Project Title:	ECOPOTENTIAL: IMPROVING FUTURE ECOSYSTEM BENEFITS THROUGH EARTH OBSERVATIONS
Project number:	641762
Project Acronym:	ECOPOTENTIAL
Proposal full title:	IMPROVING FUTURE ECOSYSTEM BENEFITS THROUGH EARTH OBSERVATIONS
Type:	Research and innovation actions
Work program topics addressed:	SC5-16-2014: "Making Earth Observation and Monitoring Data usable for ecosystem modelling and services"

Deliverable No 4.3: EO Change Detection Modules

Due date of deliverable:	30th September 2017
Actual submission date:	13 November 2017
Version:	v1
Main Authors:	UNSW, CNR, CERTH, EURAC, TdV, UIB

This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 641762

Project ref. number	**641762**
Project title	**ECOPOTENTIAL: IMPROVING FUTURE ECOSYSTEM BENEFITS THROUGH EARTH OBSERVATIONS**

Deliverable title	EO change detection modules
Deliverable number	D4.3
Deliverable version	V1
Contractual date of delivery	30 September 2017
Actual date of delivery	13 November 2017
Document status	Final
Document version	1.1
Online access	ECOPOTENTIAL website: http://www.ecopotential-project.eu
Diffusion	Public
Nature of deliverable	Report
Workpackage	WP4
Partner responsible	Univeristy of New South Wales (UNSW)
Author(s)	Richard Lucas (UNSW) and P. Blonda (CNR), C. Domingo (CREAF) (revision)
Editors	Richard Lucas (UNSW) and P. Blonda (CNR)
Approved by	
EC Project Officer	Gaëlle Le Bouler

Abstract	Deliverable, D4.3, illustrates the activity carried out, within Task 4.4 in the first 28 months of the project. It provides an overview of the algorithms used or developed to analyse spatio-temporal changes in LCLU and habitat maps, landscape fragmentation, indicators and environmental variables (EnVs) for the ECOPOTENTIAL PAs distributed across Europe, in Israel and South Africa. The change modules are included in the Earth Observation Data for Ecosystem Monitoring (EODESM) system, which makes full use of and integrates all of the biophysical, LCLU and EnVs retrieved for the different PAs in order to investigate both natural and anthropogenic change. Its development also considered the storylines described through ECOPOTENTIAL and outlined in Deliverable 2.2. A key component was to ensure that the classification and change detection modules were fully integrated and accessible within ECOPOTENTIAL's Virtual Laboratory (VL).
Keywords	Earth Observation, change detection, biophysical parameters, Land Cover, habitat mapping, ecosystem mapping.

This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 641762

Table of Contents

Executive summary

ECOPOTENTIAL WP4 is responsible for the provisioning of Earth Observation (EO) data and derived products for the Protected Areas (PAs) as well as to support other activities executed in WP6, WP7, WP8, WP9 and WP10. The final objective of the WP is to empower the PA to execute the algorithms presented here and sibling deliverables themselves by transferring the codes to the Virtual Laboratory (VL; WP10). This is complemented by WP5 that supports access to the necessary in situ data.

The Deliverable:

Deliverable D4.3 provides an overview of the modules of the Earth Observation Data for Ecosystem Monitoring (EODESM) system and now included in the VL for detecting changes in the PAs considered within the ECOPOTENTIAL Project.

General Approach:

Changes occurring within the 21 PAs are numerous and diverse and hence focus was on the development of a generic system that would allow the detection of change to be automatically registered, justified and interlinked with causality in the framework of storylines for the ECOPOTENTIAL PAs. At the same time, this system had to be flexible but also available to a wide range of users (e.g., scientists through to park managers).

Storylines: For the PAs, the changes focused on the storylines developed with consideration given to the type, spatial extent and temporal frequency of change.

Class Changes: Change was identified as a change in land cover classes and mapped using the Food and Agricultural Organisation's (FAO's) Land Cover Classification Scheme (LCCS2). Identified change refers to changes in the LCCS class in its entirety as well as its components. For example, changes in the class 'Trees closed canopy (>70-60 %) tall (14-30 m) continuous broadleaved evergreen' also considered changes in the individual components (e.g., canopy cover or height).

Changes in Variables: Change was also identified on the basis of changes in environmental variables (EnVs), with these being continuous variables that were used directly in the classification of the LCCS classes (i.e., canopy cover, hydro-period, water turbidity) or as additional descriptors specific to particular classes (e.g., above ground biomass, vegetation height, wind speed or sea surface temperature). Change was also described on the basis of variables derived from the classifications themselves, with these including for example, forest fragmentation.

Accounting for time: Across a landscape, different elements change over different periods of time. Changes can be abrupt or continuous over long time frames and dependent or independent of other changes in the landscape. The EODESM system attempts to line up changes at different points and periods of time to characterise the diversity of changes that are occurring. The detection of change is, however, dependent on the frequency of observations, as well as the modes of the sensors and their periods of operation.

Evidence for Change: A unique and novel element of the EODESM system is the ability to cumulate evidence for change. As examples, a flood event can be evidenced by a change in an object's component (thematic) classes from standing to flowing, shallow to deep and clear to turbid water, whilst forest dieback can be differentiated from defoliation by a reduction in canopy cover but also the moisture content of woody material, as determined from, for example, L-band radar.

Causes and Consequences: As well as providing evidence for change, the EODESM system also has the potential to provide automated assessments of the causes and consequences of change (including primary, secondary etc). For example, demand for timber (primary) results in deforestation (secondary) and the consequences are erosion which results in sedimentation in rivers and also movement of material (e.g., sediments) and gases (carbon).

In summary, the EODESM system allows a wide range of users to classify land covers and detect changes based on evidence from a combination of earth observation data and derived EnVs. The system is open source and has been integrated within the VL and is easy to understand and operate.

1.1 Abbreviation and acronyms

BIO_SOS project	Biodiversity Multi-Source Monitoring System: from Space to Species
CHM	Canopy Height Model
CLC	Corine Land Cover
DEM	Digital Elevation Model
EO	Earth Observation System
EODESM	Earth Observation Data for Ecosystem Monitoring
ESA	European Space Agency
EnV	Environmental Variable
FAO-LCCS2	Food And Agriculture Land Cover Classification System, version 2
GEE	Google Earth Engine
MODIS	Moderate Resolution Imaging Spectroradiometer
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
NP	National Park
PA	Protected Area
SAR	Synthetic Aperture Radar
VL	Virtual Laboratory

2. Introduction

A key aim of the EU Horizon 2020 ECOPOTENTIAL Project is to retrieve environmental variables (EnVs) from Earth Observation (EO) that could be used to describe but also contribute to the classification of landscapes within and surrounding protected areas (PAs) and the assessment of change.

The land cover classification module of the Earth Observation Data for Ecosystem Monitoring (EODESM) system was described in Deliverable 4.2. Deliverable 4.3 focuses on the approach to identify, quantify and describe change based on evidence, generated primarily (although not exclusively) from EO data.

The change detection modules within the EODESM system were developed based on recognition of the following:

a) Land cover change is highly variable, both spatially and temporally but also in terms of the state, condition and functioning of landscapes.
b) Change cannot generally be described using a single variable, as it is often a result of events and processes that lead to multiple changes in a landscape.
c) Change is often best described by considering EnVs that are often, but not necessarily, derived from remote sensing data.
d) Whilst EO-derived spectral data and indices are commonly used to describe change, these are often abstract measurements of the changes that are taking place.
e) Often, users need multiple lines of evidence to establish that a change has taken place and to determine the magnitude and directions of such change.

2.1 Main objectives

The stated operational objectives of WP4, and specifically Task 4.4, as listed in the DOW, are:

1. Design and develop a change detection system for the protected areas, with this focusing on the Earth Observation Data for Ecosystem Monitoring (EODESM) system; and integrate existing and develop new change detection modules to analyse spatio-temporal changes and trends in LULC and habitat maps, landscape fragmentation, indicators and EnVs with focus on both key anthropic and climatic drivers.

2. Support activities in WP6, WP7, WP8 and WP9 and provide results to WP10.

A major output of WP4 is the provision of comprehensive multi-source, multi-scale and multi-temporal EO products (services) that can be readily used for ecosystem monitoring and can provide an ECOPERNICUS service (WP10).

2.2 Process for satellite EO products identification

According to Objective 2 of WP4, the EO-derived products and services to be delivered and used subsequently within the modelling components of ECOPOTENTIAL were defined through the storylines for the different PAs. For this process, a questionnaire exposing WP4 data generation capabilities and pointing out the constraints and the requirements for products delivery was developed. The form was sent to all partners involved in WP4, modelling WPs (i.e., WP6, WP7, WP8, WP9) as well as those partners directly or indirectly involved in the management of the project's PAs. The survey tried also to support the conceptual framework built within WP2 for linking EO satellite data/products and in-situ data to the concept of EnVs, by contributing to their extraction within WP4. The questionnaire was successfully completed for all PAs.

The output of this process was a tabular description of the products explicitly required for each PA and storyline, including temporal and spatial resolution requirements as well as the time interval of observation and the priority level according to the PA. The Table has been regularly updated within ECOPOTENTIAL meetings (e.g., the General Assembly held on June 2016; the Review Meeting held on January 2017) and improved with information concerning the partner in charge of the production, the status of the production (pending to be assigned, assigned/to be generated, in process, available on the FTP), the expected deliverable date, the link to the data repository and a tag for metadata.

The table can be found at the following link: (http://twiki.ecopotential.creaf.cat/foswiki/pub/ECOPOTENTIAL_WP4/ProductsAndPartners/Responsibles_vs_PA_Storylines.xlsx).

2.3 Software and taxonomies

2.3.1 Software

Open source software (e.g. Python, RSGISLib) has largely been adopted for data processing within the EODESM system. Web Processing Services (WPS) have been, or are in the process of being developed, in order to guarantee open access, through the VL (WP10), to modules still based on commercial software (e.g., Matlab).

3. Approach to Change Detection

Within each of the 21 PAs, a large number of changes are occurring at any time and over time. Such changes are the result of specific events (e.g., a flood, fire or storm) or processes (e.g., road construction, plant growth and seasonal cycles). An awareness and understanding of the types and nature of change was inherent and essential to the development of the EODESM system.

3.1 Events

Change events are often disruptive in nature and are typically associated with both natural and human-induced events. In the former case, severe or extreme weather (e.g. floods or storms, cyclones and hurricanes) can lead to significant and abrupt changes in land cover. Such events are typically captured by referring to historical EO data prior to the event and the best available imagery acquired shortly after. However, events might not be detected for several days or weeks because of, for example, cloud cover or smoke or a relatively low frequency of data acquisition (e.g., 16 days in the case of Landsat). Events might also be predicted. For example, long periods of drought can lead to desiccation of forests, which then results in a wildfire. The accumulation of wood debris during previous periods of higher productivity can also increase the amount of fuel available and hence contribute to the severity of the fire. Human-induced change events are often of smaller extent and may be long term, with these including deforestation or urbanisation.

3.2 Processes

Processes typically occur over a longer time frame and can lead up to an event, as in the wildfire example presented in Section 3.1. Other examples of processes include rises in sea level (which can lead to increased inundation), rising land surface temperatures (e.g., leading to reduced snow fall) or erosion (leading to increased bare ground exposure). Others arise because of a previous event or process such as regeneration following deforestation or plant succession on previously eroded surfaces. In these cases, time series of earth observation data are essential within the respective period of time and depend upon the processes occurring (e.g., 1-2 years for the construction of an urban housing estate or 30 or more years to study regeneration to a relatively mature forest state).

3.3 Environmental variables (EnV; thematic and continuous)

The approach to detect and characterise both change events and processes within the EODESM system is to quantify a range of EnVs retrieved largely from EO data. Many of these variables have been considered essential (e.g., the Essential Biodiversity Variables (EBVs) of Pereira et al., 2015) and include those that are thematic (e.g., crop type) or continuous (e.g., above ground biomass) in nature (Tables 3.1 to 3.3). Some of these variables can be used as direct input to the LCCS classification (e.g., snow cover percentage or duration; Table 3.1) whilst others provide additional information, which is not used in the classification (e.g., land surface temperature; Table 3.2). Other variables can be derived from the classification of land covers (e.g., fire disturbance or fragmentation; Table 3.3).

Table 3.1. Environmental information retrieved from EO data and used as direct input to the EODESM system.

Topic Area	Description
Agriculture	Crop Area Crop Management and agricultural practices Crop Phenology
Biodiversity	Phenology (Species traits) Physiological traits (Species traits) Vegetation height and cover
Climate	Glaciers and ice caps (Land) Ice sheets (Land) Lakes (Land) Phytoplankton (Ocean surface) Snow cover (Land) Suspended particulates (POC, PON or POM) and PIC ++ laboratory, beam attenuation, backscatter, acidifiable, beam attenuation (Biogeochemical), with these being indicative of water turbidity.
Renewable Energy	Tidal (min, max, sea surface elevation) Urbanization
Water	Water quality, hydro-period.

Table 3.2. Environmental Information retrieved from EO data that provide additional descriptions of land cover

Topic Area	Description	Topic Area	Description
Climate	Above-ground biomass (Land)	Agriculture	Crop Type
	Albedo (Land)	Biodiversity	Net primary productivity (Ecosystem function)
	FAPAR (Land)		Population structure by age/size class (Species populations)
	LAI (Land)	Ocean	Chlorophyll (Biology and Ecosystems)
	Ocean colour (Ocean surface)		Coral Cover (Biology and Ecosystems)
	Permafrost (Land)		Large marine vertebrates: abundance/distribution (Biology and Ecosystems)
	Phytoplankton (Ocean surface)		Zooplankton, Krill biomass/abundance (Biology and Ecosystems)
	Precipitation (Atmosphere surface)	Renewable energy	Elevation, Orography
	Sea ice (Ocean surface)		Land surface temperature
	Sea level (Ocean surface).		Ocean bathymetry
	Sea state (Ocean surface)		Wave, height, direction, period
	Sea-surface temperature (Ocean surface)		
	Soil moisture (Land)		
	Surface current (Ocean surface)		
	Wind speed and direction (Atmosphere surface)		

Table 3.3. Environmental Information that can be derived from the EODESM system

Topic Area	Description
Biodiversity	Disturbance regime (Ecosystem function) Ecosystem composition by functional type (Ecosystem structure) Ecosystem extent and fragmentation (Ecosystem structure) Habitat structure (Ecosystem structure) Population structure by age/size class (Species populations) Secondary productivity (Ecosystem function) Species distribution (Species populations) Species interactions (Community composition)
Climate	Fire disturbance (Land) Land cover, including vegetation type (Land) River discharge (Land) Water use (Land)
Ocean	Mangrove Area (Biology and Ecosystems) Salt Marsh Area (Biology and Ecosystems) Seagrass Area (Biology and Ecosystems
Renewable energy	Land use, Land cover, including urbanization, hydrology, grid description Urbanization
Health	Famine early warning Short term forecasting as input of communicating diseases

4. Storylines

The following sections outline the storylines associated with each of the PAs, and focuses particularly on the changes that are of greatest interest to the protected area managers. An overview of the data layers that are available for each PA is also indicated.

4.1 Pelagos Sanctuary, Mediterranean Sea

Changes in fishing fleet and shipping behaviour within the Pelagos Sanctuary of the Mediterranean Sea (between Italy, Monaco and France) are impacting upon the distribution of marine mammals. The impacts on these mammals needs to be evaluated in relation to changes in sea conditions, including sea surface temperature (SST), and also chlorophyll-a, and bathymetry.

Main concerns: Biophysical conditions of the sea.

Causes: Changes in boat/ship movement, climate change and maritime use.

Consequences: Changes in the primary productivity of the Pelagos.

Focus: Sea Surface Temperature (SST), Chlorophyll-a and bathymetry.

4.2 Wadden Sea, The Netherlands

Water flows from rivers entering the North Sea are producing elevated levels of nutrients, which are leading to changes in primary productivity, and subsequently eutrophication. These changes are leading to declines in breeding opportunities and numbers of migratory birds. Overfishing is also contributing. The impacts on wildlife need to be evaluated in relation to changes in biophysical conditions of the sea, including SST, chlorophyll-a, turbidity and bathymetry.

Main concerns: Biophysical conditions of the sea.

Causes: Changes in nutrient loadings, particularly from terrestrial environments, and fishing activity.

Consequences: Declines in wildlife (particularly birds and shellfish)

Focus: Sea Surface Temperature (SST), Chlorophyll-a, turbidity, bathymetry.

4.3 The Camargue, France

Within the Camargue, about 400 million m^2 of water is transferred from the Rhone to agro-systems dominated by rice (including pasture meadows) but also to support ecotourism, wildlife hunting and reed harvest. Increased salinity in the Rhone and changes in rice or biofuel markets might impact on the management and hence functioning of the wetlands and their associated biodiversity. Changes in rainfall associated with climatic fluctuation might also impact on the well-being of the wetlands and proximal ecosystems.

Main concerns: Extent and conditions of wetlands in terms of water quality and vegetation.

Causes: Infrastructure development associated with agro-systems, market and climate change.

Consequences: Changes in the flow, distribution and condition of water.

Focus: Hydro-period, water depth, water turbidity and depth, extent of aquatic life forms, crop types.

4.4 Curonian Lagoon, Lithuania

Alterations in the tidal regime are leading to a loss of intertidal wetlands, including the coastal lagoons, and also in fish and invertebrate dynamics.

Main concerns: Variations in tidal regime.

Causes: Construction of embankments and dams and increases in agricultural area

Consequences: Changes in vegetation productivity, aquatic wildlife and productivity.

Focus: Hydro-period and tidal period, lifeform of aquatic vegetation.

4.5 Danube Delta, Romania and Ukraine

The construction of dams also led to alterations of river flows and changes in depth and suspended solids, with associated impacts of biodiversity. Losses in primary and secondary production and changes from lakes that had clear water and macrophytes to those that were turbid and dominated by phytoplankton also occurred.

Main concerns: Water quality and extent and condition of aquatic vegetation.

Causes: Construction of embankments and dams and increases in agricultural area

Consequences: Changes in vegetation productivity, aquatic wildlife and productivity.

Focus: Hydro-period, water depth and turbidity, extent of lifeforms, cultivated area.

4.6 Doñana NP, Spain

Doñana National Park in Spain is a large wetland complex area of fresh water seasonal marshes, temporary ponds, shrub and pine forest on sand dunes. The high inter-annual variability in Doñana's flooding regime is important for maintaining plant communities' diversity, and preserving the diversity of the waterbird community by preventing the dominance of a few species and creating opportunities for rare species (Sebastián González et al. 2016).

Main concerns: Maintenance of ecosystem services and habitats (particularly wetlands), Preservation of waterbird biodiversity.

Causes: Climate Change, Disruption of environmental (water) flows, Human-induced pressures (pollution, water diversion).

Consequences: Losses of biodiversity and ecosystem services.

Focus: Hydro-period, water extent, water depth, water turbidity, aquatic lifeforms.

4.7 Lakes Ohrid and Prespa, Former Yugoslav Republic of Macedonia

Agricultural development is leading to changes in water quality within the Lakes, which house a diverse range of flora and fauna.

Main concerns: Impact of agriculture on lake condition and its biodiversity.

Causes: Agriculture.

Consequences: Losses of fish, invertebrates and birds.

Focus: Water turbidity, cultivated area

4.8 Northern Limestone, Austria

Changes in the disturbance regimes of forests have occurred as a consequence of increases in disease but also fluctuations in climate.

Main concerns: Change in vegetation state and condition.

Causes: Climate change

Consequences: Loss and degradation of forest ecosystems.

Focus: Canopy cover, canopy height, phenology, above ground biomass, net primary productivity, leaf type.

4.9 Bavarian Forest NP, Germany

Changes in climate have resulted in outbreaks of bark beetle and declines in forest health. Nitrogen deposition is also driving inertia in ecosystem succession in mountainous areas.

Main concerns: Change in vegetation state and condition.

Causes: Climate change and pollution (namely nitrogen deposition).

Consequences: Loss and degradation of forest ecosystems and disruption of forest succession.

Focus: Canopy cover, phenology, net primary productivity, leaf type.

4.10 Gran Paradiso NP, Italy

The ecosystems within the Gran Paradiso National Park are subject to modifications of the extent and distribution of alpine and sub-alpine habitats as well as their functioning (e.g. provisioning of fodder for high-altitude animals). Increasing temperatures and changing precipitation pattern strongly affect snow phenology (considerably snow cover duration and timing of snow melt), which is one of the key drivers of plant phenology (e.g. timing of green-up).

Main concerns: Change in ecosystem health and condition

Causes: Climate change

Consequences: Movement of ecosystems and changes in functioning.

Focus: Life form, snow cover duration, vegetation phenology.

4.11 Hardangervidda NP, Norway

The main purpose of Hardangervidda National Park (HNP) is to protect a section of a valuable high mountain plateau and its cultural environment, while securing living areas for the stock of Wild Reindeer (Strand, Bevanger et al. 2006; Skogland 1978; Odland et al. 2014). Climate change is also expected to alter both the onset and the duration of spring and comprise reindeer calving time and greening (Walther et al., 2002, Post, Bøving, Pedersen, & MacArthur, 2003; Skogland, 1989).

Main concerns: Lichen extent and biomass, extent and available biomass in summer grazing pastures

Causes: Changes in grazing regime, climate change, human disturbance

Consequences: Changes in summer and winter grazing pastures

Focus areas: Extent of lichen, snow cover, GPP/ onset of greening and elevation

4.12 High Tatra Mountains, Poland and Slovakia

Substantial damage to the Slovakian forests occurred following a windstorm in November 2004, with many trees experiencing dieback and subsequently bark beetle infestations. The loss of forest and snowmelt resulted in flooding and landslides. However, the dieback facilitated the regeneration of forests that were of mixed species composition.

Main concerns: Recovery of damaged forests and management to increase resilience of existing forests.

Causes: Weather extremes

Consequences: Loss of forest cover in the short term but restoration towards more mixed species forest.

Focus areas: Life form, Canopy cover

4.13 La Palma, Spain

Invasive species are impacting upon the functioning and services of protected areas on the island and climate change may be influencing the amount of cloud cover and hence those ecosystems that depend on this.

Main concerns: Invasive species and changes in the physical environment

Causes: Introductions of flora and fauna and climate change

Consequences: Replacement of or competition with native species.

Focus: Life form, cloud cover, plant species.

4.14 Sierra Nevada NP, Spain

Changes in climate have impacted upon the functioning of ecosystems, with altitudinal changes in vegetation compromising species distributions and abundance.

Main concerns: Change in ecosystem health and condition

Causes: Climate change

Consequences: Movement of ecosystems and changes in functioning.

Focus: Life form, canopy cover, phenology, net primary productivity, leaf type.

4.15 Swiss National Park and Landshaft Davos

Land abandonment and increasing temperatures are leading to changes in the extent and distributions of ecosystems, with this including an increase in trees at higher altitudes (i.e., an upward movement of the tree line) and densification of forests. This is increasing the homogeneity of landscapes but also impacting on high mountain species, including ungulates such as the *Ibex*.

Main concerns: Extent and condition of vegetation cover (particularly woody)

Causes: Land abandonment and climate-related increases in temperature

Consequences: Upward movement of the tree line and increases in forest density

Focus: Extent of lifeforms and canopy cover as a function of altitude.

4.16 Har HaNegev, Israel.

Farming activities (including grazing) and urban expansion have impacted on the Har HaNegev and are leading to changes in the water flow and productivity of the landscape.

Main concerns: Changes in vegetation extent and productivity

Causes: Settlement development and agriculture over periods of centuries.

Consequences: Changes in the flow, distribution and condition of water and vegetation.

Focus: Lifeform, Phenology, Net Primary Production

4.17 Kruger NP, South Africa.

Shrub encroachment is impacting on the availability of herbaceous vegetation for grazing animals, with these including both wildlife and livestock. Fuelwood gathering as well as elephant pushovers are also resulting in a decline in the density and cover of trees, which is impacting on carbon budgets and future fuel availability.

Main concerns: Changes of vegetation structure and health

Causes: Overpopulation and changes in wildlife populations

Consequences: Sustainability of agriculture, loss of fuel and declines in carbon.

Focus: Canopy cover/density, extent of lifeforms, above ground biomass, net primary productivity.

4.18 Montado, Portugal

Increases in grazing pressure have led to compaction of the soil but also reduced regeneration of the native woodlands, with this exacerbated by cutting of trees. This has led to a loss of vegetation cover and fragmentation of habitats. Soil degradation has also resulted in lower infiltration of water and, together with shifts in precipitation patterns and more frequent droughts, the availability of water has reduced (Figure 4.1).

Main concerns: Changes in vegetation state and condition and soil functioning.

Causes: Agricultural policy and market pressures leading to increases in cattle density, shrub control and destructive soil tillage.

Consequences: Loss of habitat for biodiversity, non-sustainable use of forests, declines in wood crops and ecosystem functioning. .

Focus: Lifeform, canopy cover, presence and composition of understory layers, soil moisture.

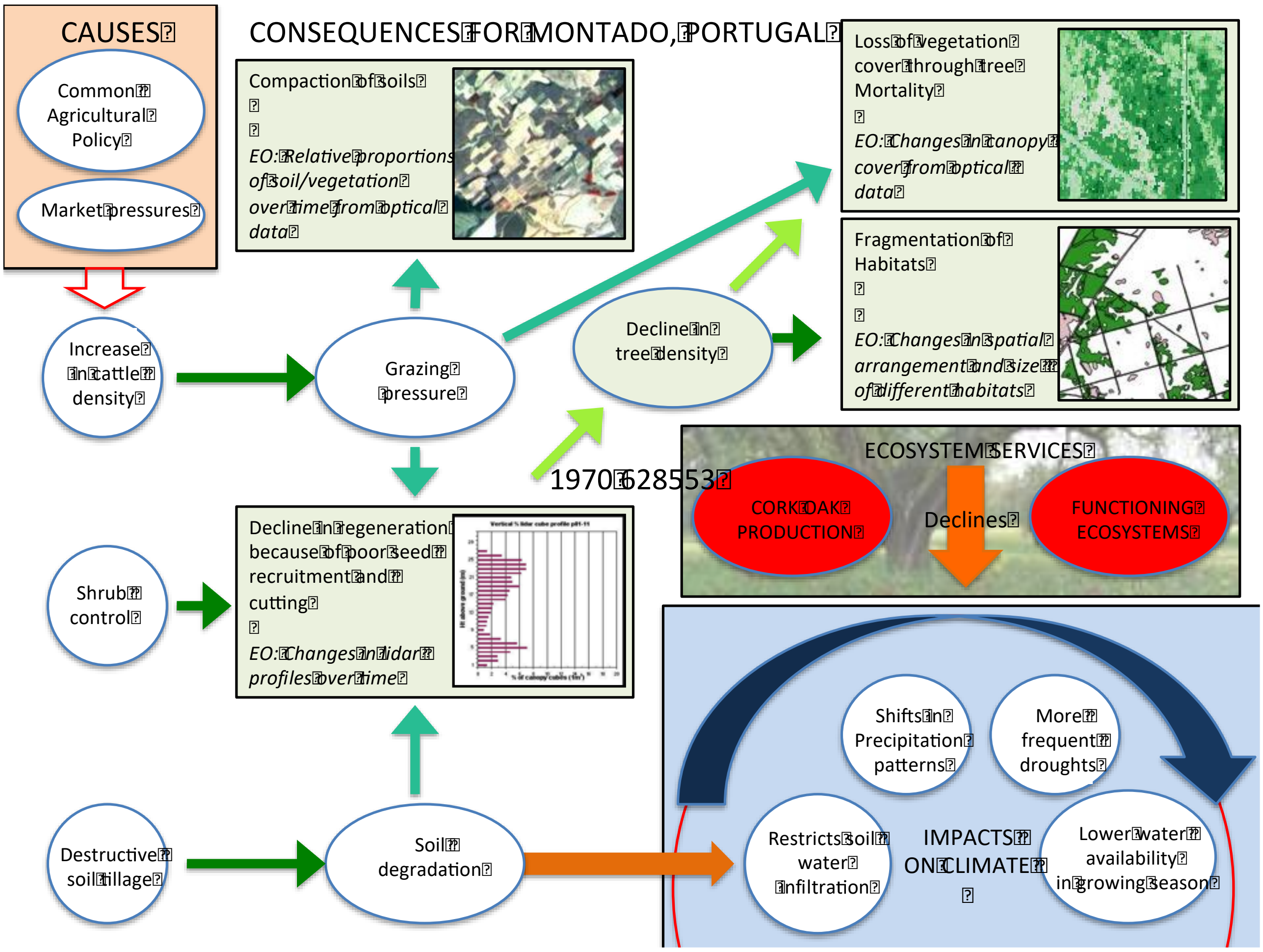


Figure 4.1. Changes in the Montado PA in Portugal. The causes and consequences of change, including on ecosystem services, are also indicated.

4.19 Murgia Alta, Italy

Agricultural intensification and expansion of cultivated lands are leading to loss and degradation of natural grasslands. The transformation of natural grasslands and semi-natural pastures into agricultural areas takes place by stone (rock) graining, inducing soil erosion and contamination in aquifer systems. Habitat degradation is exacerbated by the invasion of non-native species, illegal mining and toxic mud dumping. The entire grassland ecosystem is threatened in terms of biodiversity loss, habitat extent and condition.

Main concerns: Conservation of extent and conditions of natural ecosystems and particularly of the natural grasslands.

Causes: Conversion of grasslands and natural pastures in extensive arable lands, legal and illegal mining and toxic mud dumping, introduction of alien species.

Consequences: Habitat degradation, loss and fragmentation, biodiversity loss, soil erosion and hydrogeological instability, contamination of soils and of aquifer systems.

Focus: Lifeforms, particularly grassland extent and fragmentation, canopy cover, bare ground and materials, cultivated and artificial (urban) areas, alien plant species.

4.20 Peneda-Geres NP, Portugal

As with much of Portugal, a decline in traditional agro-pastoral systems has led to widespread scrub encroachment, with these causing changes to fire regimes. Many areas of natural and semi-natural vegetation have also experienced invasion by non-native species, including *Acacia* and *Eucalyptus.*

Main concerns: Extent and health of vegetation cover (particularly woody).

Causes: Land abandonment

Consequences: Shrub encroachment, invasive species.

Focus: Extent of life forms and canopy cover.

4.21 Samaria NP, Crete

Fragmentation of the vegetation as well as desertification induced by overgrazing and wildfires has resulted in a loss of biodiversity with this exacerbated by tourism, poaching and infrastructure development and modifications to surface and ground water.

Main concern: Loss of biodiversity

Causes: Expansion of human populations, locally and through tourism.

Consequences: Loss of vegetation cover

Focus: Terrestrial life forms, bare ground and associated material

5. Describing Change

5.1 Overview

Within the EODESM system, the detection of change is based on both a change in the component codes of the LCCS-2 classes but also EnVs, which are either used to define the land cover classes or are independent of the classification. Observed changes in both land cover and EnVs are then accumulated to provide evidence that can be considered when assigning a change category. The following sections describe the approach to change and also provide examples from the different PAs. The classification and change software has been developed to run through ECOPOTENTIAL's VL, thereby providing the capacity for a wide range of users, including PA managers, to generate their own land cover and change classifications.

5.2 Changes in component class codes

To support the classification of land covers according to the LCCS taxonomy, a test (or 'master') grid has been created, with each cell containing one or more of each of the major input layers to the classification (Table 5.1). The input name refers to the file name associated with the layers uploaded to the VL. Each input layer is also associated with a number range, indicating different component classes. For example, pixels associated with water, snow and ice are assigned the code values of 1, 2 and 3 respectively. These codes are given in Deliverable 4.2 and have been distributed as an LCCS code guide. The software for generating the LCCS categories out of these layers is applied to the grid, with an example of the classification output (for Level 4 categories) provided in Figures 5.1.

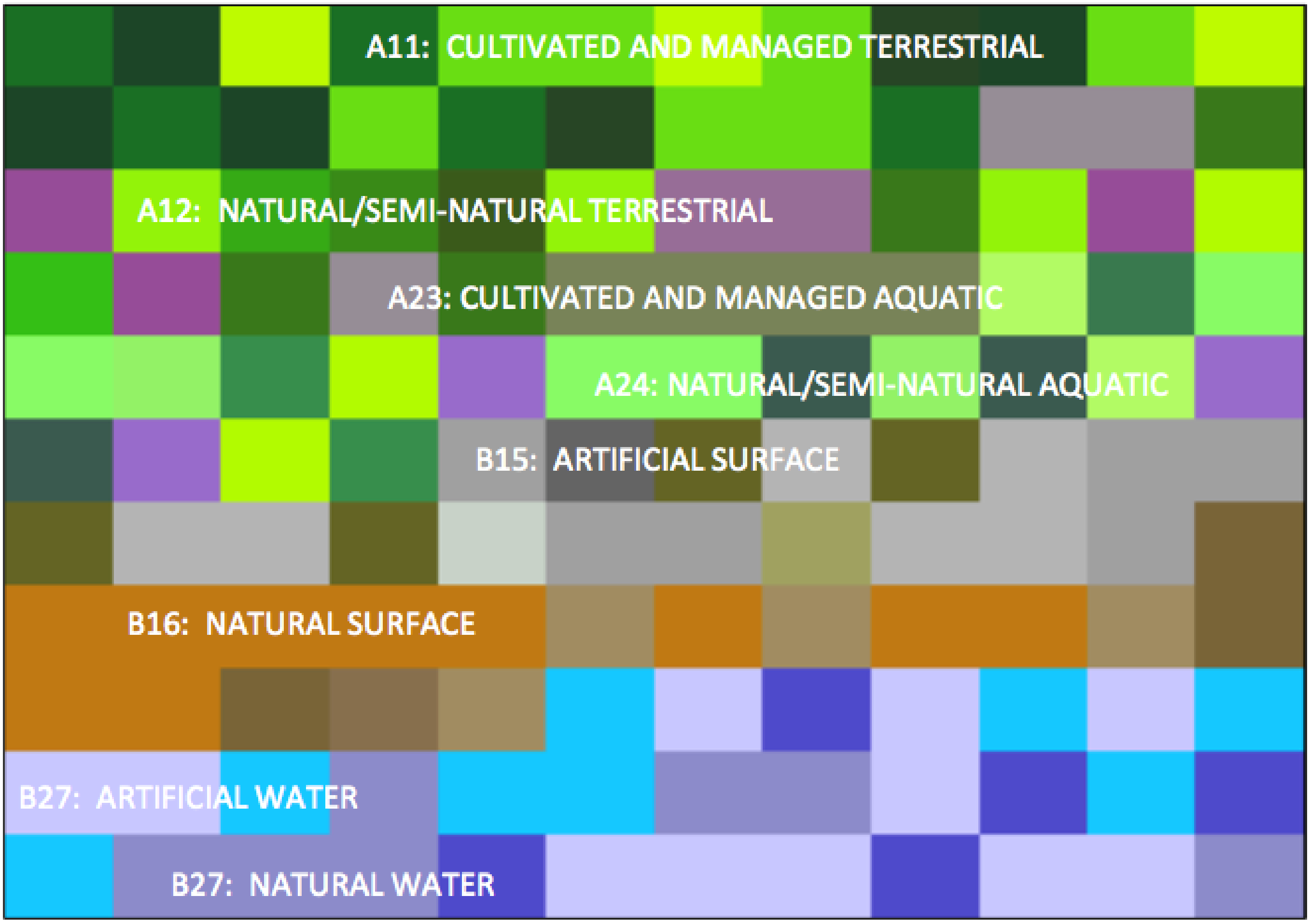


Figure 5.1. Main LCCS-4 categories.

Table 5.1 Overview of the main data layers used in the EODESM System.

Input description	Input name	Input description	Code	Input description	Code
LEVEL 3 CLASSES		LEVEL 4 CLASSES		Vegetation	
Cultivated area	L3Cultman	Lifeform	LLifeform	Plant species	Bplantsp
Urban area	L3Urbanis	Leaf type	LLeafType	Above ground biomass	BAGB
Impervious surfaces	L3Impervs	Phenology	LPhenolog	Chlorophyll a	Bchla
Bare ground	L3Baregrd	Urban vegetation	LUrbanveg	Nitrogen	Bnitrogen
Orchards	L3Orchard	Crop combinations	LCropcomb	Lignin	Blignin
Plantations	L3Plantat	Crop sequences	LCropsequ	Vegetation moisture	Bvegmos
Artificial surfaces	L3Artsurf	Crop water supply	LWatersup	Leaf area index	BLAI
Artificial water	L3Artwatr	Crop time factor	LTimefact	NPP	BNPP
Aquatic	L3Aquatic	Daily water variations	LWaterday	GPP	BGPP
CLASS MODIFIERS		Seasonal water variations	LWatersea	FPAR	BFPAR
Lifeform	MLifeform	Spatial size	Lspatsize	Burn severity	Bburnsev
Phenology	MPhenolog	Spatial distribution	Lspatdist	Start of green up	Bgreenup
Linear surfaces	Mlinearis	Number of layers	Lstrat2nd	Start of senescence	Bgreendown
Non built up areas	MNonbuilt	Lifeform of the 2nd layer	Llifef2nd	Growing season length	Bseaslength
Bare material	Mbarematr	Cover of the 2nd layer	Lcover2nd	Hydrology	
Hardpans	Mhardpans	Height of the 2nd layer	Lheigh2nd	Soil moisture	Bsoilmos
Surface material	Munstones	Artificial surfaces	Lartisurf	Snow cover fraction	Bsnowcfr
Water movement	Mwatermvt	Non-linear surfaces	Lnolinear	Snow grain size	Bsnowgrainsz
Substrate material	Msubstrat	Bare surfaces	Lbaresurf	Snow wetness	Bsnowmos

Derived measures		Macropattern	Lmacropat	Snow water equivalent	Bsnowweq
Canopy cover	DCanopyco	Water state	Lwaterstt	Snow depth	Bsnowdep
Canopy height	DCanopyht	Water depth	Lwaterdpt	Physical and bare	
Water persistence	Dwaterper	Water sediment layers	Lwsedload	Land surface temp.	BLSTemp
Urban density	Durbanden	ENVIRONMENTAL VARIABLES		Terrestrial grain size	Bterragrainsz
Snow persistence	DSnowper	Terrain		Frost days	Bfrostdays
Bare surface	Dbaresurf	Elevation	BDEM	Soil moisture	Bsoilmos
Impervious surface	Dimpervi	Slope	Bslope	Soil acidity	Bsoilacid
		Aspect	Baspect	Albedo	Balbedo
		Agriculture		Marine	
		Crop type	Bcroptype	Sea surface temp.	BmarineSST
		Crop yields	Bcropprod	Marine chlorophyll	Bmarinechl
				Marine CDOM	BmarineCDOM
				Total suspended matter	BmarineTSM
				Marine Sea Level Press.	BmarineSLP
				Bathymetry	BBathym
				Sea level pressure	BmarineSLP
				Atmosphere	
				Cloudiness	Bcloudiness
				Precipitation	Bprecip
				Humidity	Bhumidity
				Atmospheric temp.	Batmostemp
				Wind velocity	Bwindvel
				Wind direction	Bwinddir

Examples of the LCCS Level 3 and Level 4 classifications for the first (Period 1) but also a second observation period (Period 2) are given in Figure 5.2. These periods can be separated by hours, days, weeks, months, years or decades (as examples). In this figure, and with reference to the labels in Figure 5.1, there is a loss in the extent of A11 (cultivated and managed terrestrial vegetation) and a gain in A12 (Natural and semi-natural terrestrial vegetation). The area of A23 (cultivated and managed aquatic vegetation) remains stable but A24 is lost because of expansion of artificial surfaces (B15). However, the extent of artificial surfaces is also reduced because of replacement by bare ground (B16). Artificial water (B27) increases at the expense of natural water (B28). Although these grid-focused changes are simulated, the figures show how these are represented in actual temporal imagery.

Similar but more detailed changes are also illustrated for LCCS Level 4. In this case, the components of these classes are compared and all possible (and feasible) changes within the FAO LCCS component codes within each LCCS 'layer' (e.g., lifeform, canopy cover) are documented. As an example, for the layer representing urban vegetation, four categories are defined, namely Urban Vegetated (A18), Parks (A11), Parkland (A12) and Lawns (A13) and the possible changes are listed in Table 5.1.

a) b)

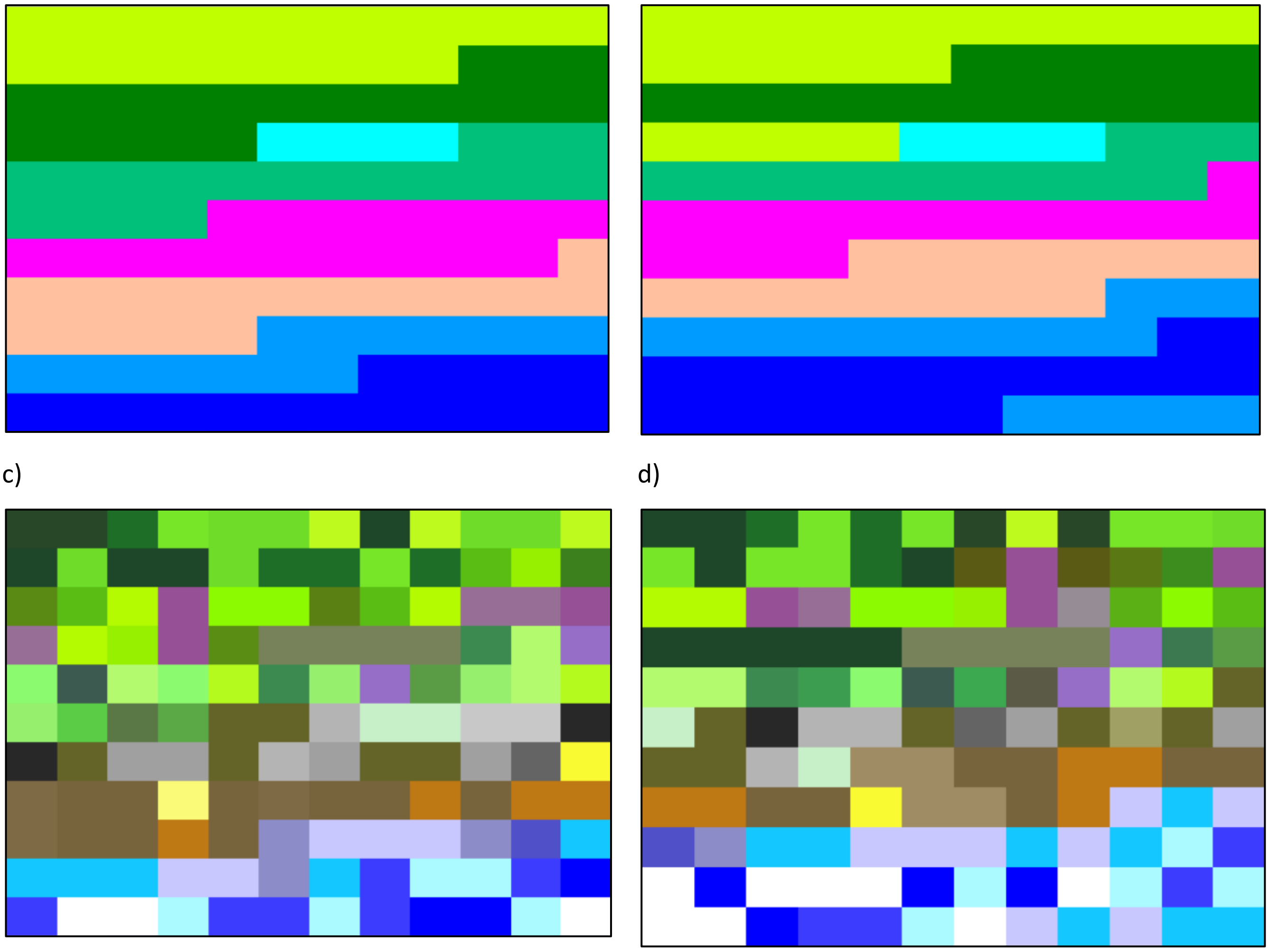


Figure 5.2. LCCS Level 3 and 4 classifications for period 1 (a,c) and 2 (b,d).

Table 5.1. Changes possible within the urban vegetated layer.

Change condition	Change condition
Remained as Urban Vegetated (A18)	Parks (A11) to Parkland (A12)
Remained as Parks (A11)	Parks (A11) to Lawns (A13)
Remained as Parkland (A12)	Parkland (A12) to Urban Vegetated (A18)
Remained as Lawns (A13)	Parkland (A12) to Lawns (A13)
Urban Vegetated (A18) to Parks (A11)	Parkland (A12) to Parks (A11)
Urban Vegetated (A18) to Parkland (A12)	Lawns (A13) to Urban Vegetated (A18)
Urban Vegetated (A18) to Lawns (A13)	Lawns (A13) to Parkland (A12)
Parks (A11) to Urban Vegetated (A18)	Lawns (A13) to Parks (A11)

An illustration of the change detection process is illustrated in Figure 5.3, which highlights both increases and decreases in the hydro-period for the Doñana PA, with this using the global water layers generated for two different periods by the Joint Research Centre (Pekel et al., 2016). The classes themselves are generated from the continuous surfaces (based on months that were inundated) and this information is retained within the objects and as attributes. This has been achieved by using a kea file format, which allows for raster attribute tables.

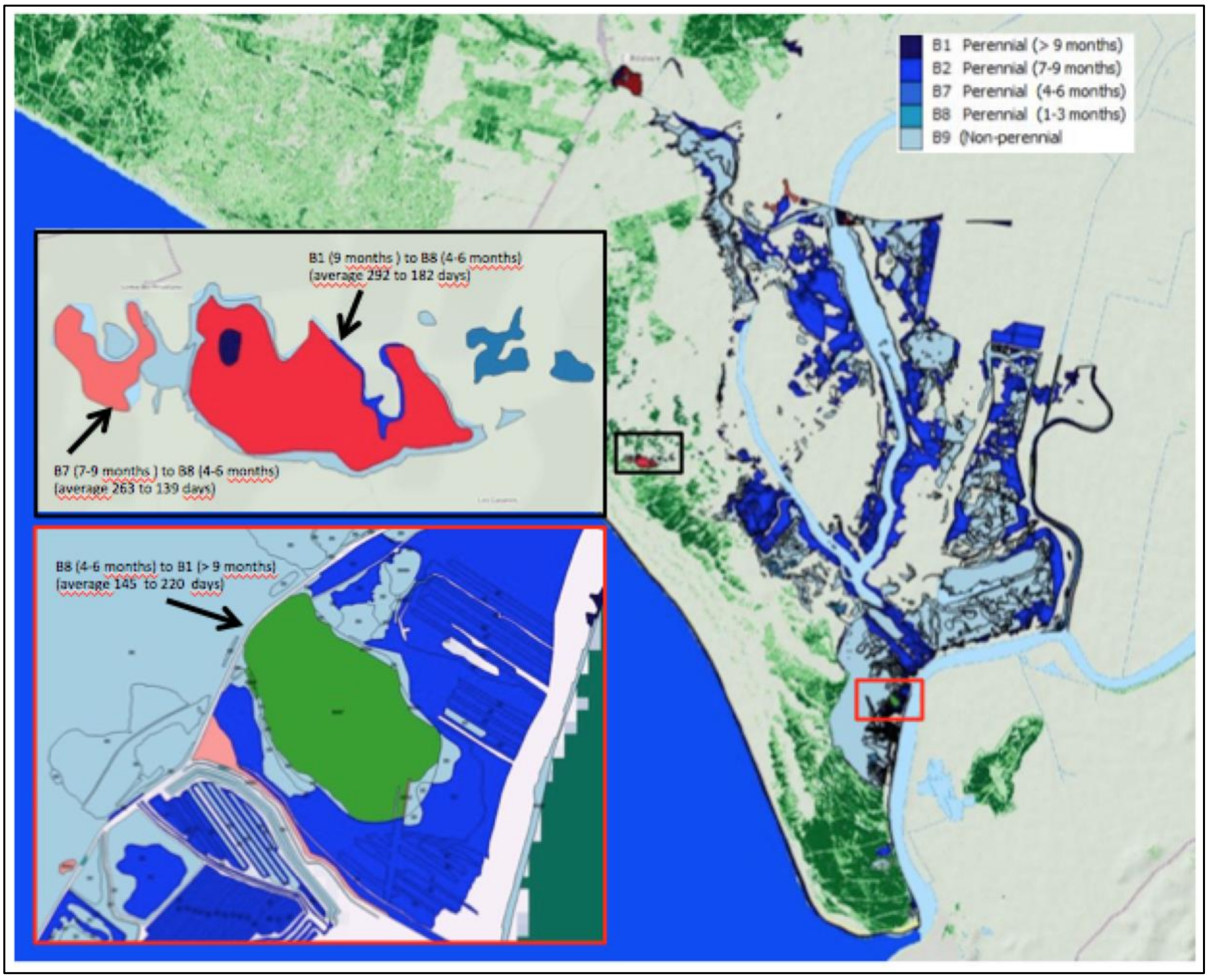


Figure 5.3. The changes in LCCS hydro-period class components between 2014 and 2015 in a subsection of the Donana National Park. The original (baseline) class is compared with that obtained in the comparative year and the continuous information is also retained.

5.3 Examples of EODESM classifications

The following sections provide examples from the ECOPOTENTIAL PAs of changes in the component codes of the LCCS classifications between two or more time-separated periods and using the EODESM software (following testing on the master grid). These examples focused on hydrological changes (water extent, hydro-period and snow cover distributions) and lifeform (e.g., lichens, grasslands and woody vegetation).

5.3.1 Changes in water extent

Water extent can be mapped from optical and SAR data using a range of algorithms, such as those outlined by Diaz-Delgado et al. (2016). For the Doñana NP, CERTH used an unsupervised algorithm to automatically classify radiometrically-corrected Sentinel-2A data (see Deliverable 4.2), with the extent of water extracted as a single class (Figure 5.4a and b). These data were acquired on an approximately fortnightly basis over the period from 1st December 2015 to 20th August 2017, and the resulting layers highlight the variability in the inundated area pattern within the PA. Figure 5.4a visualizes water extent maps for successive dates, while Figure 5.4b presents these maps with the focus on the marshland area. Each map can be used as input to the EODESM system, with this contributing a component to the full classification of both artificial and natural water. Specifically, each object is associated with the class water in the input layer of water extent (see Table 5.1; with a code value of 1 for liquid water).

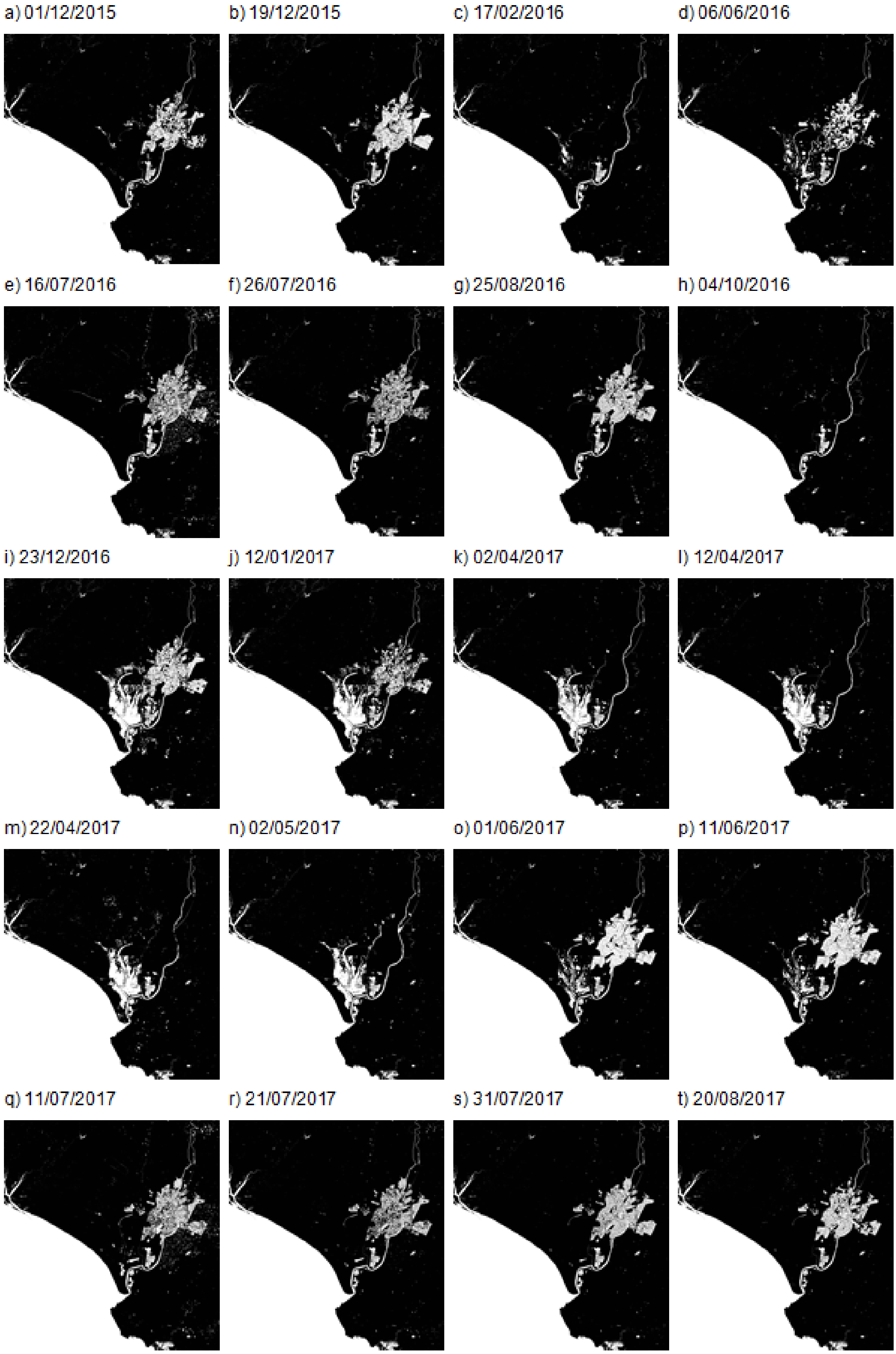


Figure 5.4a. Maps of water extent, Doñana, generated from each available cloud free observation of Sentinel-2 data.

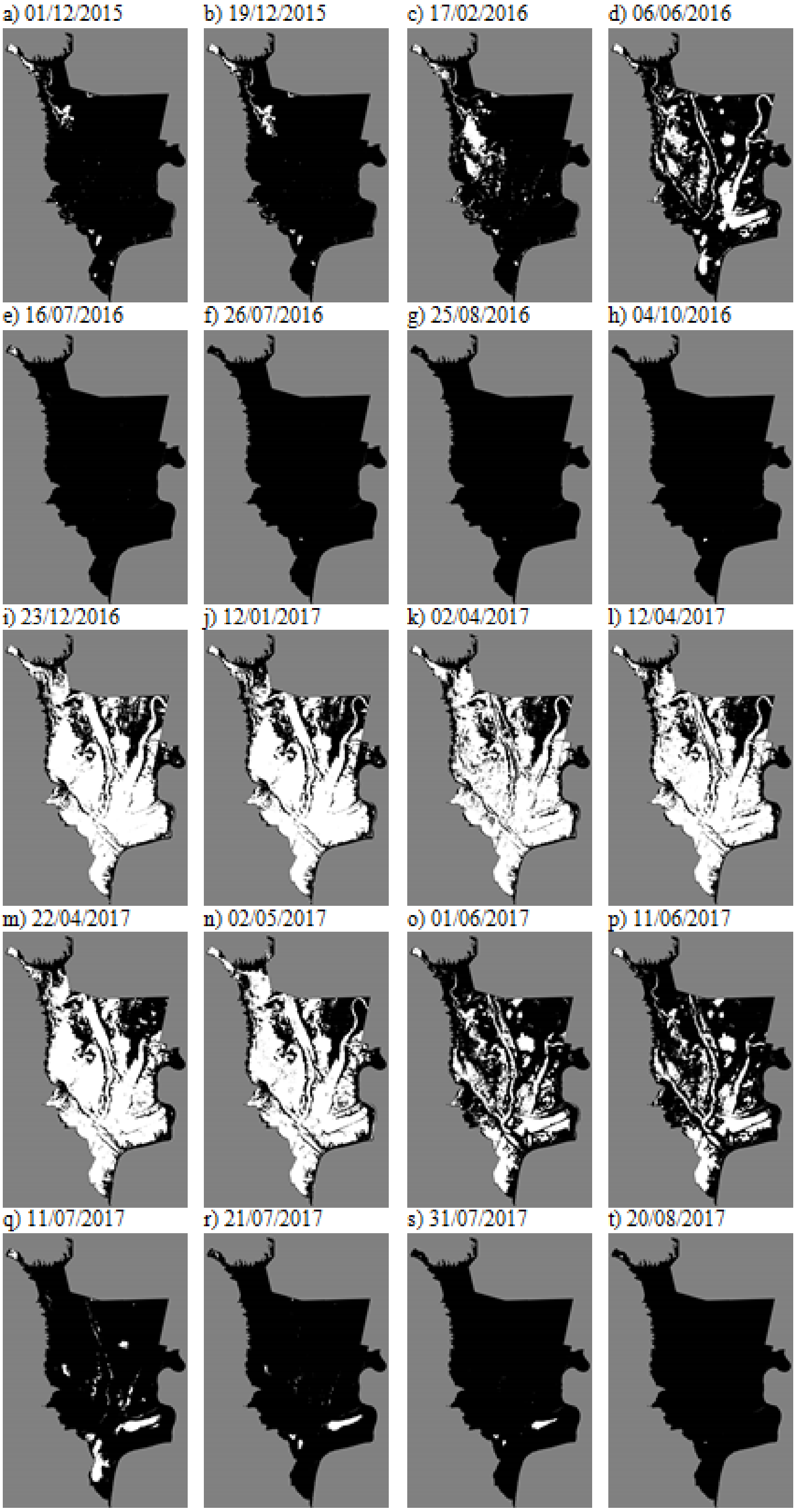


Figure 5.4b. Maps of water extent within Doñana NP, with focus on the marshland area. The maps were generated from each available cloud free observation of Sentinel-2 data.

5.3.2 Changes in Hydro-period

Changes in the hydro-period from year to year can be compared to determine whether a net drying or wetting of the landscape is occurring or whether inundation remains relatively stable. Using the Doñana National Park as an example, the annual hydro-periods for the epochs of 1st September 2015 to 31st August 2016 and 1st September 2016 to 31st August 2017 were generated from classifications of water inundation for the Donana NP (Figure 5.5) and the marshland area (Figure 5.6) generated from Landsat sensor and Sentinal-1 SAR data.

a) b

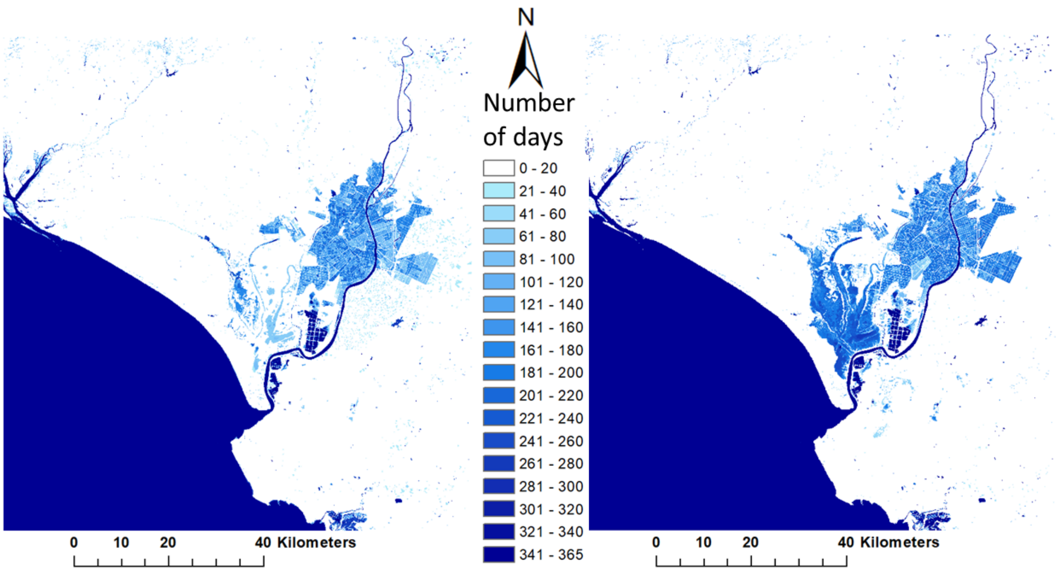


Figure 5.5a. a) Hydro-period images generated for the periods 2015-2016 and 2016 and 2017 using Sentinel-2A and Landsat sensor data.

a) b)

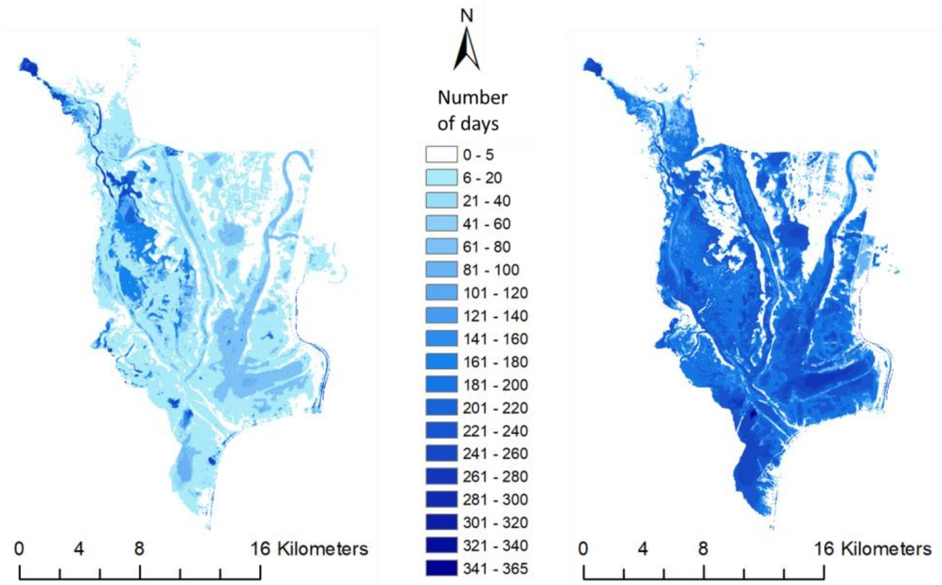


Figure 5.5b. a) Hydro-period images, with focus on the marshland area, generated for the periods 2015-2016 and 2016 and 2017 from Sentinel-2A and Landsat sensor data.

These were then translated to the LCCS-2 hydro-period classes that describe inundation frequency (e.g., < 1 month, 1-4 months, 4-7, 7-9 and > 9 month) and compared. The same translation for the Camargue PA is provided in Figures 5.7 a and b, using a hydro period layer from 2015 (JRC Global Inundation Layers) as input (see Figure 5.8). A continuous canopy cover layer, obtained from the World Resources Institute (WRI) Global Forest Watch (GFW) and also derived from Landsat sensor data, was similarly translated to discrete thematic categories. Again, these inputs provide evidence for hydrological changes across the landscape, but at a different temporal frequency compared to the changes in water state.

a) b)

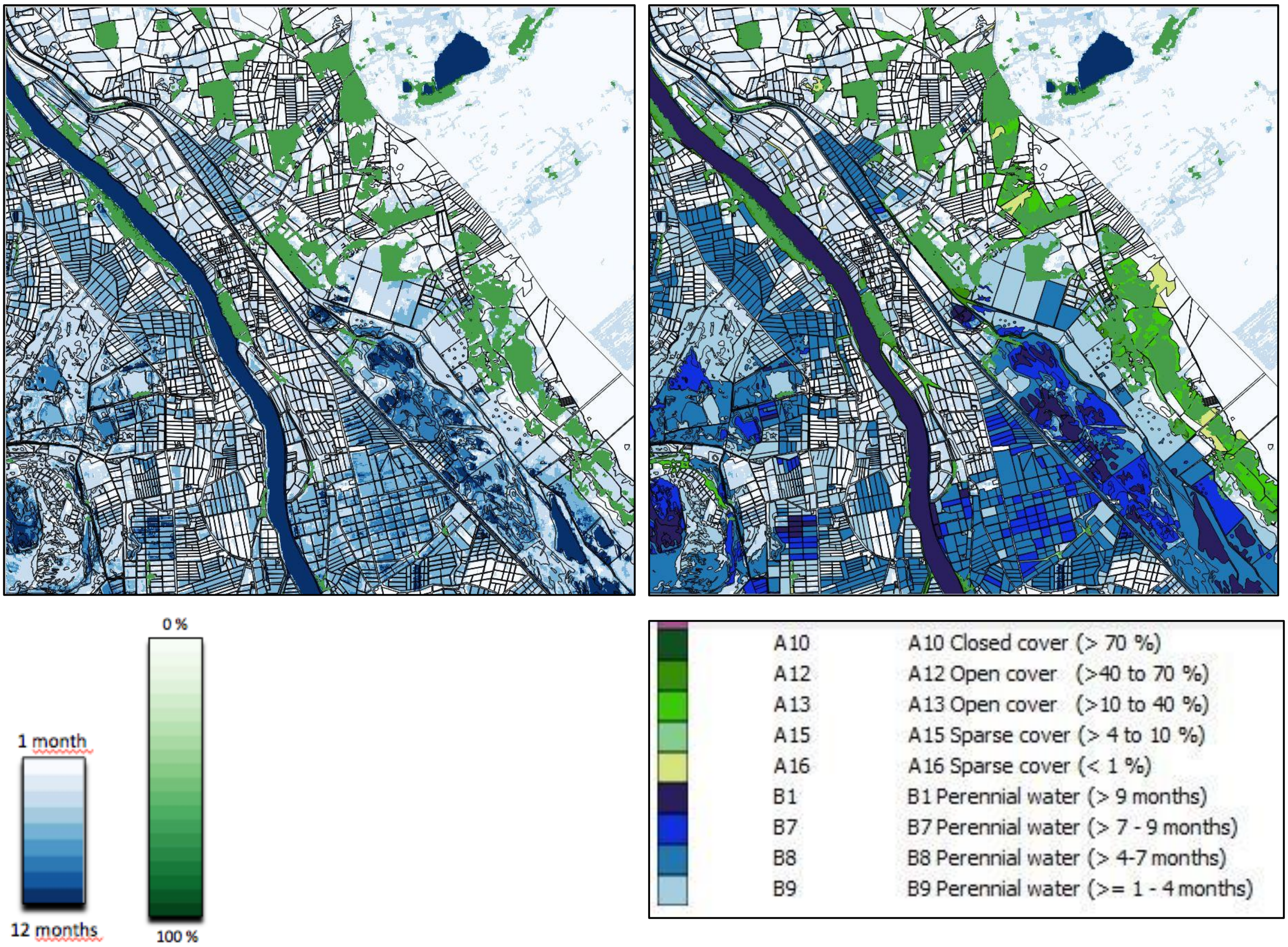


Figure 5.7. The translation of a) the hydro-period continuous layers to b) thematic LCCS categories, Camargue, France.

5.3.3 Changes in Snow Cover

As in the case of the water hydro-period, snow cover maps from moderate (e.g., Landsat or Sentinel-2A) and coarse (e.g., MODIS) resolution data can be accumulated to provide annual snow hydro-period maps (Figure 5.9) as well as information on the snow phenology (Figure 5.10). Examples have been generated for PAs, including Hardangervidda and Gran Paradiso National Parks (NP; Figure 5.11), for which annual snow cover hydro-period maps from 2000 to 2015 are available. The snow cover duration maps are provided in days but can be translated to any other desired time interval (e.g., months). As with the water hydro-period, the more detailed information on snow cover duration is translated to discrete classes defined in the LCCS-2 taxonomy. Other datasets can also be generated including the last date of snow occurrence in term of day of year (Figure 5.8). Such mapping can be used in conjunction with other datasets, including the extent of lichen cover (see Section 5.3.4), to understand change.

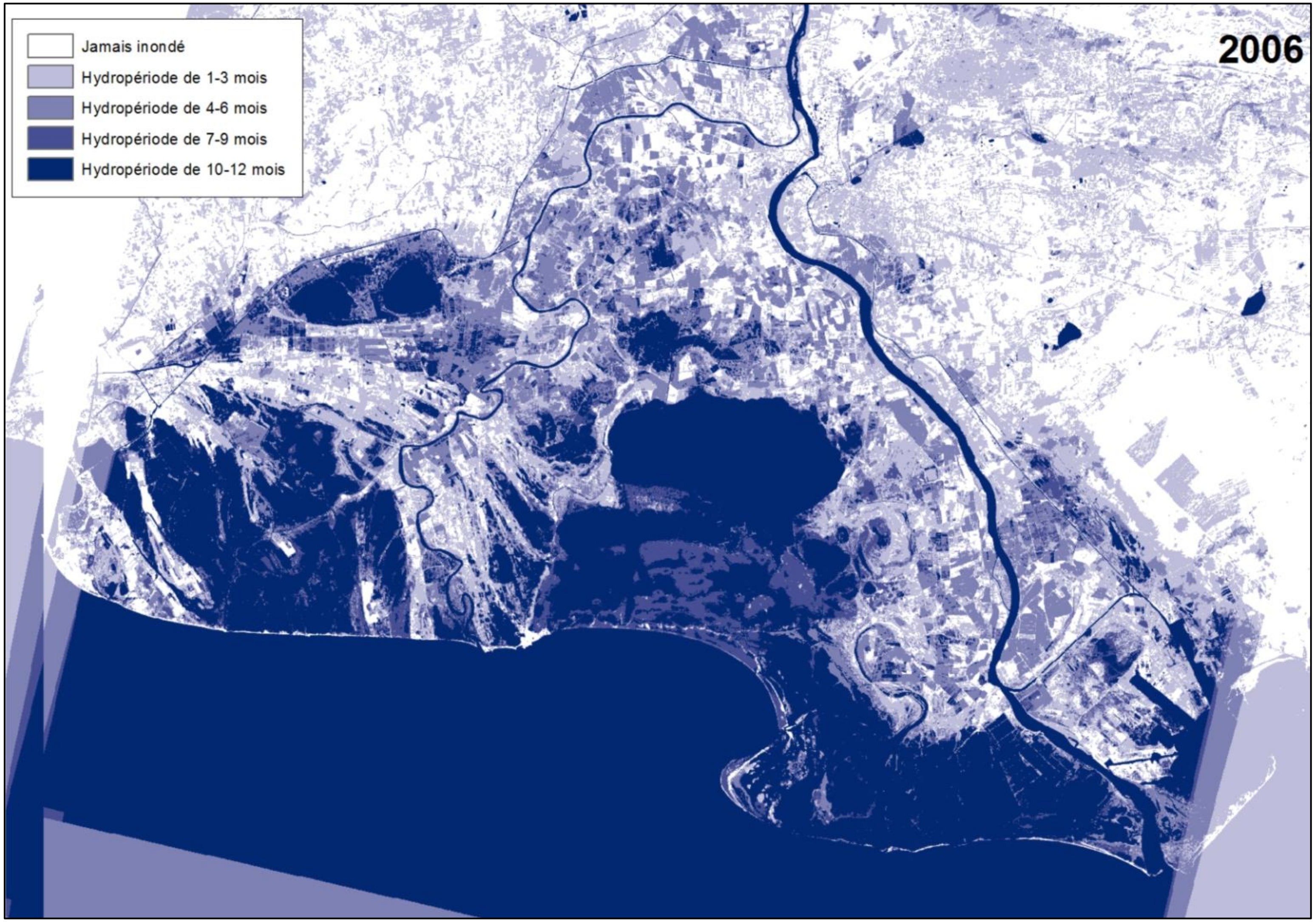


Figure 5.8. LCCS hydro period classes, Camargue, generated by Tour du Valet from 2006 SPOT data.

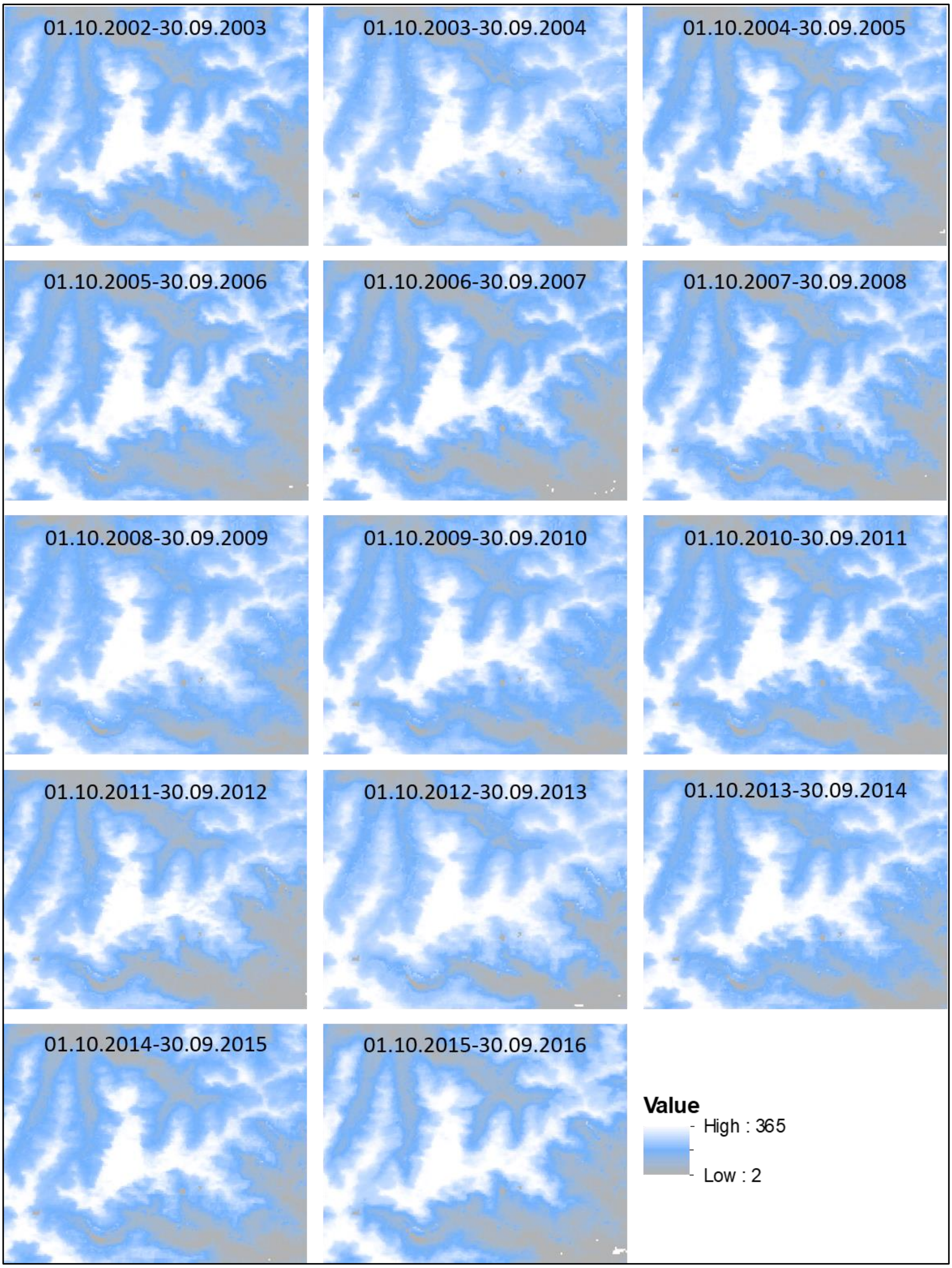


Figure 5.9. Maps of annual snow cover duration (days) for the Gran Paradiso NP derived from daily MODIS images. Numbers indicate the days per year.

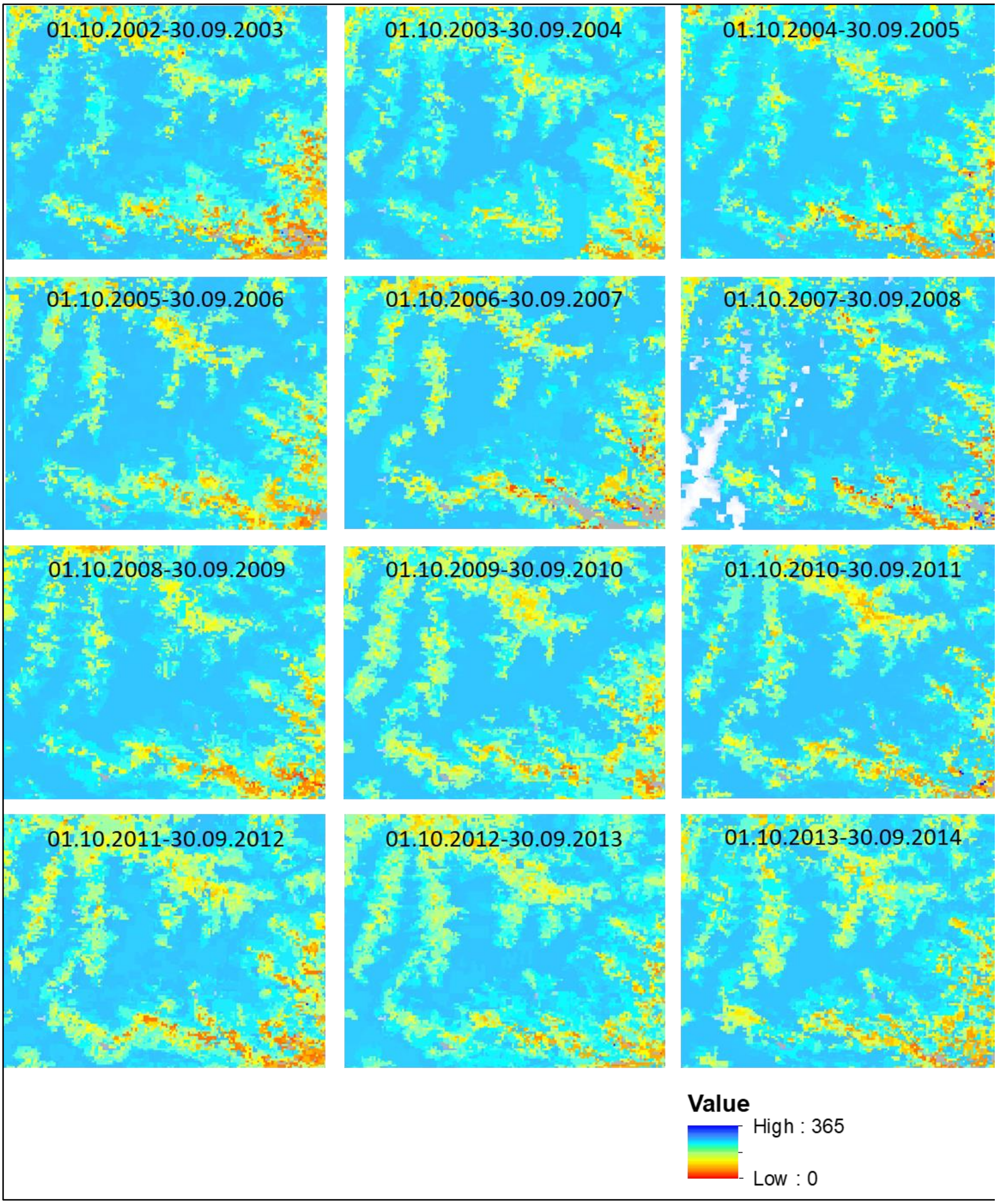
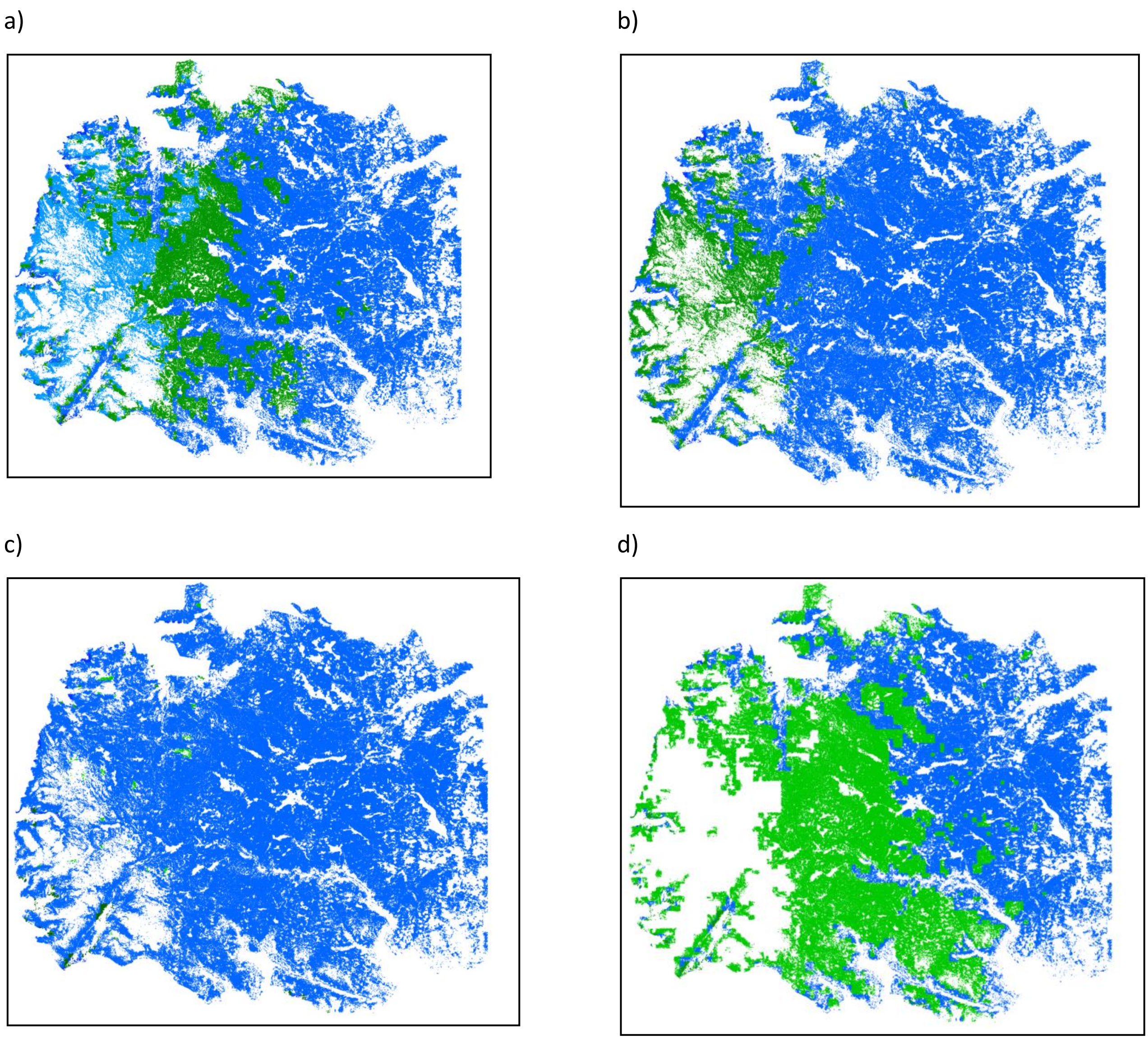


Figure 5.10. Maps of the time of last snow cover presence (day of year) for the Gran Paradiso NP derived from daily MODIS images. The maps are provided in day of year (DOY) and have been filtered in order to eliminate erroneous values (e.g. where first and last days of snow presence are the same).

Co-funded by the European Union

Snow cover duration and the time of the last snow presence are key variables representing snow phenology. These variables are continuously mapped from MODIS data for the entire alpine range in a standardized way by an automatic thresholding technique. Each of the snow variables represents the snow fall season starting from October to September in the following year. When combined, these can give an indication of the interchange between snow and vegetation.



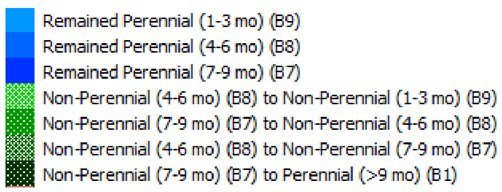


Figure 5.11. Changes in snow cover hydro-period between a) 2000 and 2003 b) 2003 and 2006 c) 2006 and 2010 d) 2010 and 2015, as generated from MODIS data. These maps have been translated to the LCCS component classes relating to water distribution across the landscape.

5.3.4 Changes in Vegetation Lifeform and Associated Variables

Across many landscapes, changes in lifeform (i.e., trees, shrubs, Graminoids, forbs, mosses and lichens) are commonplace and are captured by considering changes in classifications of these. However, there are also changes in the biophysical properties of vegetation, including those used in their classification to the LCCS-2 taxonomy (e.g., phenology, leaf type) but also those that provide quantitative descriptors of state (e.g., leaf area index, above ground biomass, foliar chemistry). Examples of detecting changes in lifeform and vegetation biophysical parameters are described in the following sections.

Lichens

In the Hardangervidda NP, changes in reindeer densities are impacting on the relative distribution and productivity of lichen and other low vegetation in the uplands. An algorithm for detecting **lichen volume** was applied to time-series of Landsat sensor data, with the resulting continuous layers then thresholded to determine the **extent of lichens** as a lifeform. Both the lichen extent and volume layer information were retained within the EODESM system (i.e., in the raster attribute table associated with each object) and used in the LCCS-2 classification. Whilst the EODESM approach was robust, the estimates of lichen volume (and hence extent) require further development in order to better identify and quantify the changes that are occurring (Figure 5.12). Additional information able to be included was the time of green up and the gross primary productivity (GPP) obtained automatically from time-series of MODIS vegetation index data for Hardangervidda National Park as well as other ECOPOTENTIAL PAs.

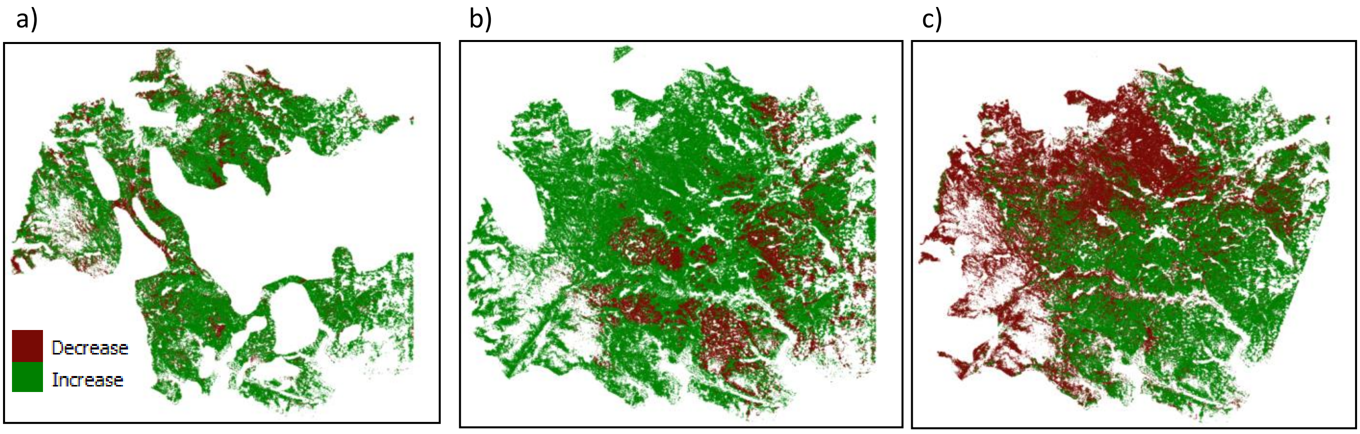


Figure 5.12. Changes in lichen volume between a) 15th September, 2002 and 9th August, 2003, b) 29th September 2010 and 16th September, 2011 and c) 16th September 2011 and 27th August 2013.

Grasslands

For several protected areas, time series comparisons of the herbaceous (grassland and/or forb) classifications can be used to indicate the changing extent of associated habitats. As an example, for Murgia Alta NP and the surrounding landscape, the extent of semi-natural grasslands was mapped in 2015 and 2016 by applying an unsupervised classification to time series of Sentinel-2A data. Comparison of the two images (Figure 5.13) indicates small losses in grasslands, with conversion typically being for cultivation. These translate to a change in both the LCCS Level 3 (semi-natural/natural terrestrial vegetation to cultivated terrestrial vegetation) and LCCS Level 4 categories (if a forb crop is grown).

a) b)

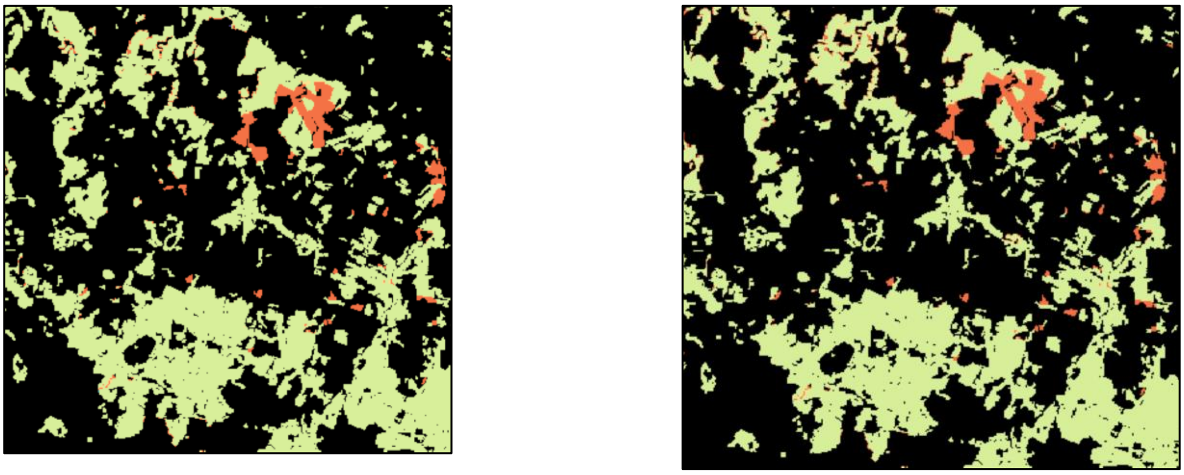


Figure 5.13. The extent of herbaceous vegetation (green) between 2006 and 2011, Alta Murgia NP, Italy.

Woody vegetation

For many of the ECOPOTENTIAL protected areas, changes within the woody lifeform (trees to shrubs and *vice versa*) and between other lifeforms (herbaceous graminoid and forbs and also cryptograms – lichens and mosses) are commonplace and can be captured by comparing time series of thematic lifeform classifications. However, continuous variables can also be quantified, including phenology, above ground biomass and canopy height and cover from EO data. Changes in both these thematic and continuous variables can then be used collectively to provide evidence of change. An example is provided for the Swiss/Davos National Park where time-series of LIDAR data (from 2003 and 2012) have been used to quantify changes in the landscape but also provide evidence for deforestation or regeneration (Figure 5.14).

5.3.5 **Vegetation Phenology.**

Phenology describes the temporal development of vegetation and holds important information about short-term and long-term vegetation changes. For Gran Paradiso NP, annual phenology information was derived from daily MODIS NDVI images covering the period from 2002 to 2015 and applying the TIMESAT algorithm. TIMESAT is a software package for analysing time series of satellite sensor data and allows the seasonality of satellite time-series data and their relationship with dynamic properties of vegetation to be investigated. Among the variety of seasonality parameters that can used to explain phenology, the start of season (SOS) parameter was chosen to mirror vegetation conditions in the growth season (Figure 5.15). The phenological information provides direct input to the EODESM as it can be used to describe phenological variants of the LCCS lifeform category but also can provide information such as the SOS, end of season and length of season, with these included as additional attributes.

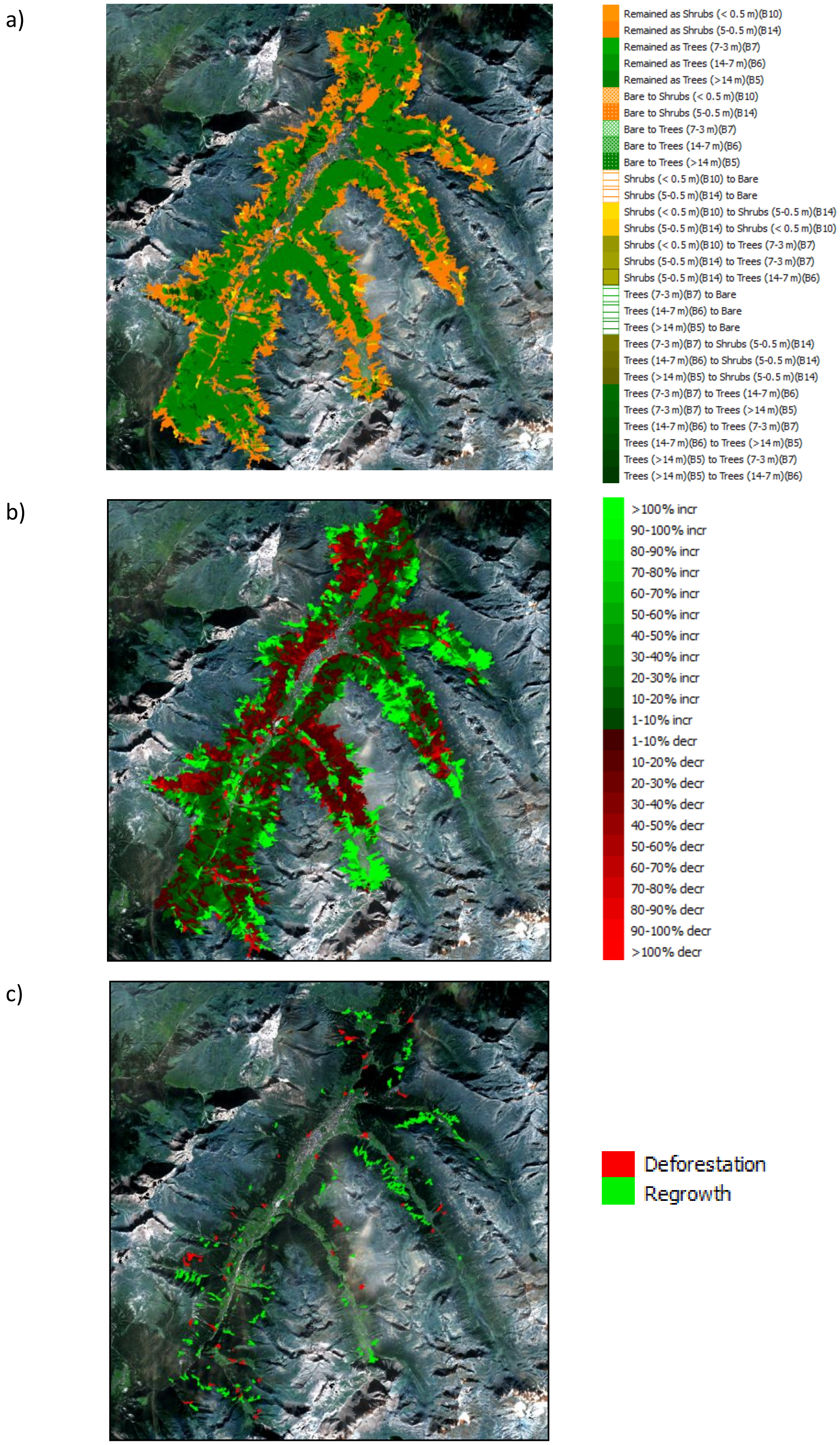


Figure 5.14. Changes in lifeform for Swiss National Park, Switzerland.

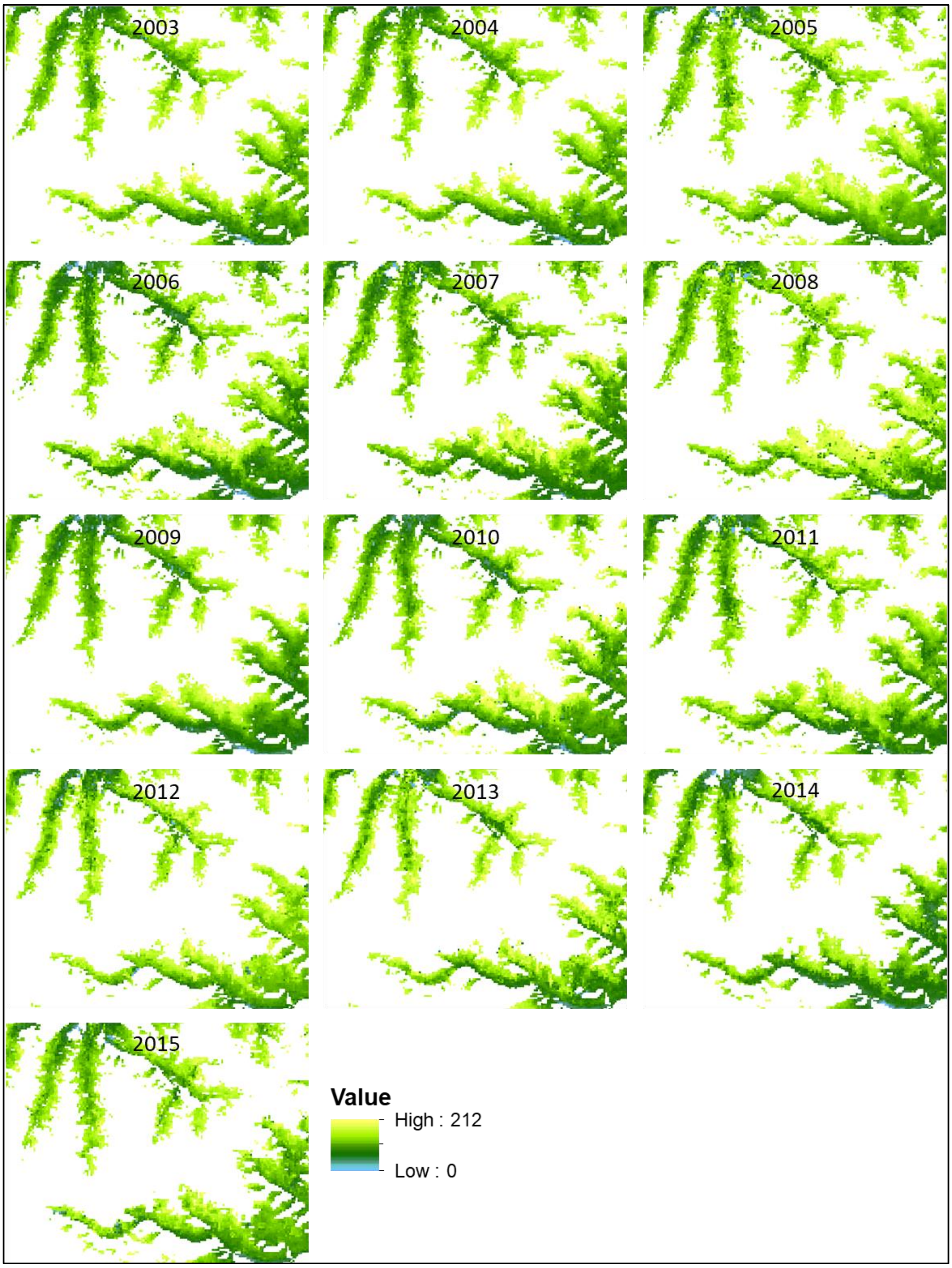


Figure 5.15. Maps of annual start of season greening for the Gran Paradiso NP derived from daily MODIS Normalized Difference Vegetation Index (NDVI) data. The numbers refer to the number of days for each year (from 1st January)

6. Changes in Variables

A number of change variables related to the storylines outlined in Section 4 have been provided by ECOPOTENTIAL partners for the different protected areas that are located in coastal and marine (Table 6.1), high mountain (Table 6.2) and semi-arid (Table 6.3) areas. In terms of detecting change, key layers that can be obtained from a time series include marine biophysical properties (e.g., sea surface temperature, chlorophyll-a, turbidity) and hydro-period. However, a number of layers are currently only available for one point in time including canopy cover and lifeform, partly because the Sentinel-2 data have only become recently available.. However, these variables are being continually updated during the course of the ECOPOTENTIAL project and hence improvements in the classification and also the detection and description of change are anticipated.

Table 6.1. Variables for change detection in coastal and marine PAs.

Site	Desirable	Available (on ftp)	Additional
1. Pelagos	Sea Surface Temperature Chlorophyll-a Turbidity Bathymetry	Sea Surface Temperature (2009-2015) Chlorophyll-a (1998-2015) N/A Bathymetry	
2. Wadden Sea	Sea Surface Temperature Chlorophyll-a Turbidity Bathymetry	Sea Surface Temperature (2013-2016) Chlorophyll-a (1998-2014) Coloured Dissolved Organic Matter (1998-2014) N/A	Wind fields (2014-2015) Ocean colour (2007-2012) Shoreline (Jan-Oct 2016)
3. Camargue	Hydroperiod Water seasonality Water turbidity Water depth Lifeforms Crop/vegetation types	Hydroperiod (2006) Water seasonality (1984-2015) N/A N/A Lifeforms (S2; 2016) LC maps (2006, 2011)	Wind fields (2014-2015) Surface water extent (2000-2012) Chlorophyll-a (1998-2014) Phenology start/end season (2000-2016) Tree cover density Sea Surface temperature (2008-2015)
4.Curonian Lagoon	Lifeform (incl. aquatic) Water seasonality Tidal period	Lifeforms (S2; 2016) Water seasonality (1984-2015) N/A	Surface water extent (2000-2012) Sea Surface Temperature Sea Ice thickness Shoreline (2016-2017)
5. Danube Delta	Lifeform (incl. aquatic) Water seasonality Water depth Water turbidity Crop/vegetation types	Lifeforms (S2; 2016) Water seasonality (1984-2015) N/A N/A LC maps (2006, 2012)	Tree cover density NDWI Surface water extent (2000-2012)
6. Doñana NP	Lifeform (incl. aquatic) Hydro-period Inundation Water seasonality Water depth Water turbidity	Lifeforms (S2; 2016) Hydro-period (2009-2014) Inundation maps (2015-2016) Water seasonality (1984-2015) Water bodies delineation	Phenology indices from S2 data (2015-2016) Surface water extent (2000-2012) GPP (2000-2016) Tree cover density
7. Lakes Ohrid and Prespa	Water turbidity Water seasonality Lifeform Soil moisture	N/A Water seasonality (1984-2015) Lifeforms (S2; 2016) Soil moisture (2008-2015)	Surface water extent (2000-2012) GPP (2000-2017) Landscape fragmentation Tree cover density Surface Soil moisture

Table 6.2. Variables for change detection in high mountain PAs.

Site	Desirable	Available (on ftp)	Additional
8.Northern Limestone	Canopy cover Canopy height Phenology Leaf type Above ground biomass Net Primary Production Crop/vegetation types	Tree cover density (2012) LIDAR (2012) Landsat NDVI/EVI (2002-2014) Landsat (2012) N/A LC maps (2014)	Elevation Snow area Water seasonality (1984-2015) Surface water extent (2000-2012) Forest disturbances GPP (2000-2017) Surface soil moisture (2014-2019)
9. Bavarian Forest NP	Canopy cover Phenology Leaf type Net Primary Production Lifeform Habitats Insect outbreaks Windthrows	Tree cover density (2012) Landsat NDVI / NDWI (1985-2016) Landsat (2012) N/A Lifeforms (S2; 2016) Habitats (1989, 2003, 2008, 2012) Insect outbreaks (2008-2010 2007 Forest disturbance	Bare ground (2010) Water seasonality (1984-2015) Surface water extent (2000-2012) Land surface temperature
10. Gran Paradiso NP	Lifeform Canopy cover Snow cover Grassland	Lifeforms (S2; 2016) Tree cover density (2012) Snow cover Grassland (2012-2016) NDVI/NDWI	Albedo (2000-2015) Bare ground (2010) Land surface temperature Surface Soil Moisture
11. Hardangervidda NP	Lifeform Lichens Snow cover Elevation	Lifeforms (S2; 2016) Phenology start/end season Tree cover density NDLI (1983-2016) Snow cover (2000 onwards) Snow area (S2) Digital elevation data	Bare ground (2010) NDMI (2000-2016) Water seasonality (1984-2015) Surface water extent (2000-2012)
12. High Tatra Mts. NP	Lifeform Canopy cover	Lifeforms (S2; 2016) Tree cover density (2012) NDVI / NDWI Tree cover density Snow cover maps	Bare ground (2010) Water seasonality (1984-2015) Surface water extent (2000-2012)
13. La Palma	Lifeform Cloud cover Plant species Cultivated	Lifeforms (S2; 2016) Cloud cover (LS/S2; 2015-2016) Existing mapping (2003-2015) Forest disturbances GPP (2000-2017) Landscape fragmentation LAI Tree cover density Vegetation height and structure	Landsat NDVI (1990-2016) Landsat NDWI (1988-2016)Climate variables (monthly averages) Elevation Water seasonality (1984-2015) Surface water extent (2000-2012) Land surface temperature
14. Sierra Nevada NP	Lifeform Canopy cover Phenology Leaf type Net Primary Production Crop/vegetation types	Lifeforms (S2; 2016) Tree cover density (2012) Landsat NDVI (1984-2011) Landsat (2012) N/A LC maps (2005, 2011) Forest disturbances GPP (2000-2017) LAI Vegetation height and structure	Elevation Albedo (2000-2015) Biodiversity indicators (1956-2007) Water seasonality (1984-2015) Surface water extent (2000-2012) Landscape Fragmentation Snow cover maps

			Land surface temperature Surface Albedo Surface Soil Moisutre
15. Swiss NP and Davos	Lifeform Canopy cover Elevation Canopy height Above ground biomass	Lifeforms (S2; 2016) Tree cover density (2012) Elevation CHM (2003, 2012) Above ground biomass (2003, 2012) GPP (2000-2017) NDVI	Roads Water seasonality (1984-2015) Surface water extent (2000-2012) Vegetation height and structure

Table 6.3. Variables for change detection in semi-arid PAs.

Site	Desirable	Available (on ftp)	Additional
16. Har Hanegev	Lifeform	Lifeforms (L8/S2; 2016)	Bare ground (2010)
	Phenology	Phenology start /end season (2000-2017)	Water seasonality (1984-2015)
	Net Primary Production	GPP (2000-2017)	GPP (2000-2017)
			Surface Soil moisture
17. Kruger NP	Lifeforms	Lifeforms (S2; 2016)	Landsat NBR (1987-2004)
	Canopy cover	Tree cover density (2012)	Bare ground (2010)
	Above Ground Biomass	AGB (Trees)	Landsat NDVI (1987-2013)
		AGB (Herbaceous)	Roads, railways
	Net Primary Production	N/A	Elevation
	Tree density	Tree cover density (2012)	Water seasonality (1984-2015)
	Land cover	LC maps (1990, 2000, 2015)	Surface water extent (2000-2012)
		Forest disturbances	
	Fires	Fires (2005-2015)	Surface soil moisture
		Landscape fragmentation	
		Phenology start /end season (2000-2017)	
		Vegetation height and structure	
18. Montado NP	Lifeform	Lifeforms (S2; 2016)	Landsat NDVI (1984-2015)
	Canopy Cover	Tree cover density (2012)	AGB
	Understory layers	Phenology start /end season (2000-2017)	Water seasonality (1984-2015)
	Soil moisture	Surface soil moisture	Surface water extent (2000-2012)
	Crop/vegetation types	Forest disturbances	
	Forest cover	Vegetation height and structure	
	Biodiversity indicators		
		Landscape fragmentation	
	Burnt areas	N/A	
		LC map (2007)	
		Forest maps (2000, 2006)	
		Biodiversity indicators (2007, 2012)	
		Burnt areas (1990-2014)	
19. Murgia Alta	Lifeform	Lifeforms (S2; 2016)	
	Canopy Cover	Tree cover density (2012)	Soil moisture (2014-2016)
	Infrastructure	Impervious surfaces	Water seasonality (1984-2015)
	Bare ground	Bare ground (2010)	Surface water extent (2000-2012)
	Bare surface material	N/A	
	Crop/vegetation types	LC maps (2006, 2011)	
	Grassland	Existing mapping (2006-2014, 2012-2015)	
20. Peneda-Geres	Lifeform	Lifeforms (S2; 2016)	Elevation
	Canopy Cover	Tree cover density (2012)	Surface Soil moisture
21. Samaria NP	Lifeform	Lifeforms (S2; 2016)	
	Bare ground	Tree cover density	Water seasonality (1984-2015)
	Bare surface material	Bare ground (2010)	Surface water extent (2000-2012)
	Habitats	N/A	
		Habitat maps (1985, 1995, 2000, 2005, 2010, 2015)	Land surface temperature
	Landscape measures		Albedo
		Landscape fragmentation measures (1985, 1995, 2000, 2005, 2010, 2015)	

7. Accounting for time

Across landscapes, numerous changes are occurring and for decades, quantifying such changes using one or only a few satellite images a year has proved a significant challenge. As an example, Figure 7.1 highlights that, within any single image, changes are occurring at different rates and magnitudes. For example, daily variations in tidal inundation might occur at the same time as changes in snow cover (which are often described on a daily to weekly timeframe), vegetation phenology (intra and inter-annual) and accumulating biomass (continual but often assessed on a 1-5 year time frame). The EODESM system has been designed such that changes occurring over different time frames are detected but also considered in unison.

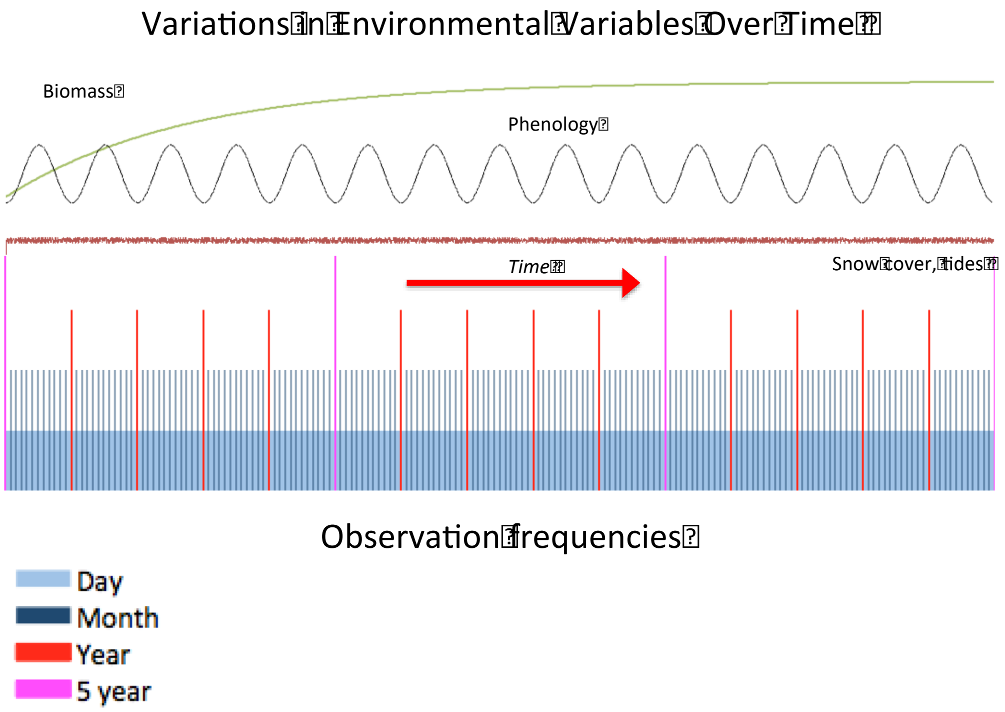


Figure 7.1 Diagrammatic representation of time-varying changes across a landscape. The letters of day, month, year etc. are rasterised in this image.

The ability to detect change has improved significantly as the availability of sensors operating in different modes has increased. This has not only led to a greater number of observations but also a better understanding of temporal signatures as a function of change events and processes. A greater number of EnVs can also be retrieved and these collectively can provide a large amount of new and often corroborating information on the state and dynamics of landscapes. This is illustrated in Figure 7.2, which highlights, using the Camargue in southern France as an example, the requirements for change information and how this can be addressed by exploiting the diversity of available sensors.

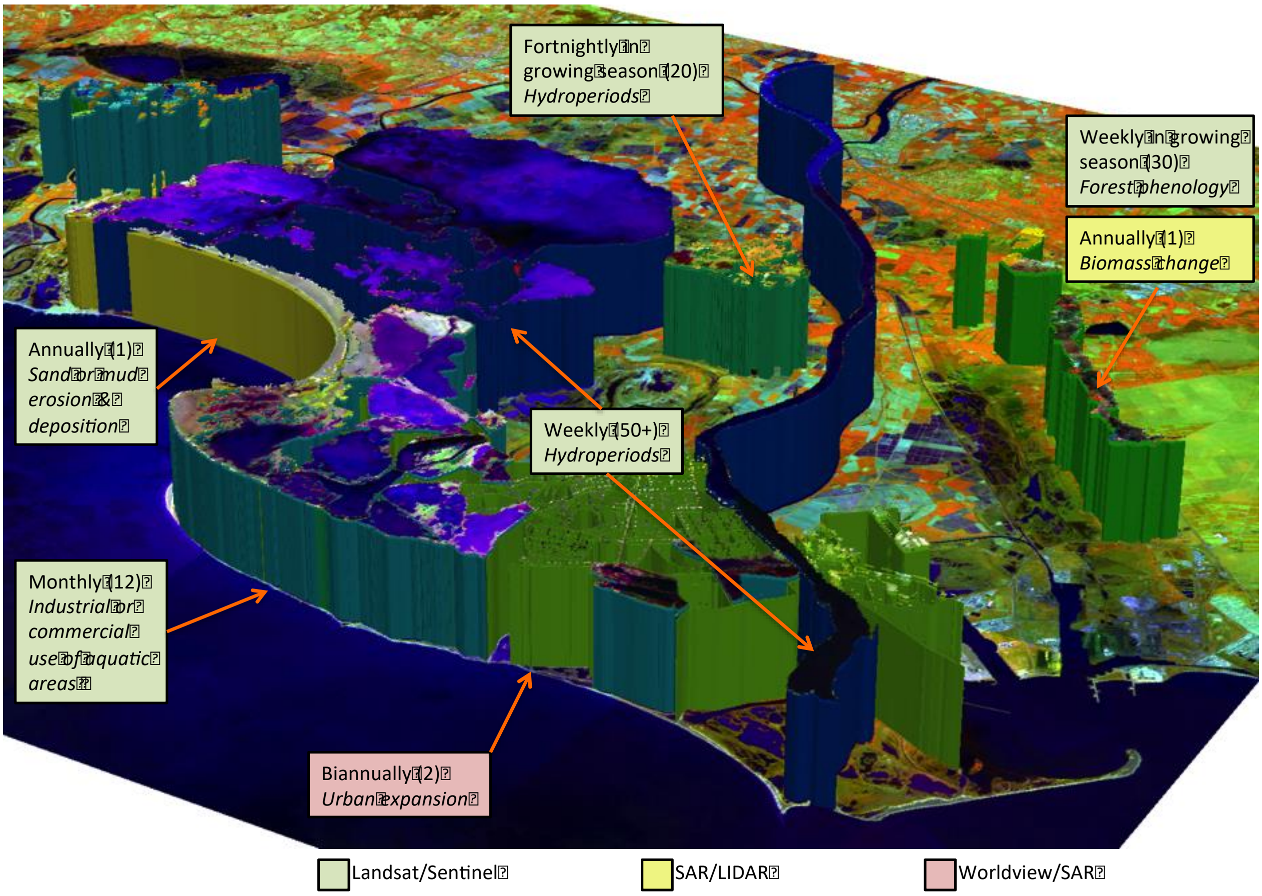


Figure 7.2. Examples of changes occurring in the Camargue over different time frames, the requirement for observations and the types of sensors that can be used collectively to identify and quantify change. The image depicts the depth of information that can be obtained over time, with this depicted by the number of levels within the 3D representation.

Despite the availability of EO data, most has been acquired at different times and so establishing links between, for example, plant productivity over time and net biomass accumulation, can be difficult. A further limitation is that the same diversity of sensors and modes are often not available early in the time series (e.g., the red edge bands currently on the RapidEye and Sentinel optical sensors). The EODESM system attempts to align observations and derived products and there is also potential capacity to interpolate between observations, particularly if knowledge of temporal trends from later dates in the time series can be exploited. Consideration needs to be given to the various data sources and resolutions of information needed to ensure that these are co-registered and meaningful in time; but also that uncertainties are addressed and accounted for. An overview of the sensors that are available to retrieve selected EnVs is provided in Tables 7.1 to 7.4.

Table 7.1. Variables relevant to all high mountain protected areas.

RS variable	Period	Frequency	Spatial resolution	Satellite	Referent expert
Phenology and productivity (derived from NDVI)[1]	From 1984	16 day images (if available and no clouds)	30 – 250 km	Landsat/Sentinel 2/MODIS	UAB/CREAF/UFZ
Snow cover	2002-2016	Daily (if available and no clouds)	250 m	MODIS TERRA/AQUA	EURAC
Snow cover duration	2002-2016	yearly	250 m	MODIS TERRA/AQUA	EURAC
Land surface temperature	2000-2017	Daily averages	1 km	MODIS TERRA/AQUA	FORTH
Soil moisture High resolution	2015-2016	12 days (6 days when S1A and S1B are both available)	From 20 m to 100 m	Sentinel 1A and 1B	EURAC
Soil moisture Low resolution	2007-2015	Daily	12.5 km	ASCAT	EURAC

[1]Includes derived metrics such as start, length and end of season, leaf area index (LAI)

Table 7.2. Variables relevant to all coastal (wetland) and marine areas

RS variable	Period	Frequency	Spatial resolution	Satellite	Referent expert
Chlorophyll a	1998-2015	monthly	4 km	Several (including MERIS)	ISPRA
Sea Surface Temperature	1986-2016	Daily	2 - 4 km	Several	ISPRA
Total suspended solids /Turbidity	From 1984	16 day images (if available and no clouds)	30 m	Landsat /Sentinel 2	EBD-CSIC
Hydroperiod	Landsat (From 1984; JRC) Sentinel: 2015/2016 (based on S-1 and S-2 data availability for the area)	About 10 days (delineation accuracy varies based on the available SAR (lower accuracy) and optical (higher accuracy) data takes)	10-30m	Landsat Sentinel 1 & 2	JRC CERTH

Table 7.3. Variables relevant to all semi-arid areas

RS variable	Period	Frequency	Spatial resolution	Satellite	Referent expert
Phenology and productivity (derived from NDVI)	From 1984	16 day images (if available and no clouds)	30 m	Landsat / Sentinel 2	UAB/CREAF
Soil moisture High resolution	2015-2016	12 days (6 days when S1A and S1B are both available)	From 20 m to 100 m	Sentinel 1A and 1B	EURAC
Soil moisture Low resolution	2007-2015	daily	12.5 km	ASCAT	EURAC
Albedo	2000-2015	Yearly	500 m	MODIS	FORTH
Land surface temperature	2000-2017	Daily averages	1 km	MODIS TERRA/AQUA	FORTH

Table 7.4. Variables relevant to all protected areas

RS variable	Period	Frequency	Spatial resolution	Satellite	Referent expert
Land Cover	From 1984	Yearly	10-30 m	Primarily Landsat and Sentinel-1/2	UNSW/CNR
GPP	2002-2016	Yearly	250 m	MODIS	UFZ
Landscape fragmentation	From 1984	Yearly	10-30 m	Primarily Landsat and Sentinel-1/2	UNSW
Phenology	2002-2016	Yearly	250 m	MODIS	UFZ

8. Assessing errors in change classifications

A major limitation in the estimation of change accuracy is the lack of information on the process of change itself. If the change is rapid, then 'before and after' observations are needed but where change is progressive, then long-term observations are essential. The following sections outline some of the types of changes that are occurring and how these might be addressed in terms of uncertainties:

8.1 Changes in classes

The accuracy in the assessment of changes in class can be determined through reference to ground-based observations of LCCS components (e.g., canopy height, lifeform). A development that has occurred alongside the ECOPOTENTAL project has been the establishment of mobile applications for recording land cover information and also change in near real time. Such timely information is essential for validation and provides an opportunity to generate, as an example, error matrices for the different components of the land covers being described. As an example, information on canopy cover and height categories can be recorded and used to validate the layers derived from, for example, LiDAR data.

8.2 Changes in variables

Determining the accuracy of changes in variables is more straightforward as accuracies depend upon the model used to generate these from earth observation data. For example, if a forest has a median canopy height of 10 m in one year and 15 m in five years, the change in height (5 m) detected (e.g., by LIDAR) will be dependent upon the accuracy of the retrieval algorithm assuming that the same is applied on both occasions.

For a more accurate quantification of the change overall accuracy the protocol described in Olofsson et al. (2013; 2014) has been adopted with a more informative presentation of the change error matrix with the advantage that change accuracy and changed area estimates can be computed directly (Tarantino et al., 2016). Examples are provided below for Murgia Alta and Gran Paradiso.

To validate the classification of change in grasslands in Murgia Alta and Gran Paradiso between two periods, a set of 673 and 208 change/no change reference polygons respectively, distributed on scene, were selected through visual inspection of Sentinel-2 imagery, orthophotos and in-field knowledge. Stratified random sampling was applied. The change detection matrices (Tables 8.1 and 8.2) indicated a high degree of correspondence in the change from grasslands to other categories.

Table 8.1. Change detection matrix obtained from Cross Correlation Approach (CCA) for Murgia Alta PA. Producer's and overall accuracies are based on stratified estimation. A_m is the mapped changed area.

Transition from Natural Grasslands to Other						
Change User's Acc.%	Change Producer's Acc.%	No Change User's Acc.%	No Change Producer's Acc.%	Overall Acc.%	A_m (ha)	Stratified changed area estimate with 95% conf. interv. (ha)
94.64±0.23	70.68±0.33	94.14±0.10	99.16±0.04	94.21±0.10	3456.16	4628.19±51.03

Table 8.2. Change detection matrix obtained from CCA for Gran Paradiso PA. Producer's and overall accuracies are based on stratified estimation. A_m is the mapped changed area.

Transition from Natural Grasslands to Other						
Change User's Acc.%	Change Producer's Acc.%	No Change User's Acc.%	No Change Producer's Acc.%	Overall Acc.%	A_m (ha)	Stratified changed area estimate with 95% conf. interv. (ha)
76.93±0.65	57.04±0.53	91.60±0.15	96.48±0.07	89.75±0.16	3947.32	5323.40±97.66

8.3 Change events and processes

The type of ground data required for assessing the accuracy of change will vary depending upon the change that is occurring. For change events, both a change in class and variable should be considered but where long-term processes occur (e.g., within a forest stand), then greater weight might be given to the change in the variable. The accuracy of the change classification would consider the component class changes where, for example, the canopy cover transitions from one class to another (e.g., open to closed) forest. The changes in the individual and separate components can then be integrated to give an overall class accuracy.

9. Identifying and describing change.

In many approaches, change is often detected by comparing the spectral values or derived measures (e.g., vegetation or water indices) from EO data between two time-separated periods (T1 and T2). Often, such approaches indicate that a change has taken place but generally do not describe the transition from one class to another. This approach differs from that adopted in the EODESM system, whereby change is both detected and described based on changes in EnVs (whether continuous or thematic), with examples being hydro-period, canopy cover and lifeform. However, the former approach to change detection can be integrated within the EODESM system as it allows identification of change events which might not necessary be detected through comparison of class codes or EnVs alone. More significantly, it focuses attention on a particular date or dates or a period or periods, during which change is occurring. Once identified, the transitions from one LCCS class to another or changes in EnVs can be better utilised.

To illustrate differences in the approaches, Figure 9.1 conveys a time-series of Normalised Difference Vegetation Index (NDVI) data for the nominal period 2000 to 2017 for a forested site, with a relatively predictable interannual variability. However, a **change event** (in this case, clearance of dry tropical forests for shifting cultivation) leads to a change in the class codes (from closed canopy continuous broadleaved evergreen trees to a cultivated herbaceous crop) and also a reduction in the NDVI (which effectively is the breakpoint) followed by an NDVI of lower magnitude and amplitude in subsequent years. However, if the cleared area is abandoned, a **change process** (in this case, regrowth) may ensue with this associated with a change from forest to bare ground and its subsequent colonisation by graminoids and forbs and then shrubs, with this progressively increasing the NDVI and its dynamical range. In the first case, the change event can be described by simply comparing an image (and associated classification and derived variables) from T1 and T2. However, a change process needs to refer to the alterations in classes but also EnVs that have taken place over a longer period of time.

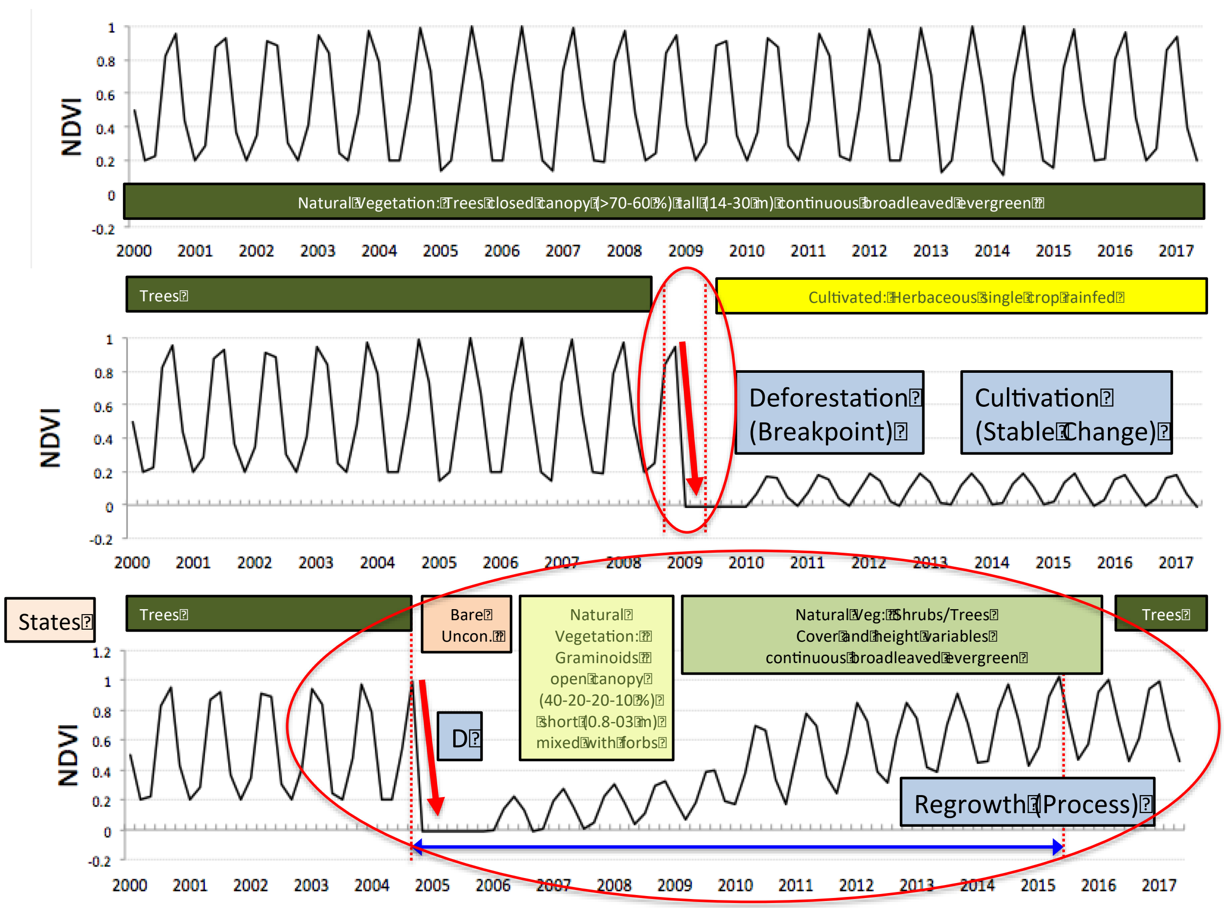


Figure 9.1. A 'typical' NDVI time-series observed from seasonal forests (top), which is disrupted by a change event (middle; deforestation). The change may lead to a long-term alteration in land cover but can also change the trajectory of a change process such as regeneration (bottom).

The description of change also based upon accumulated evidence. As illustration, evidence that the event is deforestation includes a transition from trees to bare ground and a reduction in the NDVI, with crop growth indicated by an increase in canopy cover and a transition to graminoids (Figure 9.2). In the post-event period, a continually lower NDVI provides the additional evidence that cropping has occurred. By contrast, there is more evidence to suggest that the process following deforestation is regrowth, with this including a change from trees to bare ground and a reduction in the NDVI and, as well as a transition to graminoids, shrubs and trees, an increase in plant height and above ground biomass.

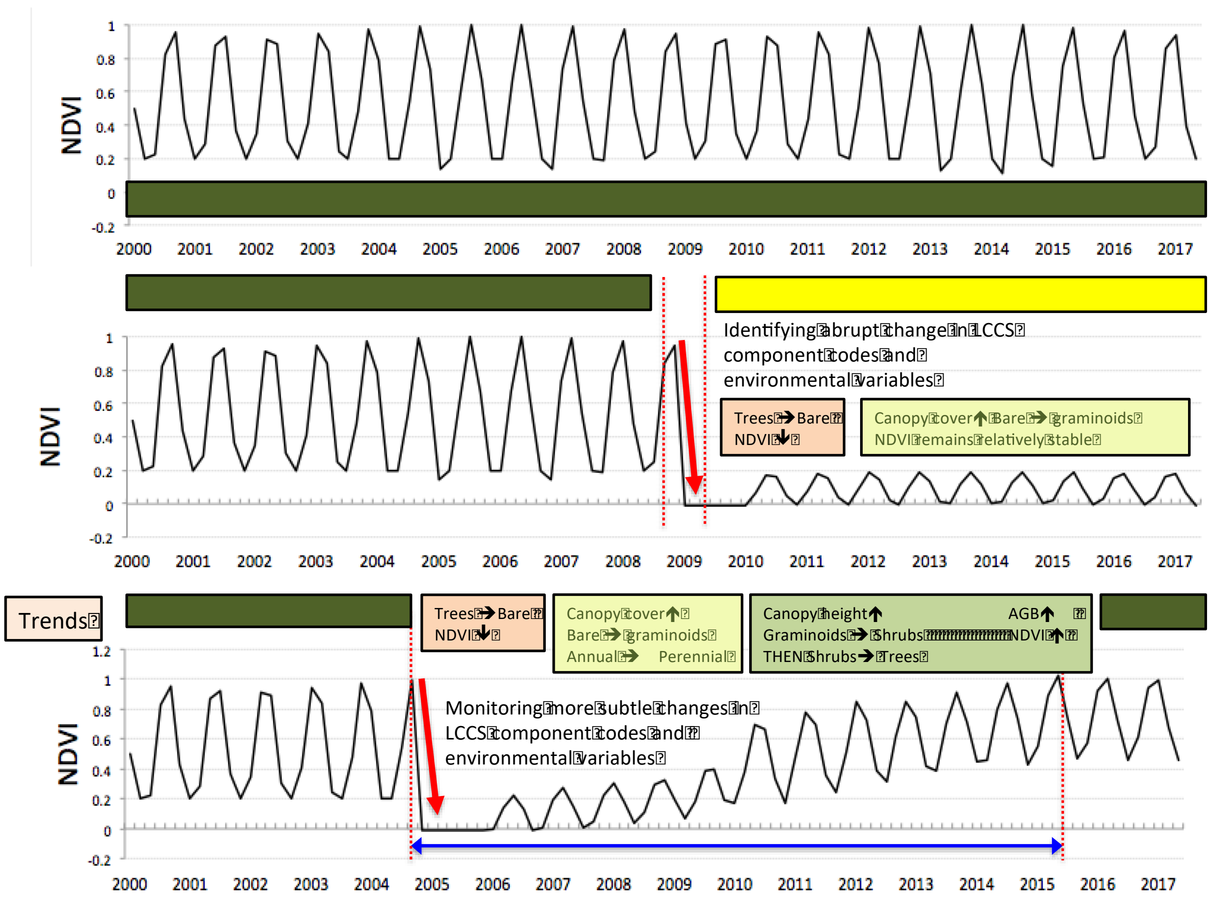


Figure 9.2. The trends in thematic classifications and EnVs associated with the change events and processes.

10. Complementary approaches to change detection

A number of approaches have been developed through ECOPOTENTIAL to detect change events or, if image acquisitions are time-separated by a long period, indicate change processes. These include the Cross Correlation Analysis (CCA) approach (described below) and the Breaks for Additive Season and Trend (BFAST or DBEST), which is described in Deliverable 4.5.

10.1 CCA

The CCA algorithm is described in Koeln and Bissonette (2000) and Tarantino et al. (2016) and the approach has been applied to detect changes in natural grasslands in Murgia Alta, Gran Paradiso and Montado national parks (Figures 6.1 to 6.3) since they were mapped in 2012 in the development of the Copernicus High Resolution Layers (i.e., for natural grasslands). In all cases, the CCA detected a loss of grasslands, both within and outside of the protected areas with this typically associated with clearance for agriculture and also shrub encroachment. In each case though, the class resulting from the change is not indicated.

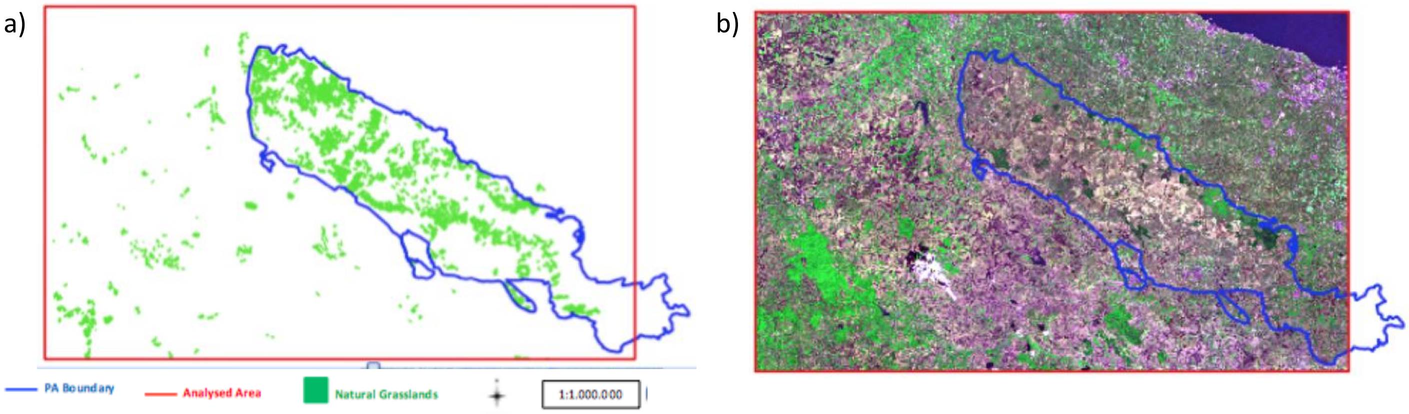


Figure 10.1 a) The extent of natural grasslands ((≈26615 ha) in the Murgia Alta Protected Area (green), as mapped for 2012 in the Copernicus Natural Grasslands Layer and b) a Sentinel-2A image (Bands 4, 8 and 2 in RGB) acquired on the 7 August 2015 (time = T2).

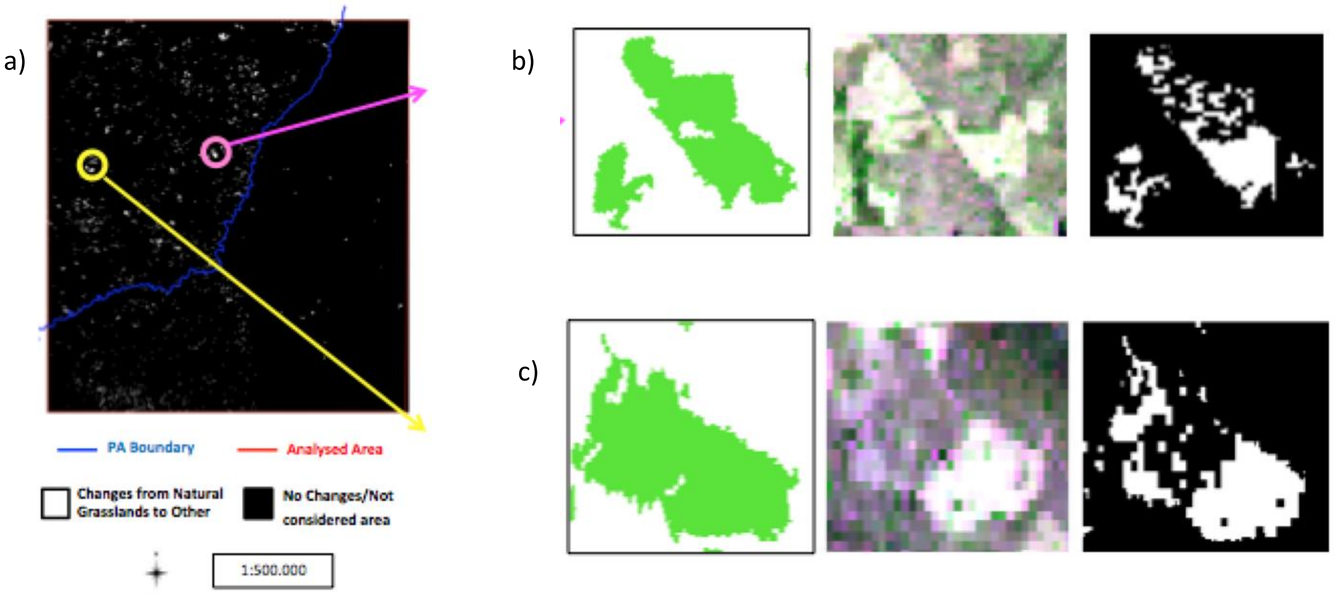


Figure 10.2 Areas where natural grasslands have changed to other categories between 2012 and 2016 for the Murgia Alta PA. More detailed subsets of the Copernicus grassland layer, a Sentinel-2A image and change areas are provided in b) and c).

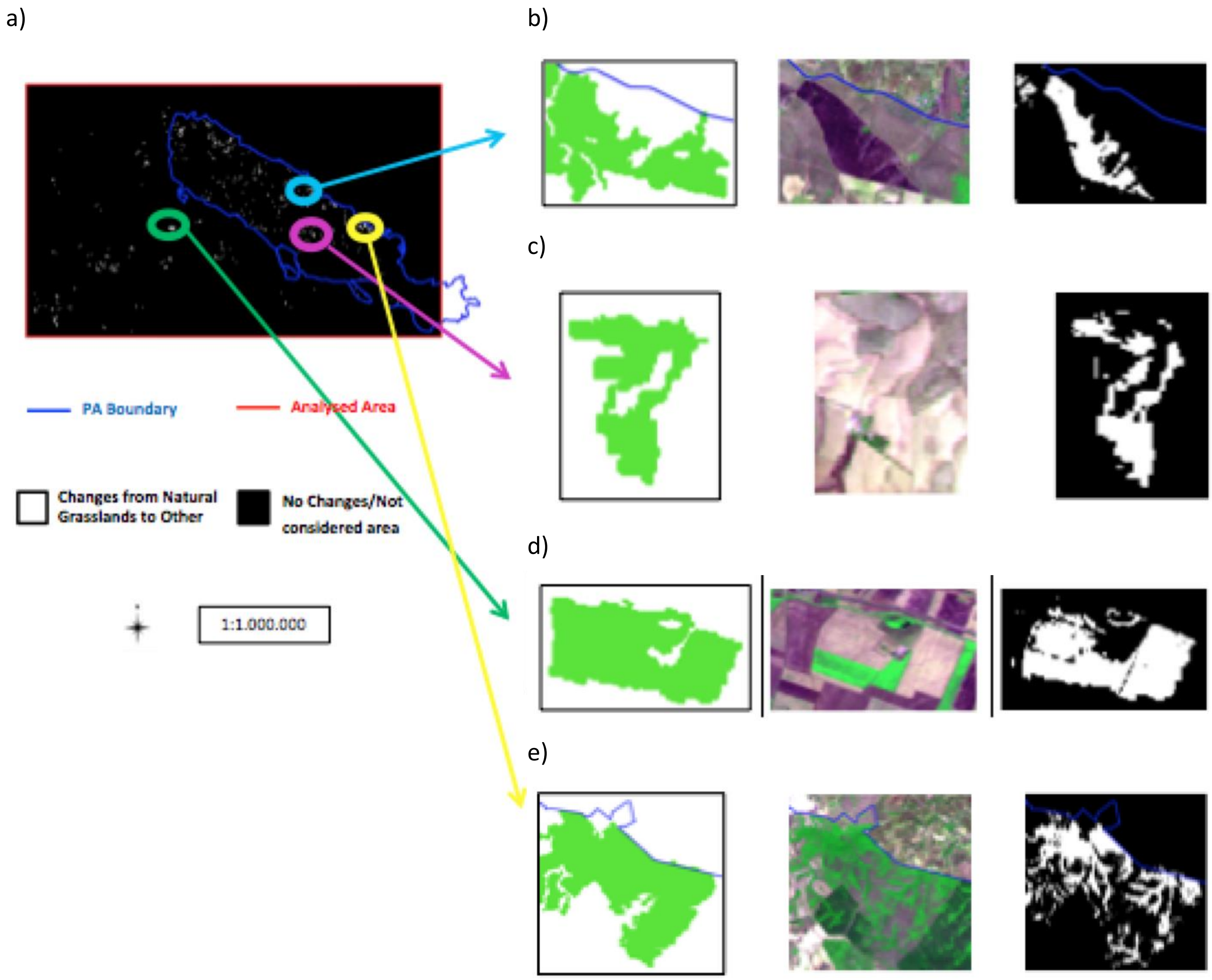


Figure 10.3. Areas where natural grasslands have changed to other categories between 2012 and 2016 for areas inside (b and c) and outside (d and e) the Murgia Alta Protected Area. Refer to Figure 6.2 for more detailed information on the subsets.

a) b)

Figure 10.4 a) The extent of natural grasslands in Gran Paradiso National Park, Italy (green), as mapped for 2012 in the Copernicus Natural Grasslands Layer and b) a Sentinel-2A image (Bands 4, 8 and 2 in RGB) acquired on the 13 August 2016 (time = T1).

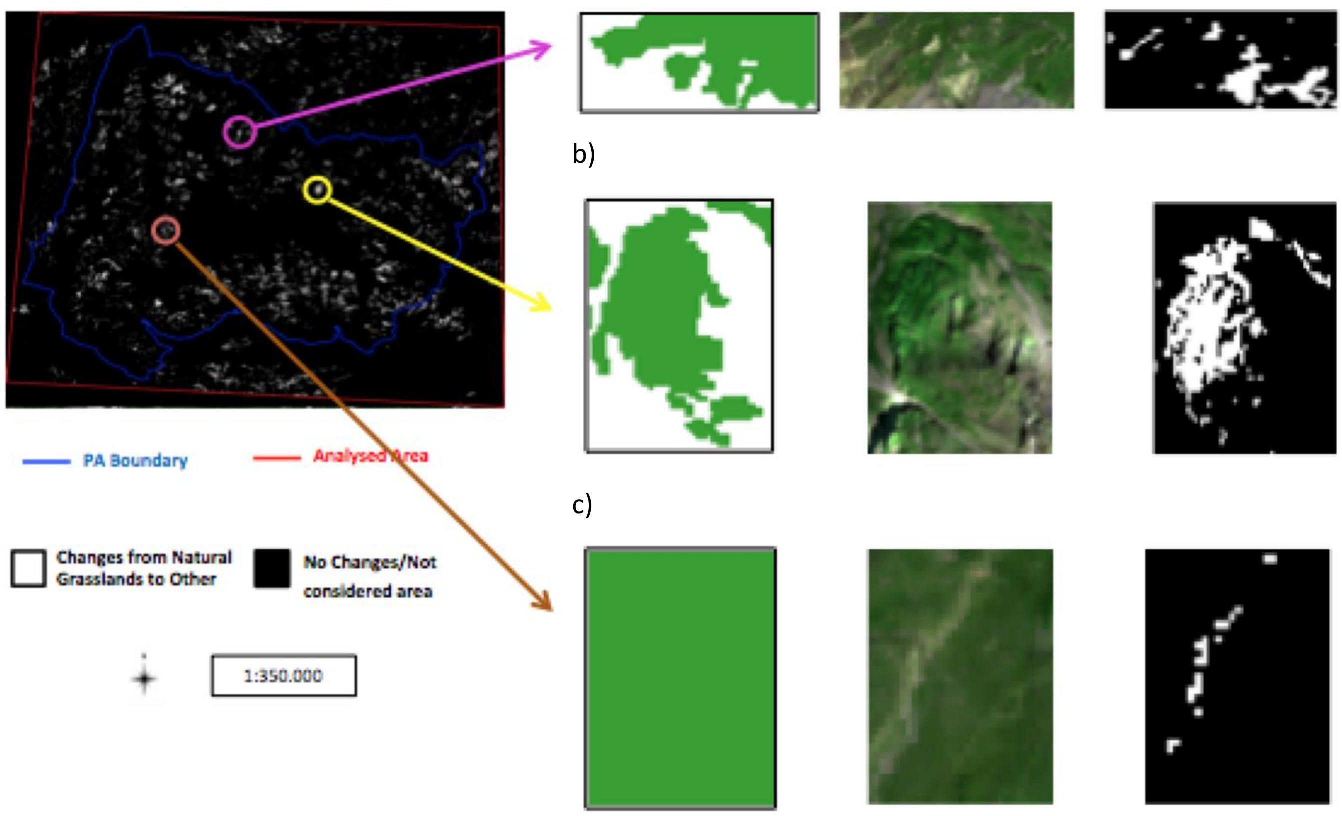


Figure 10.5. a) Areas where natural grasslands have changed to b) bare rocks/gravel and c) shrubs inside Gran Paradiso NP and b) to cultivated areas outside of the Protected Area. Refer to Figure 6.2 for more detailed information on the subsets.

a) b)

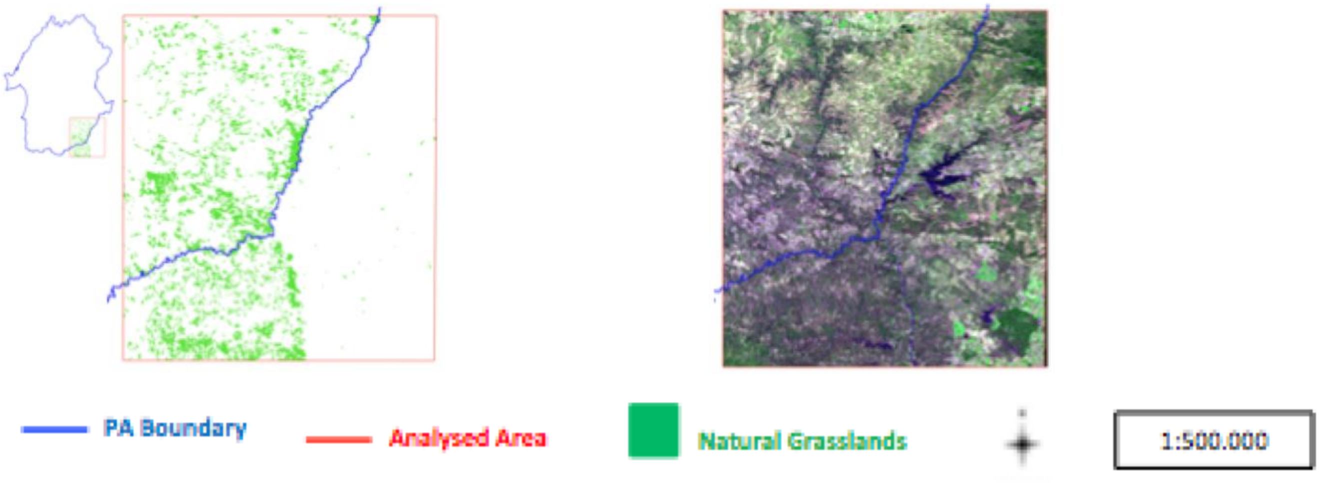


Figure 10.6 a) The extent of natural grasslands in Gran Paradiso National Park, Italy (green), as mapped for 2012 in the Copernicus Natural Grasslands Layer and b) a Sentinel-2A image (Bands 4, 8 and 2 in RGB) acquired on the 18 August 2016 (time = T1).

11. Evidence for Change

For describing changes, three stages were considered with these focusing on a) identifying all possible combinations of change, b) associating each change with a description and also a cause and a consequence and c) combining all observed changes to provide evidence of changes according to the broad types described in b).

11.1 Combinations of change

In the first stage, all combinations of change that would be encountered between the different LCCS components were listed and integrated into a single python script (module). Each change event or process was described according to the observed transitions in component classes. For example, with reference to Figure 9.2, the deforestation event, at LCCS Level 3, resulted in a change from natural to cultivated terrestrial vegetation and, at Level 3, from a closed canopy (>70 – 60 %) tall (14-30 m) continuous broadleaved evergreen trees to a herbaceous rainfed single (as opposed to multiple) crop. In the case where the deforestation event was followed by land abandonment and then regeneration, a change from natural terrestrial vegetation to bare ground and then back to natural terrestrial vegetation took place with this involving transitions to open canopy (10-20 to 40-20 % cover) short (0.3-0.8 m) grasslands mixed with forbs to shrubs and then to trees with an associated increase in canopy cover and height. In each case, the transitions could be described in terms of changes in the LCCS component classes. However, additional information on changes in other biophysical attributes (e.g., tree density, above ground biomass, leaf area index, dominant plant species) could also have been integrated. Whilst spectral data (e.g., near infrared or shortwave infrared reflectance) or derived indices (e.g., NDVI or the Plant Senescence Reflectance Index; PSRI) could also be included, these ideally need to be converted to biophysical measures such as vegetation productivity or the amount of dead or senescence material.

11.2 Types of change

In the second stage, the types of changes that were likely to be observed in any area (and which were also relevant at the global level) were listed, with these based on a review of potential (and feasible) changes. These were listed first for events or processes that lead to a change *between* the broader LCCS Level 3 categories (Table 11.1; e.g., from semi-natural/ natural vegetation to cultivated vegetation).

Table 11.1 Types of change in between LCCS Level 3 categories

Change Categories	Code	Potential causes/drivers
Vegetation clearance	VC	Expansion of agricultural production
Agricultural expansion	AG	Market pressures
Agricultural practices	AQ	Market pressures
Agricultural reclamation	AR	Government policy (e.g., setting aside land as fallow)
Agro-forestry	AG	Market pressures
Dam burst	DB	Climate change, poor dam construction
Dam creation	DM	Water supply, hydroelectricity
Dieback	DI	Climate change, flooding
Drainage or reclamation	DR	Land access, crop preferences
Land abandonment	LA	Low productivity
Plantation Establishment	PL	Expansion of wood industry
Succession (natural)	SX	Land abandonment
Tillage/ploughing	TI	Soil preparation to increase production
Lava flows	VO	Volcanic activity
Wind erosion	WE	Strong and/or persistent winds

Changes in Level 4 categories that might occur *within* areas that are cultivated or managed (Table 9.2), were natural or semi-natural (Table 9.3), urbanised (Table 9.4) or artificial or natural water (Table 9.5) were then considered. Codes were assigned against each of these as reference for subsequently programming the change within the EODESM system.

Table 11.2. Types of change in cultivated areas and potential causes.

Change	Code	Potential causes/drivers
Agricultural homogenisation	AH	Increased agricultural production
Agricultural practices	AP	Increased production or crop preferences
Coppicing	CP	Increased wood production, charcoal
Crop changes	CC	Market pressures/trends
Crop growth	CG	Natural growth of trees
Cultural practices	CX	Local conditions or introduction of new methods
Field size enlargement	FE	Removal of boundaries to increase agricultural efficiency
Field size reduction	FR	Introduction of boundaries (e.g., hobby farming)
Forest management	FM	Increased forest production
Forest restoration	FR	Conservation activities
Garden clearance	GC	Development of cooperatives in farming
Herbaceous cropping	HC	Harvesting of crops
Herbaceous reclamation	HR	Agricultural policies (e.g., set aside)
Irrigation	IR	Increased water supply to enhance crop production
Irrigation practice change	IP	Changes in watering to increase crop production
Multi-cropping (Trees to herbaceous)	MC	Changes in crop types over time.
Orchard creation	OR	Market pressures
Park creation	PC	Local/regional government policies
Park planning	PP	Local/regional government planning
Permanent cropping	SPC	Market forces and confidence in crop selection
Plantations	PL	Production of timber and timber products
Planting (of herbaceous crops)	PG	Market forces, preferences
Relay intercropping	SRI	Increased efficiencies in agricultural production.
Sequential cropping	SQC	Increased efficiencies in agricultural production.
Shift to fallow system	SFS	Increased efficiencies in agricultural production.
Shift to permanent cultivation	SPC	Increased efficiencies in agricultural production.
Shift to shifting cultivation	SSC	Increased efficiencies in agricultural production.
Shrubland restoration	SR	Conservation, land abandonment
Thickening	TK	Reduced fire activities
Thinning (trees or shrubs)	TH	Increased woody production
Tree cropping	TC	Market forces and preferences
Urban development	UD	Demand for housing, industry and infrastructure
Watered	WT	Increased production through increased water provision

Table 11.3 Types of change in natural or semi-natural terrestrial and aquatic systems and potential causes.

Change	Code	Potential causes/drivers
Increased pasture production	PPP	Fertilisation
Deforestation	DF	Agricultural expansion, mining, urban/infrastructure development
Degradation	DG	Climate change, repeated fires, fuelwood gathering
Dieback	DB	Climate change (increased temperatures, flooding, sea level rise, insect infestation)
Drying	DR	Climate change (increased temperatures, reduced rainfall), drainage
Encroachment e.g., shrubs, grasses)	EN	Nitrogen fixation
Flooding	FL	Climate change increased flooding thorugh increases in storm frequency and intensity)
Pasture degradation	PDG	Overgrazing, removal of biomass
Plantation establishment	PL	Wood production
Poor recruitment	PR	Overgrazing, fire
Regrowth	RG	Land abandonment
Replanting	RP	Conservation, REDD+, coastal protection
Sedimentation	SD	Flooding
Selective logging	SL	Timber production, sustainable management
Waterlogging	WL	Dam, levee construction, purposeful land transformation (e.g., marshland to rice)
Drying	DR	Purposeful land transformation (e.g., rice to marshland)
Woody thickening	TK	Changes in fire regimes, removal of stock

Table 11.4. Types of change in urban (artificial) areas and its potential causes.

Change	Code	Potential causes/drivers
Communications loss	CA	Better/alternative technologies, subsurface placement
Communications gain	CI	Population demand/requirements
Drainage	DR	Land reclamation
Flooding	FL	Increased rainfall
Greening	GR	Government policies, urban initiatives
Industrialisation	IN	Job creation, production
Rail abandonment	RA	Alternative transport modes or reduced demand
Rail construction	RW	Demand for more efficient movements of populations
Road abandonment	RA	Creation of wilderness areas, rural depopulation
Road construction	RC	Requirement for increased access or efficiencies
Road improvement	RI	Requirement for better surfaces and faster movements
Urban development	UD	Population increases and preferences
Urban improvement	UI	Planning for better environments (e.g., in cities)
Urban rezoning	UZ	population dynamics and infrastructure development
Urbanisation	UR	Population increases and preferences
Urbanisation to high density	UH	Overpopulation, housing close to places of work
Urban. to medium density	UM	Population increases (e.g., in peri-urban areas)
Waste dump restoration	WO	Planning for better environments (e.g., gravel pit lakes)
Water release	WR	Water level maintenance in reservoirs, flood control

Table 11.5. Types of change in aquatic systems and its potential causes.

Change	Code	Causes/drivers
Dam burst	DB	Weak dam walls, flooding
Damming	DM	Water supply, hydroelectricity
Rainfall	RF	Climate change, local weather regimes.
Flushing	FU	Clean water flows taking away pollutants or sediment
Freezing	FZ	Temperatures below 0°
Glacial flow	GF	Snow accumulation, changes in basal conditions
Ice melt	IM	Temperatures above 0°
Pollution	PL	Industrial or agricultural discharge
Sea level drop	SD	Shifts in atmospheric pressure, ocean circulation
Sea level rise	SR	Thermal expansion, ice melt
Sediment intake	SI	Flooding, erosion (e.g., from agriculture, deforestation)
Snowfall	SF	Precipitation, changes in weather patterns
Snowmelt	SM	Temperatures above zero, enhanced by rainfall.

11.3 Accumulating evidence

In the third stage, all the observed changes in component codes within each of the LCCS 3 and 4 layers are considered in combination and also with EnVs to cumulate evidence for change. As an example, shrub encroachment would be associated with a change in lifeform, canopy cover or canopy height (Table 11.6), with these determined independently (e.g., from classifications of Sentinel-2 data, retrievals from these same data based on empirical relationships and from LiDAR). These three elements combined provide strong evidence of a change event compared to if only one piece of evidence was available (e.g., a change in cover from scattered to open). As a further example, a flooding event might be associated with a change from standing to flowing, shallow to deep and clear to turbid water with the combination of these providing greater evidence compared to if each were treated separately.

12. Mapping change based on evidence

12.1 Overview

Using the test or master grid, different change inputs (component classes) and also EnVs were used to develop the code for evidence-based change detection, with the output indicated in Figure 11.1. Each of the grid cells represents the changes that might be associated with the categories listed in Tables 11.2 to 11.5. Changes in the environment which might be considered, by the user, as positive in the terrestrial environment are indicated in green, whilst negative changes are in red, with this establishing the context for near real time detection as well as monitoring. However, care needs to be taken in assigning a change as being negative or positive, as some might consider a change from semi-natural deciduous shrubland to a managed coniferous plantation has a positive impact in terms of carbon but an adverse negative effect on biodiversity. Hydrological changes are indicated in blue, with these considering changes in water, ice and snow and associated attributes.

Table 11.6. Evidence for shrub encroachment (based on types of combinations of change observed within the layers of lifeform, canopy cover and vegetation canopy height).

Changes in Life form	Changes in Canopy Cover	Changes in Vegetation Canopy Height
Herbaceous (A2) to Woody (A1)	Scattered (4-1 %)(A16) to Sparse (<20-10 - 4%) (A15)	Forbs and/or graminoids (3-0.8 m) (B11) to Shrubs (< 0.5 m) (B10)
Herbaceous (A2) to Trees (A3)	Scattered (4-1 %)(A16) to Open (40-20 to 10 %) (A13)	Forbs and/or graminoids (3-0.8 m) (B11) to Shrubs (3-0.5) (B9)
Herbaceous (A2) to Shrubs (A4)	Scattered (4-1 %)(A16) to Open (70-60 to 40 %) (A12)	Forbs and/or graminoids (3-0.8 m) (B11) to Shrubs (5-3 m) (B8)
Shrubs (A4) to Trees (A3)	Scattered (4-1 %)(A16) to Closed to open (100-40 %) (A11)	Forbs and/or graminoids (3-0.8 m) (B11) to Trees (7-3 m) (B7)
Forbs (A5) to Woody (A1)	Sparse (<20-10 - 4%)(A15) to Open (40-20 to 10 %) (A13)	Forbs and/or graminoids (3-0.8 m) (B11) to Trees (14-7 m) (B6)
Forbs (A5) to Trees (A3)	Sparse (<20-10 - 4%)(A15) to Open (70-60 to 40 %) (A12)	Forbs and/or graminoids (3-0.8 m) (B11) to Trees (>14 m) (B5)
Forbs (A5) to Shrubs (A4)	Sparse (<20-10 - 4%)(A15) to Closed to open (100-40 %) (A11)	Shrubs (< 0.5 m) (B10) to Shrubs (3-0.5) (B9)
Graminoids (A6) to Woody (A1)	Open (40-20 to 10 %)(A13) to Closed to open (100-40 %) (A11)	Shrubs (< 0.5 m) (B10) to Shrubs (5-3 m) (B8)
Graminoids (A6) to Trees (A3)	Open (70-60 to 40 %)(A12) to Closed to open (100-40 %) (A11)	Shrubs (< 0.5 m) (B10) to Trees (7-3 m) (B7)
Graminoids (A6) to Shrubs (A4)		Shrubs (< 0.5 m) (B10) to Trees (14-7 m) (B6)
Lichens/mosses (A7) to Woody (A1)		Shrubs (< 0.5 m) (B10) to Trees (>14 m) (B5)
Lichens/mosses (A7) to Trees (A3)		Shrubs (3-0.5) (B9) to Shrubs (5-0.5 m) (B14)
Lichens/mosses (A7) to Shrubs (A4)		Shrubs (3-0.5) (B9) to Shrubs (5-3 m) (B8)
Lichens (A8) to Woody (A1)		Shrubs (3-0.5) (B9) to Trees (7-3 m) (B7)
Lichens (A8) to Shrubs (A4)		Shrubs (3-0.5) (B9) to Trees (14-7 m) (B6)
Mosses (A9) to Woody (A1)		Shrubs (3-0.5) (B9) to Trees (>14 m) (B5)
Mosses (A9) to Trees (A3)		Shrubs (5-3 m) (B8) to Trees (7-3 m) (B7)
Mosses (A9) to Shrubs (A4)		Shrubs (5-3 m) (B8) to Trees (14-7 m) (B6)
		Shrubs (5-3 m) (B8) to Trees (>14 m) (B5)

Using the same code, the change detection was run through the ECOPOTENTIAL VL for different ECOPOTENTIAL PAs, with the legend being the same as for the grid shown in Figure 11.1 and based on the LCCS combined codes.

12.1.1 Example: Donana NP, Spain

Doñana NP was declared as a PA in the 1960s for the protection of waterbirds (Méndez et al. 2012). Birds species' spatial distribution is the result of spatial habitat diversity and temporal changes of wetland feature (e.g., different waterbird species show preference for wetland habitats with particular characteristics, including the duration of flooding period, etc) and at different times of year (breeding, stop-over, wintering). As described earlier, Landsat and Sentinel-2 time series have were used to map water inundation for each year Doñana (Díaz-Delgado et al. 2016). In the marshland area, these data provide information on the spatio-temporal dynamics of biomass production, which are aimed at adjusting stocking rates for domestic herbivores to balance the nesting needs of the water birds. Therefore, by combining the outputs of the EODESM through ECOPOTENTIAL's VL (Figure 11.2) with in situ bird monitoring data, a better understanding of how bird occurrence is related to wetland features can be obtained. This will allow also the vegetation response to different flooding regimes and grazing pressures to be determined in order to calculate optimal and sustainable livestock stocking rates compatible with high water bird biodiversity.

12.1.2 Example: Camargue NP, France

Within the Camargue, maintaining the seasonal variations is water level is crucial for ensuring that emerged and submerged macrophytes and associated flora are maintained. The changes in hydroperiod mapped using ECOPOTENTIAL's VL show an increase in inundation area between 2006 and 2015 but also some areas of loss (Figure 11.3). Similar changes can be mapped for any two time-separated periods and evidence can be built up to support these changes.

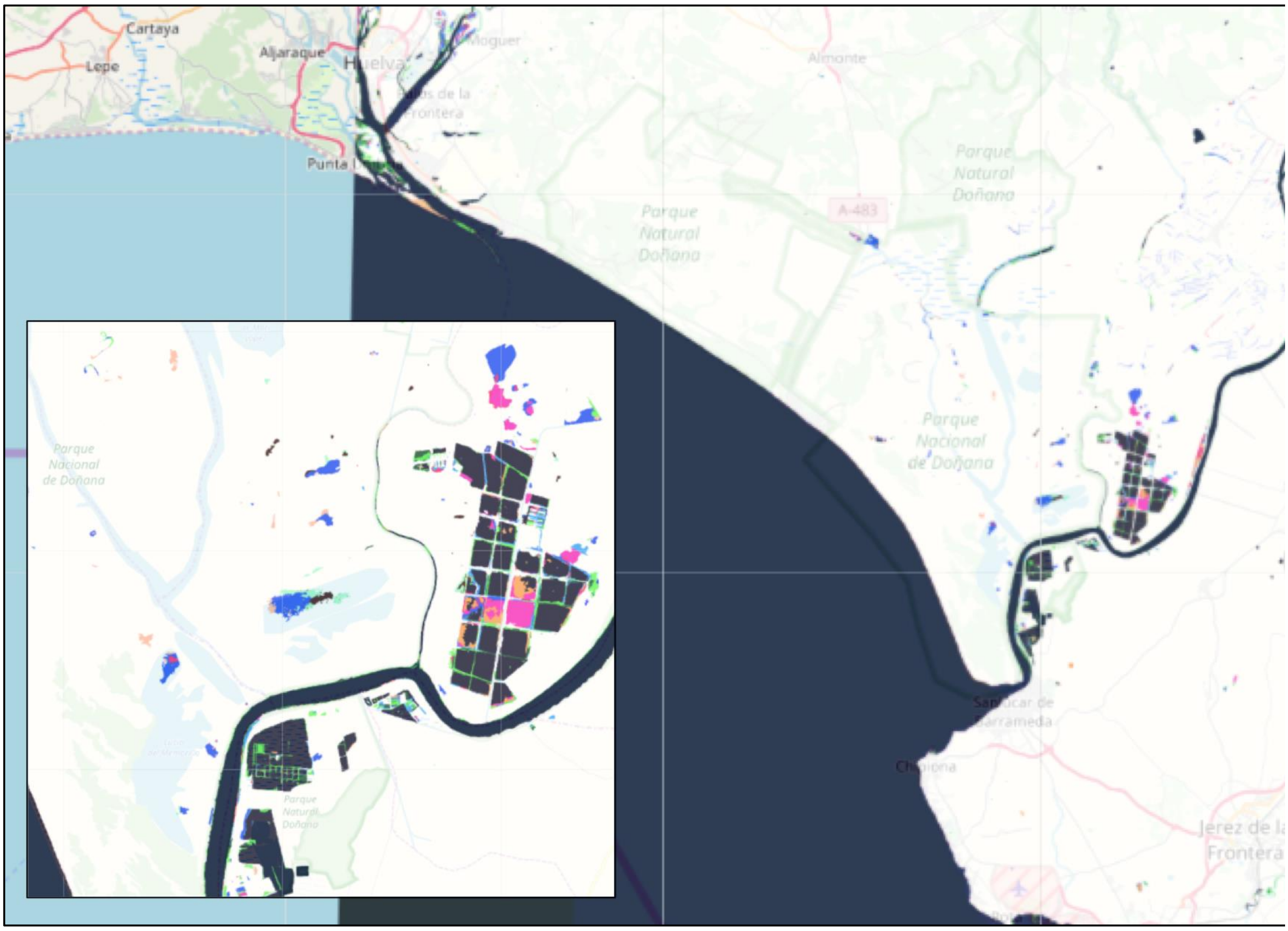
12.1.3 Example: Gran Paradiso

The mountain ecosystems of Gran Paradiso NP are fragile environments and sensitive to climate change. The analysis of the relationship between snow and plant phenology and their changes over time is essential to understand the impact of climate change on ecosystem functioning. For two years in the mid 200s, the annual duration of snow cover, the last day of snow cover presence and the green up time for the same period were compared based on changes in the thematic LCCS classification (Figure 11.4). The snow cover duration changed at the margins from 7-9 months to 6-7 months during this period. There was an increase in snow cover duration averaging 10 days but also the green up period was brought forward by an average of 5 days. Likewise, the time of the last snow cover presence shifted to a later point in time. The evidence accumulated in the EODESM system indicated that there had been an increase of snow cover between the two years, which impacts on the productivity of high-alpine grasslands

These examples illustrate the capacity of the ECOPOTENTIAL VL to combine a diverse range of environmental layers that are available globally, regionally or locally to produce land cover classifications for time-separated periods and change maps based on evidence. A wide range of input layers, and almost all of these generated or collated through WP3, are considered and pre-defined change categories are mapped based on evidence. Of significance, is that the EODESM within the VL can be used for any site in Europe and indeed worldwide and by any potential user to generate information that can be actively used for conservation of PAs in a timely manner. Furthermore, the EODESM system has the potential to consider both the causes and consequences of change with Tables 12.1 and 12.2 indicating how changes detected and mapped using the EODESM system can be used to support the development of storylines that can then support nature conservation.

Co-funded by the European Union

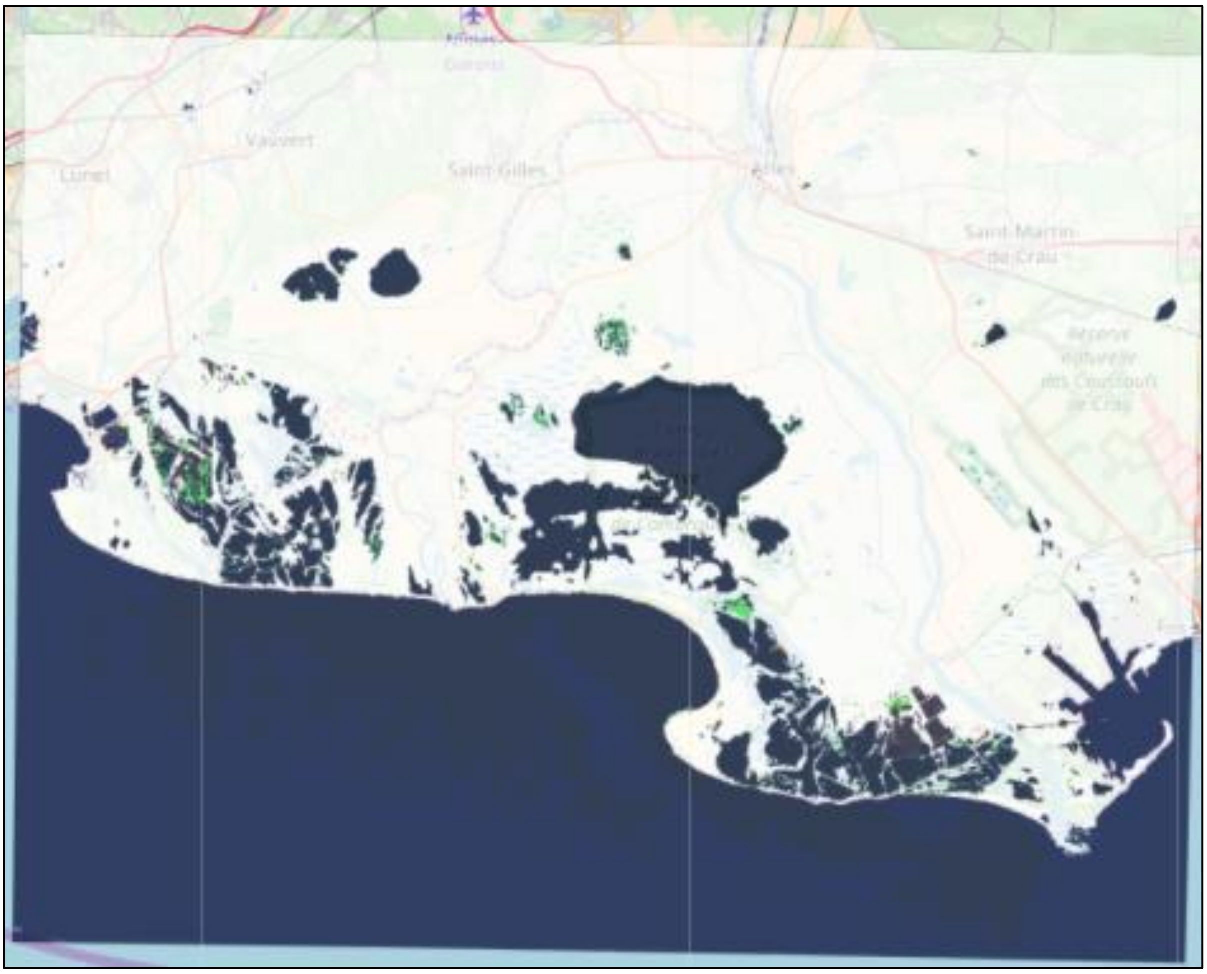
a)



Remained Perennial (> 9 months) (B1)	Tidal Area (B3) to Perennial (9-7 months) (B7)
Remained Non-perennial (< 9 months) (B2)	Tidal Area (B3) to Perennial (6-4 months) (B8)
Remained as Tidal Area (B3)	Tidal Area (B3) to Perennial (3-1 months) (B9)
Remained as Perennial (9-7 months) (B7)	Perennial (9-7 months) (B7) to Perennial (> 9 months) (B1)
Remained as Perennial (6-4 months) (B8)	Perennial (9-7 months) (B7) to Non-perennial (< 9 months) (B2)
Remained as Perennial (3-1 months) (B9)	Perennial (9-7 months) (B7) to Tidal Area (B3)
Perennial (> 9 months) (B1) to Non-perennial (< 9 months) (B2)	Perennial (9-7 months) (B7) to Perennial (6-4 months) (B8)
Perennial (> 9 months) (B1) to Tidal Area (B3)	Perennial (9-7 months) (B7) to Perennial (3-1 months) (B9)
Perennial (> 9 months) (B1) to Perennnial (9-7 months) (B7)	Perennial (6-4 months) (B8) to Perennial (> 9 months) (B1)
Perennial (> 9 months) (B1) to Perennial (6-4 months) (B8)	Perennial (6-4 months) (B8) to Non-perennial (< 9 months) (B2)
Perennial (> 9 months) (B1) to Perennial (3-1 months) (B9)	Perennial (6-4 months) (B8) to Tidal Area (B3)
Non-perennial (< 9 months) (B2) to Perennial (> 9 months) (B1)	Perennial (6-4 months) (B8) to Perennial (9-7 months) (B7)
Non-perennial (< 9 months) (B2) to Tidal Area (B3)	Perennial (6-4 months) (B8) to Perennial (3-1 months) (B9)
Non-perennial (< 9 months) (B2) to Perennial (9-7 months) (B7)	Perennial (3-1 months) (B9) to Perennial (> 9 months) (B1)
Non-perennial (< 9 months) (B2) to Perennial (6-4 months) (B8)	Perennial (3-1 months) (B9) to Non-perennial (< 9 months) (B2)
Non-perennial (< 9 months) (B2) to Perennial (3-1 months) (B9)	Perennial (3-1 months) (B9) to Tidal Area (B3)
Tidal Area (B3) to Perennial (> 9 months) (B1)	Perennial (3-1 months) (B9) to Perennial (9-7 months) (B7)
Tidal Area (B3) to Non-perennial (< 9 months) (B2)	Perennial (3-1 months) (B9) to Perennial (6-4 months) (B8)

Figure 11.2. Change in hydro period between 2015/16 and 2016/17 as generated through the VL. The legend conveys the various transitions between periods of inundation. Blue represent an increase in hydroperiod and yellows a decrease.

a)



b)

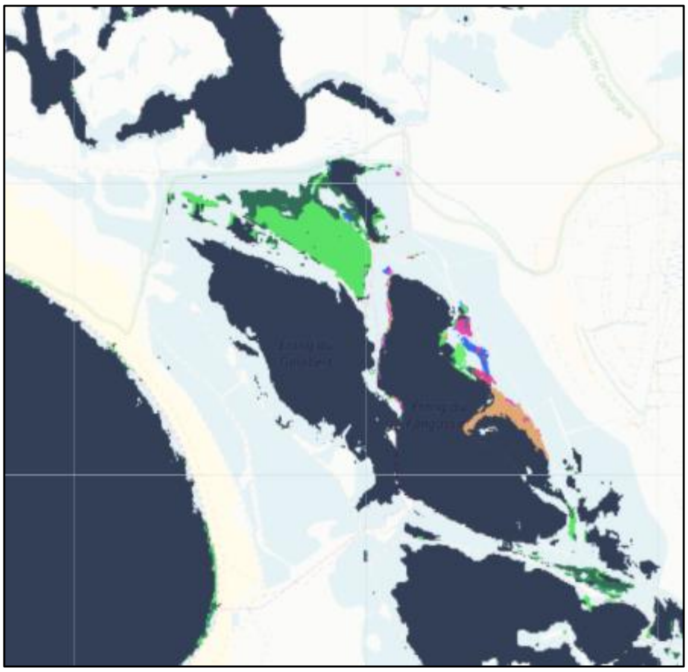


Figure 11.3. Change in hydroperiod between 2006 and 2015, as generated through the ECOPOTENTIAL VL.

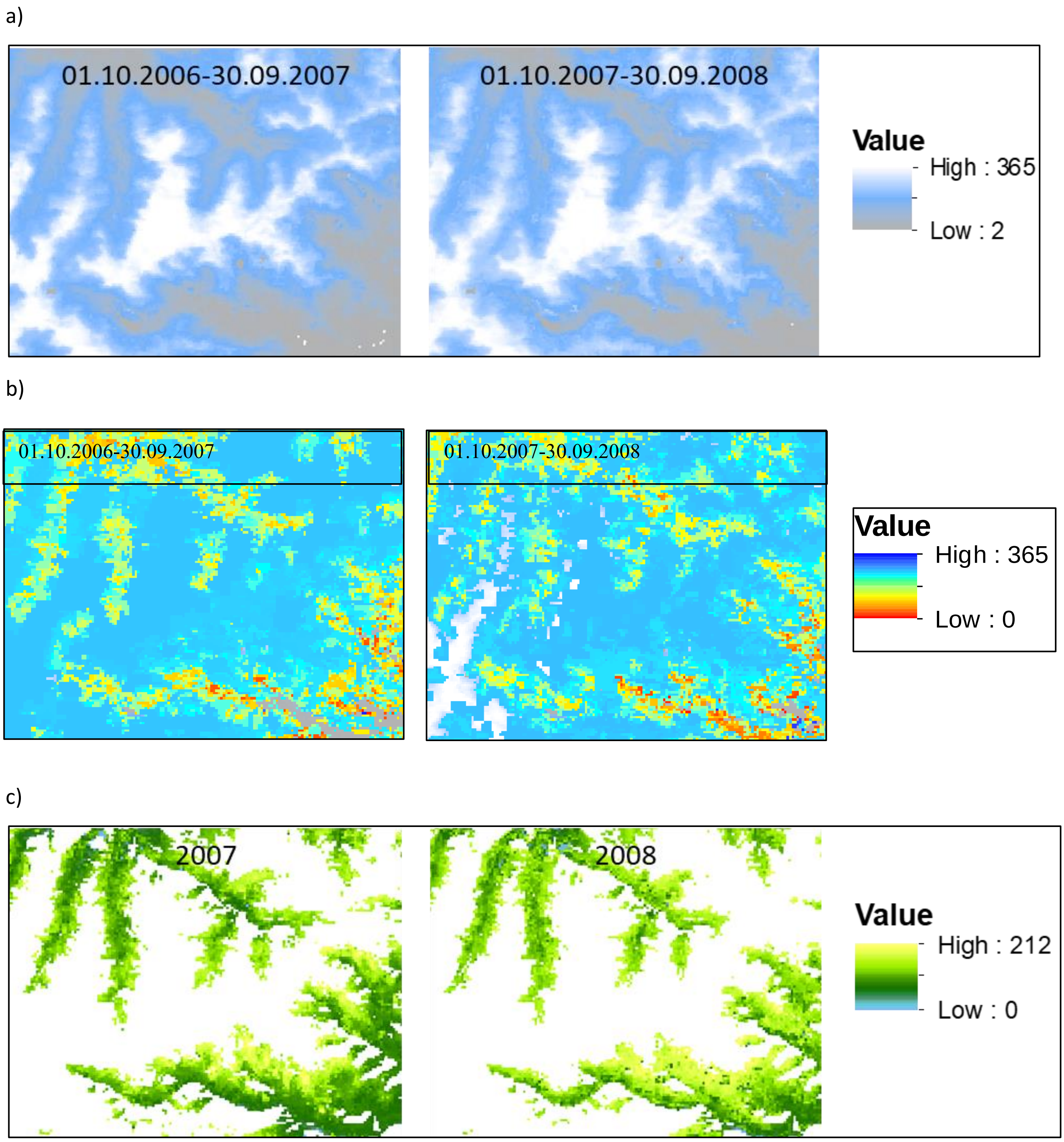


Figure 11.4. Changes in a) the snow duration (days) between 2007 and 2008, b) the last day of snow cover presence (day no) and c) the green up date (day no) for the same period, Gran Paradiso NP.

PERIOD/FREQUENCY OF OBSERVATION			A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	Time series available					
			SPECIFIC CHANGE TO BE CONSIDERED					CHANGE IN THE CANOPY COVER TO BE CONSIDERED				INFORMATIVE LAYER (TO BE EXTRACTED)							YEAR					
Site	**Causes**	**Consequences**	GRASSLANDS (A12_A2A6) to CTV (Cultivated Terrestrial Vegetation - A11)	GRASSLANDS (A12_A2A6) to BARE ROCKS (B16_A1A3)	GRASSLANDS (A12_A2A6) to INFRASTRUCTURES (B15_A1A3A11)	GRASSLANDS (A12_A2A6) to INDUSTRIAL AREAS (B15_A1A4A12)	GRASSLANDS (A12_A2A6) to MINING AREAS (B15_A2A6)	Closed (>70-60 %) (A10) to Open (70-60 to 20-10 %) (A11)	Closed (>70-60 %) (A10) to Sparse (20-10 - 1%)(A14)	Open (70-60 to 20-10 %)(A11) to Sparse (20-10 - 1%)(A14)	Closed to open (100-15 %)(A20) to Sparse (20-10 - 1%)(A14)	Grasslands (A12_A2A6) Extension	Cultivated Terrestrial Vegetation (A11) Extension	Canopy cover (A12_A2A6A10 & A12_A2A6A11 & A12_A2A6A14 & A12_A2A6A20)	Bare rocks (B16_A1A3)	Infrastructures (B15_A1A3A11)	Industrial Areas (B15_A1A4A12)	Mining Areas (B16_A2A6)	2006	2009	2011	2014	2015	2016
Alta Murgia	Conversion of grasslands and natural pastures in extensive arable lands	Vegetation (habitat) fragmentation	•					•	•	•	•	•	•	•					Land Cover Map by local authorithies	Hydrogeomorphological layers	Land Cover Map by local authorithies; Cadastral map	Landsat 8: August,10	Sentinel-2: August,7; October,6	Sentinel-2: January,14; May,23
		Soil erosion																						
		Stone graining		•								•			•									
		Hydrogeological instability																						
	Wind farms and photovoltaic systems expansion	Vegetation (habitat) fragmentation			•	•						•				•	•							
		ecological alterations (avifauna)																						
	Legal and illegal mining	alterations of the natural ecosystems					•					•						•						
	Toxic mud dumping	Soil and underground aquifer system heavy metal contamination																						

Figure 12.1. Changes in the Alta Murgia protected area and the associated causes and consequences.

PERIOD/FREQUENCY OF OBSERVATION			A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	D	D	D	A	A	A	A	A	A	A	A	A	A	A	A	A	D	W	W	W	W	A	A	A	D	D	A	D	A	W	W	D	W	W	A
Site	**Causes**	**Consequences**	NTV-BS	NAV-CAV (etc.)	CAV-NAV (etc)	NTV-AS	NTV_CTV	NTV-CAV	Cultural practice (rainfed) (D1) to Irrigated (D3)	Irrigated (D3) to Cultural practice (rainfed) (D1)	Lichens/mosses (A7) to Herbaceous (A2)	Lichens/mosses (A7) to Forbs (A5)	Lichens/mosses (A7) to Graminoids (A6)	Herbaceous (A2) to Woody (A1)	Herbaceous (A2) to Shrubs (A4)	Shrubs (A4) to Trees (A3)	Graminoids (A6) to Woody (A1)	Graminoids (A6) to Shrubs (A4)	Forbs (A5) to Woody (A1)	Forbs (A5) to Shrubs (A4)	Herbaceous (A2) to Trees (A3)	Graminoids (A6) to Trees (A3)	Forbs (A5) to Trees (A3)	Sparse (20-10 - 1%)(A14) to Closed to open (100-15 %)(A20)	Sparse (20-10 - 1%)(A14) to Closed (>70-60%) (A10)	Open (70-60 to 20-10%)(A11) to Closed (>70-60%) (A10)	Closed (>70-60%) (A10) to Open (70-60 to 20-10 %) (A11)	Closed (>70-60%) (A10) to Closed to open (100-15 %)(A20)	Closed (>70-60%) (A10) to Sparse (20-10 - 1%)(A14)	Open (70-60 to 20-10%)(A11) to Sparse (20-10 - 1%)(A14)	Closed to open (100-15 %)(A20) to Sparse (20-10 - 1%)(A14)	Continuous (B5) to Scattered (clustered) (B6)	Continuous (B5) to Scattered (isolated) (B7)	Rooted forbs (A8) to free floating forbs (A9)	Forbs and/or graminoids (3-0.3 m)(B15) to Forbs and/or graminoids (0.03-0.3 m)(B13)	Forbs and/or graminoids (0.03-0.3 m)(B13) to Forbs and/or graminoids (3-0.8 m)	Lost the second layer (F1)	With sediment(D2) to Almost no sediment (D1)	Almost no sediment (D1) to With sediment(D2)	Deep to medium (> 2 m) (C1) to Shallow water (< 2 m) (C2)	Shallow water (< 2 m) (C2) to Deep to medium (> 2 m) (C1)	Perennial (> 9 months) (B1) to Non-perennial (< 9 months) (B2)	Snow cover (hydro) period	Hydroperiod	Tree species	Canopy cover	Fire frequency and intensity	Fragmentation of specific habitats	Albedo	Sea Surface Temperature	Salinity	Baythymetry	Chlorophyll a	Turbidity	Net Primary Productivity
Hardangervidda	Projected climate warming Reductions in grazing pressure	Encroachment of forests onto moorland	•											•	•	•	•	•	•	•	•	•	•	•	•	•																				•									
	Snow cover High long term grazing pressure by reindeer	Reduces availability of lichen pastures									•	•	•																														•												
Peneda Geres	Decline of traditional agro-pastoral systems	Widespread shrub encroachment												•	•	•	•	•	•	•	•	•	•																																
		Changes in fire regimes																																													•								
	Invasion by non-native species	Changes in tree species composition																																										•											
Swiss NP	Land abandonment	Changes in extent and distribution of ecosystems (including the tree line)												•	•	•	•	•	•	•	•	•	•																																
	Increased temperatures	Densification of previously grazed forests																					•	•	•																					•									
		Reductions in landscape heterogeneity																																														•							
Pelagos	Climate change	Changes in bathymetry, SST and chlorophyll A																																															•		•	•		
Wadden Sea	Influxes of water and elevated nutrients	Higher leves of primary productivity and eutrophication																																																				•
Danube Delta	Intensive embankments	Conversion of wetlands to agriculture		•																																																		
	Damming	Changes in discharge, water depth and suspended solids (turbidity)																																			•	•	•	•													•	
		Changes in primary productivity of wetlands																																																				•
		Changes from macrophytes to phytoplankton																															•																			•		
Camargue	Activity associated with irrigated agro-systems dominated by rice	Seasonal variations in water level.																																							•		•											
		Changes in irrigated area							•	•																																												
	Reed harvest	Increases in salinity																																•	•																•				
	Climate change	Extent, duration and inter-annual variability of wetlands.		•	•																																																	
Har Hanegev	Grazing and framing activities	Changes in water flow and landscape productivity																																							•		•											
	Urban and agricultural expansion	Changes in species and habitat distributions and productivity.				•	•	•																																														
Kruger NP	Illegal logging and elephant pushovers	Changes in tree cover																					•	•	•	•	•	•	•																	•									
Montado	Increases in cattle density and grazing pressure Shrub control	Decline in regeneration Loss of canopy cover and tree density Loss of canopy layers																					•	•	•	•	•	•	•																										
	Destructive soil tillage	Soil compaction																																														•						
	Land use	Fragmentation of habitats																																															•					

Figure 12.2. Changes in the LCCS component codes associated with different events and processes in other protected areas.

13. Conclusions

WP4 has delivered a new approach to the classification of land covers and change, which is available within ECOPOTENTIAL's VL. The system requires the generation of thematic and continuous input layers that relate to EnVs, many of which have been generated by the ECOPOTENTIAL partners (see Deliverable 4.2). The VL is being made available to ECOPOTENTIAL partners but also potentially facilitates the classification of land covers and change for any site in Europe and beyond. Many of the inputs have, indeed, been generated by the PAs themselves with assistance from ECOPOTENTIAL but a period of training, familiarisation and understanding will be needed. Some refinement of the evidence-based code will also be necessary to encompass new situations that might arise and the provision of new (including time series) datasets.

In summary, the EODESM system allows:

- Consistent classification of land covers for any site using EO using the FAO LCCS-2 taxonomy, with capacity to integrate data from other sources (e.g., the outputs from hydrological or forest growth models).
- Inclusion of EnV layers (thematic and continuous), including time-series (e.g., hydro period, snow cover, phenology), within the classification.
- Integration of EnV layers that are not necessarily used in the classification (e.g., above ground biomass, plant species composition, water chemistry).
- Detection of change in LCCS codes and also EnVs over varying time frames.
- Evidence-based approach to change detection and description.
- Capacity for integration of detecting change events and processes based on, for example, algorithms such as CCA or BFAST.
- Attribution of change to a potential cause and consequence (in development).
- Capacity to translate LCCS to Habitat and other taxonomies, with existing functionality in translating to General Habitat Categories (GHCs).
- Linking with the ECOPOTENTIAL storylines.

The EODESM system has the following advantages.

- A wide range of data sources can be used to contribute input, including knowledge, into the classification.
- Locally-derived, European and/or global layers can be integrated.
- The classification and change detection is applicable at any scale, from drones through to MODIS data.
- The LCCS-2 and change classification be replicated with *in situ* data, with potential for uptake using mobile applications.
- All forms of earth observation and other geographical (spatial) data and derived products can be ingested.
- Ease of use and simple to understand and implement
- Is informative, utilizes ecological knowledge, and allows for targeted applications.
- Operates entirely using open source software (Python, RSGISLib, KEA, EODESM, ARCSI)
- Well suited for protected area classification (and of surrounding areas).

14. References

Díaz-Delgado, R., Aragonés, D., Afán, I., and Bustamante, J. (2016). Long-term monitoring of the flooding regime and hydroperiod of Doñana marshes with Landsat time series (1974–2014). *Remote Sensing*, 8(9), 775.

Méndez, P., Isendahl, N., Amezaga, J., & Santamaría, L. (2012). Facilitating transitional processes in rigid institutional regimes for water management and wetland conservation: experience from the Guadalquivir Estuary. Ecology and Society, 17(1).

Odland, A., et al. (2014). "Estimation of lichen biomass with emphasis on reindeer winter pastures at Hardangervidda, S Norway." Rangifer **34**(1): 95-110.

Olofsson, P., Foody, G. M., Herold, M., Stehman, S. V., Woodcock, C. E., & Wulder, M. A. (2014). Good practices for estimating area and assessing accuracy of land change. *Remote Sensing of Environment*, 148, 42–57.

Pekel, J., Cottam, A., Gorelick, N. and Belward, A.S. (2016). High-resolution mapping of global surface water and its long-term changes. Nature, 540, 418-422;

Pereira, H.M., Ferrier, S., Walters M., Geller, G.N., Jongman, R.H.G., Scholes, R.J. et al. (2013). Essential Biodiversity Variables. Science, 339 (6117), 277-278.

Post, E., et al. (2003). "Synchrony between caribou calving and plant phenology in depredated and non-depredated populations." Canadian Journal of Zoology **81**(10): 1709-1714.

Sebastián-González, E., and Green, A. J. (2016). Reduction of avian diversity in created versus natural and restored wetlands. *Ecography*, *39*(12), 1176-1184.

Skogland, T. (1978). "Characteristics of the snow cover and its relationship to wild mountain reindeer (Rangifer tarandus tarandus L.) feeding strategies." Arctic and Alpine Research: 569-579.

Skogland, T. (1989). "Cooperative social organization of wild reindeer in relation to food, maters and predator abundance." PAUL PAREY, BERLIN. 1989.

Strand, O., et al. (2006). "Reinens bruk av Hardangervidda." NINA Rapport 131: 67 pp. **131**.

***Tarantino, C.**, Adamo, M., Lucas, R., Blonda P. (2016). Detection of changes in semi-natural grasslands by Cross Correlation Analysis with WorldView-2 images and new Landsat 8 data. *Remote Sensing of Environment*. Vol. 175, 15 March 2016, Pages 65–72, DOI:10.1016/j.rse.2015.12.031.

Walther, G.-R., et al. (2002). "Ecological responses to recent climate change." Nature **416**(6879): 389-395.