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Review

Wetland extent tools for SDG 6.6.1 reporting from the Satellite-based Wetland Observation Service (SWOS)

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ABSTRACT

Wetlands are the most fragile and threatened ecosystems worldwide, and also one of the most rapidly declining. At the same time wetlands are typically biodiversity hotspots and provide a range of valuable ecosystem services, such as water supply and purification, disaster risk reduction, climate change adaptation, and carbon sequestration.

Pressures on wetlands are likely to further intensify in the coming decades due to increased global demand for land and water, and due to climate change. Stakeholders at all levels of governance have to be involved to slow, stop and reverse these processes. However, the information they need on wetland extent, their ecological character, and their ecosystem services is often scattered, sparse and difficult to find and access.

The freely available Sentinel satellite data of the Copernicus Programme, as well as the Landsat archive, provide a comprehensive basis to map and inventory wetland areas (extent), to derive information on the ecological status, as well as long- and short-term trends in wetland characteristics. However, making use of these Earth Observation (EO) resources for robust and standardized wetland monitoring requires expert knowledge on often complex data processing techniques, which impedes practical implementation. In this respect, the Satellite-based Wetland Observation Service (SWOS), a Horizon 2020 funded project (www.swos-service.eu) has developed and made disseminated monitoring approaches based on EO data, specifically designed for less experienced satellite data users.

The SWOS monitoring tools aim at assisting countries in conducting national wetland inventories for their Sustainable Development Goals (SDG) reporting and monitoring obligations, and additionally facilitates other monitoring obligations such as those required by the Ramsar Convention and supports decision-making in local conservation activities. The four main components of the SWOS approach are: map and indicator production; software development; capacity building; and initializing the GEO Wetlands Community Portal. Wetland

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managers and data analysists from more than fifty wetland sites and river basins across Europe, the Middle East, and Africa investigated the benefits and limitations of this EO-based wetland mapping and monitoring approach.

We describe research that applies the SWOS tools to test their potential for the mapping of wetlands in a case study based in Albania, and show its effectiveness to derive metrics relevant to the monitoring of SDG indicator 6.6.1.

1. Introduction

Wetlands are rich in biodiversity and provide diverse and valuable ecosystem services such as water supply and purification, disaster risk reduction, recreation, climate change adaptation and carbon sequestration (Mitsch et al., 2015; Junk et al., 2013; van Asselen et al., 2013; Keddy et al., 2009; Brander et al., 2006; Schuyt, 2005). However, at the same time wetlands are the most fragile and threatened ecosystem types worldwide, and also one of the fastest declining. Approximately 35% of the natural wetlands have been lost worldwide between 1970 and 2015 (Ramsar, 2018; Darrah et al., 2019; Davidson et al., 2018) and 76% of freshwater plants and animals disappeared during the same period (Davidson, 2014; Ramsar, 2018).

Furthermore, the pressure on wetlands is likely to intensify in the coming decades due to increased global demands for land, water and energy. Of particular concern are African wetlands (Langan et al., 2018). Increasing rates of land conversion to agriculture, infrastructure development, water diversion, and water pollution are some of the main factors causing wetland degradation and loss (Schuyt, 2005; MEA, 2005).

Water scarcity, more frequent and severe droughts, and floods are major threats to society. The degradation of wetlands exacerbates these threats (Ramsar, 2018). For example, hydrological disconnection of floodplains from rivers leads to a decline in habitat for biodiversity while enhancing the risk of devastating flood events (BRGM, 1998; Acreman and Holden, 2013). Drained peatlands lose their essential properties in terms of water storage and regulation, causing soil subsidence and contributing to climate change due to the release of enormous quantities of greenhouse gases into the atmosphere because of peat carbon oxidation or peat fires (Konecny et al., 2016; Page et al., 2002).

In the context of wetland loss and degradation worldwide, appropriate planning and management for wetlands is essential. The development and implementation of policies can address the drivers of wetland loss as well as the solutions to prevent, mitigate and reverse such loss (Ramsar, 2018). In many cases, restoration measures are necessary to recover a good ecological status of aquatic ecosystems (Carvalho et al., 2019; Grizzetti et al., 2017). The implementation of measures requires careful planning and management, as well as reliable, regularly-updated spatial information on the status of wetlands: their extent, ecological character and ecosystem services (Finlayson et al., 2016).

Timely qualitative and quantitative information about wetlands is usually not available to decision makers, and to address this situation there is a growing interest in the use of Earth Observation (EO) for wetland monitoring. Satellite-based information can fill information gaps and enables support planning, management and reporting by users and decision-makers (Rebelo et al., 2018). EO enables access to the necessary historical and up-to-date geospatial monitoring information for small and large areas for data-driven and evidence-based decision-making processes involving stakeholders at all levels of governance. Satellite-based mapping helps to identify and define measures to derive baseline information on wetland ecosystem quality, diagnose wetland threats and pressures, monitor changes in extent and condition, and inform improved management.

Many different data sources are used for wetland monitoring including aerial photos, synthetic aperture radar (SAR), multispectral and hyperspectral data, and light detection and ranging data (LiDAR), across different spatial resolutions (Guo et al., 2017). Compared to systems such as Landsat or TERRA, Copernicus operational missions, also known as the Sentinels, offer valuable monitoring possibilities through: (i) increased availability of EO data from different sensors (SAR and optical); (ii) improved spatial resolutions; (iii) larger coverages; and (iv) shorter repetition cycles (Berger et al., 2012). The Sentinel satellites are therefore an excellent data source to map wetland extent, to derive information on the ecological status and trends in wetlands and to map long- and short-term changes (Mahdianpari et al., 2019; Muro et al., 2016). The data are consistently available for every part of the world, including large, remote and inaccessible areas. The data are also complemented by the archive of Landsat data from the 1970s onwards, allowing the monitoring of changes and the impact of conversion, drainage and other threats to wetlands over long periods (Vogelmann et al., 2016; Jin et al., 2017). Satellite-based assessment of wetlands is often impeded by their dynamics, frequent cloud cover, and their sometimes transitional nature (Dronova et al., 2015). SAR data are frequently used to assess highly dynamic wetlands and wetlands in cloud-prone areas (Dabboor and Brisco, 2018; White et al., 2015; Wohlfart et al., 2018). However, in addition to satellite data, ground data are indispensable for calibrating and validating satellite-based mapping results. Ground information is often complemented by very high resolution (VHR) data through visual interpretation of Google Earth or similar data layers (Amani et al., 2019; Liao et al., 2019). Original VHR data are very costly and only cover small areas and often with only few acquisitions. The revisit time is not as high and consistency not as good as for freely available data such as Landsat or Sentinel. VHR (and likewise hyperspectral and LiDAR) data are usually thus not feasible for reproducible, robust and operational wetland monitoring. Large-scale operational wetland monitoring requires consistent data, flexible and powerful methods that are capable of dealing with heterogeneous data, and common standards, definitions and guidelines towards user-friendly tools (Rebelo et al., 2018). Wetland mapping activities at regional or even national level, require powerful computational architectures such as cloud computing platforms (Amani et al., 2019; Hird et al., 2017).

In support of Sustainable Development Goal (SDG) 6 and its target 6.6, in this paper we demonstrate an EO-based approach to the mapping of, and reporting on, the extent of water-related ecosystems (indicator 6.6.1), based on a case study for Albania. We address the geospatial information needs of the global indicator framework as developed and implemented by the Inter-agency and Expert Group on SDG Indicators (IAEG-SDGs) of the United Nations Statistical Commission (https://unstats.un.org/sdgs/metadata/files/Metadata-06-06-01a.pdf), whilst showing how the SWOS indicator tools also have utility for Ramsar national reporting.

2. The 2030 agenda for sustainable development and SDG indicator 6.6.1

The United Nations (UN) Conference on Sustainable Development, also known as the Earth Summit 2012, led to the foundation of the Agenda 2030 for Sustainable Development, which was subsequently agreed and adopted by the UN General Assembly. The 2030 Agenda is data and evidence driven, consisting of a framework of 17 Sustainable Development Goals (SDGs) and 169 targets, supported by 247 indicators as established by the IAEG-SDGs. Each government is required to define their own targets, guided by the global level of ambition, but taking into account their national circumstances and specificities (UN, 2016). The indicators are intended as a management tool for countries to implement development strategies and report on progress towards the SDG targets. It is important, therefore, that countries have strategies in place for regular and routine monitoring in order to report on their indicators, assess progress, and set targets. Yet the indicator framework represents a challenge for countries, especially those with low in-country capacity in terms of human and infrastructural resources, to follow indicator methodological guidelines which involve complex analyses of statistical and non-statistical sources of data, such as EO (UN Water, 2018a). EO has a key role to play in providing the primary observations for some of the SDG indicators, fulfilling the monitoring function required by countries (Paganini et al., 2018). The EO-based mapping products and associated methodologies provided by the SWOS project can contribute to reporting on SDG 3 (health and wellbeing), SDG 6 (water and sanitation), and SDG 15 (life on land) in particular. Here we demonstrate the utility of the SWOS tools for SDG 6.6.1.

SDG 6 focuses on water resources. It aims to "ensure availability and sustainable management of water and sanitation for all" by 2030 and is a major step towards tackling water access issues and ensuring global sustainable water management (UN Water, 2018b). There are eight targets under SDG 6 (targets 1 to 6 plus targets 6.a and 6.b), of which target 6.6 is most relevant for the EO approaches of the SWOS project: "By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes" (UN Water, 2018c). This target recognizes the importance of wetlands and other ecosystems for providing a regular supply of freshwater for domestic, agricultural and industrial usage (Dickens et al., 2017). It is served by a single indicator, 6.6.1 – change in extent of water-related ecosystems over time – for which there are five sub-indicators to cover the three main aspects of extent: quantity, quality and the spatial extent or surface area (Table 1). The IAEG-SDGs categorize the indicators in different Tier levels and updated indicator 6.6.1 as a Tier I indicator (the most mature of the three) as of March, 2019. This means that the indicator is conceptually clear, has an established methodology and data are regularly produced by a critical mass of countries. However, in reality data are not regularly produced by countries and the five sub-indicators represent a significant challenge for ongoing and routine reporting by countries. The Ramsar Convention Secretariat has put forward a second methodology, based on existing Ramsar national reporting, such that there are now two reporting lines and methodologies in place.

Defined approaches for deriving the five sub-indicators of SDG indicator 6.6.1 at national level exist (Table 1). In contrast, the Ramsar approach is based on a single indicator, namely wetland extent. In both cases, change represents a shift from one condition of extent to another over time and is measured against a baseline. For the SDG sub-indicators, baseline conditions vary across the different sub-indicators. Sub-indicator 1 uses a five-year baseline (average national spatial extent from 2001 to 2005). Sub-indicators 3 and 5 use historical or modelled data, while sub-indicator 4 uses a natural reference condition. For sub-indicators 1 and 2, all globally available EO data will be shared with countries by indicator custodians for validation. Data will be shared annually at national, sub-national and water-body scales. Reporting requires countries to validate these data every five years to ensure accuracy of global datasets.

There are some essential differences between the SDG and Ramsar indicators (see also Table 1):

- Ramsar includes marine, salt and brackish wetlands (up to a depth not exceeding 6 meters at low tide), whilst the SDG framework only considers freshwater wetlands, with the exception of mangroves and estuaries;
- The categories for Ramsar reporting are marine/coastal, inland and man-made wetlands, whilst the categories for SDG reporting are lakes, river and estuaries, artificial waterbodies, and vegetated wetlands;
- Ramsar considers only one indicator on spatial extent of wetlands in a country (in kilometers squared or hectares), whilst the SDG indicator 6.6.1 has additional sub-indicators for water quality and quantity;
- Ramsar requires countries to provide data, which are often unverified, whilst for SDG indicator 6.6.1 global EO datasets are used and then countries are responsible for validating them.

Table 1 provides an overview of the SDG 6.6.1 sub-indicators and the Ramsar indicator with the approaches to derive them as well as the contribution of the Satellite-based Wetland Observation Service (SWOS) project. Since SDG indicator 6.6.1 refers to change, the sub-indicators listed in Table 1 have to be examined for multiple times steps

Table 1
SDG 6.6.1 monitoring: IAEG-SDGs and Ramsar approaches compared (based on UN Water, 2018b and Finlayson, 2018).

(Sub-) indicator		Approach	Categorization	SWOS contribution
IAEG-SDG				
Sub-indicator 1	Spatial extent of water-related ecosystems	Global EO-derived products presented to countries to validate	Lakes, rivers and estuaries	Indicator on total wetland extent derived from the SWOS LULC map product.
			Artificial water bodies	Natural open water bodies
			Vegetated wetlands (including mangroves)	Artificial water bodies Vegetated wetlands
Sub-indicator 2	Water quality of lakes and artificial water bodies	Countries report based on national data	Chlorophyll a (Chl-a) Total suspended solids (TSS)	SWOS water quality indicators including Chl-a, TSS and coloured dissolved organic matter (CDOM)
Sub-indicator 3	Quantity of water (discharge)	Countries report based on national data	Rivers Estuaries	None (based on *in situ* sampling)
Sub-indicator 4	Water quality imported from SDG Indicator 6.3.2[a]	Countries report based on national data		None (based on *in situ* sampling)
Sub-indicator 5	Quantity of groundwater within aquifers	Countries report based on national data		None (boreholes for water level detection)
Ramsar				
Single indicator only (no sub-indicators)	Spatial extent of water-related ecosystems	Countries report through Ramsar national reporting	Marine/coastal	Indicator on total wetland extent derived from the SWOS LULC map product and integrating the same definitions provided by the Ramsar methodology:
			Inland Man-made wetlands	Marine/coastal Inland Man-made wetlands

[a] Proportion of bodies of water with good ambient water quality.

to enable a comparison and assessment of trends.

3. The Satellite-based Wetland Observation Service (SWOS) project

The Satellite-based Wetland Observation Service (SWOS; Horizon 2020 Grant No 642088, 2015-2018) has developed tools for using Sentinel and other remotely-sensed data to assist wetland management, monitor and report on obligations of environmental policies at different scales (from local to global), and contribute to an improved integration of wetlands in the development of policies. The SWOS objectives were to:

1. Develop tools for map and SWOS indicator production, demonstrated for wetland locations in Europe, Africa and the Middle East (see 5.3 and Table 2 for details).
2. Develop software in the form of a freely available SWOS software toolbox called GEOclassifier, a compilation of methods developed within SWOS
3. Provide training in order to develop capacity in using satellite data and analysis tools
4. Initialize the GEO Wetlands Community Portal, which is making available all maps produced in the frame of SWOS.

Different service cases have been implemented in SWOS to demonstrate how satellite derived information could be applied and integrated into very different services for planning, management and reporting for users working at local, national and global levels. The service cases have been developed based on user requirements from organizations in Europe, Africa and the Middle East. Maps and SWOS indicators for about fifty demonstration sites (including wetland sites and their catchment areas) have been produced. The maps and SWOS indicators were used as inputs to the development of service cases, which included national wetland inventory and delineation, national Ramsar reporting, land transformation and national wetland policies, monitoring wetlands in arid and semi-arid regions, mangrove monitoring, peatland monitoring, the European Union water framework directive and SDG 6.6.1 reporting under the 2030 Agenda for Sustainable Development (Abdul Malak et al., 2019).

3.1. Approach

Our methodological approach to operationalizing an open-access EO-based monitoring protocol and tools for 6.6.1 monitoring and reporting consisted of four steps. Firstly, recognizing inconsistencies in the definition and mapping of wetlands across different policy frameworks and geographical settings, we developed a standardized nomenclature to allow wetland classes to be accurately assigned to the 6.6.1 reporting categories. Secondly, we developed the 'GEOclassifier' toolbox that incorporates indicator tools and allows the computation of wetland extent values according to the 6.6.1 reporting categories. Thirdly, we developed an on-line portal (the GEO-Wetlands Community Portal, http://portal.swos-service.eu) to provide access to the maps and EO data sources required as input datasets for 6.6.1 reporting. Fourthly, we generated a national service case demonstration of the approach based on the country of Albania.

3.2. Nomenclature

Due to the transitional and dynamic nature of wetlands, many inconsistencies appear in their mapping and delineation. Wetland mapping is challenging due to the nature of wetlands as a composition of different land cover types with a variety of specific characteristics including how they change at different temporal and spatial scales (Gallant, 2015). Questions on how to delineate the boundaries of wetlands vary according to the user and context. As a result, the exact upper and lower limits of wetlands are arbitrary boundaries in any definition (Mitsch and Gosselink, 2015). Similarly, when it comes to their classification, different systems are used by different users leading to inconsistencies at global (Hu et al., 2017) and regional (Amler et al., 2015) levels. However, when nomenclatures do not contain many wetland-relevant classes, a significant proportion of wetland areas can go undetected as they are merged with larger classes such as agriculture (Perennou et al., 2012). Additionally, there is a common confusion between inundated areas and wetland habitats, which could lead to some interpretation errors when it comes to their classification using EO-based tools (Perennou et al., 2018).

In SWOS, standards and guidelines were developed to facilitate more accurate and consistent wetland mapping in the future. Using standardized nomenclatures allows comparability between different wetland locations and mapping dates and to producing harmonized

Table 2
Examples of SWOS indicators and SWOS sub-indicators used for SDG 6.6.1 and Ramsar reporting. The listed indicators can be derived using tools included in the GEOclassifier software; the SWOS sub-indicators listed are examples. A comprehensive list of SWOS indicators and sub-indicators can be found in Abdul Malak et al., 2019. All indicators that calculate changes require at least two LULC mapping results.

SWOS indicator	SWOS sub-indicator
1 Total wetland extent	Total wetland extent
	Natural wetland extent (Ramsar definitions)
	Human-made wetland extent (Ramsar definitions)
	Vegetated wetland extent (SDG 6.6.1 definitions)
	Lakes rivers and estuaries (SDG 6.6.1 definitions)
	Artificial water bodies (SDG 6.6.1 definitions)
	Selected classes extent
2 Change in wetland area	Surface change for all wetland classes
	Surface change for natural wetland classes
	Surface change for artificial wetland classes
3 Change to agriculture & urbanization	
4 Wetlands artificialization and degradation	
5 Status of wetland threats	
6 Extent of open water	Wetland habitats with permanent open water
	Wetland habitats with temporary open water
	Wetland habitats without open water
	Flooded areas that are not wetland habitats
7 Status and trend of water quality	
8 Ecosystem Fragmentation	

mapping results within countries, regions and globally. Mapping of wetland ecosystems becomes user and policy relevant if the right nomenclature can be applied. SWOS integrated the Ramsar typology (Finlayson, 2018) into three widely used classification systems for mapping and reporting purposes: CORINE Land Cover (CLC), FAO Land Cover Classification System (LCCS FAO) and the Mapping and Assessment of Ecosystem Services classification system (MAES), enhanced with new wetland classes based on the European Nature Information System (EUNIS) classification. Additionally, we also integrated a Land Use/Land Cover (LULC) change nomenclature, largely inspired by the Land and Ecosystem Accounting (LEAC) classification system, enhanced with new classes to report on conversions from wetland and water classes to other land cover classes and *vice versa*.

The three standard nomenclatures were used in combination with the Ramsar typology for covering both the non-wetland and wetland habitats within the total area being mapped. For example, CLC incorporates some of the non-identified Ramsar wetland types as an additional (4th) level of the original CORINE Land Cover hierarchical system. The new classes have been integrated under all the CORINE land categories: “artificial areas”, “agricultural areas” and “forests and semi-natural areas”, as well as under “wetlands” and “water bodies”.

3.3. Software for map and indicator generation

The GEOclassifier toolbox was developed to provide a suite of powerful tools for viewing, processing and analyzing optical and SAR remote sensing data. It allows the performing of segmentation, classification and indicator calculation (Table 2). In addition to the freely available satellite data of the Sentinel and Landsat missions, the GEOclassifier toolbox can be applied to data in raster format from any satellite. The classifier algorithm is a maximum likelihood approach, which classifies the land cover types according to training samples to be generated by the user in the toolbox. Other classification approaches will be integrated into the toolbox in the future. The generation of representative training samples is a crucial step in the classification process, which requires expert knowledge or training, in addition to ancillary data. Particularly in the Ramsar nomenclature, some classes/ecosystems can consist of a diversity of land covers, generally making it difficult to classify using satellite data. This means that the feasibility/limitation of mapping classes using satellite data, as well as the incorporation of ancillary data and expert knowledge, must be considered in the classification (Perennou et al., 2018).

All GEOclassifier tools, (developed in the frame of SWOS and several previous and parallel projects) have been made available in a stand-alone graphical user interface. Selected tools are implemented also in a Cloud version, so far just for demonstration. The image viewer, as a key component of the software, has been designed to provide comfortable and easy-to-use functionalities for the collection of training areas and integration of ground knowledge for a supervised classification. Any of the three available nomenclatures for LULC mapping, or the nomenclatures for LULC change and the Surface Water Dynamics (SWD) mapping, can be applied. Updates or additional hierarchical nomenclatures can be integrated easily into the GEOclassifier software.

3.4. The GEO-wetlands community portal

The SWOS Portal was developed (http://portal.swos-service.eu/), acting at the same time as the Community Portal of GEO-Wetlands (https://geowetlands.org/), which is an initiative of the Group on Earth Observations (GEO). The portal provides geospatial data and information on wetlands. The maps and indicators resulting from the SWOS project are visualized on the portal together with additional data, such as geo-located images, videos, an overview of available satellite data, and external resources. In addition to the GEOclassifier, other software was used to calculate additional indicators (Abdul Malak et al., 2019) and to generate and design the maps available through the GEO-Wetlands Community Portal (e.g. SNAP, QGIS, R, Erdas Imagine, ENVI/IDL, eCognition, ArcGIS).

4. Service case demonstration at national level: The example of Albania

Within the SWOS project, maps for about fifty wetlands across a wide range of climate zones were produced as a demonstration of how the SWOS tools are applicable globally. These wetlands were proposed by several stakeholders and users during consultations according to the wetlands’ specific characteristics and national or international significance and interest. In this paper, we showcase the example of Albania and the producing of baseline data for reporting against the 6.6.1 wetland extent sub-indicator. Albania is a small country in south-east Europe with a size of about 28.784 km^2. It is characterized by a diverse landscape and pronounced topography, particularly in the east, with elevations reaching more than 2,700 m. Most rivers run westwards to the Adriatic Sea forming floodplains largely used for agriculture. Besides numerous channelized rivers with a certain level of hydropower infrastructure, there are still a number of largely unregulated rivers – among the last in Europe (Lazaj & Xhelilaj 2017). According to the Köppen-Geiger climate classification Albania covers several zones with hot-summer Mediterranean (Csa) and oceanic climates (Cfb) dominating, and warm-summer Mediterranean (Csb), warm humid continental (Dfb) and humid subtropical (Cfa) climates also occurring (Kottek et al., 2006). On a regional to global level, Albania is favoured by relatively little cloud coverage (Sudmanns et al., 2019; Wilson and Jetz, 2016). Wetland monitoring with optical data, however, is often hampered by a greater degree of cloud coverage at local scales due to higher evaporation rates and locations in topographic depressions acting as cloud traps. The study area comprises the total land area of Albania plus the coastal zone, because of its significance for wetland areas.

5. Methods

The methodology was based on the mapping of wetlands and water-related ecosystems using optical Landsat-8 satellite images combined with hydrological parameters derived from Digital Elevation Models (DEMs) according to three steps: potential wetlands mapping; land use land cover (LULC) and habitats mapping; and SWOS indicators computation.

5.1. Potential wetlands mapping

Potential wetlands mapping allows the delineation of areas where water-related ecosystems could occur with a high level of probability. The delineation of (potential) wetlands often relies on topographic indices or their combination with EO data (Beven and Kirkby, 1979; Bwangoy et al., 2010; Agren et al. 2014; Ludwig et al., 2019; Rapinel et al., 2019). The present assessment was based on the mapping of open surface water dynamics (SWD) using optical Landsat-8 time series for the year 2015, which was combined with hydrological and topographic indices derived from a DEM (EU-DEM with ~25 m of spatial resolution). These DEM-derived metrics include the slope (calculated in degrees directly from the DEM), the Topographic Wetness Index (TWI) using the algorithm proposed and tested by Merot et al. (2003) and Sørensen et al. (2006) and a new enhanced hydro-geomorphological index for the delineation of floodplain areas, mainly inspired by the Path Distance methodology provided by the European Joint Research Centre (JRC) for the modelling of stream riparian zones (Clerici et al., 2013).

The resulting product is a layer that integrates many different LULC classes (not only wetland habitats) and represents the influencing area of wetland ecosystem functions and services. Thus, it should not be considered as a delimitation of the actual/existing wetland habitats. In this case it has been used to define and delineate the mapping area where most of the wetlands and water-related ecosystems occur in Albania, and also to detect potential ancient wetlands that have been lost (Abou Diwan and Doumit, 2016), typically due to their conversion into agricultural lands during the last century. As the result is a layer depicting potential wetlands (probabilities) according to their topographic position and short-term water dynamics, validation is not unequivocal since there are no equivalent reference data or straightforward validation techniques.

5.2. Land use land cover mapping, wetland classification and validation

The second implementation step of the methodology aimed to produce a LULC map for the country of Albania, within the functional envelope surrounding wetland and water-related ecosystems (delineation of actual wetlands in contrast to probability mapping of potential wetlands). The mapping process was undertaken using the maximum likelihood classifier implemented in the SWOS software (GEOclassifier) with the segmentation and classification of Landsat-8 images using the same data as for the SWD mapping. The final sub-product is a map representing the location and delineation of actual wetland and water-related ecosystems that are characterized according to the CLC-Ramsar hybrid nomenclature. Both potential wetland and LULC maps were validated against the existing national wetlands inventory (Marieta et al., 2003).

Validation of remote sensing derived wetland map products is often a challenging task because of the dynamic and complex nature of these ecosystems and so requires a totally different validation procedure.

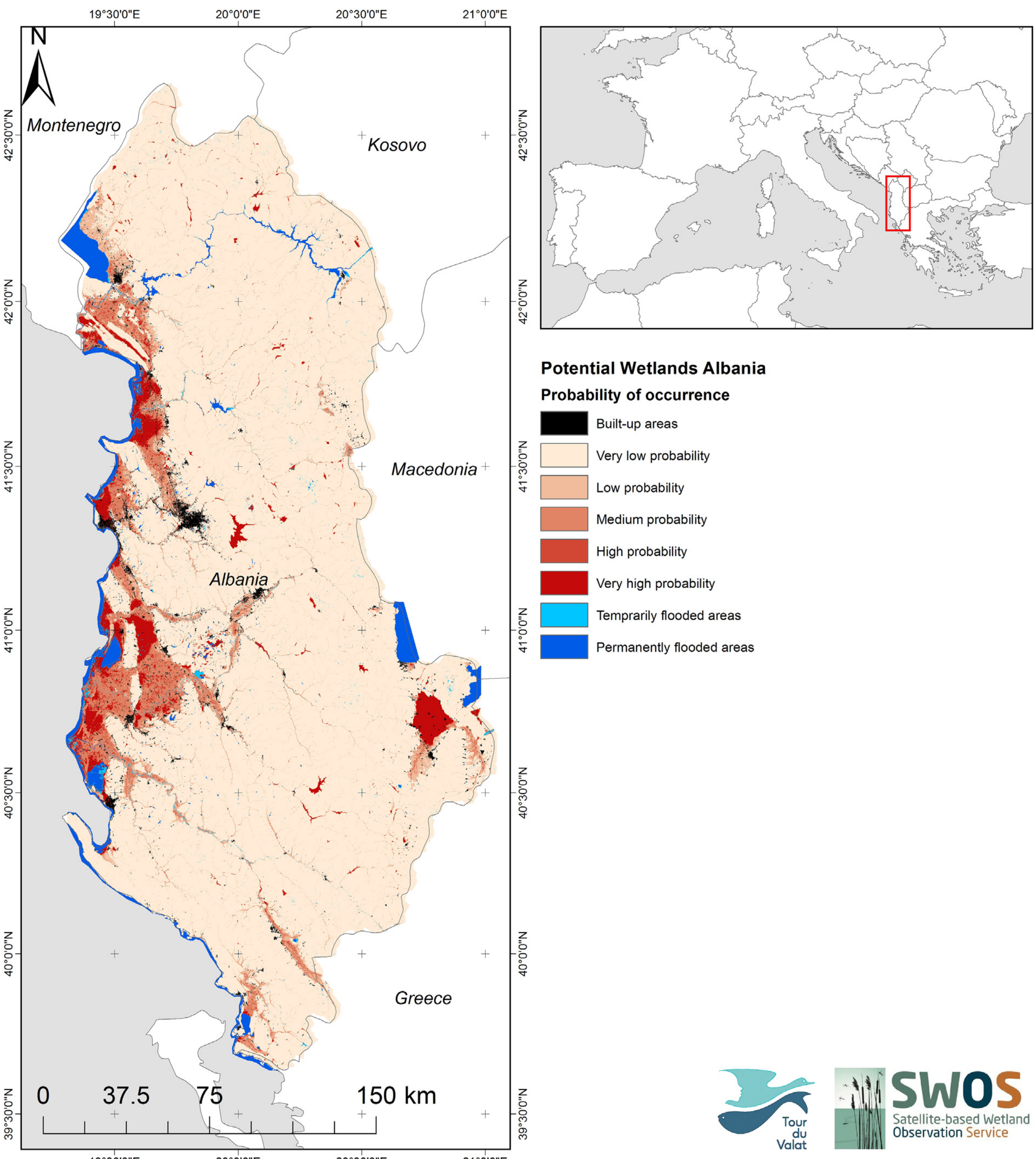

Fig 1. Potential wetlands in Albania mapped by combining surface water dynamics with topographic and hydrological indices

Whereas the validation of LULC products are pretty straightforward, surface water dynamics, water quality or potential wetland maps need historical data for validation, in-situ sampling of water constituents and specific sampling procedures. The validation strategy for the LULC map products in SWOS follows a tried and trusted quantitative approach, adapted from Olofsson et al. (2014).

The selection of validation data is a critical step to appraise map accuracy as it serves as a reference dataset and is deemed to be the "truth" for what is being mapped. A combination of a location-based validation by users and an external validation of LULC mapping products is recommended.

Location-based validation attempts to engage users, where possible, to provide samples for a subset of points at their site, via field campaigns or, if not possible, via photointerpretation by experts with knowledge of wetland sites.

External validation has the objective to achieve a more consistent and independent accuracy assessment using a standard protocol for multiple wetland sites. This work can be done using LACO-Wiki (https://laco-wiki.net/), an established, open and free online validation package, which gives access to Google and Bing imagery, Copernicus web services and other datasets available through a Web Map Service (WMS).

In any case the dates for satellite and field data acquisition should be as close as possible and use the same nomenclature. The number of points should be determined from an equation derived from the multinomial distribution (Congalton and Green, 2009) through stratified random sampling, so as to be certain that all classes will have control points and therefore be assessed.

5.3. Indicators calculation

Within the SWOS GEOclassifier there is an indicators toolbox with a variety of SWOS indicators and sub-indicators for monitoring wetland status and trends (see Table 2, Abdul Malak et al., 2019). The SWOS indicator for wetland extent uses the categories of water-related ecosystems according to the reporting requirements of the SDG indicator 6.6.1 (https://unstats.un.org/sdgs/metadata/files/Metadata-06-06-01a.pdf). This categorizes wetlands into the three classes 1) Lakes, rivers and estuaries, 2) Artificial water bodies and 3) Vegetated wetlands. Based on the LULC map, it is then possible to map all water-related ecosystems according to the three categories.

6. Results & discussion

A nationwide Potential Wetlands map for the country of Albania was generated, distinguishing between areas ranging from very low probability of occurrence of wetlands to very high probability as well as temporarily and permanently flooded areas that are also considered here as having an important potential to hold wetland habitats (Fig. 1). The map excludes all built up areas using an urban mask derived from the Global Urban Footprint dataset (Esch et al., 2013); such land conversions are generally considered irreversible and the probability of finding functional wetland habitats is very low, although urban wetlands can provide important ecosystem services locally (Boyer and Polasky, 2004). Most of the wetland area in Albania is distributed in the west of the country, where extensive floodplains are found. The wetlands encompass the internationally famous sites of the Buna Delta, Skadar Lake, and the Karavasta Lagoon. Many other smaller wetlands such as glacial lakes, karst lakes and small peatlands were successfully identified in the middle and the eastern parts of the country. Coastal areas are depicted as permanently flooded areas as well.

According to the validation results (Fig. 2), more than 97 % of the wetland habitats identified in the existing national inventory dataset are included within the four highest probability classes of the Potential Wetlands map: "High" probability (6.07 %), "Very high" probability (19.21 %), "Temporarily" flooded area (32.16 %) and "Permanently" flooded area (39.81 %). If the two probability classes "Medium" and "Low" are added to the previous four, the total area covered represents 18 % of the country. Given that inventoried wetlands represent 3 % of the national territory (excluding rivers and streams, which were not included in the national inventory), it is important to note that the Potential Wetlands map could highly overestimate the extent of "real" wetland habitats.

The produced potential wetlands map (Fig. 1) revealed several interesting features, such as the Maliqi former swamp, north to the city of Korçë (40°43'19.15"N, 20°47'31.98"E). It appears with the highest probability of being a wetland (Fig. 3), although it is now a large agricultural area. It was indeed a large swamp before it was drained during the middle of the last century (Qafko, 1995).

The mapping of actual wetland areas (Fig. 4) shows the presence of 18 wetland habitat types (both natural and human-made) according to the CLC-Ramsar nomenclature. Of note are the previously mentioned sand, shingle or pebble shores, the coastal lagoons, and coastal marshes. The abundant small water storage areas spread all over the country were also successfully identified, as well as some large vegetated

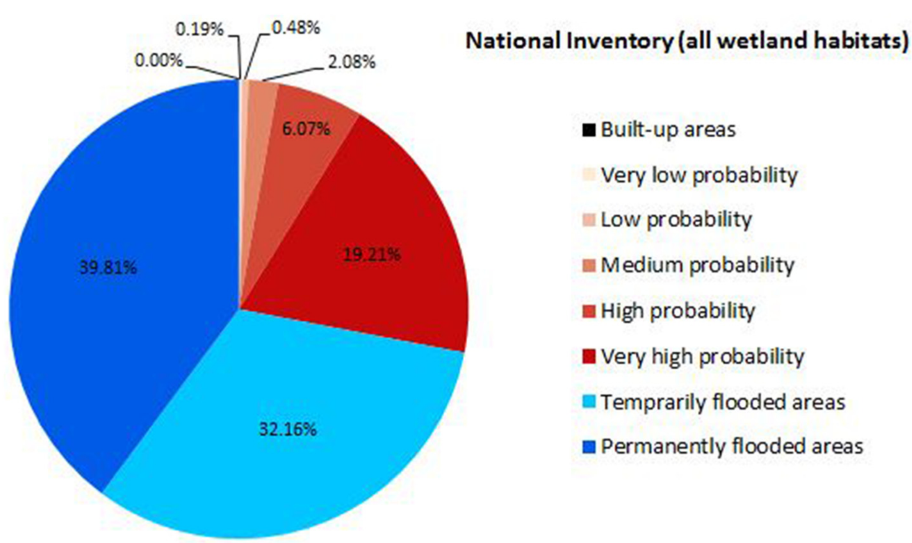

Fig 2. Evaluation of the Potential Wetlands product by comparison with the national wetlands inventory dataset of Albania (cover percentage of each class of the Potential Wetlands map within the national inventory dataset, Marieta et al., 2003).

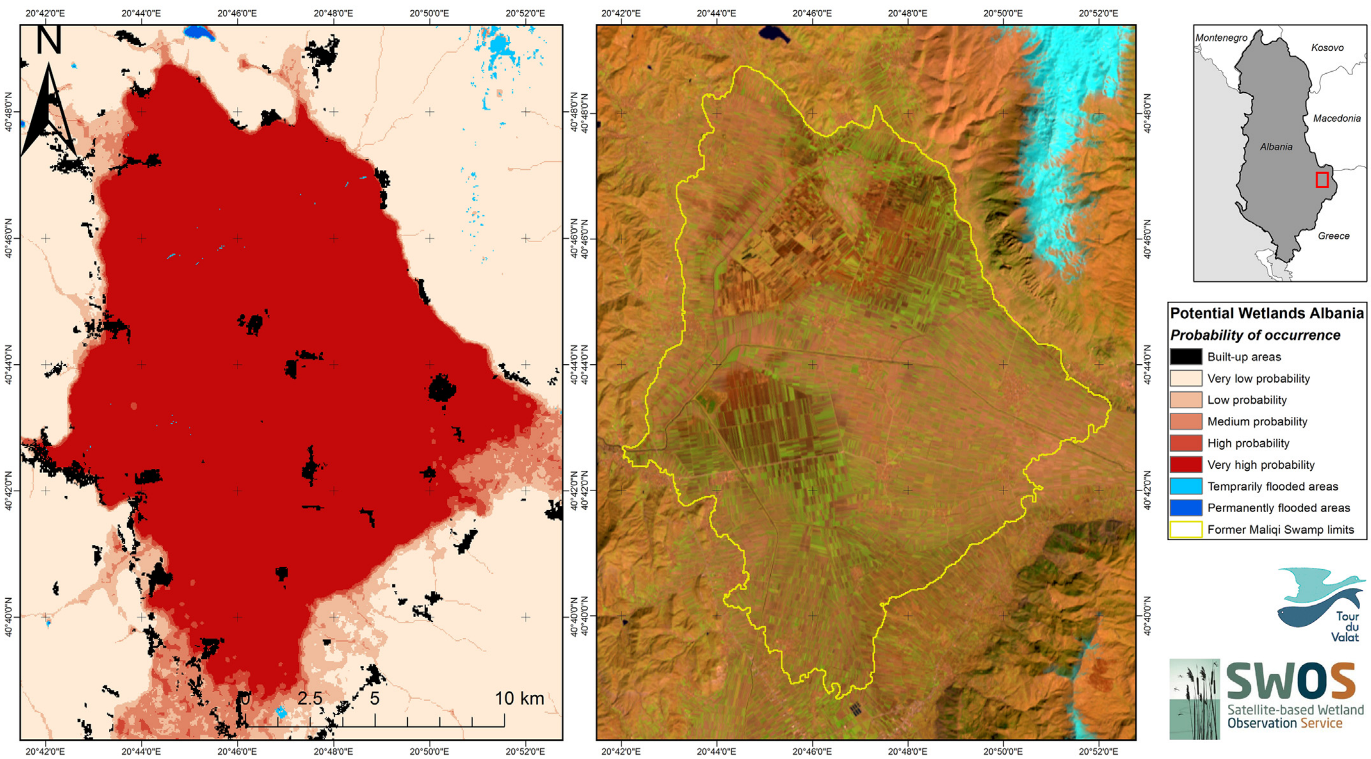

Fig 3. Former Maliqi Swamp appears with a very high probability in the Potential Wetlands map (on left). The former wetland has been drained and is used for intensive agriculture as shown on a Landsat-8 image from April 2014 (on right, R-G-B: SWIR-NIR-Green). This land use transformation was considered in the consecutive LULC classification when the area was not delineated as an actual wetland (see Fig. 4).

wetland habitats like wet meadows, riparian forests, small natural inland marshlands and karst lakes.

The SWOS tool enabled the generating of data to compute indicator SDG 6.6.1, more precisely the areas of "Lakes, rivers and estuaries", "Artificial water bodies" and "Vegetated wetlands". Fig. 5 provides values of direct relevance for national reporting on the wetland extent sub-indicator. Areal statistics are provided in Table 3. The comparison of these results with the data extracted from the national wetlands inventory shows very good agreement, with low error rates equal to 6.28% and 4.70% for omission and commission errors, respectively (Table 4). There are several explanations for the differences between the national inventory data and our results. First, our results are based only on optical and DEM data. Specific wetland types might be missed in the potential wetland mapping since optical data are of limited use in detecting wetlands under dense forest canopies (Chapman et al., 2015). Second, at large scales a general increase in wetland area is reported, which can be attributed to improved technologies, particularly higher spatial resolutions of EO sensors, and improved methods rather than a real increase in wetland extent (Davidson et al., 2018). Wetland identification, characterization and monitoring by means of satellite data are among the most complex topics in environmental remote sensing, due to the complex and spatio-temporally dynamic ecosystem variables of wetlands (Perennou et al., 2018; Gallant, 2015). In order to minimize inaccuracies in information derived from EO data, and thus misleading guidance for policy and management decisions, a thorough understanding of wetland ecosystems combined with remote sensing expertise is fundamental. In this regard, the capacity development of SWOS, mainly achieved through several user workshops and trainings, was a major outcome of the project. Even though the GEOclassifier was designed in a user-friendly interface, users who intend to produce maps and indicators still need training. The main aim of training sessions is to teach users how to translate satellite data into service cases and how to work in accordance with the developed SWOS methodologies, for the sake of harmonization of products. A precondition to participate in the training is to have basic GIS and image processing knowledge. At least two 3-days trainings are recommended. The first training is a hands-on training to guide through the whole processing; the second training is more in-depth, directly responding to use cases of the participants. For a trained user who knows the wetland area of interest, it can be assumed that it takes in average about five days to produce maps and to derive the inputs for SDG 6.6.1 sub-indicator reporting for an area of max 100 x 100 km^2.

The SWOS indicators toolbox (part of the SWOS GEOclassifier) allows the derivation of indicators that assess the status and trends of wetland ecosystems; some of them directly link to SDG sub-indicators (i.e. wetland extent uses the categories of water-related ecosystems for SDG 6.6.1). The SWOS water quality products provide only a partial picture of the spatial variation in water quality parameter levels in large open water bodies over time, thereby addressing a subset of the needs of SDG 6.6.1, sub-indicator 2. These products can nevertheless be helpful in assessing water quality status and trends over time (including spatial variations), especially in countries where other data do not exist or where water quality is irregularly monitored (Olmanson et al., 2015). Although it is not a formal SDG sub-indicator, countries with the required capacity should monitor ecosystem health. EO derived products can indicate change in health of ecosystems but countries should implement suitable ground-based surveys. The SWOS LULC change and SWD products can be used to compute indicators that could help assess the health of wetland ecosystems. For example, of relevance would be the detection of a high turnover of natural to artificial land cover, suggesting an overall intensification in land use (e.g. Leemhuis et al., 2017), as would an increase in the area of open water in artificial wetlands while it decreased in natural ones (MWO, 2018). Both cases could be representative of a decline in ecosystem health and allow the planning of restoration activities.

Another important result of the SWOS project is catalysing the establishment of the GEO-Wetlands community, an open and collaborative initiative centred on an advanced spatial data infrastructure that

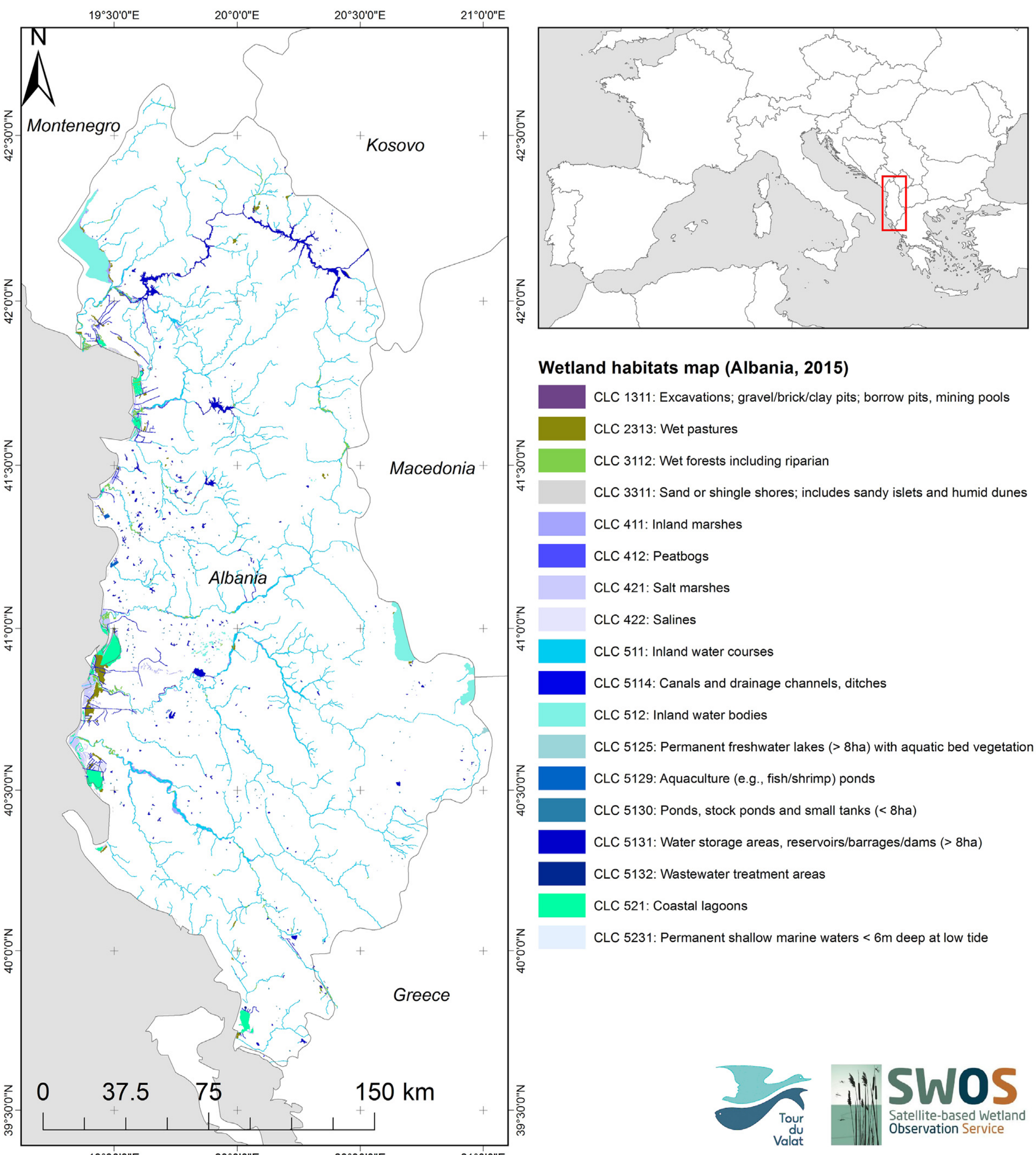

Fig 4. Identification of "actual" wetlands within the Potential Wetlands layer of Albania using a LULC classification based on the CLC-Ramsar nomenclature.

serves open data on wetlands to users. It will assist the implementation of EO-based wetland monitoring through disseminating best practices. The initiative is part of the Group on Earth Observations (GEO) Work Program since 2017. GEO Wetlands is the home of the GEO-Wetlands Community Portal and a wetlands knowledge base (www.geowetlands.org). The initiative functions as a collaborative framework for the whole wetland EO community. Its success therefore is grounded on the participation and active contribution of users of wetland data, data providers and remote sensing experts, and wetland policy experts. These partnerships are crucial to serve the needs of Agenda 2030 and particularly to assist countries with their reporting obligations under target 6.6 on water-related ecosystems. One relevant example is the willingness of the Tunisian Ramsar National Authority (represented by the General Directorate of Forestry) to better integrate these new innovative EO-based approaches in the future monitoring program of their wetlands (mainly those provided by SWOS), and this is being built into the framework of the Tunisian National Wetlands Strategy (implementation phase 2020–2025).

7. Conclusions

The pressure on wetlands today is intense and is likely to build in the coming decades due to climate change and increased global demand for land and water (Junk et al., 2013; Middleton and Souter, 2016; Moomaw et al., 2018). The rising availability of free and open EO data, such as the Sentinel satellite data of the Copernicus program and long-term Landsat archive, provide the basis for mapping wetlands and contributing to SDG reporting obligations. The SWOS mapping and

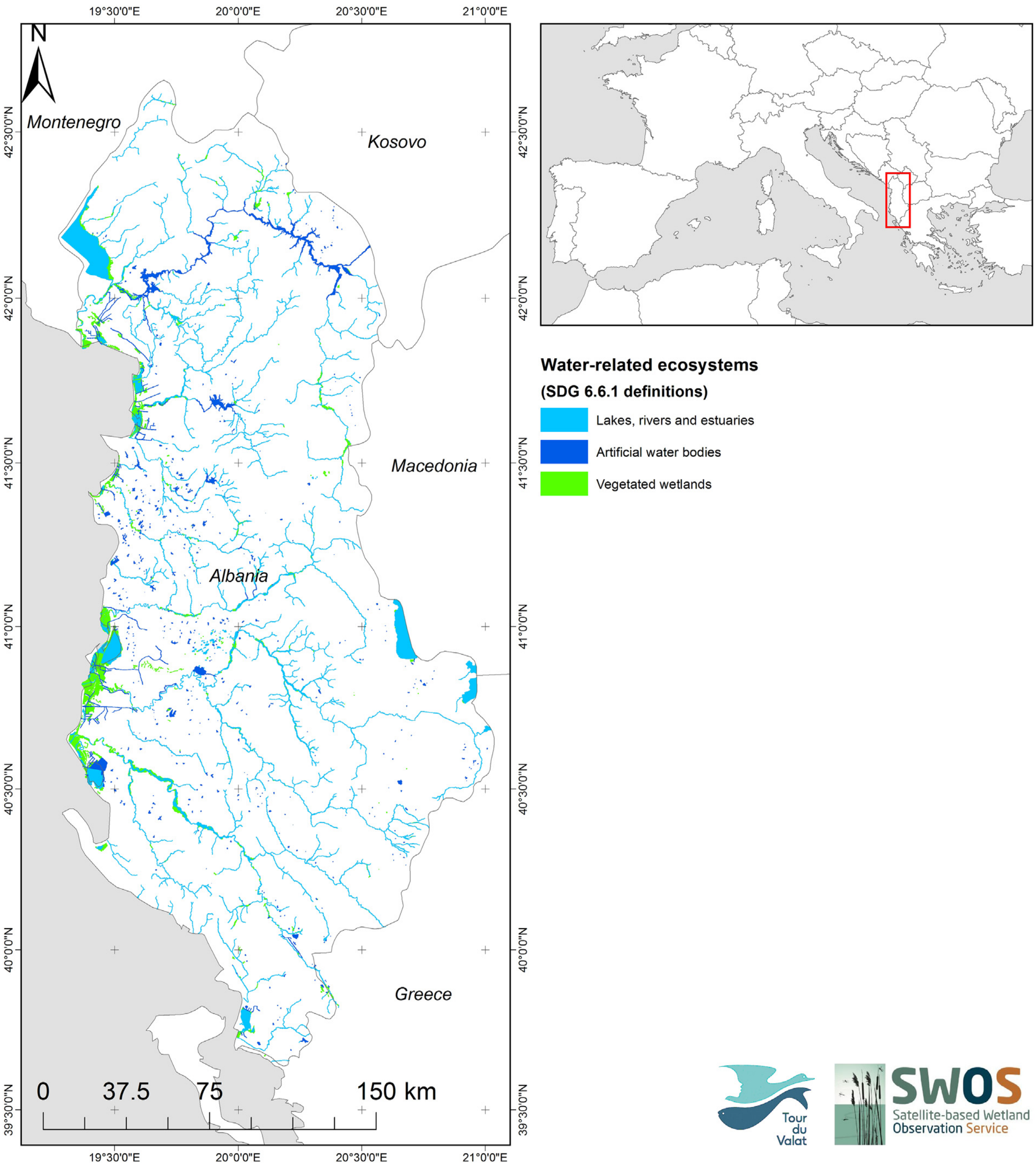

Fig 5. Water-related ecosystems in Albania mapped according to the SGD 6.6.1 definition.

Table 3
Relevant statistics for reporting on SDG indicator 6.6.1 in Albania.

Total area of lakes rivers and estuaries	663 km^2
Total area of artificial water bodies	163 km^2
Total area of vegetated wetlands	175 km^2

monitoring tools are designed to assist countries in acquiring baseline information regarding water-related ecosystems for the SDG reporting and monitoring obligations, facilitating Ramsar-related and other monitoring obligations, and supporting decision-making in local conservation activities. We have demonstrated how SWOS tools can generate statistics on the extent of wetland and water-related ecosystems in support of SDG indicator 6.6.1 reporting. The utility of such tools is of relevance to national government departments, agencies and ministries responsible for issues related to the environment, water and natural resources, and therefore also the monitoring of the 6.6.1 sub-indicators. Wetland maps and products were generated for about fifty wetland locations across Europe, Africa and the Middle East, and Albania was used as a national demonstration of key wetland mapping functionalities serving international reporting obligations. The SWOS tools were designed to be as intuitive as possible, but capacity development is needed to ensure the right use and consistent outcomes. The capacity development activities of SWOS showed that it is important to clearly focus on the feasibility of remote sensing-based wetland monitoring, but also its limitations. Guidance documents were therefore developed to facilitate the correct and proper use of the tools. Equipped with this right information, and working across all sectors and levels of

Table 4
Confusion matrix of the classified wetland habitats in the produced LULC map using the GEOclassifier compared with those derived from the national inventory of Albania (classes are grouped based on the SGD 6.6.1 definitions).

		National wetlands inventory				
		None	Lake, rivers and estuaries	Artificial water bodies	Vegetated wetlands	Commission errors
LULC	Other Classes	0.00%	0.94%	1.86%	2.00%	100.00%
	Lake, rivers and estuaries	0.00%	90.44%	0.23%	4.29%	4.76%
	Artificial water bodies	0.00%	0.15%	97.36%	0.36%	0.52%
	Vegetated wetlands	0.00%	8.47%	0.55%	93.36%	8.81%
	Omission errors	N/A	9.56%	2.64%	6.64%	
			Overall commission error		4.70%	
			Overall omission error		6.28%	

governance, decision makers can help to slow, stop and reverse wetland degradation processes.

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