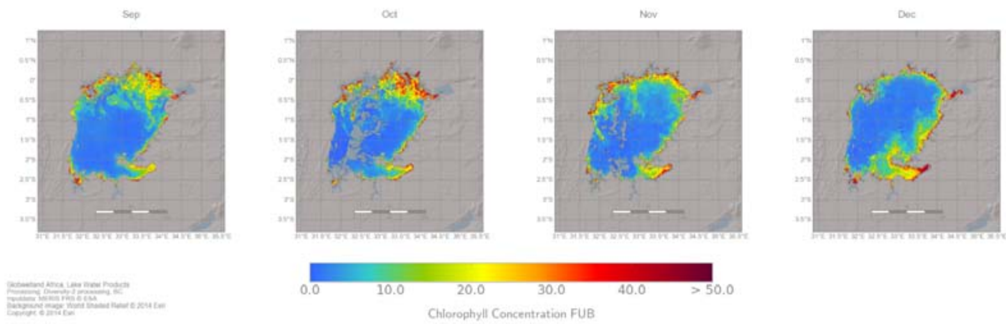


Figure 7
Time series of chlorophyll-α concentration (FUB algorithm; Free University of Berlin) for Lake Victoria in 2008. The chlorophyll concentration maps can be used as a proxy for phytoplankton abundance and algal biomass, an indicator of eutrophication (note: Grey areas represent land and/or clouds). Image produced using MERSIS data. *Source: GlobWetland Africa.*

Beside surface water temperature, which has an accepted accuracy at a sub-degree level, EO-derived water quality parameters are intrinsically difficult to validate, as they strongly depend on the specific lake environment and suitable *in-situ* data for validation is lacking for most lakes. Still, the general experience of applying EO to derive water quality is that outputs tend to be in accordance with expected spatiotemporal patterns and comparing well to published numbers (Gholizadeh, M. H. *et al.*, 2016). In summary, EO-based water quality should not replace *in-situ* networks (availability of *in-situ* data is essential to calibrate and validate the retrieval algorithm), but may complement them, offering cost-effective solutions. EO-based water quality products represent in fact an up-scaling in space and time of the conventional field measurements and may capture the spatio-temporal variability of critical lake water quality parameters more accurately than ongoing monitoring programs.

Resources for users

A number of resources are available for users. The toolboxes developed by the SWOS project[3] and the GlobWetland Africa project[4] provide tools and guidance for the delineation of

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3 See: http://swos-service.eu.

4 See: http://globwetland-africa.org/.

wetlands as well as open water body extent. Further, they contain tools for mapping water dynamics over time. Tools for the assessment of water quality are provided by the Diversity II project,[5] as well as the SWOS and GlobWetland Africa toolboxes mentioned above.

The Global Reservoir and Lakes Monitor[6] freely provides near real-time, high accuracy water level information for many large lakes and reservoirs. Global high-resolution maps of surface water occurrence, change, seasonality and recurrence have been produced by the EU Joint Research Centre and made available in the Global Surface Water Explorer.[7] Dutch research institute Deltares has produced a 30-year time-series of surface water change and made this available via the AquaMonitor.[8]

Benefits and Limitations

As demonstrated, an EO approach is particularly useful to get relevant information on water extent, water level, changes and seasonality. However, the adoption of a particular EO approach needs to be tailored to the area of interest to provide the data and information expected. One relevant difficulty is the mapping of floating vegetation and flooding below vegetation canopies (Rosenqvist *et al.* 2007). These are difficult to detect using optical and/or C-band SAR alone. L-band SAR data such as ALOS 2 might be helpful for such purposes, but this represents an advanced approach and the data are not freely available and need to be purchased. The use of G-REALM radar altimeters which currently have limited coverage is expected to be improved with data from Sentinel 3 for surface water levels, lake surface temperature and other water quality parameters. The water quality tools and methodologies are quite advanced and to measure water quality parameters in absolute values, as opposed to relative values, extensive ground-truth information from the same period and time as the EO data is required for calibration.

Case Study 4

EO for mangrove mapping and change assessment

The example provided below illustrates the practical applications of EO for mapping the extent or area of mangroves and their changes over time. It also shows how data can provide information on the presence and dominance of mangroves within a site.

Context and Ecological character

Mangrove swamps are forested intertidal ecosystems that are distributed globally between approximately N32° to S39°. They are classed under *Marine/Coastal Wetlands* (Intertidal forested wetlands, type I) in the Ramsar Classification System for Wetland Type (The Ramsar Convention on Wetlands, 2002; Lucas *et al*., 2014). Mangroves perform critical landscape-level functions related to the regulation of freshwater, nutrients and sediment inputs into marine areas. They help to control the quality of marine coastal waters, and are of critical importance as breeding and nursery sites for birds, fish, and crustaceans. Nearly two thirds of all fish harvested globally in the marine environment ultimately depend on the health of tropical coastal ecosystems (Lucas *et al*., 2014). Mangroves receive large inputs of matter and energy from both land and sea, and constitute important pools for carbon storage (Lucas *et al*., 2014).

Pressures and threats

Once abundant along the world's tropical and subtropical coastlines, mangroves are in decline at a rate similar to that of terrestrial (natural) forest, with about four to five percent of the global coverage lost during the past two decades (FAO, 2015). Significant drivers of change include removal for aquaculture, agriculture, energy exploitation and other industrial development (Thomas *et al.* 2017), with an unknown proportion of the remaining mangroves fragmented and degraded. Mangroves are also sensitive to climate change effects such as sea level rise, temperature extremes and geographic range, and changes in hydrology.

Information needs

Information on the state and change trends of mangroves at both national and global levels is limited. This is due in part because mangroves often fall between the national jurisdictions of

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5 See: http://www.diversity2.info.

6 See: https://ipad.fas.usda.gov/cropexplorer/global_reservoir/.

7 See: https://global-surface-water.appspot.com/.

8 See: http://aqua-monitor.deltares.nl/.

wetlands and for forestry, and in part because of their often remote and inaccessible locations, which make periodic mapping and monitoring by conventional means costly and time consuming. Starting in 2018, Ramsar Contracting Parties have been required to report on the change in the extent of water-related ecosystems over time (SDG 6.6.1), which includes mangroves (Ramsar Convention on Wetlands, 2018). Mangroves are furthermore categorised as forests within the UN Framework Convention on Climate Change's REDD+ (reducing emissions from deforestation and forest degradation in developing countries, and the role of conservation, sustainable management of forests, and enhancement of forest carbon stocks in developing countries) scheme (IUCN 2017), and should therefore be included in national emissions reports.

EO approach

An example of an operational EO-based national-scale system for mangrove mapping and monitoring is the Sistema de Monitoreo de los Manglares de México (SMMM) (Mexico's mangroves monitoring system). The SMMM, which begun in 2005 and is undertaken every five years, is based on manual rendition by expert interpreters of 10 meter resolution optical (SPOT-5) satellite data. Approximately 130 SPOT scenes are required for a national coverage of Mexican mangroves (CONABIO, 2018). The resulting mangrove maps are at 1:50,000 scale with a minimum mapping unit (MMU) of one hectare (Idem.). The maps are validated by use of very high resolution aerial (helicopter) photographs. To minimise interpretation errors and to assure consistency between maps from the different epochs, updates are performed by change interpretation compared to the map from the previous epoch (CONABIO, 2018, Rodríguez-Zúñiga *et al.*, 2012).

A national mangrove monitoring system such as the SMMM, which is based on interpretation of high resolution geospatial data by a team of local experts, is of course the preferred approach when financial and staff resources are available. When such resources are not at hand, however, the use of available global mangrove datasets can provide a practical substitute or starting point.

Global maps of mangrove extent have been generated for the time period 1997-2000 by the United States Geological Survey (USGS) (See Giri *et al.* 2011), derived from 30 meter resolution optical satellite (Landsat) data, and for the time period 1999 to 2003 by the International Tropical Timber Organisation (ITTO) and the International Society for Mangrove Ecosystems (ISME) (See Spalding *et al.* 2010), based on a combination of optical satellite data and national statistics, processed by the UN Environment World Conservation Monitoring Centre (UNEP-WCMC) or the Food and Agriculture Organisation of the United Nations (FAO). For a number of countries, existing (WCMC-012 (1997)) or newly available (vector) data were incorporated. Both datasets are available in the public domain and provide a comprehensive picture of the geographical distribution of the world's mangroves at the turn of the millennium.

A time series of maps of the global mangrove extent has been generated within the framework of the Global Mangrove Watch (GMW) (Bunting *et al.* 2018). The GMW is an international collaborative project established within the framework of JAXA's Kyoto & Carbon Initiative science programme and Wetlands International's Mangrove Capital Africa programme. It was set up to provide geospatial information about mangrove extent and changes to wetland practitioners, decision makers and NGOs.

The time series of maps is based on the 25 meter resolution global mosaic data from the Japanese radar satellites (JERS-1, ALOS and ALOS-2), and optical (Landsat) satellite data. The radar mosaics, Landsat data, and the mangrove maps derived from these are all publicly available at no cost.[9] Amongst the advantages of using satellite radar is the capacity of the microwave (radar) signals to penetrate clouds and haze, which often is a limiting factor in cloud-prone coastal zones and in regions affected by extensive and persistent fires, such as Sumatra and Kalimantan in Indonesia. Thus, maps derived from radar sensors can be generated within a narrow time window of typically a few months, which is preferred to minimise seasonal effects when comparing observations over several years. One of the strengths of optical satellite data, on the other hand, is that it has a better ability to distinguish between different vegetation types and therefore provide more accurate distinction of the mangrove landward border (Bunting *et al.* 2018).

The GMW has produced to date (October 2018) maps of global mangrove extent (Figure 8a) for seven epochs: 1996, 2007, 2008, 2009, 2010, 2015 and 2016, from which corresponding change maps can be derived (Figure 8b). The 2017 map will be released in late 2018,

9 Radar mosaics can be accessed at: https://www.eorc.jaxa.jp/ALOS/en/palsar_fnf/data/index.htm and Landsat data can be accessed at: https://landsat.usgs.gov/landsat-data-access.

and annual maps are foreseen after that. For Ramsar Sites, these datasets provide the information needed to describe wetland extent and area, the presence and dominance of mangroves in a site and the general ecological features (zonation, seasonal variations and long-term changes) (GMW).

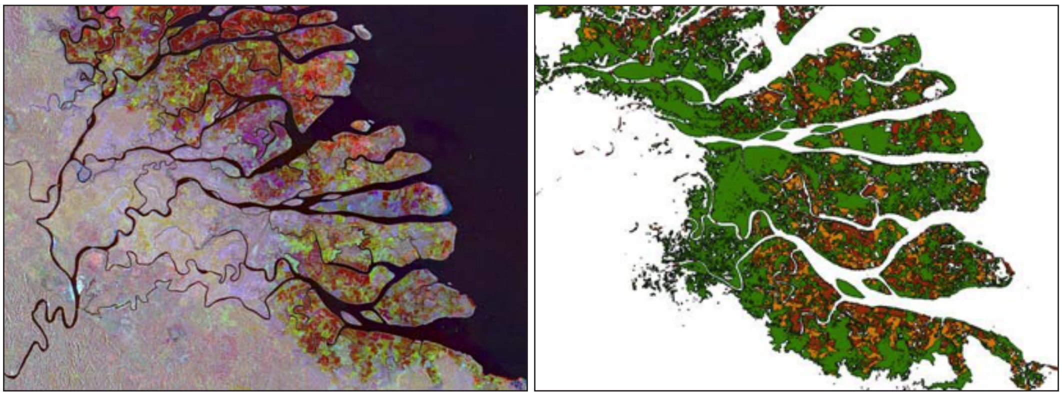

Figure 8
Kahan River Delta, North Kalimantan, Indonesia.
8a (left) Multi-temporal radar image composite (1996 JERS-1 SAR and 2016 ALOS-2 PALSAR-2);
8b (right) Mangrove extent and changes; red – mangroves lost 1996-2007; orange – loss 2007-2016; green – mangrove cover in 2016. © *JAXA/METI.*

Resources for users

All of the mangrove maps referred to in this example are available in the public domain (see Table 2).

Table 2: **Information on the maps used for mangrove mapping and assessment**

Base year	Base data	Source	Reference	Available at
1996	JERS-1 SAR (radar) 1996	Global Mangrove Watch	Bunting *et al.* 2018	https://www.globalmangrovewatch.org/datasets/ UNEP-WCMC Ocean Data Viewer
2000	Landsat (optical) 1997-2000	USGS	Giri *et al.* 2011	http://data.unep-wcmc.org/datasets/4
2000	National statistics, Landsat (optical) data 1999-2003	ITTO/ ISME	Spalding *et al.* 2010	http://data.unep-wcmc.org/datasets/5
2007 2008 2009 2010	ALOS PALSAR (radar) 2007-2010 and Landsat (optical) 2010	Global Mangrove Watch	Bunting *et al.* 2018	https://www.globalmangrovewatch.org/datasets/ http://data.unep-wcmc.org/datasets/45
2015 2016	ALOS-2 PALSAR-2 (radar) 2014-2016	Global Mangrove Watch	Bunting *et al.* 2018	https://www.globalmangrovewatch.org/datasets/ http://data.unep-wcmc.org/datasets/45

Benefits and Limitations

EO provides an effective means for periodic mapping and monitoring of mangroves over regional to global scales, and in a uniform manner where the same type of data and classification algorithms are used over all areas and over several epochs. This enables a more consistent comparison of extent between different countries and regions, and analysis of change trends over time, than comparing data obtained from different sources.

It should, however, not be expected that global datasets, such as the ones described above, can achieve the same high level of accuracy everywhere as a local scale map derived through ground surveys and the use of very high spatial resolution geospatial data, such as the Mexican SMMM mentioned above. A global area mapping exercise using consistent data and methods (although supplemented with ground-based data for calibration and validation) generally requires a trade-off in terms of local scale accuracy. Nonetheless, global maps can be improved locally (or nationally) by adding improved information (*in-situ* data and aerial or drone data) for training and re-classification.

All satellite data and classification software[10] used within the GMW are free and open source. Non-experienced users can use GMW maps as provided and experienced users may replicate or improve classifications using improved local information.

Case Study 5

EO for national wetland inventory

To date, many national wetland inventories are largely site-based compilations of wetlands considered important for different reasons (such as those qualifying for designation as Ramsar Sites). However, such inventories do not cover the whole set of national wetlands. Many individual, small wetlands may not have been quantified, but taken together they form a major component of this habitat and deliver significant functions and ecosystem services. The approach described here, developed for a comprehensive national wetland inventory for Myanmar under a Myanmar-Norway wetland wise use initiative, capitalises on the increasing availability of interpreted remotely-sensed data-layers to first assess the size and distribution of all wetlands in the country. This, then, sets the context for the identification of those wetlands considered nationally and internationally important to inform implementation of national wetland policy.

Context and Ecological character

Comprehensive wetland inventory has been repeatedly recognised by the Ramsar Convention as an essential variable that is pre-requisite for the wise use of wetlands, through the management of human activities and maintenance of the wetland ecological character (Ramsar Secretariat, 2010a).

Without knowledge of where wetlands are in a country, and what sort of wetlands they are, decisions affecting wetlands may not contribute to delivering their wise use. As well as providing a sound knowledge-base on the overall size and distribution of the Myanmar wetland resource, the inventory will also support identification of the full suite of internationally important Myanmar wetlands as candidates for future Ramsar Site designation.

Pressures and threats

With recent changes in the political situation in Myanmar and the opening up of the country, economic development pressures are rapidly increasing. Numerous drivers of change to the ecological character of Myanmar wetlands are recognised in Myanmar's National Wetland Policy (4th draft, August 2017) (McInnes *et al.* 2016). These include invasive species, overfishing and illegal fishing, silt deposition, drainage and reclamation, overgrazing, agricultural land expansion, saline intrusion, desiccation, bird-trapping, illegal settlement, expansion of aquaculture, pollution, mining, hunting, catchment deforestation, erosion and damming of pristine rivers. Underlying causes of these drivers are considered to be: increasing resource demand from population growth and rapid economic growth; a large number of economically disadvantaged people relying heavily on natural resource exploitation; climate change; weakness of environmental safeguards; limited public and governmental awareness; and poor coordination of, and impact assessment of, development activities.

Information needs

A 2004 site-based Myanmar wetland inventory covered 99 wetlands in parts of Myanmar, but a full inventory is lacking. The Myanmar government has recognised that a comprehensive national wetland inventory is a high priority for enhancing their Ramsar implementation capacity (McInnes *et al.* 2016).

The Myanmar inventory needs to include all types of wetlands (inland and coastal, as well as natural and human-made) covered by the scope of the Ramsar Convention. Importantly, this includes the extent and distribution of nearshore shallow marine wetlands (to a permanent inundation depth of 6 metres), an important Ramsar wetland type which has seldom, if ever, been covered by national wetland inventories (Finlayson *et al.* 1999).

10 See: https://rsgislib.org/.

EO approach

The Myanmar wetland inventory forms a component of a major Myanmar project, *Conservation of biodiversity and improved management of protected areas in Myanmar* and its *Action Plan for the delivery of improved management and wise use of valuable wetlands*, started in 2016 and supported by the Government of Norway (McInnes *et al.*, 2016).

The method is a phased approach, with phase one (2016 to 2018) consisting on accessing and overlaying as wide a range as possible of spatial data layers relevant to wetlands (McInnes *et al.* 2016). These include: a Digital Terrain Model (DTM) from the Shuttle Radar Topography Mission (SRTM), HydroBasins for drainage basins, river networks and lakes, coastal bathymetry data and MODIS 2012 land cover data, along with new data layers as they become available, such as Landsat-based land cover mapping from the International Water Management Institute (IWMI), mangroves from JAXA's GMW, intertidal areas from the University of New South Wales and various data layers held by the Myanmar Government (Ibid.).

Overlain on these national-scale wetland-related data resources are a number of spatially organised sources, with boundary shapefiles, where available, which identify important wetlands. These sources include the 1989 Asian Wetland Directory, the 2004 Myanmar inventory, Important Bird and Biodiversity Areas (IBAs), Key Biodiversity Areas (KBAs) and other published sources for specific wetlands (Ibid.).

The inventory is being generated using the ArcGIS software, and is a combination of collating data in existing ArcGIS format and digitizing wetland areas from satellite imagery where very little spatial information is given, such as just a central latitude-longitude point or an aerial extent between two or more latitude-longitude points. Other data in raster format (i.e., a grid of equal sized pixels), such as the MODIS land cover data are being analysed so that specific land cover units are extracted (e.g., water bodies), compared with satellite imagery and the full extents digitised from the location of the unit pixels. Some areas without any existing mapping will be derived using surrogate data. For example, wetlands which are seasonally flooded by rivers are being identified from a flood extent modelling routine within ArcGIS based on the underlying DTM.

Additionally, spatial eco-regional information overlays (Marine Ecoregions of the World (See Spalding *et al.* 2007) and Freshwater Ecoregions of the World (See Abell *et al.* 2008) covering Myanmar will support identification of internationally important wetlands under Ramsar Site designation Criteria one and three.

The datasets will be classified into specific wetland classes such as rivers, natural lakes, man-made lakes, paddy fields, seasonally inundated areas, peatlands, mangroves, mudflats and coral reefs (McInnes *et al.*, 2016). The numbers and total area for each class will be summarised by the Myanmar region, fresh water or marine ecoregion area, and main drainage basin area (Ibid.).

Following phase one, there will be further phases (2019 onwards) to: a) reconcile discrepancies in spatial distributions of wetlands from different sources and b) establish a strategy for, and ground-truthing of, selected wetlands to cover all regions of Myanmar and all types of wetlands represented in the country (Ibid.).

A further phase is to analyse the compiled spatial data to report on the size and distribution of the overall Myanmar inland and coastal wetland resource and of different wetland types, with identification of particularly important wetlands within this overall resource (Ibid.).

Resources for users

The Myanmar wetland inventory will be delivered as an online GIS-based national wetland inventory, hosted and managed by the Myanmar Ministry of Natural Resources and Environmental Conservation (MONREC), and made accessible to users.

The spatial inventory will be supported by a site-based inventory database to be developed and aligned with the structure and content of the RIS.

Benefits and limitations

The inventory will provide an improved wetland knowledge base resource for government officials in their future decision-making on wetlands and their wise use, as well as supporting the work of NGOs and civil society concerned with the conservation and wise use of wetlands. It will contribute directly to improving the parallel ongoing work in Myanmar to develop a national strategy and priorities for identification and future designation of Ramsar Sites.

It is anticipated that the Myanmar wetland inventory approach could be readily transferable to other countries needing to undertake (or update) comprehensive wetland inventory. An example of expected outputs is presented in Figure 9.

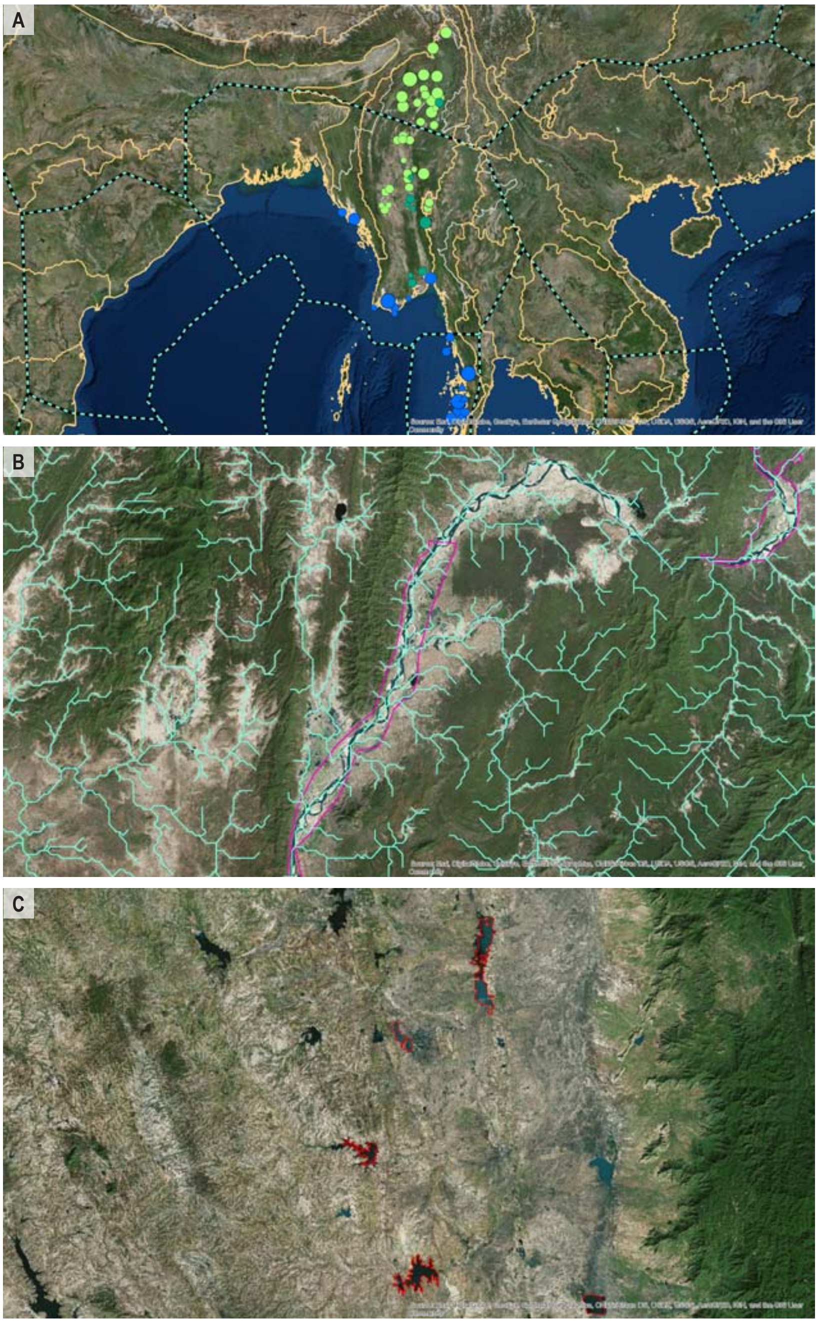

Figure 9
Three examples of preliminary products from the Myanmar wetland inventory.
A). Location and size of actual and potential internationally important wetlands (green = inland; blue = coastal; compiled from multiple sources) overlain with Marine (blue dotted lines) and Freshwater (yellow lines) Ecoregions. Note the lack of any identified important inland wetlands in the eastern part of Myanmar;
B). Part of the Myanmar river network, with river reaches identified by previous site-based inventories shown as red polygons;
C). An area of Myanmar Lakes, with lakes identified in previous inventories shown as red polygons.
© Myanmar-Norway wetland wise use project.

Case Study 6

EO for tropical peatland mapping

This case study provides an example of a best practice for a national level approach to EO-based mapping of tropical peatland extent and peat depth. The approach described here was selected as the best methodology to measure the extent and depth of peat in Indonesia in the framework of the Indonesian Peat Prize and was developed in direct support of the Indonesian Government's One Map Policy.

Context and Ecological character

Peat, characterized by dense, wet layers of dead and partially decomposed organic matter built up over thousands of years, can be found in many tropical ecosystems but Indonesia is home to the largest peat swamp forests in the world. Tropical peatlands store large amounts of carbon, current estimates indicate that they cover an area in the range of 39 to 66 million hectares with a total peat carbon pool of 82 to 92 Gigatones (Gt), of which 65 percent is located in Indonesia (Page *et al.* 2011). Peatlands are often drained for agriculture and plantations, which leads to bacterial decomposition of the peat and high vulnerability to burning (Jaenicke *et al.*, 2008). Natural peatland ecosystems have a wealth of ecological and hydrological functions such as retention of water, flood regulation, protection against seawater intrusion, storage of carbon, support of high levels of endemism, and as a retreat for endangered species (Page & Rieley, 1998). Peatlands are of global importance and listed in the Ramsar Classification System for Wetland Types as Non-forested peatlands and as Forested Peatlands (The Ramsar Convention on Wetlands, 2012).

Pressures/Threats

Although many peats are still in a natural state, many others are drained and degraded. Such disturbances significantly reduce peatlands capability to store or sequester carbon and lead to the emissions of large amounts of Greenhouse Gases (GHGs). Peat is a major source of GHG emissions when it burns or decomposes (Page *et al.*, 2002; Ballhorn *et al.*, 2011; Hooijer *et al.*, 2012; Jauhiainen *et al.*, 2012). It is estimated that in 2015, peatlands were responsible for 42 percent of Indonesia's total emissions; approximately 1.62 billion metric tons of GHG emissions have been released by forests and peat fires, and the total costs for the Indonesian economy were estimated at USD 16 billion[11]. Due to their high sensitivity to disturbances and their enormous amount of stored carbon, very high emissions can occur from small areas. But this also means that peatland conservation and restoration can be very effective climate change adaptation and mitigation measures, even in small peatland areas.

Information needs

Information on the location, extent and condition of peatlands is limited, fragmentary and based on a variety of mapping approaches. In addition, information on peat depth is scarce, even though it is a key variable for determining the impact of disturbance through drainage and fire. Uncertainty around data and information on peatland, particularly the depth of peat, has delayed protection and restoration measures for Indonesia's peatlands, often resulting in peat drainage and fires. The Indonesian Peat Prize was, therefore, created by the Geospatial Information Agency (BIG) in response to the lack of accurate and up-to-date information around peatlands in Indonesia (Indonesian Peat Prize). BIG will start a standardization process by issuing a regulation on peatland mapping that serves Indonesian government's One Map Policy. This will also address the information needs for SDG reporting (SDG 6.6.1, which includes peatlands), the UNFCCC REDD+ scheme regarding national GHG emission reports, as well as Indonesia's NDCs relating to peatland restoration.

Earth Observation approach

Since most tropical peatlands are difficult to access, field mapping of peatlands is a considerable challenge at regional, national and global scales (Ballhorn *et al.* 2011; Jaenicke *et al.* 2008). A combination of field measurements and remote sensing can provide map products of peatland extent and peat depth with an optimal balance between comprehensive coverage, reasonable accuracy and quantifiable uncertainties (Lawson *et al.* 2014).

Whereas the presence of peat cannot be assessed directly by remote sensing, various sensed features give a fair indication of the presence of peatlands. Four key features that distinguish tropical peatlands from surrounding dryland forest, which are detectable with the help of airborne and space borne remote sensing data, have been identified (Lawson *et al.* 2014):

- low vegetation diversity;
- distinctive vegetation structure;
- distinctive topography/elevation; and
- high water table.

Any of the four key features individually is not sufficient to definitely identify peatland areas, but a combination of two or more leads to much clearer identification (Draper *et al.* 2014). Based on the underlying six principles of accuracy, affordability, speed, simplicity, scalability and adjustability, a multistage approach was developed, using multiple remote sensing, including passive and active instruments, and *in-situ* datasets. The final methodological framework was designed in a way that all input datasets are scalable and adjustable to specific mapping requirements. Figure 10 shows the workflow of the proposed methodological framework.

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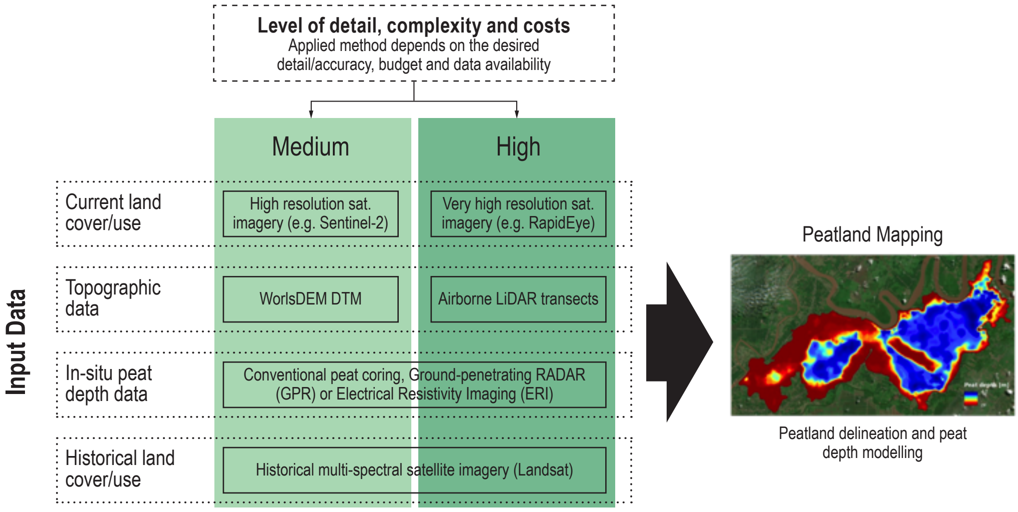
11 See: https://www.wri.org/news/2018/02/release-indonesian-peat-prize-announces-winner-1-million-international-peat-mapping

Figure 10
Methodological framework. The approach has two phases: collection and processing of input data (left: current land cover/use, topographic elevation data, *in-situ* peat depth data and historical land cover/use), which then goes into peatland mapping, including peatland delineation and peat depth modelling. An increase of detail and accuracy together with a decrease in uncertainty leads to an increase of costs and methodological complexity.



Optical satellite imagery with medium to very high resolution is the primary data source for mapping land cover and land use. Whereas Landsat data is used for the historical assessment, higher spatial resolution data from new generation sensors are used for the current land cover assessment (e.g., Sentinel-2, RapidEye or other very high resolution data depending on the level of required detail). Peat depth is modelled using the peatland outline, the topographic elevation data, the *in-situ* peat depth data and spatial interpolation. The method is following assumptions for typical dome-shaped ombrogenous peatlands:

1. Dome-shaped peatlands tend to have a biconvex cross section resulting from their formation in more or less basin-shaped depressions in the landscape as well as different rates of peat accumulation in the dome centre as compared to the margins (Rieley & Page, 2005).
2. Peat depth along peat dome margins is 0.5 m (Jaenicke *et al.* 2008). In addition, 0.5 m is the minimum thickness used in the Indonesian system of peat classification (Radjagukguk, 1997; Rieley & Page 2005).

Based on these assumptions, the combination of topographic elevation and *in-situ* peat depth data allows to model peat depth using different interpolation approaches. A tool was developed in the open source statistical software package R incorporating different interpolation approaches to choose from. The freely available script is easy to use, as it only requires the peatland outline, the remotely sensed topographic elevation data and the *in-situ* peat depth measurements to derive a ready to use and cross-validated peat depth model of the area.

Resources for users

Information about the Indonesian Peat Prize and the selected methodology can be found on the official website.[12] EO-based land use and land cover classification and change (LULCC) mapping is supported by a wide range of open source and proprietary software. The free and open data policies regarding Landsat[13] or Sentinel data[14] allow for cost-free land cover assessments. Low cost higher resolution data such as RapidEye[15] can be used for small peatlands that require higher resolution assessments. Regarding topographic data, the presented methodology used the WorldDEM Digital Terrain Model (DTM),[16] as this has the best cost-benefit ratio for the developed peatland mapping approach. The R script for interpolating peat depth and the final report of the methodology will be available online soon. For global data overview, the Global Wetlands Map from CIFOR is an initiative to collect and share information on tropical wetlands in a visual format, where users can access data and contribute their own data[17].

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12 See: http://indonesianpeatprize.com/.

13 See: https://landsat.usgs.gov/.

14 See: https://sentinel.esa.int/web/sentinel/home.

15 See: https://www.planet.com/.

16 See: http://www.intelligence-airbusds.com/worlddem/.

17 See: http://www.cifor.org/global-wetlands/

Benefits and Limitations

Comprehensive and reliable national spatial data on peatlands is often scarce and spread within various national authorities (e.g., ministries for agriculture and forestry, etc.). Even though the presence of peat cannot be assessed directly by remote sensing, various sensed features are used to map peatlands. The existing available range of EO data allowed for the development of an effective methodology for mapping the extent of peatlands and for the quantification of peat on a national scale. It can fill the existing information gap through periodic mapping and monitoring of peatlands from local, to regional to national scales. As with all EO-based approaches, adequate ground data has to be collected, to validate the derived maps, which is often difficult to access and expensive.

Once this approach becomes a standard in the Indonesian National peat mapping regulation, it will allow for a more consistent assessment and comparison of peatland information. The EO-based peatland mapping approach can support the information needs for reporting in the context of SDG indicators, UNFCCC REDD+ and Indonesia's NDCs relating to peatland restoration.

Current limitations and future developments

Limitations in the use of EO for routinely deriving wetland information have included: the cost of the technology; the technical capacity needed to use the data; the unsuitability of the data available for some basic applications (in particular in terms of spatial resolution); the lack of clear, robust and efficient user-oriented methods and guidelines for using the technology; and a lack of solid track record of successful case studies that could form a basis for operational activities. Other commonly stated obstacles to the scaling-up and operational use of EO in wetland monitoring were: restrictive data access policies, difficulties to discover and access relevant datasets, the lack of standardisation, the lack of "fit for purpose" products, a frequency of observations insufficient to track wetlands changes at appropriate scales, the need for continuity of observations on the long-term and insufficient training programmes to build capacities in the countries.

Over the past fifteen years a great deal has changed in this field with the emergence of open and free access policies to publicly-funded satellite data (such as the United States Government decision in 2008 to give free and open access to the entire Landsat archive) and new generations of EO satellites with increased spatial and temporal resolution (such as the Sentinels of the European Copernicus program), resulting in ever expanding and increasingly comprehensive global archive of data suitable for environmental applications.

There are still, however, a number of challenges that need to be addressed to fully leverage these developments. Effective use of EO in an operational context could be improved by:

- Increasing cooperation between ecologists, hydrologists and remote sensing experts in the implementation of wetland inventory and assessment programs;
- Developing more systematic and consistent guidelines and protocols for wetland mapping processes; and
- Implementing systematic quantification of uncertainties needed for more accurate assessment of the reliability of the EO-derived products;

At the same time, extensive research and development is leading to new approaches and tools, increasing the potential to deliver the information needed by Contracting Parties to the Ramsar Convention. The opening of data archives and the move of data providers towards increasingly open data policies, alongside the advancement of information and communication technology, means that barriers to data access and analysis of large datasets are constantly being lowered. Access to cloud computing infrastructures and storage facilities as well as the development of big data analysis tools are making it more straightforward to access and analyse large EO datasets. In addition, space agencies have recently been prioritising efforts to further improve access for potential users by providing analysis ready data, which opens up the use of EO to a wider audience than ever before, lowering the technical capacity needed to extract at least basic information from the data.

A number of EO research priorities need to be addressed including the development of solid and scientifically sound approaches for: wetland inventory, the separation of wetlands from inundated areas, mapping flooded areas under dense vegetation, distinguishing the natural hydrological variability from long term trends, adequately mapping "difficult" wetland habitats such as wet meadows, assessing the wetland use intensity and assessing the value of historical satellite archives for conducting retrospective studies on wetland change.

Guidelines for the use of new emerging global data sets such as the Global Mangrove Watch from JAXA and the Global Surface Water Explorer from JRC in a national context, and the integration of field based assessments and validation to complement the use of the EO data are required in order to avoid misinterpretation at the local scale.

Conclusions

In addition to providing information that is directly applicable to the management of wetlands, EO can support national reporting to the Ramsar Convention by Contracting Parties and for implementing the Fourth Ramsar Strategic Plan 2016-2024, as well as reporting under the SDGs and NDCs. EO information can be used for wetland inventory, assessment and monitoring, especially as the availability and accessibility of suitable datasets has increased dramatically in recent years. In particular, EO can provide standard and comparable geo-information about the status and trends of the ecological character of wetlands.

EO provides an effective means for periodic mapping and monitoring over national to regional and global scales, and in a uniform manner where the same type of data and classification algorithms are used over all areas and over several epochs. This enables a more consistent comparison of extent between different countries and regions and analysis of change trends over time, than comparing data obtained from different sources.

It should, however, not be expected that global datasets can achieve the same high level of accuracy everywhere as a local scale map derived through ground surveys and the use of finer resolution (aerial, drones) geospatial data. A global area mapping exercise using consistent data and methods generally necessitates a trade-off in terms of local scale accuracy.

Although mapping of land cover and land uses are one of the most common uses of EO data, there are still challenges in assessing the current status and changes in wetlands over time. Monitoring historical trends and changing patterns of wetlands is complicated by the lack of medium to high-resolution data, in particular prior to 2000.

EO data has the unique advantage of enabling a large number of wetland sites, or even broader regions encompassing many wetlands, to be analysed in a homogeneous way, using the same methods. Wetland assessments may be of interest to Contracting Parties at a national scale, or for supra-national agreements at regional or continental scales.

Many of the technical barriers which previously limited the use of EO data have been reduced or overcome. Open data policies are making data more accessible, and the development of open source and open access toolboxes are reducing software licensing costs. These changes have resulted in the rapid development of methods and automated processing approaches. The increasing availability of cloud computing facilities has enabled EO data archives to be more readily exploited to assess past changes and establish baselines.

While a global wetland inventory or a single, large scale monitoring system for wetlands, which would allow for assessments of both the current status and long-term changes in wetlands, has yet to be implemented, various global, high resolution datasets, which document the extent and change in specific wetland types, have recently been released and made publicly available.

An increasing number of collaborative efforts in the field of wetland science are ensuring continued exploitation of EO data and advances in the field of wetland science. (EO, ecology and conservation, among others) and between different sectors (science, governance/policy, management and industry, among others), as well as to increase the availability and accessibility of EO based data and knowledge.

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Glossary[18]

Analysis Ready Data: Earth Observation (EO) data that have been processed to a minimum set of requirements and organized into a form that allows immediate analysis without additional user effort and interoperability with other datasets both through time and space

Article 3.2 Reporting: Under Article 3.2 of the Convention, Parties are expected to report to the Secretariat any changes or threats to the ecological character of their listed wetlands and to respond to the Secretariat's inquiries about such reports received from third parties.

Change in ecological character: refers to the "the human-induced adverse alteration of any ecosystem component, process, and/or ecosystem benefit/service" (See also Resolution IX.1, Annex A)

Contracting Parties: are countries that are Member States to the Ramsar Convention on Wetlands, 169 as of January 2016. Membership in the Convention is open to all states that are members of the United Nations, one of the UN specialized agencies, or the International Atomic Energy Agency, or are Party to the Statute of the International Court of Justice.

Ecological character: is "the combination of the ecosystem components, processes and benefits/services that characterise the wetland at a given point in time" (the latest definition can be found in Resolution IX.1 Annex A).

Earth Observation: "Earth Observation" (EO) is increasingly being used to refer to the gathering of information about planet Earth's physical, chemical and biological systems using a range of approaches and through different types of observations (e.g. ground-based, from airborne sensors, or from environmental satellites) (Mayer *et al.* 2018). In this report, EO refers to the acquisition of data through the use of satellite-based remote sensing.

Ecosystem services: are "the benefits that people receive from ecosystems, including provisioning, regulating, and cultural services" (Millennium Ecosystem Assessment, 2005).

Functions of wetlands: are activities or actions which occur naturally in wetlands as a product of interactions between the ecosystem structure and processes. Functions include flood water control; nutrient, sediment and contaminant retention; food web support; shoreline stabilization and erosion controls; storm protection; and stabilization of local climatic conditions, particularly rainfall and temperature (As adopted by Resolution VI.1).

Group on Earth Observations (GEO): is a voluntary, intergovernmental partnership of over 100 member governments (including the European Commission) and more than 100 participating organizations fostering open and collaborative production and use of EO data in support of global decision making (GEO).

GEO Wetlands Initiative: is part of the GEO Work Programme for 2017-2019 and provides a framework for cooperation, development and communication in the field of EO of wetlands. The Ramsar Convention Secretariat is one of the co-leads of this initiative together with Wetlands International and the University of Bonn. GEO-Wetlands offers a Community of Practice as a platform for cooperation and knowledge-exchange; thereby, serving as a framework for collaborative development of the Global Wetlands Observation System (GWOS) (GEO).

GlobWetland Africa (GW-A): is a large EO application project initiated to facilitate the exploitation of satellite observations for the conservation, wise-use and effective management of wetlands in Africa and to provide African stakeholders with the necessary Earth Observation (EO) methods and tools to better fulfil their commitments and obligations towards the Ramsar Convention on Wetlands. GW-A is funded by the European Space Agency and supported by the Ramsar Convention Secretariat (GW-A a).

Global Mangrove Watch (GMW): is an international initiative led by the Japan Aerospace Exploration Agency (JAXA) in collaboration with the Ramsar Convention, Wetlands International, UNEP-WCMC and the universities of New South Wales (Australia) and Aberystwyth (UK). The GMW aims to provide annual maps about changes in the global mangrove extent by the use of the Japanese JERS-1, ALOS and ALOS-2 radar satellites (Lucas *et al.* 2014).

Practitioners: include wetland managers and stakeholders, and others from related fields, such as protected area managers and staff of wetland education centres (as defined in Resolution XII.5).

Ramsar Criteria: are cited for determining international importance; and an array of additional data on, inter alia, hydrological values, flora and fauna, land uses, socio-cultural factors, conservation measures, and potential threats – were approved in 1990 by the Conference of the Parties (Recommendation 4.7) and have been updated regularly since then. The

18 The definitions in this glossary have largely been drawn from Ramsar Handbook 1 (5th ed.), except where indicated otherwise.

information presented in the Information Sheets is entered into the Ramsar Sites Database and forms a basis both for monitoring and analysis of the ecological character of the site and for assessing the status and trends of wetlands regionally and globally. A new format of the RIS was adopted at COP11 by Resolution XI.8 (Annex 2), *Strategic Framework and guidelines for the future development of the List of Wetlands of International Importance of the Convention on Wetlands (Ramsar, Iran, 1971) – 2012 revision,* and can be accessed at: https://rsis.ramsar.org/.

Ramsar Information Sheet (RIS): is the means by which Contracting Parties present information on wetlands designated for the List of Wetlands of International Importance, and by which the List is kept up to date. The items to be reported in the RIS include factual data on surface area, altitude, wetland types, location, legal jurisdiction, etc.

Ramsar Information Sheet updated data: Resolution VI.13 (1996), asks Contracting Parties to update their RIS for all Ramsar Sites at least every six years and to submit the updates to the Secretariat to ensure the data, publicly available in the Ramsar Sites Database, is sufficiently up to date and can be used as a management tool for the detection and monitoring of changes at the sites over time.

Scientific and Technical Review Panel (STRP): the Convention's subsidiary scientific advisory body, established in 1993, which advises the Secretariat and the Standing Committee and the Conference of the Parties on a range of scientific and technical issues. The STRP is made up of 18 core members with appropriate scientific and technical knowledge, plus Observers representing the International Organization Partners (IOPs), scientific and technical expert(s) recommended by Contracting Parties and other organizations recognized by the COP.

Satellite-based Wetland Observation Service (SWOS): is an Horizon 2020 project funded by the European Commission, to assist wetland practitioners with wetland monitoring and with reporting obligations for environmental policy implementation at different scales (SWOSa).

Toolbox: refers to a library of customized workflows for importing, processing and analysing optical and radar EO data in support of wetland management.

Values of wetlands: is the perceived benefits to society, either direct or indirect, that result from wetland functions. These values include human welfare, environmental quality, and wildlife support (As adopted by Resolution VI.1).

Wetland Assessment: is the identification of the status of, and threats to, wetlands as a basis for the collection of more specific information through monitoring activities.

Wetland Inventory: is the collection and/or collation of core information for wetland management, including the provision of an information base for specific assessment and monitoring activities.

Wetland Monitoring: is the collection of specific information for management purposes in response to hypotheses derived from assessment activities, and the use of these monitoring results for implementing management. (Note that the collection of time-series information that is not hypothesis-driven from wetland assessment should be termed surveillance rather than monitoring, as outlined in Resolution VI.1.).

Wise Use of Wetlands: refers to "[t]he maintenance of their ecological character, achieved through the implementation of ecosystem approaches, within the context of sustainable development" (See the latest definition in Resolution IX.1 Annex A, 2005. The pioneering definition of 1987 read: "Sustainable utilization of wetlands for the benefit of mankind in a way compatible with the maintenance of the natural properties of the ecosystem" (Recommendation 3.3)).

Workflow: refers to step-by-step data processing.