BIO_SOS

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| **Project Title:** | **BIO_SOS Biodiversity Multisource Monitoring System: from Space TO Species** |
| **Contract No:** | FP7-SPA-2010-1-263435 |
| **Instrument:** | |
| **Thematic Priority:** | |
| **Start of project:** | 1 December 2010 |
| **Duration:** | 36 months |

Deliverable No: D6.8

# Developing a methodology to identify locally recognizable pressures and quantify their impact on habitats

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| **Due date of deliverable:** | 31 July 2012 |
| **Actual submission date:** | 29 October 2012 |
| **Version:** | 2nd version |

BIO_SOS

**Main Authors:** Harini Nagendra (P5), Paola Mairota (P8), Palma Blonda (P1), Carmela Marangi (P1), Dino Torri (P1), Richard Lucas (P11), Panayotis Dimopolous (P2), João Pradinho Honrado (P9), Madhura Niphadkar (P5), Sander Mücher (P4), Valeria Tomaselli (P1)

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| **Project ref. number** | **263435** |
| **Project title** | **BIO_SOS: Biodiversity Multisource Monitoring System: from Space to Species** |

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|---|---|
| **Deliverable title** | Methodology to identify and quantify local pressures |
| **Deliverable number** | D6.8 |
| **Deliverable version** | <Version, e.g. Version 2> |
| **Previous version(s)** | <List of previous versions, if any> |
| **Contractual date of delivery** | 31 July 2012 |
| **Actual date of delivery** | 29th October 2012 |
| **Deliverable filename** | BIO_SOS_6.8 _V2.doc |
| **Nature of deliverable** | R |
| **Dissemination level** | PU = Public |

COOPERATION

BIO_SOS

| | |
|---|---|
| **Number of pages** | 72 |
| **Workpackage** | WP 6 Task 6.4 |
| **Partner responsible** | Partner 5 (ATREE) |
| **Author(s)** | Harini Nagendra (P5), Paola Mairota (P8), Palma Blonda (P1), Carmela Marangi (P1), Dino Torri (P1), Richard Lucas (P11), Panayotis Dimopolous (P2), João Pradinho Honrado (P9), Madhura Niphadkar (P5), Sander Mücher (P4), Valeria Tomaselli (P1) |
| **Editor** | Harini Nagendra (P5) |
| **EC Project Officer** | Florence Beroud |


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| **Abstract** | This deliverable provides an operational contribution to the implementation of "threat analysis" (Salafsky et al., 2003, 2008), which is required as an input for scenario building and evaluation. A review of existing terminologies and frameworks for assessment of locally recognizable pressures and their impact on habitats is conducted, along with reviews of experiences from conservation assessments conducted using these terminologies and frameworks. Based on this, we assess the strengths and weaknesses of different approaches. Our goal is to develop a methodology that can be used to extract information from EO data on changes in the extent and intensity of pressures over time, and we develop a framework for this based on the assessments of impacts of pressures, building on the approach developed by Salafsky et al., and widely used. This framework is used to describe pressure-induced impacts in BIO_SOS sites, followed by a literature analysis, based on which methods for mapping changes in pressure-related impacts are proposed. |


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| **Keywords** | Local pressures, threat analysis, monitoring impact |

## Signatures

| Written by | Responsibility- Company | Date | Signature |
|---|---|---|---|
| Harini Nagendra | Editor (P5) | 31/07/2012 | |
| **Verified by** | | | |
| Palma Blonda | Coordinator (P1) | 03/03/2012 | |
| **Approved by** | | | |
| Palma Blonda | Coordinator (P1) | 03/03/2012 | |
| Fifamè Koudogbo | QAP (P7) | 02/08/2012 | |

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# 1. Executive summary

Deliverable D6.8 is the output of WP6-Task 6.5 (start month 8, end-month 30) activity, with this strictly related to the activity of WP5-Task 5.4 (start month 16, end month 30), on change detection and the activity of both Task 6.2 (start month 8, end-month 30) and Task 6.7 in WP6 (start month 8, end-month 30).

Analysis of pressures is rarely conceptualized or performed in a well-defined, standardized way by most conservation agencies or park managers. Thus, there remains a degree of fuzziness in development, definition and measurement, which can lead to significant challenges to measure deviation from conservation objectives, and to map trajectories such that conservation objectives are achieved. This is definitely the case for types of pressure that are unanticipated, previously unknown and/or with significant uncertainties, such as climate change. However, unfortunately, even in the relatively simpler and more dominant situations of locally recognizable pressures (which is the main focus within this project), there is a lack of basic understanding of potential and actual impacts. In particular, the combined effect of land use and climate changes can lead to ambiguities, with some land uses that supposedly had positive effects becoming pressure-building agents. There is therefore a need for a standardized convention to describe and categorize pressures and threats. For this purpose, a set of different frameworks used for pressure analysis are first summarized, followed by a presentation of conservation studies which have utilized these frameworks for threat assessment in different protected areas.

These discussions are used to compare the commonly used frameworks in existence, and to discuss their strengths and weaknesses for pressure analysis.

The use of EO data in conjunction with spatial pressure mapping seems very suitable to address many of the existing challenges of current frameworks. As these pressures build up over time, the intention of this deliverable is to see how EO datasets may be used to extract trends from multiple-time land cover/land use changes, within Task 5.4, identifying potential pressure growth. This can be compared with other observations involving the use of EO data such as the induced modification in habitat destruction, modification of habitat connectivity (Task 6.2 and 6.3), or alterations in species distribution within a landscape (Task 6.4).

Accordingly, a hierarchical system for the identification, analysis and monitoring of pressure-derived impacts on land cover/habitats, communities and species is proposed, building on Salafsky et al. (2003, 2008) and adapting this approach for use with EO data observation. This framework is used to develop matrices to categorize pressure-derived impacts on BIO_SOS sites in six countries - Greece, Italy, Portugal, Wales, India, and The Netherlands. An examination of peer-reviewed literature on the use of EO data for pressure analysis is used to propose methods that can be utilized for identification of pressures at the first and second levels of detail proposed by this deliverable, and related to the pressure-derived impacts identified at different sites based on the site-specific matrices developed. The outputs from this deliverable, and in particular the comparison provided by Table 5 and Section 3.3, as well as Table 12, are anticipated to be very important to feed into scenario building and production/quantification of indicators and expected trends, within Task 6.7

This Deliverable thus provides an operational contribution to the implementation of “threat analysis” (Salafsky et al., 2003, 2008), which is useful for scenario building and evaluation (Task 6.7).

## 2. Introduction

The BIO_SOS project is within the FP7- SPACE-2010-1 call (Topic SPACE.2010.1.1-04) “Stimulating the development of GMES services in specific areas", with application to (B) BIODIVERSITY. The focus on this WP is to consider the use of multi-annual surveys of 'sampling' sites under 'pressure' for monitoring changes in the distribution and status of ecosystems, thereby assisting Member States in their conservation efforts. In particular, effective and timely monitoring of changes in the land cover within and along the borders of protected areas is needed to judge the effectiveness in protecting and conserving the regions ***from human impacts such as poaching, hunting, logging, urbanization, agriculture, mining, and road construction*****.**

In WP2, Task 2.2, and for each site, an analysis of pressures and threats was carried out within the framework of Convention on Biological Diversity (CBD) and Streamlining European 2010 Biodiversity (SEBI) indicators with focus on three main headline indicators covering: (i) habitats of European interest in the context of a broad habitat assessment; (ii) abundance and distribution of selected plant species; and (iii) fragmentation of natural and semi-natural areas. BIO_SOS will also look at indicators for pressure that can be detected through land cover changes, such as change from natural or semi-natural Annex 1 habitat type into a non-Annex 1 habitat type (cultivated land, urban areas, etc.).

Within previous GMES and FP5-FP6 projects global indicators have been developed mainly on the base of low and medium resolution data. Further developments of both already established and new indicators, such as those required for agricultural expansion, fire and pollution monitoring (first focal area) and for pollinator abundance, soil biodiversity, habitat and ecosystems quality monitoring (second focal area), do require the combined analysis of multi-source (including in-situ data), multi-scale and multi-temporal EO data because of the complexity of involved processes. In addition, global biodiversity changes depend on regional and local environmental changes, which in turns depend on regional and local management strategies. Therefore, there is an urgent need of a quasi-real time operational monitoring system, based on the analysis of high and mainly very high spatial resolution EO data.

The present deliverable complements and integrates the analysis carried out in D2.2 from WP2 (Task 2.2), which concerns the identification of pressures and threats for each site, and D2.1 from WP2 (Task 2.1), which focuses on biodiversity indicator selection, with the main aim being to provide a method for direct and indirect measurement of pressures/threats and evaluation of impacts on habitats.

# 3. Pressures and their impacts on habitats: developing an integrated definition

In order to develop a standardized system for BIO_SOS, the terminologies used by other organizations and investigators need to be understood such that an integrated system useful for the objectives of BIO_SOS can be developed. Thus, the next section describes and compares the different terminologies developed by various groups and discusses their utility for pressure/threat identification and monitoring.

## 3.1 Terminologies used by different conservation agencies and managers

Building on Salafsky et al. (2003) and more recent literature (journals and conservation project reports from researchers and conservation agencies), different terms that have been used to define pressures and impacts on habitats are described.

### 3.1.1 SWOT

'SWOT' analysis – Strengths, Weaknesses, Opportunities and Threats – provide a useful, quick approach for analyzing information on the status of protected areas that is easily understood by managers as well as policy makers (Hockings et al. 2006; Valencia and Dunce 2006). Such approaches can be useful in quickly highlighting common and obvious threats at many sites, such as mining or urbanization – but lack a strategic, standardized and comparative analytical framework and approach to assessment that make it difficult to use for comparisons across sites, or for monitoring (Valencia and Dunce 2006).

### 3.1.2 WCPA/IUCN framework

The framework developed by the International Union for Conservation of Nature and Natural Resources (IUCN)'s World Commission of Protected Areas; WCPA) develops an overall set of assessment systems and standards for assessment and monitoring of protected areas for adaptive management (Hockings et al., 2000, 2006). This approach also uses the terms 'threat' and 'pressure' interchangeably. Threats to protected areas can be at scales ranging from global (e.g. climate change) to regional (e.g. habitat fragmentation) and/or local (e.g. poaching). The authors stress the need to identify threats and report on both threats within the protected area (which can be addressed by managers) and those outside (which may be beyond the scope of managers, but which are important to flag and address through for instance changes in policy). They also concur with other assessment typologies that it is important to separate the immediate impacts of threats from their underlying or root cause, and to identify both existing threats and those that have the potential to become important in the future, in order for managers to be pro-active.

This report also provides an interesting and useful summary of the threats to protected areas reported by different large-scale studies, which highlights how differences in the approach to envisaging and defining threats can result in significant divergences between the major threats identified by different assessment systems. For instance, a study of 43 of the world's most threatened protected areas (IUCN, 1984), a study of 135 parks (Machlis and Tichnell 1985) and an IUCN survey of protected area professionals in 1994 (Hockings et al. 2006) all highlight the lack of adequate management resources and personnel to be a major 'threat' as well as a barrier to effective management. This would not however fit as a threat or a pressure within many other classification systems, including the PSR and DPSIR frameworks described in the next section. Yet, it is clearly an important variable and even if perhaps not included as a direct threat, should be mentioned somewhere (perhaps as an underlying driver, or some other associated variable). The capacity of protected area managers to themselves manage the park based on their staff, resources, and training should also be monitored over time.

### 3.1.3 PSR and DPSIR

The Pressure-State-Response (PSR) framework is widely used for environmental assessment and conservation monitoring, including by the Organisation for Economic Cooperation and Development

(OECD), the Convention on Biological Diversity (CBD) Birdlife International, and MIRABEL (Models for Integrated Review and Assessment of Biodiversity in European Landscapes, Petit et al., 2001). The goal is to report on identified environmental indicators, described using a causality chain. The PSR framework builds on an original Stress-Response framework developed by Rapport and Friend (1979), which linked environmental stress to the state of the ecosystem, and ecosystem responses, and a subsequent modification by the OECD (1991), which developed a Pressure State Response model (Gabrielsen and Bosch 2003). The framework is conceptually simple, stating that human activities exert pressure (such as land use change or pollution) on the environment, which induces change in the state of the environment (such as alternations in habitat diversity or water flows), which lead in turn to responses by society (such as environmental policies and legislation) intended to prevent, reduce or mitigate pressure (LEAD, 1999).

The CBD (2003) defines these components in greater detail, as follows

**Pressure** - includes indirect or direct human-induced pressures that affect biological diversity. Indirect pressures are related to demography, economy, technology, culture and governance. Direct pressures include inter alia land use, alien invasive species, climate change, emissions of nutrients and pollutants, fragmentation and exploitative human uses;

**State** - is the abiotic state of soil, air and water, as well as the state of the biological diversity at ecosystem/habitat, species/community and genetic levels. State includes ecosystem goods and services, the direct benefits of biodiversity and the societal impacts of biodiversity loss;

**Responses** are the measures taken to change the state, pressure or use. They include measures to protect and conserve biodiversity in situ and ex situ. They include measures to promote the equitable sharing of the monetary or non-monetary gains arising from the utilization of genetic resources. Responses also include steps taken to understand the causal chain and to develop data, knowledge, technologies, models, monitoring, human resources, institutions, legislation and budgets required to achieve the objectives of the Convention.

Pressures therefore can be treated as somewhat equivalent to **threats** in this framework (Petit et al., 2001; Otieno et al., 2004; Valencia and Duncan 2006), with direct threats being similar to direct human-induced pressures as defined in CBD (2003) while indirect or underlying threats can be treated as equivalent to indirect pressures.

The DPSIR framework (Driving forces, Pressure, State, Impact and Response) developed by the European Environmental Agency (EEA) is a further elaboration of the PSR framework that is used extensively to define common standards for European reporting (EEA 1995, Gabrielsen and Bosch 2003, Kristensen 2004). The DPSIR framework assumes multiple cause and effect relationships between human activities, environmental impacts, and societal responses to these impacts, as shown in Figure 1 below.

**Drivers** of environmental change (such as urbanization) result in

**Pressures** on the environment (such as discharge of industrial and domestic waste), which create changes in the

**State** of the environment (e.g. water quality), creating

**Impacts** on society and ecology, leading to

**Responses** (e.g. policy responses) – which in turn impact Drivers, but also lead to changes in Pressures, State and Impact indicators

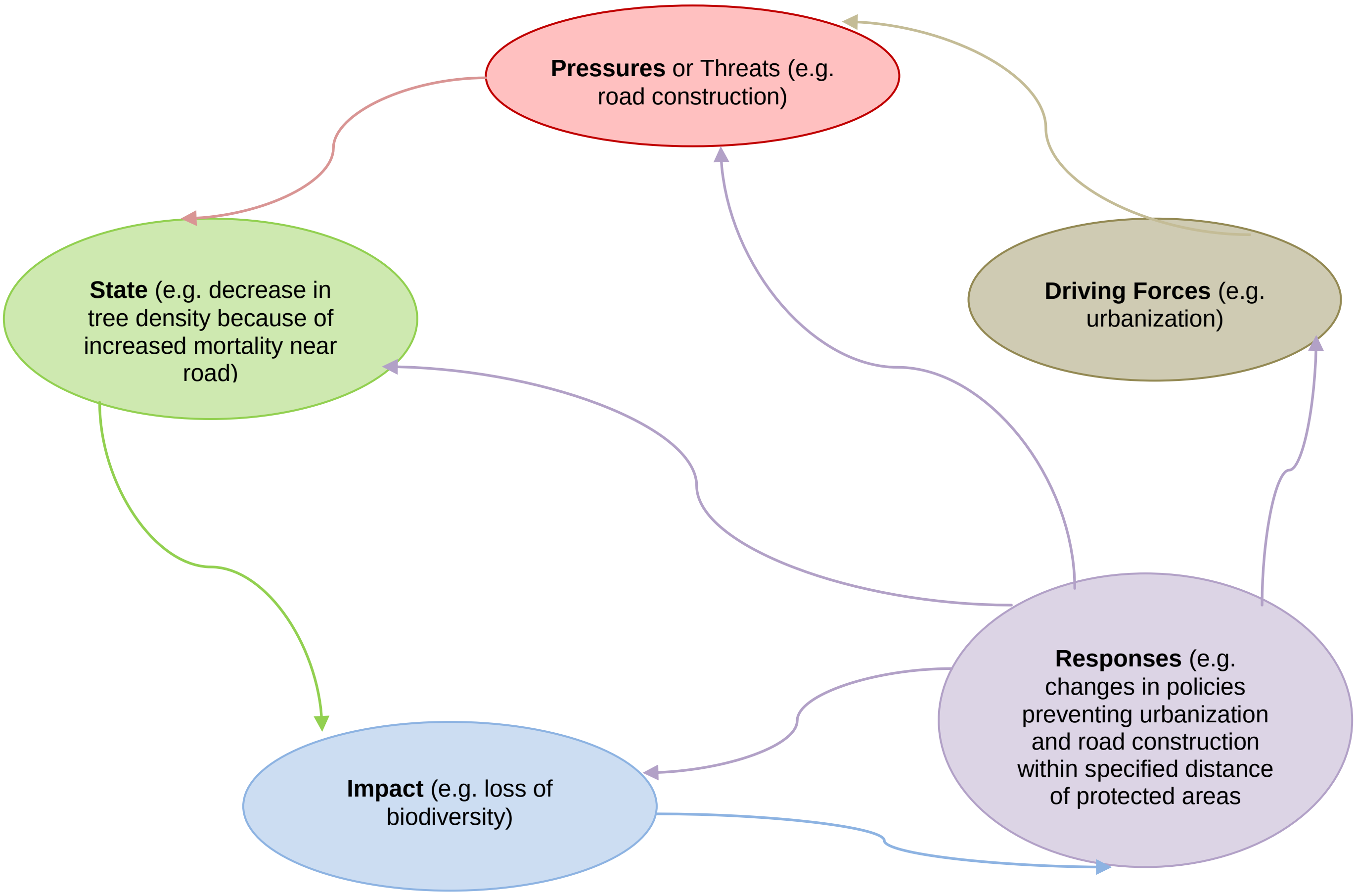


**Figure 1. The DSPIR Framework (adapted from Gabrielsen and Bosch, 2003).**

This framework has been critiqued for creating confusion as compared to the relatively simpler PSR framework, as the distinction between driver and pressure indicators, and between state and impact, can be difficult to establish (Valencia and Duncan 2006). Thus, MIRABEL, the CBD, Birdlife International and the Western Hemisphere Shorebird Reserve Network, for example, have retained the PSR framework. Other authors critique both PSR and DPSIR for ignoring non-human drivers of environmental change, and for depicting a mostly linear and uni-directional chain of causation, in contrast to the interlinked, multi-directional and non-linear interactions that actually occur (Svarstad et al. 2007). However, some recent studies argue that the DPSIR is a framework and not a model, and that the various components within this can be represented by more complex interactions that include feedbacks and non-linear behaviour (Rounsevell et al. 2010).

Perhaps a more important issue from the point of view of this deliverable is that, while pressures in the DPSIR framework (and direct pressures within the PSR framework) are related to threats, they do not directly incorporate an assessment of immediate threats (the purpose of this deliverable). Further, pressures in the DPSIR framework are basically processes that influence changes in ecosystem state, and the difference between a driver and a pressure depends on whether it is exogenous to the system (hence a driver) or endogenous (hence a pressure). Thus changes to the definition of system boundaries, or the scale of observation, can result in a driver becoming a pressure or vice versa (Rounsevell et al. 2010).

The project RUBICODE developed a new formulation of the DPSIR, which is partially an adaptation of the Millennium Assessment framework to ecosystem services, which they term the “Framework for

Ecosystem Service Provision" – this provides greater explication of the various components and the linkages between these components (Rounsevell et al. 2010). As can be seen from Figure 2 below, this framework also makes the role of anthropogenic drivers of change more explicit, but does not really incorporate a consideration of threats either.

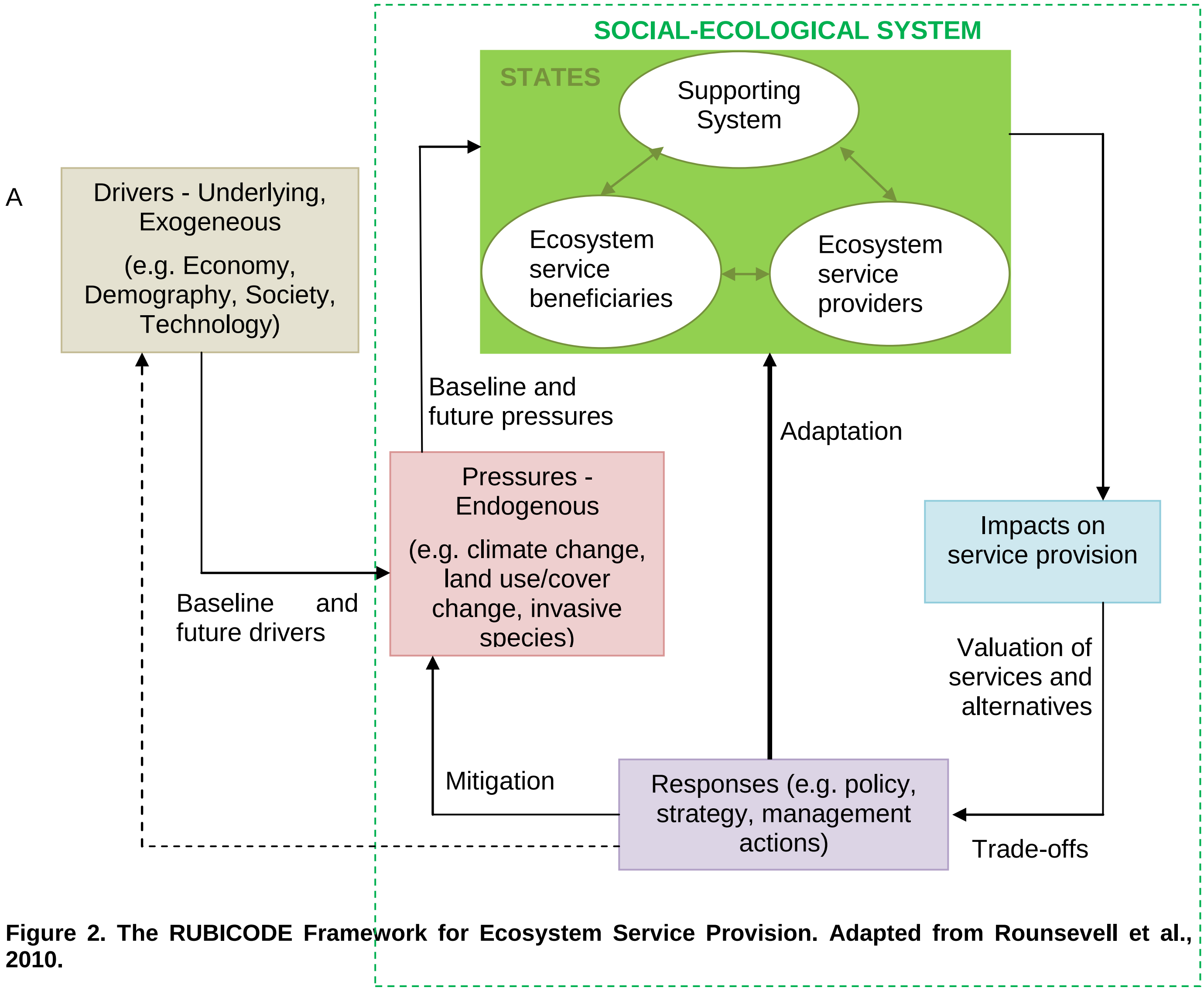


**Figure 2. The RUBICODE Framework for Ecosystem Service Provision. Adapted from Rounsevell et al., 2010.**

### 3.1.4 RAPPAM

The Rapid Assessment and Prioritization of Protected Area Management (RAPPAM) methodology developed by the World Wildlife Fund for Nature (WWF) has been widely used for assessment of the management effectiveness of protected areas (Ervin 2003; Ervin and Parrish 2006). This approach helps to quickly identify the main threats affecting the protected area, and assess their seriousness through a study of their scope (extent), impact (the 'degree to which pressures affected overall protected area resources'), and longevity ('length of time needed for the protected area resource to recover with or without management intervention'. Past pressures are defined as "forces, activities, or events that had already had a detrimental impact on the integrity of the protected area (i.e., that had diminished biological diversity, inhibited regenerative capacity, or impoverished the area's natural resources), and separated from present pressures, as well as from future threats (defined as "potential or impending pressures that were likely to cause a detrimental impact to occur or continue.")

Each threat is characterized according to its extent, impact and longevity as described in Table 1 below.

**Table 1. Threat rating system proposed by RAPPAM – from Ervin and Parrish 2006**

| Indicator | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Extent | Localized | Scattered | Widespread | Throughout |
| Impact | Mild | Moderate | High | Severe |
| Longevity | Short term | Medium term | Long term | Permanent |

Each threat is then given an overall rating by multiplying its scores in the categories of extent, impact and permanence –with an overall rating of 1-3 rated as a mild threat; 4-9 as moderate; 12-24 as high; and 27-64 as severe.
As shown in Figure 3 below, threats are also categorized as tractable ('activities whose impacts can be prevented, mitigated, or reversed through a reasonable degree of funding, capacity building, policy reform, or management intervention'), and intractable ('threats that require unrealistic amounts of resources or staffing or that cannot be solved easily with existing technology). The activities and their impacts are often difficult to detect and monitor, are the result of multiple underlying causes, and are deeply embedded in a protected area's social and cultural milieu). At a further level of detail, tractable threats can be categorized as being of two kinds – strategic ('likely to have a high degree of impact and yet are relatively easy to resolve, in some cases with the simple stroke of a pen) and background threats ('can typically be resolved with a modicum of policy reform or improved management and are unlikely to be major sources of park degradation.') Intractable threats can similarly be classified into wicked ('like a low-grade fever, can exhaust management efforts and gradually erode protected area resources over time') and pernicious threats ('critical and intractable problems on which the success or failure of protected area management may ultimately depend.')

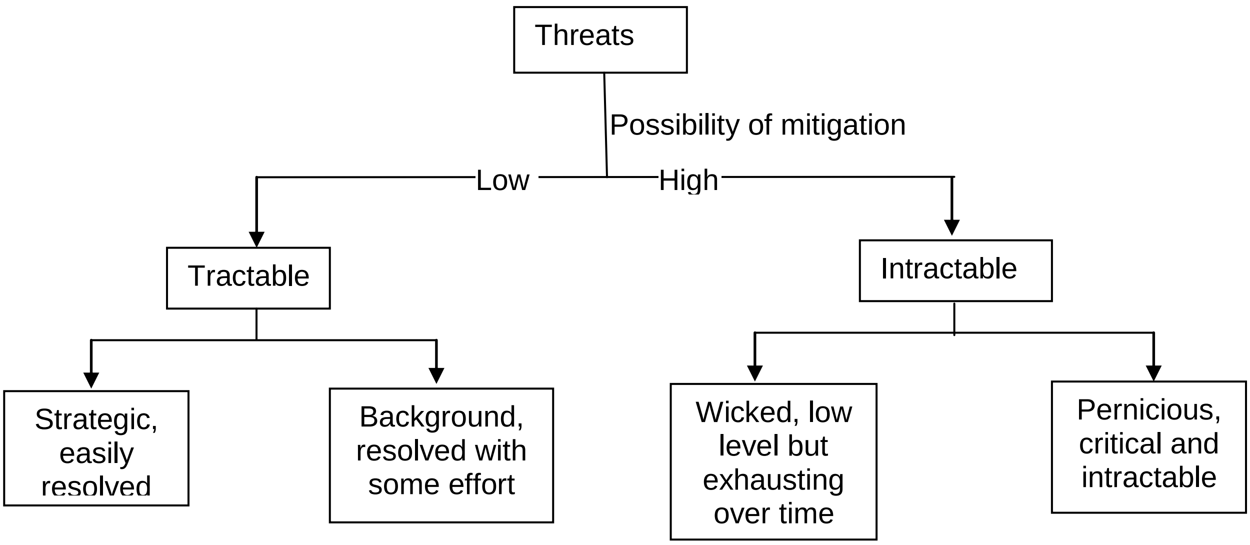


**Figure 2. The RAPPAM categorization of threats (Ervin and Parrish 2006)**

### 3.1.5 The Nature Conservancy Conservation Action Planning/5-S

The Nature Conservancy (TNC) has developed an approach for Conservation Action Planning (CAP) to help to plan and implement conservation projects and measure and monitor their success (TNC 2007). CAP builds on the previous 5-S framework of TNC and aims to identify the most critical threats for conservation action through a process of threat identification, ranking and prioritization. **Focal targets** are defined, which could range from single species to ecological communities and ecosystems.

A set of **key ecological attributes** is identified for each target, such as its population size, or landscape context. **Stresses** that impact these conservation targets, by affecting the key ecological attributes (for instance, severely reducing population levels of a focal species of interest) are noted. Stresses are caused by **sources of stress** (i.e., direct pressures or threats) that are, in turn, impacted by **indirect threats** as well as **opportunities**. Finally, conservation plans need to utilize this information to develop **strategies** for management.

Sources of stress (direct pressures) are mostly limited to anthropogenic activities in this framework, although there is recognition that, in some instances, the distinction between a naturally occurring event such as wildfire and a human-caused fire may be difficult to make. Sources of stress are defined as current, future (likely to occur in the next 10 years) or historical. Each stress is given a rating in terms of its scope (geographic extent of impact that can be reasonably expected in 10 years if the current situation were to continue unchanged) and severity (level of damage to the focal target that can be expected in 10 years if the current situation were to continue unchanged). The source(s) of stress is/are also rated according to its contribution (expected contribution if this pressure were acting alone), and irreversibility (the extent to which the effects of a source of a stress can be reversed, and key ecological attributes restored). All ratings were developed according to a four-point qualitative scale – very high, high, medium and low.

The TNC 5-S Framework further outlines how threats ratings for multiple targets, or for multiple threats to a single target can be combined through an explicit rule-based procedure using the “3-5-7 rule”: 3 high ranked threats are equivalent to 1 very high-ranked threat; 5 medium ranked threats are equivalent to 1 high-ranked threat, and 7 low ranked threats are equivalent to 1 medium-ranked threat.

### 3.1.6 IUCN Conservation Measurement Partnership

Salafsky et al. (2003) addressed the then-widespread lack of a standardized taxonomy for describing threats and pressures in conservation sites, by developing a framework for defining threats and related factors, a taxonomy for naming direct threats and pressures, a system for measuring the magnitude of threats, a procedure for combining threats across targets, threats and projects, and a method for the spatial mapping of threats. This system has since been expanded and elaborated on (Salafsky et al. 2008, 2009) and is now widely adopted across the conservation community (e.g. Stagliano 2006, Willson and Abnigall 2009).

**Threats** are defined as “any human activity or process that has caused, is causing or may cause the destruction, degradation and/or impairment of biodiversity and natural processes.” Threats are used interchangeably with pressures. These include both **direct threats** (‘factors that immediately cause stress to conservation targets by physically causing their destruction or degrading their integrity and underlying causes’) and **underlying causes** (‘a condition or environment, usually social, economic, political, institutional, or cultural in nature, that enables or otherwise contributes to the occurrence and/or persistence of a direct threat). Further, this framework allows for the differentiation of underlying causes into **indirect threats** (factors with a negative effect) and **opportunities** (factors with a positive effect), representing a significant step forward from what is possible under the PSR and DPSIR frameworks, WWF’s RAPPAM framework, and other previous approaches. Threats are further classified into **past threats** – those that are no longer active (such as large scale habitat clearing in some European landscapes), although their effects on targets may still persist; **current threats** – those still actively occurring in the landscape; and **future threats** – those not actively occurring, but which are likely to occur in the future.

Salafsky et al. (2003, 2008) also develop a classification system for threats that is widely used, which has the following properties – it is hierarchical, comprehensive, consistent (all entries at a given level of the taxonomy are of the same type), expandable, exclusive (a given threat can only be placed in one cell in the hierarchy) and scalable (the same names can be used for the same threats occurring in another location). This taxonomy restricts itself to the classification of direct threats only. Further, it does not make any distinction between different actors undertaking the same action (for instance, discriminating between logging by local people vs logging by an outside company).

At the upper level of the taxonomy, eight broad categories of direct pressure are defined. Salafsky et al. (2003), in the initial approach, defined these as habitat conversion (e.g. clearing of forest for housing), transportation infrastructure (e.g. roads), abiotic resource use (e.g. mining), consumptive biological resource use (e.g. fishing), non-consumptive biological resource use (e.g. hiking), pollution (e.g. acid rain), invasive species, and modification of natural processes, ecological drivers or disturbance regimes (e.g. modified fire regimes). Subsequently, Salafsky et al. (2008) developed on this further to derive a hierarchical three-level system, with eleven first-level and 39 second-level categories, as well as an expandable set of third-level categories.

**Table 2. The first and second level categorization of threats developed by Salafsky et al. (2008).**

| **Number** | **Name** | **Definition** | **Second level categories** |
|---|---|---|---|
| 1 | Residential and commercial development | Human settlements or other nonagricultural land uses with a substantial footprint | 1.1 housing and urban areas<br>1.2 commercial and industrial areas<br>1.3 tourism and recreation areas |
| 2 | Agriculture and aquaculture | Threats from farming and ranching as a result of agricultural expansion and intensification, including silviculture, mariculture, and aquaculture | 2.1 annual and perennial nontimber crops<br>2.2 wood and pulp plantations<br>2.3 livestock farming and ranching<br>2.4 marine and freshwater aquaculture |
| 3 | Energy production and mining | threats from production of nonbiological resources | 3.1 oil and gas drilling<br>3.2 mining and quarrying<br>3.3 renewable energy |
| 4 | Transportation and service corridors | threats from long, narrow transport corridors and the vehicles that use them including associated wildlife mortality | 4.1 roads and railroads<br>4.2 utility and service lines<br>4.3 shipping lanes<br>4.4 flight paths |
| 5 | Biological resource use | threats from consumptive use of "wild" biological resources including deliberate and unintentional harvesting effects; also persecution or control of specific species | 5.1 hunting and collecting terrestrial animals<br>5.2 gathering terrestrial plants<br>5.3 logging and wood harvesting<br>5.4 fishing and harvesting aquatic resources |
| 6 | Human intrusions and disturbance | threats from human activities that alter, destroy and disturb habitats and species associated with nonconsumptive uses of biological resources | 6.1 recreational activities<br>6.2 war, civil unrest and military<br>6.3 work and other activities |
| 7 | Natural system modifications | threats from actions that convert or degrade habitat in service of "managing" natural or seminatural systems, often to improve human welfare | 7.1 fire and fire suppression<br>7.2 dams and water management/use<br>7.3 other ecosystem modifications |
| 8 | Invasive and other problematic species and genes | threats from non-native and native plants, animals, pathogens/microbes, or genetic materials that have or are predicted to have harmful effects on biodiversity following their introduction, spread and/or increase in abundance | 8.1 invasive non-native/alien species<br>8.2 problematic native species<br>8.3 introduced genetic material |
| 9 | Pollution | threats from introduction of exotic and/or excess materials or energy from point and nonpoint sources | 9.1 household sewage and urban waste water<br>9.2 industrial and military effluents<br>9.3 agricultural and forestry effluents<br>9.4 garbage and solid waste<br>9.5 air-borne pollutants |
| 10 | Geological events | threats from catastrophic geological events | 10.1 volcanoes<br>10.2 earthquakes/tsunamis<br>10.3 avalanches/landslides |
| 11 | Climate change and severe weather | long-term climatic changes that may be linked to global warming and other severe climatic or weather events outside the natural range of variation that could wipe out a vulnerable species or habitat | 11.1 habitat shifting and alteration<br>11.2 droughts<br>11.3 temperature<br>11.4 storms and flooding |

Further, a system for measurement of the magnitude of threats was developed, with the intention to be measurable, scalable (across different spatial and temporal scales), consistent, combinable and elegant. The system proposed is described in Table 3 below.

**Table 3. Threat rating system proposed by Salafsky et al. (2003)**

| Variable | Continuous Measurement | Categorical Measurement | Comment |
|---|---|---|---|
| **Scope (Spatial)**<br>The area affected by a threat within 10 years | Area threatened (in hectares or as a % of total area) | 4 = Throughout (>50%)<br>3 = Widespread (15 – 50%)<br>2 = Scattered (5 – 15%)<br>1 = Localized (< 5%) | Should be calculated as the percentage of possible area (i.e., water pollution is % of aquatic habitat at a site, not entire site) |
| **Scope (% of Targets)**<br>The number of target occurrences affected by a threat within 10 years | Number or percentage of targets affected within a project area | 4 = Most or all (>50%)<br>3 = Many (25 – 50%)<br>2 = Some (5 – 25%)<br>1 = Few (< 5%) | Is an alternative way of measuring scope |
| **Severity**<br>The degree to which a threat has an impact on the viability/integrity of targets within the project area within 10 years | Actual measure of reduced target viability/integrity (e.g., nesting success, stream temperature) | 4 = Serious damage or loss<br>3 = Significant damage<br>2 = Moderate damage<br>1 = Little or no damage | This measure is independent of area; Different continuous measures are needed for each target type |
| **Timing**<br>Time until a threat will start having impact on targets | Years | 4 = Current (< 1 year)<br>3 = Imminent (1-3 years)<br>2 = Near-term (3-10 years)<br>1 = Long-term (> 10 years) | Refers to onset of the impact, not the duration of the threat |
| **Likelihood**<br>The probability that a threat will occur within the next 10 years | Fraction or percentage likelihood | 4 = Existing threat (100%)<br>3 = High probability (50-99%)<br>2 = Moderate probability (10-49%)<br>1 = Low probability (0-9%) | Difficult to estimate, may not be included in most calculations; can also be applied to other variables |
| **Reversibility**<br>Degree to which effects of a threat on target occurrences can be restored | Resources (money, time, ecological capital, etc.) required to reverse a threat | 4 = irreversible (e.g., extinction)<br>3 = reversible with difficulty<br>2 = reversible with some difficulty<br>1 = easily reversible | Need to distinguish between technical, economic and practical reversibility |
| **Contribution**<br>The degree to which a threat causes multiple and cascading threats and/or has widespread ecological impacts | Number of targets and/or target occurrences affected by a threat | 4 = Very high<br>3 = High<br>2 = Moderate<br>1 = Low | Has some potential overlap with *Scope* |

All measurements are not required to be conducted across all sites, instead depending on site-specific or region-specific information needs as well as perhaps on the availability of information and capacity levels of the personnel conducting the evaluation, certain measurements can be selected, and given a continuous rating, a categorical rating, or a qualitative evaluation into, for instance, low, medium, high and very high threat categories.

Threat ratings can be combined across targets, threats or projects using different approaches, again depending on local information needs. Arithmetic procedures for combining ratings (such as those used in WWF-RAPPAM, Ervin (2003), as described above) combine ratings by multiplying or adding them. Threshold rule-based procedures specify rules to indicate how different parameters should be combined, for instance the rules developed by BirdLife International (2006), specify that if two threats are two be

combined, and one is low but the other is very high, the final rank is very high. While arithmetic procedures are easy to interpret, particularly if there are two to three variables involved, rule-based procedures may have greater conservation significance especially if spatial methods of threat analysis are utilized.

The framework and procedures outlined by Salafsky et al. (2003, 2008) have explicitly incorporated ideas of spatial threat analysis, mapping and combination, and is perhaps the first such approach to explicitly do so. Despite the now widespread adoption of this framework, some authors (Balmford et al. 2009) have critiqued this system for being "a one-dimensional hybrid of mechanism and source that omits several key threat mechanisms." For instance, the first-level types of threats combine considerations of the mechanisms or processes impacting conservation targets (such as habitat clearing or invasive species) with the sources, or sectors of human activity through which these mechanisms act (such as agriculture, residential development or mining). Importantly, habitat loss – a major direct pressure on many protected areas – is not listed as a threat but instead as a stress within this system. These authors propose a different system (the Cambridge Conservation Foundation - CCF system) for classification of threats, in a two way matrix that defines threats based on their mechanism as well as source. This matrix has been further critiqued by Salafsky et al. (2009) for being too complex. Both set of arguments seem to have some merit, and perhaps what is needed is a modified approach that draws largely on Salafsky et al. (2009) but with some modifications (such as adding ecosystem conversion or habitat clearing as a direct threat rather than a stress).

## 3.2 Experiences from conservation prioritization and management efforts

This section discusses some experiences from conservation organizations that have used the frameworks described in section 3.1 for monitoring, with the aim of understanding the potential strengths and weaknesses of different approaches.

### 3.2.1 PSR and DPSIR

BirdLife International (2006) uses the PSR framework to monitor progress in Important Bird Areas (IBAs) – sites of international biodiversity conservation importance for birds and other taxa. Monitoring is conducted regularly in these areas to assess the effectiveness of conservation measures as well as to provide early warning signals of threats and other problems. Such monitoring is especially relevant for IBA sites in Europe in the context of the Birds Directive of the European Union. The monitoring approach used is based primarily on qualitative data and, although the report acknowledges the potential utility of EO datasets for this purpose, it states that this approach is only being tested for selected sites as remotely sensed data, "need careful interpretation, may provide little information on habitat quality and are likely to require ground-truthing". As the indicators used are deliberately kept simple and easy to assess at a qualitative level across all sites at regular periods of time, some limitations emerge. Specifically, the report notes that the indicators used can only identify fairly broad-level alterations such as habitat or land cover change, and may be less capable of detecting changes in species populations, or habitat quality. Lack of monitoring capacity in some sites is identified as a major challenge because of the poor level of existing data, as well as dearth of monitoring capacity.

BirdLife International develops a method for assessing and scoring threats to IBAs, and monitoring trends over time, as expressed in Table 4 below, based on the timing, scope and severity of threat.

**Table 4. Threat rating system developed and used by BirdLife International (2006)**

| **Timing of threat** | **Timing score** |
|---|---|
| Happening now | 3 |
| Likely in short term (within 4 years) | 2 |
| Likely in long term (beyond 4 years) | 1 |
| Past (and unlikely to return) and no longer limiting | 0 |
| **Scope of threat** | **Scope score** |

| | |
|---|---|
| Whole population (>90%) | 3 |
| Most of population/area (50-90%) | 2 |
| Some of population (10-50%) | 1 |
| Few individuals/small area (<10%) | 0 |
| **Severity of threat** | **Severity score** |
| Rapid deterioration (>30% over 10 years or 3 generations, whichever is longer) | 3 |
| Moderate deterioration (10-30% over 10 years or 3 generations) | 2 |
| Slow deterioration (1-10% over 10 years or 3 generations) | 1 |
| No or imperceptible deterioration (<1% over 10 years or 3 generations) | 0 |

The total Impact score is a sum of the Timing score, Scope score and Severity score. However, if the score for any of the given threats = 0, then the Impact score for that threat is always kept as 0.Threats are scored individually in relation to how likely they are to affect 'trigger' bird species – those species based on which the site has been recognized as an IBA. Based on an approach of "weakest links" being assigned greatest importance, the highest impact score of any threat pertinent to an IBA is then used to derive a threat status for the IBA on a score of 0 to -3, with low threats (0 score) corresponding to an IBA where the highest impact score of any threat ranges from 0-2; medium threat (-1) corresponding to an IBA where the highest impact score of any threat ranges from 3-5; high threat (-2 score) corresponding to an IBA where the highest impact score of any threat ranges from 6-7; and very high threat (-3 score) corresponding to an IBA where the highest impact score of any threat ranges from 8-9. Trend scores for IBA sites can then be assessed by monitoring every 4 years or so, and the BirdLife International (2006) report proposes the following scoring for assessing trends in threats = +3 = large improvement; +2 = moderate improvement; +1 = small improvement; 0 = no change; -1 = small deterioration; -2 = moderate deterioration; -3 = large deterioration. In this, the authors point out that this does not provide a mechanism to update indicators from past assessments retrospectively as a result of improvement in information (which often happens across many conservation sites), and such a mechanism needs to be developed in order to make trend assessments as representative of the best knowledge available and of genuine changes over time as is feasible. Lack of technical capacity for monitoring by local field staff also presents a challenge for sustained high quality monitoring across all sites.

This approach has some strength in terms of its reliance on qualitative assessments, standardization of variables and terms across locations, and simplicity of analysis and interpretation. Yet, although its reliance on the "weakest link' (i.e., the most extreme threat) has some justification, the approach used (an exclusive reliance on the most dominant threat) makes it difficult to correctly evaluate changes in sites where less dominant threats have increased over time, or been effectively contained. A weighted ranking based on a combination of all threats, with weights assigned according to their severity, may present a better alternative approach that could also be easy to implement. Further, remote sensing could be easily used to help quantify threats in addition to this presentation of qualitative rankings, and this deliverable will later outline a suggested approach.

The Birdlife International Partnership has adopted this approach to prioritize Important Bird Areas (IBAs) that are important for conservation of birds in Kenya, identifying 60 IBAs and monitoring changes over time (Otieno et al.,2004). Overall conclusions indicate that human population and changes in land use are the main drivers, resulting in encroachment, fragmentation and degradation of natural habitat. Specifically, this analysis finds that illegal logging, charcoal burning and firewood collection are the most widespread threats in the forest sites; agricultural encroachment is the most dominant threat in the wetland sites and an important factor across other habitat types as well; encroachment for livestock grazing is prevalent across most sites; and human wildlife conflict is a serious issue, but occurring in a relatively small proportion of sites. Yet this study also identifies major information gaps, especially in some lesser-known and lesser-visited areas, and capacity building for monitoring and habitat assessment in these areas is critical.

The WHSRN has monitored 64 wetland sites in the Americas using the PSR framework as well as the TNC 5-S framework (Valencia and Dunce 2006). Evaluation and monitoring of threats focuses on direct threats. Past, present and future threats are included, as well as threats occurring as a result of natural

phenomena without a direct anthropogenic cause (but with underlying human drivers), such as increased frequency of drought, and spreading of disease. In addition to threats inside the site, they also incorporate a consideration of threats taking place outside the site (such as a dam) that impact the site. Threats are scored based on their timing, extent (scope) and severity (i.e., likely impact on the overall ecological integrity of the site), combining information as suggested in the BirdLife International (2006) report, using a 'weakest link' approach.

In this analysis, the terms threat and pressure are used interchangeably. These authors point to some problems with the use of the PSR framework, namely that this framework suggests that all human interventions have a negative impact, and does not include scope for consideration of positive interventions that are not necessarily active responses aimed at threat reduction, but instead for instance traditional agricultural or water management practices that are sustainable. Lack of data (e.g., similar information on land use change across all sites that enables comparison at a broader scale), is identified as a major challenge for application of the framework (and one that has been addressed by BIO_SOS). Further, this report stresses the need for including users and local site managers in the monitoring (thus lending support to the framework of BIO_SOS).

The DPSIR framework is also widely used by many organizations to structure the analysis of indicator sets (e.g. Liuzzi et al. 2003; Krisensen et al. 2004; Mace and Baillie 2007). These tend to include some discussions of broader pressure and drivers, but generally provide less focus on the identification of immediate threats. However, a discussion of threats is found in the Streamlining European Biodiversity Indicators (SEBI) activity jointly coordinated by the EEA, the European Centre for Nature Conservation and the UNEP World Conservation Monitoring Centre explicitly draws on the DPSIR framework to develop a European set of biodiversity indicators to track progress towards the targets set by the Convention on Biological Diversity. The SEBI 2010 process identified a set of 26 indicators for monitoring, of which three indicators are of relevance to this deliverable as these relate to threats to biodiversity – Nitrogen deposition (tracked by seeing if there is critical load exceedance for nitrogen), trends in invasive alien species (tracked by assessing invasive alien species in Europe), and impact of climate change on biodiversity (tracked by monitoring the occurrence of temperature-sensitive species). These indicators seem to be too broad to be of use for monitoring in specific protected areas, as envisaged by BIO_SOS, as they have been developed for use at a regional, pan-European level.

### 3.2.2 RAPPAM

In an application of RAPPAM to four countries – Bhutan, China, Russia and South Africa, Ervin (2003) find that it has great utility for the rapid and cross-site evaluation of pressures and threats affecting protected areas at a regional scale. However, the accuracy is limited by lack of data, and in particular it was difficult to accurately identify the extent, impact and permanence of threats. This was particularly so for wicked threats. Further, as Ervin and Parrish (2006) point out, the approach of combining threat ratings by multiplication to derive an overall threat index has its limitations, as some threats may have low scores individually, but in combination may have severe impacts on ecosystems and biodiversity. These authors suggest that it is important to explicitly map the spatial configuration of threats, as these provide ways to better predict the magnitude of potential impacts, and can also assist in development of more effective management and containment strategies. Although these reports do not mention the use of remote sensing and GIS based spatial approaches for such spatial threat analysis, they indicate the importance of finding a way forward in this direction. Such spatial prioritization of threats has also been recommended by other assessments in Australia (Watson et al. 2009).

Lu et al. (2012) assess the effectiveness of five protected areas in Taiwan using the RAPPAM framework. While they conclude it has great utility, they identify challenges that limit the scope for in-depth analysis, and subjectivity of reporting. Further, since RAPPAM was designed for regional studies, they modified it for site-level analyses. One aspect that this study points out is that expressed perceptions of threat differ greatly when local communities are asked, as against protected area managers – one of the limitations of RAPPAM is that it has been largely reliant on site managers for information, whereas in this study local communities explicitly criticized park managers and identified them as a threat to the protected area. The most frequently mentioned pressure in this study was

pollution. Yet major categories of pressure and the extent of pressure differed with the remoteness of the area, suggesting that the threat analysis was able to identify actual pressures operating on different areas with success.

### 3.2.3 TNC-CAP and IUCN-CMP

Willson and Abnigall (2009) used the approach of The Nature Conservancy (2007) and Salafsky et al. (2009) to conduct a threat analysis as an input into a management plan for the recovery of threatened species in a region of South Australia. The recovery plan they develop addresses 203 threatened species and 18 threatened ecological communities in the Adelaide and Mounty Lofty Ranges (AMLR) region, to satisfy the requirements of the Commonwealth Environment Protection and Biodiversity Act (EPBA), 1999. Only direct threats – defined as those currently impacting the area, of with potential to impact within the next five years (which represents the duration of the plan), were incorporated in this plan. Further, this plan explicitly avoided analysis of fundamental drivers (such as population increase, or land use policy).

**Threats** were grouped into ten broad categories and further classified into sub-categories following the TNC-CAP classification proposed by Salafsky et al. (2008). The **Severity** (intensity) and **Scope** (spatial range) of each threat was rated, and these ratings combined to create overall threat **Magnitude** ratings of low, medium, high or very high for each threat sub-category. A second category of analysis, **Ecological Stresses** – degraded key ecological processes (such as hydrological regimes and fire regimes) taking place due to threats – were also defined and listed for the study area. Vulnerable species and ecological communities – those at greater risk due to their increased susceptibility to threat – were then prioritized for planning. In addition, following the EPBC Act, a **Key Threatening Process** was defined as a process that can cause a native species or ecological community to become eligible for inclusion into a threatened list; cause an already listed threatened species or ecological community to become endangered; or to adversely affect two or more listed threatened species or ecological communities.

Some threats were very highly ranked across flora and fauna (particularly freshwater fish) – these included climate change, water management and use and grazing. Other threats, such as weed invasions, were highly ranked across flora and most fauna, but less relevant for freshwater fishes.

The authors identify several challenges to conducting such threat analyses.

1. Lack of understanding – some threats are poorly understood, may be known to be important but without knowledge of how to control or address these threats, may be considered low priority now but may later emerge to become important, or may even remain unknown. There is also insufficient understanding of the nature, extent and relative importance of threats at the species level, which makes it difficult to identify and triage the management of especially vulnerable species.

2. Many threats do not act individually or additively in conjunction with other threats, but instead act in conjunction as groups, with synergistic or antagonistic interactions. For instance, grazing can result in the exacerbation of other types of threats such as habitat degradation, soil enrichment, weed invasion and the pollution of waterways, and such effects can become more severe during periods of climate change, especially during drought events. Yet grazing can also have positive effects on habitats, stimulating the growth of native grasses. Such threat categories have high levels of assessment uncertainty, which needs to be flagged during analysis and planning for management, and requiring careful research and monitoring during management.

3. Again complex inter-relationships between ecological stresses and threats make it difficult to conceptually and practically separate these factors. For instance, in the AMLR region, broad-scale vegetation clearance is not a current but rather a past historical threat, and as such, should not be considered in this plan. Yet, many of the current ecological stresses observed (such as vegetation fragmentation and reduced population size) are a consequence of this historical threat, and thus this requires to be understood for current management as well.

4. Threat analysis has been performed only at the regional scale – yet, for effective management, finer scale information on the spatial distribution of threats is required.

These challenges for managers are of especial interest to BIO_SOS. In particular, this report concludes that in addition to managing direct threats, it is crucial for managers to address knowledge gaps, and improve spatial knowledge-base systems, which is an important point of learning.

Stagliano (2006) conducted one of the few spatial assessments using the TNC approach to threat prioritization and the Conservation Measurement Effectiveness taxonomy of threats and (Salafsky et al. 2003, 2008; TNC 2007). This assessment evaluates aquatic targets within the Montana region of the Northern Great Plains Steppe Ecoregional Plan, and determines biodiversity viability measures, threat status and protection of these targets using a combination of field data and GIS, using landscape variables such as percent grazing in riparian habitat, density of road and stream crossings, percent agriculture, dam and diversity density, and oil and gas wells. For instance, to assign threat scores to grazing, public and private grazing land polygons were overlaid onto riparian habitat to determine the percentage of grazing in riparian areas, with <3% grazing classified as low threat, 3-6% as moderate, 6-10% as high and >10% as very high. This study demonstrates a quantitative approach, using readily available GIS data coupled with field information, to provide ratings of direct threats or sources of stress, along with spatial maps that can be very useful for management and monitoring.

### 3.2.4 Protected Area Management Effectiveness Assessments in Europe

Nolte et al. (2010) conducted a review of assessments of protected area management effectiveness across Europe, recording 1846 individual site-level assessments (of which only 227 were repeat assessments, indicating the widespread lack of monitoring follow-up). Forty different assessment methodologies were encountered – although those developed by WWF (RAPPAM), WCPA and the Conservation Measurement Partnership (Salafsky et al. 2008) were common, as many as 31 of the methodologies used were specific to their location or to Europe and not found elsewhere. In terms of threat taxonomies, the study combines the threats identified by various studies into the standardized approach developed by Salafsky et al. (2008) but concludes that of all the diverse monitoring approaches used, RAPPAM provides the most detailed classification of threats, followed by BirdLife and the Tracking Tool. Recreational activities were identified as the most prevalent threat, while hunting, logging, grazing, development, pollution and dams were other commonly identified serious threats. The authors recommend that regular monitoring is very critical for effective management, while most assessments have been conducted only at a single time point; they also suggest that it is very critical for management plans to broaden their focus beyond the limited boundaries of their protected area to integrate considerations of wider landscape planning.

## 3.3 Strengths and weaknesses of different approaches

Table 5 compares the different frameworks discussed in section 3.1, building on the experiences from conservation prioritization efforts discussed in 3.2, to compare the strengths and weaknesses of different approaches for assessing and monitoring pressures, threats and impacts in different contexts. SWOT is not considered in this summary as it lacks a standardized analytic framework that can be used to characterize its application (Valencia and Dunce 2006).

We assess, among other issues, if

a) Do frameworks make a distinction between proximate and underlying causes, i.e. can they help in distinguishing between factors that can be readily addressed by conservation managers, and others that relate to broader political, cultural, socio-economic or institutional changes and need to be addressed at the national or regional level?

b) Do frameworks make a distinction between State/Condition/Stress of the ecosystem (in terms of its key ecological attributes), and Impact (changes in the target ecosystem, community or species over time)?

c) What kind of management responses do they consider, and from what kinds of actors?

d) Do they enable differentiation of past, current and future pressures, i.e. can they be useful for scenario development or only for historical analysis?

e) Do they enable rating of threats along a severity gradient, taking into consideration different aspects of threat severity? Do they enable information from different threats to be combined for a single target (ecosystem, community, species)?

f) Do they enable the separation of positive and negative pressures (i.e. threats vs opportunities)?

g) Do they include spatial approaches to map the distribution and magnitude of threats within a site, with respect to the distribution of targets?

h) Do they acknowledge and deal with the non-additive synergies and inter-relationships between threats?

i) Do they only consider uni-directional relationships between drivers, threats, stresses, impacts and responses, or do the frameworks permit the consideration of multi-directional influences (including positive and negative feedback loops)?

j) Do they enable a hierarchical diagnosis of impacts at different scales that can enable managers to deal with threats at different levels of detail, depending on information needs and availability?

**Table 5**. **A comparison of different frameworks discussed in section 3.1 to assess their strengths and weaknesses**.

| | WCPA/IUCN | PSR | DSPIR | RAPPAM | TNC CAP/5-S | IUCN-CMP |
|---|---|---|---|---|---|---|
| Underlying Driver | Root causes, or sources of threats | No distinction between underlying and proximate drivers | Defined as exogeneous to system | Considered causal factors, and drivers of threats | Underlying causes (social, economic, political, institutional or cultural), enables consideration of these as indirect threats as well as opportunities | Underlying causes (social, economic, political, institutional or cultural), enables consideration of these as indirect threats as well as opportunities |
| Proximate Driver/ Pressure/ Threat | Includes direct threats taking place within the protected area, as well as those that fall outside the boundaries but affect the attainment of management objectives | No distinction between underlying and proximate drivers | Defined as endogeneous to system | Activities with a detrimental impact on biological diversity, inhibiting regenerative capacity, or impoverishing the area's natural resources | Source of stress, or direct threat to target – largely due to human activities | Source of stress, or direct threat to target – largely due to human activities |
| State/ Condition | State of ecosystem (e.g. population of birds | State of ecosystem (e.g. population of birds) | Quantity/ quality of physical (e.g. temperature), biological (e.g. fish stocks) or chemical (e.g. pollutants) phenomena in an area | State of ecosystem; not directly assessed, but evaluated through assessment of threats | Stress – changes in key ecological attributes (changes in the target's biology or ecology that, can lead to loss of target over time) | Stress – changes in key ecological attributes (changes in the target's biology or ecology that, can lead to loss of target over time) |
| Impact | No distinction between State of ecosystem | No distinction between State of ecosystem | Impacts on biodiversity, ecosystem and | No distinction between State of ecosystem | Changes in target – ecological | Changes in target – ecological |

| | | | | | | |
|---|---|---|---|---|---|---|
| | and Impact | and Impact | human health, resource availability, and manufactured capital as a consequence of changes in State | and Impact; not directly assessed, but evaluated through assessment of threats | system, community or species | system, community or species |
| Response/ Actions | Societal or management response to pressure/ threat | Societal or management response to pressure/ threat | Positive and negative responses by individuals, groups and governments to prevent, and mitigate threats, or to compensate for, or adapt to changes in state. | Focuses on effectiveness of local management of protected area, with some consideration of broader contextual factors such as macro-level policies | Management responses taken by stakeholders in response to threat analysis | Focuses on effectiveness of local management of protected area, with some consideration of broader contextual factors such as macro-level policies |
| Separation of past, present and future threats | Not specified | Not specified, but can be incorporated into assessments | Not specified, but can be incorporated into assessments | Separates identification of past, present and future threats | Separates identification of past, present and future threats | Separates identification of past, present and future threats |
| Threat Rating | Not part of the framework, but framework can be extended to incorporate assessment and rating of threats along various dimensions, including rating, and combination of rating into overall threat scores for prioritization of action | Not part of the framework, but framework can be extended to incorporate assessment and rating of threats along various dimensions, including rating, and combination of rating into overall threat scores for prioritization of action | Tend to focus on assessments of broader, underlying drivers; limited use for the assessment of specific direct pressures | Explicitly incorporated, based on extent, impact and longevity | Explicitly incorporated, with individual threats rated on severity, scope, and irreversability and combines ratings from different threats based on their relative contribution to target stress | Explicitly incorporated, based on scope, severity, timing, likelihood, severity and contribution, depending on information available |
| Separation of positive and negative pressures/ threats | Not considered within this framework | Not considered within this framework | Not considered within this framework | Not considered within this framework | Separately assesses threats and opportunities, but does this only for underlying (indirect) threats | Separately assesses threats and opportunities, but does this only for underlying (indirect) threats |
| Spatial distribution of pressures/ threats | Not considered within this framework | Not considered within this framework | Not considered within this framework | Encourages mapping of spatial distribution of individual threats followed by overlay of multiple layers | Encourages mapping of spatial distribution of threats | Develops an approach for spatial depiction of threats, targets and links between these, with the purpose of creating threatshed |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | maps that depict changes in the distribution of a threat and its magnitude over time |
| Synergies between pressures/ threats | Not considered within this framework | Not considered within this framework | Not considered within this framework | Explicitly assesses synergies and inter-relationships between threats | Not considered within this framework, although it permits different threats that contribute to stress on a common target to be combined into a single threat rating based on their relative contribution to target stress | Not considered within this framework |
| Consideration of multidirectional relationships between pressures/ threats and other factors such as drivers and responses | Unidirectional relationship between root causes, threats, stresses and management responses | Unidirectional relationship between drivers and threats, but acknowledges multi-directional relationship between and threat and response | Unidirectional relationship between drivers and threats, but acknowledges multi-directional relationship between and threat and response | Considers multidirectional relationship between drivers and threats, and threats and response | Unidirectional relationship between underlying threats and opportunities, direct threats, stresses, changes in target, and responses | Unidirectional relationship between underlying threats and opportunities, direct threats, stresses, changes in target, and responses |
| Hierarchical framework for identification of threats at different levels of detail | Not considered | Not considered | Not considered | Not considered | Utilizes the hierarchical framework developed by IUCN-CMP | Develops and utilizes a three-level hierarchical framework for the identification of threats at different levels of detail |

As is clear from Table 5, conservation threat assessments have evolved over time, from relatively broad frameworks that do not provide a useful delineation between direct threats and underlying drivers, do not permit differentiation of threats and opportunities, and do not allow for a standardized approach for threat rating and comparison across locations and targets, to frameworks that incorporate a careful consideration of all these aspects. Spatial mapping of threats is an approach being strongly recommended by recent frameworks, especially that of the IUCN-CMP (Salafsky et al. 2003, 2008), and this supports the focus of BIO_SOS towards the use of EO data for the spatial mapping of threats, for the creation of “threatshed” maps (Salafsky et al. 2003) that can enable managers to prioritize efforts, with the aim of providing adaptive, efficient, rapid and effective mitigation and amelioration of threats.

Despite the considerable progress that has been made in this regard, some challenges still remain. Apart from the IUCN-CMP framework (and to some extent, RAPPAM) no comprehensive list of threats has been attempted. The listing provided by IUCN-CMP is considered comprehensive at the first (broadest) level, and has the advantage of being hierarchical in enabling successive delineation threats

at progressively finer levels – for instance, identifying (consumptive) 'Biological Resource Use' at the broadest level (level 5 in IUCN-CMP Guidance Threat Classification version 3.1), then locating this as an example of Logging and Wood Harvesting at the next level (level 5.3), and finally, specifying this as an instance of 'Intentional Use: Subsistence/Small Scale' at the third and most detailed level of classification (level 5.3.1). Yet, as has been pointed out by others (Balmford et al. 2009) this is not exclusive, and a single pressure can find itself in multiple locations within this list, depending on the point of view of the person or organization conducting the classification. This is perhaps a difficult challenge to deal with, as any framework for threat analysis will be required to have some flexibility to adopt to the context of the study area and the question(s) of interest, and the ability to group targets into different sets can be argued to be a required part of such flexibility. The IUCN-CMP threat classification system has other advantages – it is developed in such a manner as to be capable of expansion to add new categories, and to be capable of extension to new sites and regions with potentially different ecologies, local anthrophic challenges and consequently different pressures.

Yet, from the point of view of BIO_SOS, this threat classification system is difficult to directly adopt for the standardized identification and quantification of pressures (from EO data, in conjunction with expert opinion and field information). Take for instance the example provided above, of identifying threats within the broader level of 'Biological Resource Use'. Within this (level 5.0), are 4 sub-categories – hunting, gathering plants, logging, and fishing – that impact very different ecosystems, communities and species. Thus, at the broadest level of classification, this system does not appear very useful for managers focused on the conservation of specific targets (as is most frequently the case). At the intermediate level of detail, logging and wood harvesting (level 5.4) combines a consideration of small scale subsistence harvesting and commercial logging, which have very different scale-related impacts on landscapes. Yet, if one then moves to the most detailed level of threat delineation, in the hope that this is useful for managers, then this is further confusing, providing a level of detail that is actually not relevant for managers – for instance, separating the intentional effects of small scale logging (i.e. when the species being logged is the target of monitoring) from unintentional effects (when another species is the target of monitoring). Yet, in both cases, the pressure is exactly the same; it is only the target of the pressure that is different (i.e. different species).

A further challenge, which no classification system has addressed (apart from RAPPAM, which attempts to deal with this qualitatively, by using expert inputs) is the fact that threats do not, for the most part, act in isolation, or even additively. Instead, they act synergistically, with positive and negative feedbacks, frequently leading to unanticipated outcomes. Further, human impacts can be positive and negative, again sometime switching direction of impact based on context and scale. For instance, fire, grazing and logging may be part of long standing management interventions used to maintain the integrity of many protected areas with a long history of settlement (such as in Italy or India), and may be positive instances of pressure, but can quickly become negative and turn to threats if the climate changes, or the degree of pressure becomes more intense, or spatially more extensive, for instance. Thus, a good framework should enable the consideration of positive and negative direct pressures – sadly, as indicated in Table 5, most do not.

Finally, most frameworks incorporate a fairly simplistic, uni-directional consideration of linkages between factors, with underlying drivers influencing pressures, pressures creating stresses (changes in key ecological attributes of targets), stresses impacting targets (state variables of ecosystems, communities, species), and these impacts leading to management responses. Some frameworks such as PSR and DPSIR incorporate a consideration of multiple influences of management responses on underlying drivers, pressures, stresses as well as targets. This is far from sufficient, though. Each of these factors can and often does have complex multi-directional linkages with other factors and often have synergistic effects on target systems, which needs to be factored in for effective management.

Spatialization of pressures provides a possible way to address many of these issues. Deriving effective maps of pressure distribution and intensity, as well of as target status and distribution, will enable a more accurate association of pressures with targets, and will also permit the consideration of positive pressures (opportunities) as well as negative pressures (threats). Positive pressures such as contained grazing can be easily converted to negative pressures using spatial map overlays, depending on changes in context and scale, with reference to field inputs from experts and/or field data. Pressures of

different kinds can be combined linearly as well as synergistically, using models of landscape change – and real world challenges of different combinatorial groups of pressures acting at different spatial scales can be easily dealt with explicitly and quantitatively within a monitoring framework when spatialized. Combining the spatialization of pressures with models of landscape change using EO data can be used to explicitly incorporate considerations of multi-directional linkages between pressures, targets and responses as well.

Thus, the approach proposed by BIO_SOS seems not only feasible, but can also provide a very valuable addition to existing approaches for pressure evaluation and monitoring. We propose to develop an alternate theoretical framework to understand how human impacts, both positive and negative, influence changes in habitat, land cover change, and landscape fragmentation and connectivity, incorporating multi-directional linkages, and the possibility of synergistic interactions between different aspects. This forms a part of Task 6.5, but is not associated with the current deliverable D6.8, instead the development of an alternative framework will be explored in deliverable D6.9 at a later stage in the project. In this deliverable, we however propose a different approach to threat classification, building on Salafsky et al. (2003, 2008) but adapting this system for consideration of inputs on pressure derived from EO data – the main objective of this deliverable.

# 4. Integrated approach to threat classification suggested by BIO_SOS

The focus of BIO_SOS is to develop an operationalizable system for the systematic identification and quantification of locally recognizable pressures at a given site and in its surroundings, using EO data and analysis coupled with expert information. Given this focus, we will attempt to integrate the systems described above to provide a hierarchical, integrated classification of pressures that will be adopted in the further discussion of this Task and its associated Deliverables.

Given that the objective of this exercise is to assess the use of and employ EO data for pressure identification, we suggest a hierarchical taxonomy for threat classification that builds on that proposed by Salafsky et al. (2003, 2008) but deviates from it in some aspects. First, we point to some important distinctions between pressures/threats (stresses) and impacts (state/condition of ecosystem, communities, species or other targets of conservation). EO data and associated spatial techniques such as GIS, landscape pattern analysis and Ecological Niche Modelling, can provide information on changes in the state/condition of ecosystems, communities and species more readily. These changes can be used to infer evidence of pressures, but EO data cannot, in many instances, be directly used to identify pressures. For instance, assume that excessive collection of Non-Timber Forest Products has led to widespread changes in forest vertical structure, leading to simplification in structural diversity, which can be detected by EO datasets such as LiDAR. This can be used to *infer* that there is excessive NTFP collection, but it is not as though EO datasets provide the possibility to directly observe NTFP collection (i.e. to directly observe the pressure acting on the landscape). Similarly, EO data can be used to observe altered fire regimes (with, for instance, changes in spatial coverage or in intensity over time) – but while observation of such change can be used to *infer* changes in human activity, changes in fire patterns could also be due to alterations in climate with increased drought patterns and hence increased susceptibility to fire (while human interventions in the landscape remain unchanged), or even due to natural disturbances such as lightning. EO data will not provide any opportunities for direct observation of these activities. Instead, expert interpretation, coupled with field data, is required. Thus the classification scheme proposed also naturally differs from that suggested by Salafsky et al. (2003, 2008), who focus on the direct delineation of threats, whereas we suggest the use of EO data (from a more practical perspective, taking into account the use of EO data for monitoring by local managers) to identify impacts on conservation targets, from which pressures can be inferred, with the help of expert knowledge of the landscape and/or field data.

EO data are known to provide information on changes in land cover and habitat type somewhat more easily, and can also provide information in some cases on changes in habitat quality (e.g. vegetation density, D 5.4), alterations in ecosystem functioning and ecological regimes (e.g. changes in the intensity of fires and hydrological cycles as analysed through a combination of GIS and EO data e.g. D 6.5), changes in spatial connectivity (through the coupling of GIS and spatial analysis techniques with EO datasets, e.g. D6.2, 6.3 and 6.4), disruptions in plant and animal community structure (as analysed through approaches such as Ecological Niche Modelling coupled with EO data, e.g. D 6.5 and D 6.6) and the identification of fine scale spatial pressures with large spatial impacts. Based on these ideas, we outline a hierarchical taxonomy of pressure classification that can be used to collect data on pressures using EO data, and use this to describe pressures in different BIO_SOS sites as described in Table 6 below.

**Table 6. Suggested hierarchical classification to describe pressures in different sites, building on and modifying Salafsky et al. (2003, 2008) with the explicit aim of using EO data for pressure identification and monitoring.**

| Broad categories of observed impacts (changes in state of conservation target) | Specific types of impact | LCCS/GHC categories where this is likely to be an issue | Proximate pressures | Underlying factors | Chronology of change | Types of data needed for identification and/or quantification |
|---|---|---|---|---|---|---|
| Land | e.g. Forests to | Lists of | e.g. farm | Economic, | Past, | Expert, field, or |

| | | | | | | |
|---|---|---|---|---|---|---|
| cover/habitat conversion | Agriculture<br>Plantations to Housing, etc | categories | expansion<br>housing construction | Demographic, Social, Technological | present or future | EO data |
| Land cover/habitat modification | e.g. Decrease in tree density<br>Simplification of vertical structure<br>Loss in species diversity<br>Soil degradation<br>Freshwater pollution, etc | Lists of categories | e.g. illegal and legal logging<br>Etc<br>e.g. Agricultural runoff | Economic, Demographic, Social, Technological | Past, present or future | Expert, field, or EO data |
| Disruption/ modification of ecological regimes | E.g. Changed fire regime<br>Altered grazing pattern<br>Loss of keystone species | Lists of categories | Anthropogenic fires | Economic, Demographic, Social, Technological | Past, present or future | Expert, field, or EO data |
| Changes in spatial connectivity | E.g. Decrease in patch size<br>Increased inter-patch distance<br>Increased edge effects, etc. | Lists of categories | e.g. Transportation corridors | Economic, Demographic, Social, Technological | Past, present or future | Expert, field, or EO data |
| Disruption of plant and animal community structure | E.g. Change in species composition<br>Change in dominance or evenness values<br>Spread of invasive species, etc | Lists of categories | e.g. Non-Timber Forest Product harvesting | Economic, Demographic, Social, Technological | Past, present or future | Expert, field, or EO data |
| Fine spatial scale pressures with large spatial impacts | e.g. Buildings<br>Tree falls<br>Point pollution sources, etc. | Lists of categories | e.g. Transportation Corridors | Economic, Demographic, Social, Technological | Past, present or future | Expert, field, or EO data |

We must stress here that differences between land cover/habitat conversion and land cover/habitat modification can be challenging to delineate, as this depends very much on the level of thematic detail used in classification. For instance, if a landscape is classified at the level of the Food and Agricultural Organisation's Land Cover Classification System (LCCS) Level 1, into 'Primarily Vegetated' and 'Primarily NonVegetated' categories (see D5.3 for further details), then a change in land use from forest to agriculture will not be considered land cover conversion, but modification. In contrast, if the same landscape is classified at the LCCS Level 3, separating 'Cultivated and Managed Areas' from '(Semi) Natural Vegetation', then this change in land use will be considered to be land cover conversion, instead of modification. Thus, the level of delineation of impact depends on the amount of information (i.e. thematic detail) available with the manager in terms of existing maps of land cover/land use, and also on the degree of reliability/accuracy of these maps in terms of their spatial coverage.

We also stress that care must be taken in defining the role of pressures (or human interventions) that can play a positive role under some instances, and a negative role in other instances. Take for instance logging, which represents a threat across several BIO_SOS landscapes. Logging in many studies is

used in an unclear fashion, as a catch-all umbrella phrase potentially referring to all silvicultural activities. Logging, or timber harvesting, when carried out illegally or in an unplanned and high intensity mode, is well known to be associated with forest ecosystem degradation and destruction. Yet in many contexts, from Europe to North America, and even Asia (e.g. Japan) timber harvesting or extraction is legal and planned, even in protected areas, and operated by means of silvicultural practices relating to coded silvicultural systems based on forest ecology.

On one hand it is true that, from an ecological point of view, silviculture can be regarded as a kind of disturbance, often associated with other disturbances, such as road, and cableways, or leading to other pressures such as soil degradation and disruption of micro-connectivity. However, it has to be considered that many forests occurring in protected areas are “managed” forests with some degree of human intervention, often over decades or even centuries. Intact (virgin, pristine) forests are very rare and very scattered all over the world, as most of them have experienced some sort of “management”. As with intact forest ecosystems which are driven by natural disturbances acting at many scales, many silvicultural systems (e.g., selective harvest, shelterwood, clear-cutting, coppicing) are characterised by different disturbance regimes (intensity, duration frequency) and are normally applied to already disturbed plant communities, with the purpose of providing ecological goods and services, while maintaining regeneration. Similarly with grazing, and fire. Thus, paradoxically, management interventions aimed at limiting fire, grazing and logging can paradoxically sometimes transform protected and threatened habitats into other habitat types or result in habitat degradation, as an unintended consequence of well intentioned management responses.

## 4.1 Italian sites

### Table 7. Pressures in Italian BIO_SOS sites

| Broad category | Specific types of change | LCCS/GHC category or Annex I habitat type where this is likely to be an issue | | | | | | Proximate pressure | Underlying factors | Past, Present or Future Pressure | Types of data needed for impact identification or quantification |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | IT1 Annex I (*) | IT2 Annex I (**) | IT3(***) | | IT4 (****) | | | | | |
| | | | | LCCS/DIC | LCCS/HIER | LCCS/DIC | LCCS/HIER | | | | |
| Land cover/habitat conversion | Grasslands to agriculture (Cereal crops IT1-IT3) (Irrigated olive groves IT2-IT4) | 5330/ 62A0/ 6220 | 1310/ 1410 | A.12 | A2.A5.A10.B12.E7<br>A2.A10.B12.E6<br>A2.A6.A10.F2.F5.F10.G2.B12 | A.24 | A2A5A13B4C2E5-B13E7<br>A2A6A12B4C2E5-B11E6 | Agriculture intensification, farm expansion Establishment of irrigated plantations | Agricultural policies and incentives | Past (mainly) | Expert/Field/EO data |
| Land cover/habitat conversion | Beaches to urban | \ | \ | | \ | A.12<br>A.24 | A2A5A11B4XXE5-A13B13E7<br>A2A6A11B4XXE5-A12B12E6<br>A2A6A10B4XXE5-B11E6 | Building for recreation infrastructure and tourist facilities (Trails, kiosks facilities) | Tourism | Past - Present - Future | field/EO data |
| Land cover/habitat conversion | Grasslands and agricultural covers to urban | 62A0/ 6220 + 211 | \ | A.12<br>A.11 | A2.A5.A10.B12.E7<br>A2.A10.B12.E6<br>A2.A6.A10.F2.F5.F10.G2.B12<br>A3.A4 | | \ | Wind and solar farms | Alternative energy policies | Past - Present - Future | EO data |
| Land cover/habitat conversion | Grasslands and shrubs to forestry | \ | \ | A.12 | A2.A5.A10.B12.E7<br>A2.A10.B12.E6<br>A2.A6.A10.F2.F5.F10.G2.B12A1.A4.A10..D1.E1.B9 | A.12 | A2A6A10B4XXE5-B11E6<br>A1A4A10B3XXD2E1-B9 | Plantation of non-autochthonous woods | Agricultural policies and incentives | Past | EO data |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Land cover/habitat conversion | Forest plantations to urban | 312/ 313 | \ | A.11 | A1.A8.A9.W7 (outside NP) | | \ | Building construction (Scattered urban areas) | Urban expansion Regional law 12/2012 art 2 comma 2 (enforcing national law Dlgs. 227/2001) | Future | EO data |
| Land cover/habitat conversion | Vegetation change | Potentially all non forest LC and non Annex I | \ | Potentially all non forest LC and non Annex I | | | \ | Plantation of autochthonous woods | Compensation Regional law 12/2012 art 2 comma 3 (enforcing national law Dlgs. 227/2001) | Future | Expert/Field/EO data |
| Land cover/habitat conversion | Grasslands and agricultural covers to urban | 62A0/ 6220 + cereal crops | \ | A.12 | A2.A5.A10.B12.E7<br>A2.A10.B12.E6<br>A2.A6.A10.F2.F5.F10.G2.B12<br>A3.A4 | | \ | Road construction (associated with wind farms and scattered urban ) | Urban expansion | Past - Present - Future | EO data |
| | | | | A.11 | A3.A4 | | | | | | |
| Land cover/habitat conversion | Grasslands to urban | 5330/ 62A0/ 6220/ 8210 | \ | A.12 | A2.A5.A10.B12.E7<br>A2.A10.B12.E6<br>A2.A6.A10.F2.F5.F10.G2.B12<br>A2.A5.A14 | | \ | Quarring | Urban expansion | Past | EO data |
| Land cover/habitat modification | Changes in vegetation cover, height, life form | 62A0/ 6220 | \ | A,12 | A2.A5.A10.B12.E7<br>A2.A10.B12.E6<br>A2.A6.A10.F2.F5.F10.G2.B12 | | \ | Agriculture and zootechnics abandonement (Shrubs and woody encroachment) | Socio-economic factors (may include those agricultural policies and incentives) | Present - Future | Expert/Field/EO data |
| Land cover/habitat modification | Soil degradation | \ | \ | | \ | A.12 | A2A5A11B4XXE5-A13B13E7<br>A2A6A11B4XXE5-A12B12E6 | Clearing and cleaning of beaches with heavy machinery | Tourism | Past - Present - Future | Field/EO data |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | A.24 | A2A6A10B4XXE5-B11E6 | | | | | |
| Land cover/habitat modification | Dumping of rubbish or toxic muds and radioactive substances | \ | \ | A.11 | A3.A4 | | \ | Dumping of rubbish or toxic muds and radioactive substance | Urban expansion, illegal activities | Past - Present | Expert/Field/EO data |
| Land cover/habitat modification | Decrease in ground vegetation density and soil degradation (compaction) | 62A0/ 6220 | \ | A.12 | A2.A5.A10.B12.E7<br>A2.A10.B12.E6<br>A2.A6.A10.F2.F5.F10.G2.B12 | | \ | Intensive grazing (enclosures) and impact by excessive livestock numbers | Agricultural policies and incentives | Past | Field/Expert |
| Disruption / modification of ecological regimes | Fire regime | \ | \ | A.12 | A1.A3.A10.D1.E2.B7<br>A1.A4.A10.D1.E2.B9<br>A1.A4.A10.D1.E1.B9 | A.11 | A1B1XXC1D1W7-A8A9B3 | Forest wild fires | Socio-economic conflits (past), vegetation dynamics due to agriculture/forestry/ grazing abandonment (present-future), climate change (future) | Past - Present - Future | Expert/Field/EO data |
| | | | | A.11 | A1.A8.A9.W7 | | | | | | |
| Disruption / modification of ecological regimes | Fresh water depletion | \ | 1150/ 1310/ 1410/ 1420/ 1510 | | \ | | \ | Agriculture intensification urban expansion | Agricultural policies and incentives/urban polarisation | Past - Present - Future | Expert/Field/EO data |
| Change of plant and animal community structure | Changes in community composition and structure | ? | ? | A.12 | A1.A3.A10.D1.E2.B7<br>A1.A4.A10.D1.E2.B9<br>A1.A4.A10.D1.E1.B9 | | ? | Invasive species | Domestication, changes in distribution ranges (species migration due to climate change) | Past - Present - Future | Expert/Field/EO data |
| | | | | A.11 | A1.A8.A9.W7 | | | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Changes in spatial connectivity | Edge effects | 62A0/ 6220 | \ | A.12 | A2.A5.A10.B12.E7 A2.A10.B12.E6 A2.A6.A10.F2.F5.F10. G2.B12 | | \ | Occurrence isolated or at distribution boundaries | Habitat loss and fragmentation | Past - Present - Future | Expert/Field/EO data |
| Fine spatial scale pressures with large spatial impacts | Point pollution sources | \ | 1150 | | \ | A.24 | A2A5A13B4C1E5-A15B12E6 A2A5A13B4C2E5-B13E7 A2A6A12B4C2E5-B11E6 | Airborne or direct nutrient input or fertilization of adjacent or far off fields | Agriculture intensification (may include those agricultural policies and incentives) | Past - Present - Future | Expert/Field/EO data |
| Fine spatial scale pressures with large spatial impacts | Point water uptake apparates (wells, pumps) | \ | 1150/ 1310/ 1410/ 1420/ 1510 | | \ | A.24 | A2A5A13B4C1E5-A15B12E6 A2A5A13B4C2E5-B13E7 A2A6A12B4C2E5-B11E6 A1A4A12B3C2D3-B10 | Agriculture intensification, farm expansion | Agricultural policies and incentives | Past - Present - Future | Expert/Field/EO data |
| Fine spatial scale pressures with large spatial impacts | Point pollution sources | \ | 1150/ 1310/ 1410/ 1420/ 1510 | | \ | | \ | Sewers draining in water courses | Urban expansion | Past - Present | Field/Expert |
| | | **(*) LCCS not yet identified** | **(**) LCCS not yet identified** | | **(***) As defined by P1 - correspondence table provided to P8 on July 10 2012** | | **(****) As defined in Tomaselli et al contribution to RSE in prep, circulated within BIOSOS (table 2)** | | | | |

| **Broad category** | **Specifc types of change** | **LCCS/GHC category or Annex I habitat type where this is likely to be an issue** | | | | **Proximate pressure** | **Underlying factors** | **Past, Present or Future Pressure** | **Types of data needed for impact identificaton or quantification** |
|---|---|---|---|---|---|---|---|---|---|
| | | **IT1 Annex I (*)** | **IT2 Annex I (**)** | **IT3 LCCS/HIER (***)** | **IT4 LCCS/HIER (****)** | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Land cover/habitat conversion | Grasslands to agriculture | 5330/ 62A0/ 6220 | 1310/ 1410 | A2.A5.A10.B12.E7 A2.A10.B12.E6 A2.A6.A10.F2.F5.F10 .G2.B12 | A2A5A13B4C2E5-B13E7 A2A6A12B4C2E5-B11E6 | Agriculture intensification, farm expansion | Agricultural policies and incentives | Past (mainly) | Expert/Field/EO data |
| Land cover/habitat conversion | Beaches to urban | \ | \ | \ | A2A5A11B4XXE5-A13B13E7 A2A6A11B4XXE5-A12B12E6 A2A6A10B4XXE5-B11E6 A2A5A11B4XXE5-A13B13E7 | Building of recreation infrastructure and tourist facilities | Tourism | Past - Present - Future | field/EO data |
| Land cover/habitat conversion | Grasslands and agricultural covers to urban | 62A0/ 6220 + 211 | \ | A2.A5.A10.B12.E7 A2.A10.B12.E6 A2.A6.A10.F2.F5.F10 .G2.B12 A3.A4 | \ | Wind and solar farms | Alternative energy policies | Past - Present - Future | EO data |
| Land cover/habitat conversion | Non-irrigated to irrigated agriculture land covers | \ | \ | \ | A2A5A13B4C2E5-B13E7 A2A6A12B4C2E5-B11E6 | Establishment of irrigated plantations | Agricultural policies and incentives | Past - Present - Future | field/EO data |
| Land cover/habitat conversion | Grasslands and shrubs to forestry | \ | \ | A2.A5.A10.B12.E7 A2.A10.B12.E6 A2.A6.A10.F2.F5.F10 .G2.B12 | A2A6A10B4XXE5-B11E6 A1A4A10B3XXD2E1-B9 | Plantation of non-autochthonous woods | Agricultural policies and incentives | Past | EO data |
| Land cover/habitat conversion | Forest plantations to urban | 312/ 313 | \ | A1.A8.A9.W7 (outside NP) | \ | Building construction | Urban expansion Regional law 12/2012 art 2 comma 2 (enforcing national law Dlgs. 227/2001) | Future | EO data |
| Land cover/habitat conversion | Vegetation change | Potentially all non forest LC and non Annex I | \ | Potentially all non forest LC and non Annex I | \ | Plantation of autochthonous woods | Compensation Regional law 12/2012 art 2 comma 3 (enforcing national law Dlgs. 227/2001) | Future | Expert/Field/EO data |
| Land cover/habitat conversion | Grasslands and agricultural covers to urban | 62A0/ 6220 + cereal crops | \ | A2.A5.A10.B12.E7 A2.A10.B12.E6 A2.A6.A10.F2.F5.F10 .G2.B12 A3.A4 | \ | Road construction | Urban expansion | Past - Present - Future | EO data |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Land cover/habitat conversion | Grasslands to urban | 5330/ 62A0/ 6220/ 8210 | \ | A2.A5.A10.B12.E7<br>A2.A10.B12.E6<br>A2.A6.A10.F2.F5.F10 .G2.B12<br>A2 | \ | Quarring | Urban expansion | Past | EO data |
| Land cover/habitat modification | Secondary succession, or woody (shrubs and trees) encroachment | 62A0/ 6220 | \ | A2.A5.A10.B12.E7<br>A2.A10.B12.E6<br>A2.A6.A10.F2.F5.F10 .G2.B12 | \ | Agriculture and zootechnics abandonement | Socio-economic factors (may include those agricultural policies and incentives) | Present - Future | Expert/Field/EO data |
| Land cover/habitat modification | Soil degradation | \ | \ | \ | A2A5A11B4XXE5-A13B13E7<br>A2A6A11B4XXE5-A12B12E6<br>A2A6A10B4XXE5-B11E6<br>A2A5A11B4XXE5-A13B13E7 | Clearing and cleaning of beaches with heavy machinery | Tourism | Past - Present - Future | Field/EO data |
| Land cover/habitat modification | Dumping of rubbish or toxic muds and radioactive substances | \ | \ | A3.A4 | \ | Dumping of rubbish or toxic muds and radioactive substance | Urban expansion, illegal activities | Past - Present | Expert/Field/EO data |
| Land cover/habitat modification | Decrease in ground vegetation density, and soil degradation (compaction) | 62A0/ 6220 | \ | A2.A5.A10.B12.E7<br>A2.A10.B12.E6<br>A2.A6.A10.F2.F5.F10 .G2.B12 | \ | Intensive grazing (enclosures) and impact by excessive livestock numbers | Agricultural policies and incentives | Past | Field/Expert |
| Disruption/ modification of ecological regimes | Fire regime | \ | \ | A1.A3.A10.D1.E2.B7<br>A1.A4.A10.D1.E2.B9<br>A1.A8.A9.W7<br>A1.A4.A10.D1.E1.B9 | A1B1XXC1D1W7-A8A9B3 | Forest wild fires | Socio-economic conflits (past), vegetation dynamics due to agriculture/forestry/grazing abandonment (present-future), climate change (future) | Past - Present - Future | Expert/Field/EO data |
| Disruption/ modification of ecological regimes | Fresh water depletion | \ | 1150/ 1310/ 1410/ 1420/ 1510 | \ | \ | Agriculture intensification urban expansion | Agricultural policies and incentives/urban polarisation | Past - Present - Future | Expert/Field/EO data |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Change of plant and animal community structure | Changes in community composition and structure | ? | ? | A1.A3.A10.D1.E2.B7<br>A1.A4.A10.D1.E2.B9<br>A1.A8.A9.W7<br>A1.A4.A10.D1.E1.B9 | ? | Invasive species | Domestication, changes in distribution ranges (species migration due to climate change) | Past - Present - Future | Expert/Field/EO data |
| Changes in spatial connectivity | Edge effects | 62A0/<br>6220 | \ | A2.A5.A10.B12.E7<br>A2.A10.B12.E6<br>A2.A6.A10.F2.F5.F10<br>.G2.B12 | \ | Occurrence isolated or at distribution boundaries | Habitat loss and fragmentation | Past - Present - Future | Expert/Field/EO data |
| Fine spatial scale pressures with large spatial impacts | Point pollution sources | \ | 1150 | \ | A2A5A13B4C1E5-A15B12E6<br>A2A5A13B4C2E5-B13E7<br>A2A6A12B4C2E5-B11E6 | Airborne or direct nutrient input or fertilization of adjacent or far off fields | Agriculture intensification (may include those agricultural policies and incentives) | Past - Present - Future | Expert/Field/EO data |
| Fine spatial scale pressures with large spatial impacts | Point water uptake apparatus (wells, pumps) | \ | 1150/<br>1310/<br>1410/<br>1420/<br>1510 | \ | A2A5A13B4C1E5-A15B12E6<br>A2A5A13B4C2E5-B13E7<br>A2A6A12B4C2E5-B11E6<br>A1A4A12B3C2D3-B10<br>A2A6A12B4C2E5-B11E6 | Agriculture intensification, farm expansion | Agricultural policies and incentives | Past - Present - Future | Expert/Field/EO data |
| Fine spatial scale pressures with large spatial impacts | Point pollution sources | \ | 1150/<br>1310/<br>1410/<br>1420/<br>1510 | \ | \ | Sewers draining in water courses | Urban expansion | Past - Present | Field/Expert |
| | | **(*) LCCS not yet identified** | **(**) LCCS not yet identified** | **(***) As identified by P1 - correspondence table provided to P8 on July 10 2012** | **(****) As identified in Tomaselli et al contribution to RSE in prep, circulated within BIOSOS (table 2)** | | | | |

## 4.2 Greek sites

**Table 8. Pressures in Greek BIO_SOS sites**

| **Broad Categories of observed change** | **Specific types of change** | **LCCS/GHC categories where this is likely to be an issue** | **Proximate pressures** | **Underlying factors** | **Past, Present and/or Future pressure** | **Types of data needed for identification and/or quantification** |
|---|---|---|---|---|---|---|
| Land cover/habitat conversion | Forests to Agriculture | A1A3A10B2XXD1E2-B6E4/TRS-FPH/DEC<br>A1A3A10B2XXD1E2F1-B7/TRS-FPH/DEC<br>A1A3A10B2XXD1E2-B6/TRS-FPH/DEC | Farm expansion | Agricultural policies | Mainly past | EO data |
| Land cover/habitat conversion | Salt marshes to agriculture | A1A4A12B3C2D3-B10/THE+SPV/TER | Farm expansion | Agricultural policies | Has been tried but unsuccessfully because of soil salinity | EO data |
| Land cover/habitat conversion | Other habitat types to agriculture | A1A4A11B3C1XXXXF1-A12B9/TRS-SCH/EVR | Farm expansion | Agricultural policies | Limited pressure | EO data |
| Land cover/habitat conversion | Almost bare saline land to communities with *Tamarix* spp. | A2A6A12B4C3-B11/SHY/HEY+EHY/HEL | Ecological succession | Changes in soil water and soil salinity | Present and/or future pressure | Expert/field/EO data |
| Land cover/habitat conversion | Communities with *Tamarix* spp. to reed beds | A1A4A11B3-A12B14/TRS-TPH/EVR+TRS-FPH/EVR | Increase in water level | Changes in water level | Present and/or future pressure | Expert/field/EO data |
| Land cover/habitat conversion | Grassland to water body | A2A6A11B4C2E5-A12B11E6/HER-LHE/CHE | Rise in water level | Rise in water level (perhaps related to climate change?) | Present and/or future pressure | Expert/field/EO data |
| Land cover/habitat modification | Change in tree density | A1A4A11B3-A12B14/TRS-TPH/EVR+TRS-FPH/EVR | Grazing-Animal breeding | Agricultural policies | Past, present and future pressure | Field/EO data |
| Land cover/habitat modification | Loss in species diversity | A1A3A10B2XXD1E2-B6E4/TRS-FPH/DEC<br>A1A3A10B2XXD1E2F1-B5/TRS-FPH/DEC<br>A1A3A10B2XXD1E2F1-B7/TRS-FPH/DEC<br>A1A4A10B3XXD1E1F1-B9/TRS-LPH/EVR<br>A1A4A10B3XXD1E1F1-B8/TRS-MPH/EVR<br>A1A4A11B3XXD1E2F1-A12B9/TRS-SCH/DEC | Intense anthropogenic activities | | Past, present and future pressure | Expert/field |
| Land cover/habitat modification | Water pollution - Eutrofication | A2A5A13B4C1E5-A15B12E6/AQU+TER+SHY+EHY+CHE+LHE/CHE<br>A1B1C2D2-A4/SEA+TER+SHY+EHY+CHE+LHE/CHE<br>A2A5A16B4C3-A8A17B13/HER-SHY | Agricultural runoff, river deposits | Agricultural policies and practices | Past, present and future pressure | Expert/field/EO data |

| | | | | | | |
|---|---|---|---|---|---|---|
| Land cover/habitat modification | Soil degradation-erosion | A2A5A14B4XXE5-B13E6/LHE+CHE+LHE/ CHE+SCH/EVR+TER+HCH | Agricultural practices (fire, grazing) | Agricultural policies and practices | Past, present and future pressure | Expert/field/EO data |
| Land cover/habitat modification | Aquacultures | A1B1C2D2-A4/SEA+TER+SHY+EHY+ CHE+LHE/CHE | Aquacultures | Socio economic | Past, present and future pressure | Expert/field/EO data |
| Land cover/habitat modification | Sand extraction from river | A2A5A13B4C3XXE5F2F5F10G2F1- A8A15B11E6G7/HER-HEL+TRS-TPH | | Economic activities | Past, present and future pressure | Expert/field/EO data |
| Disruption/ modification of ecological regimes | Fire regime | A1A4A10B3XXD1E1F1-B9/TRS-LPH/EVR<br>A1A4A10B3XXD1E1F1-B8/TRS-MPH/EVR | Anthropogenic and natural fires | | Even though it's been a long time since the last fire, it is a constant threat | EO data |
| Disruption/ modification of ecological regimes | Grazing pattern | A2A6A11B4C2E5-A12B11E6/HER-LHE/CHE<br>A1A4A11B3C1XXXXF1-A12B9/TRS-SCH/EVR | Agricultural practices (fire, grazing) | Agricultural policies and practices | Past, present and future pressure | Expert/field/EO data |
| Disruption/ modification of ecological regimes | Climate change | A2A6A11B4C2E5-A12B11E6/HER-LHE/CHE<br>A2A6A12B4C3-B11/SHY/HEY+EHY/HEL<br><br>A2A5A13B4C3XXE5F2F5F10G2F1- A8A15B11E6G7/HER-HEL+TRS-TPH | Sea level rise | Climate change | Present and future pressure | Expert/field/EO data |
| Disruption/ modification of ecological regimes | Hunting-Fishing | A1B1C2D2-A4/SEA+TER+SHY+EHY+CHE+ LHE/CHE<br>A2A6A12B4C3-B11/SHY/HEY+EHY/HEL<br>A2A5A16B4C3-A8A17B13/HER-SHY | | Anthropogenic pressures | Past, present and future pressure | Expert/field |
| Disruption/ modification of ecological regimes | Tourism | A2A5A11B4XXE5-A13B13E7/HER-LHE/CHE | Touristic facilities | Anthropogenic pressures | Present and future pressure | Expert/field |
| Changes in spatial connectivity | Fragmentation | A2A6A12B4C2E5-B11E6/HER-LHE/CHE+SCH | Anthropogenic activities | | Past, present and future pressure | EO data |
| Changes in spatial connectivity | Decrease in patch size | A1A3A10B2XXD1E1F1-B7/TRS-FPH/DEC | Anthropogenic activities | Anthropogenic pressures | Past, present and future pressure | EO data |
| Changes in spatial connectivity | Increased inter-patch distance | A1A3A10B2XXD1E1F1-B7/TRS-FPH/DEC | Anthropogenic activities | Anthropogenic pressures | Past, present and future pressure | EO data |
| Changes in spatial connectivity | Increased edge effects | A1A3A10B2XXD1E1F1-B7/TRS-FPH/DEC<br>A1A3A10B2XXD1E2F1-B5/TRS-FPH/DEC | Anthropogenic activities | Anthropogenic pressures | Past, present and future pressure | EO data |
| Disruption of plant and animal community structure | Change in species composition | Remains to be seen | Anthropogenic activities | Anthropogenic pressures | Past, present and future pressure | Expert/field |
| Disruption of plant and animal community structure | Change in dominance and evenness values | A1A4A11B3-A12B14/TRS-TPH/EVR+TRS- FPH/EVR<br>A2A6A12B4C3-B11/SHY/HEY+EHY/HEL | Anthropogenic activities | Anthropogenic pressures | Past, present and future pressure | Expert/field |

| | | | | | | |
|---|---|---|---|---|---|---|
| Fine spatial scale pressures with large spatial impacts | Roads (light traffic) | A1A4A13A14/URB-ART/NON<br>A1A4A13A16/URB-ART<br>A1A4A13A17/URB-ART | Anthropogenic activities | Anthropogenic pressures | Past, present and future pressure | EO data |

## 4.3 Welsh sites

**Table 9. Pressures in Welsh BIO_SOS sites**

| Broad Categories of observed change | Specific types of change | LCCS Cat. | LCCS/GHC categories where this is likely to be an issue | Proximate pressures | Underlying factors | Past, Present and/or Future pressure | Types of data needed for identification and/or quantification |
|---|---|---|---|---|---|---|---|
| Land cover/habitat conversion | Salt marshes to agriculture | A24 | A2.A6.A13.B4.C1_ B13.C5<br>HER/HEL<br>(saltmarsh) | Sheep grazing | Demand for grazing space | Past and present | Field/EO data |
| Land cover/habitat modification | Encroachment of Degraded Bog vegetation, e.g. Molinia | A12 | A2.A6.A10.B4.C1.E5_B12.E6<br>HER/CHE<br>Herbaceous grasslands (e.g. dominated by *Molinia caerulea)* | Encroachment of Molinia Grasses | Nitrogen deposition | Past and present | Expert/field/EO data |
| Land cover/habitat modification | Vegetation denuded, associated sand dune collapse | B16 | A6.B6<br>SPV/SAN<br>Shifting sand dunes | Touristic facilities, e.g. golf course and car park | Tourism and recreational development | Past, present and future | EO data and ancillary layers, e.g. urban fabric |
| Disruption/ modification of ecological regimes | Secondary or degraded bog to shrubs and woodland | A12 | A1.A3.A10.B2.C2.D1.E2.B5<br>URB/TRE or TRS/TPH/DEC or TRS/FPH/DEC<br>Broad-leaved trees<br><br>A1.A4.A11.B3.C2.D1.E2.B14<br>URB/TRE or TRS/MPH/DEC or TRS/TPH/DEC<br>Broad-leaved shrubs | Ecological succession | Changes in soil water | Present | Expert/field/EO data |
| Disruption/ modification of ecological regimes | Active bog to secondary bog | A24 | A1.A4.A20.B3.C1.D1.E1.F2.F4.F7.G4_C4<br>TRS /DCH/EVR or TRS/SCH/EVR or TRS/LPH/EVR or TRs/MPH/EVR or HER/EHY/HEL/SHY-FLO/LEA<br>(active bog) | Shrub encroachment<br>Seawater intrusion<br>Nitrogen deposition | Excavation of peat disturbs the structural integrity of the bog surface | Past | Field/EO data |
| Disruption/ modification of hydrological regime | Canalisation and diversion of rivers and streams | B28 | A1.B1.C2_A4<br>SPV/AQU<br>Shallow perennial rivers and streams (non-tidal) | Anthropogenic pressures | Land Drainage | Past | EO data |
| Changes in hydrological regime | Drying out of bog surface | B27or B28 | A1.B1.C1_A5<br>SPV/AQU<br>Stationary ponds | Mitigation measures by site wardens | Digging of drainage channels for peat excavation | Past and present | Expert /Field/EO data |

## 4.4 Portuguese sites

### Table 10. Pressures in PT1 site (Rios Sabor e Maçãs)

| Broad Categories of observed change | Specific types of change | LCCS/GHC categories where this is likely to be an issue | Proximate pressures | Underlying factors | Past, Present and/or Future pressure | Types of data needed for identification and/or quantification |
|---|---|---|---|---|---|---|
| Land cover/habitat conversion | All terrestrial classes to water | A12/ A1.A4.A11.B3.D1.E1.F1 (B8/B9/B10)/TRS – TPH/NLE<br>A12/A1.A4.A10.B3.D1.E1.F1 (B8/B9/B10)/TRS – TPH/EVR | Permanent flooding of main valley | Construction of hydroelectric dam | Future pressure | EO data |
| Land cover/habitat conversion | Agriculture to forest | A12/A2.A6.E6-A10B4E5F1-B12/ HER – LHE/CHE | Extensification of management | Agricultural policy and subsidies<br>Lower workload required | Past, Present and Future pressure | EO data |
| Land cover/habitat conversion | Agriculture to scrub | A12/A2.A6.E6-A10.B4.E5.F1-B12/ HER –CHE/THE<br>A12/ A1.A4.A11.B3.D1.E1.F1 (B8/B9/B10)/TRS – TPH/NLE | Abandonment and succession | Abandonment of rural activities | Past, Present and Future pressure | Expert/field/EO data |
| Land cover/habitat conversion | Annual crops to perennial crops | A11/ A3.A4.B2.C1.D1/ CUL - CRO | Extensification of management | Agricultural policy and subsidies<br>Market demand<br>Lower workload required | Past, Present and Future pressure | Expert/field/EO data |
| Land cover/habitat conversion | Scrub to perennial crops | A12/ A1.A4.A11.B3.D1.E1.F1 (B8/B9/B10)/TRS – TPH/NLE | Intensification of management | Agricultural policy and subsidies<br>Market demand | Past, Present and Future pressure | Expert/field/EO data |
| Land cover/habitat conversion | Scrub to forest | A12/ A1.A4.A11.B3.D1.E1.F1 (B8/B9/B10)/TRS – TPH/NLE | Intensification of management | Agricultural policy and subsidies<br>Market demands | Past, Present and Future pressure | Expert/EO data |
| Land cover/habitat conversion | Scrub to woodland | A12/ A1.A4.A11.B3.D1.E1.F1 (B8/B9/B10)/TRS – TPH/NLE | Extensification of management | Abandonment of rural activities | Past, Present and Future pressure | Expert/field/EO data |
| Land cover/habitat modification | Scrub encroachment as undergrowth ("matrix") in open forests | A12/A2.A6.E6-A10.B4.E5.F1-B12/ HER – CHE/THE | Extensification of management | Abandonment of rural activities | Past, Present and Future pressure | Field/EO data |
| Disruption/ modification of ecological regimes | Fire regime | A12/A1.A4.A10.B3.D1.E1.F1 (B8/B9/B10)/TRS – TPH/EVR<br>A12/A1.A3A11.B2.C1.D1.E1/TRS – FPH/EVR | Wildfires | Anthropogenic ignitions<br>Scrub and wood encroachment | Past, Present and Future pressure | EO data |

| **Broad Categories of observed change** | **Specific types of change** | **LCCS/GHC categories where this is likely to be an issue** | **Proximate pressures** | **Underlying factors** | **Past, Present and/or Future pressure** | **Types of data needed for identification and/or quantification** |
|---|---|---|---|---|---|---|
| Changes in spatial connectivity | Fragmentation (structural and functional) | A12/ A1.A4.A11.B3.D1.E1.F1 (B8/B9/B10)/TRS – TPH/NLE<br>A12/A1.A4.A10.B3.D1.E1.F1 (B8/B9/B10)/TRS – TPH/EVR | Flooding of main valley | Construction of hydroelectric dam | Future pressure | EO data |
| Changes in spatial connectivity | Fragmentation (structural and functional) | A12/A1.A4.A10.B3.D1.E1.F1 (B8/B9/B10)/TRS – TPH/EVR<br>A12/A1.A3A11.B2.C1.D1.E1/TRS – FPH/EVR | Wildfires | Anthropogenic ignitions<br>Scrub and wood encroachment | Past, Present and Future pressure | EO data |
| Changes in spatial connectivity | Landscape homogenization and increase of connectivity | A12/A1.A3A11.B2.C1.D1.E1/TRS – FPH/EVR<br>A12/A2.A6.E6-A10.B4.E5.F1-B12/ HER – CHE/THE | Wildfires<br>Extensification of management | Anthropogenic ignitions<br>Abandonment of rural activities | Past, Present and Future pressure | Field/EO data |
| Disruption of plant and animal community structure | Change in species composition<br>Change in dominance and evenness values | A12/A1.A3.A11.B2.C1.D1.E2/ TRS – FPH/DEC | Changes in management regimes<br>Fragmentation<br>Invasive species<br>Game and sport fishing | Agricultural policy and subsidies<br>Changes in land ownership<br>Infrastructure development | Past, Present and Future pressure | Field data |
| Fine spatial scale pressures with large spatial impacts | Roads | Most terrestrial categories | Construction of roads | Regional road connections | Present and Future pressure | EO data |
| Fine spatial scale pressures with large spatial impacts | Buildings | Most terrestrial categories | Localized urban development | Tourism and leisure | Present and Future pressure | EO data |

**Table 11. Pressures in PT2 site (Peneda-Gerês).**

| Broad Categories of observed change | Specific types of change | LCCS/GHC categories where this is likely to be an issue | Proximate pressures | Underlying factors | Past, Present and/or Future pressure | Types of data needed for identification and/or quantification |
|---|---|---|---|---|---|---|
| Land cover/habitat conversion | Several terrestrial classes to water | A12/A1.A3A10.B2C1D1E2/TRS – FPH/DEC | Permanent flooding of valleys | Construction of hydroelectric dams of various sizes | Past and Future pressure | EO data |
| Land cover/habitat conversion | Agriculture to forest | A12/A2.A6.E6-A10B4E5F1-B12/ HER – LHE/CHE | Extensification of management | Agricultural policy and subsidies<br>Lower workload required | Present and Future pressure | EO data |
| Land cover/habitat conversion | Agriculture to scrub | A12/A2.A6.E6-A10B4E5F1-B12/ HER – LHE/CHE | Abandonment and succession | Abandonment of rural activities | Past, Present and Future pressure | Expert/field/EO data |
| Land cover/habitat conversion | Annual crops to perennial grasslands and enclosed pastureland | A11/ A3.A4.B2.C1.D1/ CUL – CRO | Extensification of management | Agricultural policy and subsidies<br>Market demand<br>Lower workload required | Past, Present and Future pressure | Expert/field/EO data |
| Land cover/habitat conversion | Scrub to woodland | A12/ A1.A4.A11.B3D1E2-(B8; B9)/ TRS – MPH/EVR/NLE | Extensification of management | Abandonment of rural activities | Past, Present and Future pressure | Expert/field/EO data |
| Land cover/habitat conversion | Scrub to forest | A12/ A1.A4.A11.B3D1E2-(B8; B9)/ TRS – MPH/EVR/NLE | Intensification of management | Agricultural policy and subsidies<br>Market demands | Past, Present and Future pressure | Expert/field/EO data |
| Land cover/habitat conversion | Native scrub to patches of woody invaders | A12/A1.A4A10.B3D1E2F2F5F10G2-B8(B9)/TRS – TPH/EVR/NLE | Invasion by alien plants which become invasive | Changes in fire and management regimes | Past, Present and Future pressures | Expert/field/EO data |
| Land cover/habitat modification | Change in the structure and heterogeneity of grassland habitats | A12/A2.A6.E6-A10B4E5F1-B12/ HER – LHE/CHE | Intensification and enclosure of hay meadows | Specialization in enclosed cattle raising | Present and Future pressure | Field/EO data |
| Disruption/ modification of ecological regimes | Fire regime | A12/A1.A3A10.B2C1D1E2/TRS – FPH/DEC<br>A12/A1.A3A10.B2.D1E1/TRS – FPH/EVR | Wildfires | Anthropogenic ignitions<br>Scrub and wood encroachment | Past, Present and Future pressure | EO data |
| Disruption/ modification of ecological regimes | Changes in water and nutrient cycles | A12/A2.A6.E6-A10B4E5F1-B12/ HER – CHE<br>A12/ A1.A4.A11.B3D1E2-(B8; B9)/ TRS – | Changes in water and nutrient availability | Changes in fire and management regimes | Past, Present and Future pressure | Field/EO data |

| Broad Categories of observed change | Specific types of change | LCCS/GHC categories where this is likely to be an issue | Proximate pressures | Underlying factors | Past, Present and/or Future pressure | Types of data needed for identification and/or quantification |
|---|---|---|---|---|---|---|
| | | LPH/EVR | | | | |
| Changes in spatial connectivity | Fragmentation (structural and functional) | A12/A1.A3A10.B2C1D1E2/TRS – FPH/DEC | Flooding of main and secondary valleys | Construction of hydroelectric dams of various sizes | Past, Present and Future pressure | EO data |
| Changes in spatial connectivity | Fragmentation (structural and functional) | Several terrestrial categories | Barriers to dispersal and fauna activity | Construction of wind farms | Present and Future pressure | Field/EO data |
| Changes in spatial connectivity | Fragmentation (structural and functional) | A12/A1.A3A10.B2C1D1E2/TRS – FPH/DEC<br>A12/A1.A3A10.B2.D1E1/TRS – FPH/EVR | Wildfires | Anthropogenic ignitions<br>Scrub and wood encroachment | Past, Present and Future pressure | EO data |
| Changes in spatial connectivity | Landscape homogenization and increase of connectivity | A12/A2.A6.E6-A10B4E5F1-B12/ HER – LHE/CHE | Wildfires<br>Extensification of management | Anthropogenic ignitions<br>Abandonment of rural activities | Past, Present and Future pressure | Field/EO data |
| Disruption of plant and animal community structure | Change in species composition<br>Change in dominance and evenness values | A12/A2.A6.E6-A10B4E5F1-B12/ HER – LHE/CHE<br>A12/A1.A3A10.B2C1D1E2/TRS – FPH/DEC<br>A12/ A1.A4.A11.B3D1E2-(B8; B9)/ TRS – LPH/EVR | Changes in management regimes<br>Fragmentation<br>Invasive species<br>Game and sport fishing | Agricultural policy and subsidies<br>Changes in land ownership<br>Infrastructure development | Past, Present and Future pressure | Field data |
| Fine spatial scale pressures with large spatial impacts | Roads | Most terrestrial categories | Construction or improvement of roads | Local road connections | Present and Future pressure | EO data |
| Fine spatial scale pressures with large spatial impacts | Buildings | Most terrestrial categories | Localized urban development | Tourism and leisure<br>Modern facilities for cattle raising | Present and Future pressure | EO data |

## 4.5 Indian sites

### Table 12. Pressures in IN1 site (BRT).

| Broad Categories of observed change | Specific types of change | LCCS cat. | LCCS categories where this is likely to be an issue | LCCS Most likely final class | Proximate pressures | Underlying factors | Past, Present and/or Future pressure | Types of data needed for identification and/or quantification |
|---|---|---|---|---|---|---|---|---|

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Land cover/habitat conversion | Forests to Agriculture | A12 | A3A14B2XXD1E2F2F4F10G4-A15B7E3G11<br>A3A14B2XXD1E2F2F4F10G4-A15B7G11 | Farmland | Farm expansion | Encroachment | Mainly past | EO data |
| Land cover/habitat conversion | Forests to Plantation | A12 | A3A10B2XXD1E1F2F6F7G3F1-B5E4F9G9<br>A2B1XXC2D3D9-B4C3C7C17D6-S13W7 | Coffee plantation | Coffee Plantation expansion | Encroachment | Past, present and future | EO data/Field |
| Land cover/habitat modification | Change in tree density | A12<br>A12<br>A12 | A3A11B2XXD1E2F2F6F7G3F2F4F7G4-B7E3F9G9G11<br>A3A14B2XXD1E2F2F4F10G4-A15B7E3G11<br>A3A14B2XXD1E2F2F4F10G4-A15B7G11 | Does not apply | Grazing | Anthropogenic activities | Past, present and future pressure | Field/EO data |
| Land cover/habitat modification | Water pollution - Eutrophication | A2<br>A12<br>A12 | A2B1XXC2D3D9-B4C3C7C17D6-S13W7<br>A3A10B2XXD1E1F2F6F7G3F1-B5E4F9G9<br>A3A10B2XXD1E1F2F6F7G3F1-F9<br>*Riparian....... LCCS class undefined* | Does not apply | Agricultural runoff from coffee plantations | Plantation practices | Past, present and future pressure | Expert/field/EO data |
| Disruption/ modification of ecological regimes | Fire regime | A12<br><br><br>A11 | A3A10B2XXD1E1F2F6F7G3F1-B5E4F9G9<br>A3A11B2XXD1E2F2F6F7G3F2F4F7G4-B7E3F9G9G11<br>A3A14B2XXD1E2F2F4F10G4-A15B7E3G11<br>A3A14B2XXD1E2F2F4F10G4-A15B7G11<br>A3A11B2XXD1E2F2F6F7G3F2F4F7G4-A12B5E3F9G9F9G12<br>A2B1XXC2D3D9-B4C3C7C17D6-S13W7<br>A3A10B2XXD1E2F2F6F7G3F1-B6F9G9 | Does not apply | Anthropogenic fires | Tourism, Settlements within the park | Annual event, Past, Present and Future | EO data, Field data |
| Disruption/ modification of ecological regimes | Grazing pattern | A12 | A3A11B2XXD1E2F2F6F7G3F2F4F7G4-B7E3F9G9G11<br>A3A14B2XXD1E2F2F4F10G4-A15B7E3G11<br>A3A14B2XXD1E2F2F4F10G4-A15B7G11 | Does not apply | Grazing practices | Settlements mainly around and inside the park | Past, present and future pressure | Field data |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | A3A10B2XXD1E2F2F6F7G3F1-B6F9G9<br>A3A11B2XXD1E2F2F6F7G3F2F4F7G4-A12B5E3F9G9F9G12 | | | | | |
| Disruption/ modification of ecological regimes | Hunting-Fishing | A12 | A3A10B2XXD1E1F2F6F7G3F1-B5E4F9G9<br>A3A10B2XXD1E1F2F6F7G3F1-F9<br>A3A11B2XXD1E2F2F6F7G3F2F4F7G4-B7E3F9G9G11<br>A3A14B2XXD1E2F2F4F10G4-A15B7E3G11<br>A3A14B2XXD1E2F2F4F10G4-A15B7G11<br>A3A10B2C2D1E1F2F6F7G3-B5C5F9G9-P10<br>A6A10B4C2E5-B11C5E6-P10<br>A3A11B2XXD1E2F2F6F7G3F2F4F7G4-A12B5E3F9G9F9G12<br>A3A10B2XXD1E2F2F6F7G3F1-B6F9G9 | Does not apply | Poaching | Anthropogenic pressures | Past, present and future pressure | Expert/field |
| Disruption/ modification of ecological regimes | Tourism | A12<br>B15 | A3A10B2XXD1E1F2F6F7G3F1-B5E4F9G9<br>A3A10B2XXD1E1F2F6F7G3F1-F9<br>A3A14B2XXD1E2F2F4F10G4-A15B7E3G11<br>A3A14B2XXD1E2F2F4F10G4-A15B7G11<br>A4-A44 | Does not apply | Solid waste dumping | Anthropogenic pressures | Past, present and future | Field |
| Disruption/ modification of ecological regimes | Tourism | A11<br>B15<br>A11 | A4B2B5C1D1D9-S0306X2<br>A4-A44<br>A2B1XXC2D3D9-B4C3C7C17D6-S13W7 | A11 - Increase in farmland<br>B15<br>Built-up area of hotels, restaurants etc | Expansion of touristic facilities causing pressure on resources such as water | Anthropogenic pressures | Present and future pressure | Expert/field |
| Changes in spatial connectivity | Fragmentation | A12 | A3A11B2XXD1E2F2F6F7G3F2F4F7G4-B7E3F9G9G11<br>A3A14B2XXD1E2F2F4F10G4-A15B7E3G11<br>A3A14B2XXD1E2F2F4F10G4- | Does not apply | NTFP collection (eg grass and fuelwood) | Anthropogenic pressures | Past, present and future pressure | Field/EO data |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | A15B7G11<br>A3A10B2C2D1E1F2F6F7G3-B5C5F9G9-P10<br>A6A10B4C2E5-B11C5E6-P10<br>A3A11B2XXD1E2F2F6F7G3F2F4F7G4-A12B5E3F9G9F9G12<br>*Scrub Woodland thickets with Bamboo... LCCS class undefined* | | | | | |
| Changes in spatial connectivity | Increased edge effects | A12 | A3A11B2XXD1E2F2F6F7G3F2F4F7G4-B7E3F9G9G11<br>A3A14B2XXD1E2F2F4F10G4-A15B7E3G11<br>A3A10B2XXD1E1F2F6F7G3F1-B5E4F9G9<br>A3A10B2XXD1E1F2F6F7G3F1-F9<br>A3A14B2XXD1E2F2F4F10G4-A15B7G11<br>A3A11B2XXD1E2F2F6F7G3F2F4F7G4-A12B5E3F9G9F9G12<br>A3A10B2XXD1E2F2F6F7G3F1-B6F9G9 | Does not apply | Anthropogenic activities | Anthropogenic pressures | Past, present and future pressure | EO data |
| Disruption of plant and animal community structure | Change in species and community composition and structure | A12 | A3A10B2XXD1E1F2F6F7G3F1-B5E4F9G9<br>A3A10B2XXD1E1F2F6F7G3F1-F9<br>A3A10B2C2D1E1F2F6F7G3-B5C5F9G9-P10<br>A6A10B4C2E5-B11C5E6-P10 | Does not apply | Change in rainfall and temperature regimes | Climate change | Present and future pressure | Expert/field/ EO data |
| Disruption of plant and animal community structure | Change in species and community composition and structure | A12 | A3A10B2XXD1E1F2F6F7G3F1-B5E4F9G9<br>A3A10B2XXD1E1F2F6F7G3F1-F9<br>A3A10B2C2D1E1F2F6F7G3-B5C5F9G9-P10<br>A6A10B4C2E5-B11C5E6-P10<br>A3A11B2XXD1E2F2F6F7G3F2F4F7G4-B7E3F9G9G11<br>A3A14B2XXD1E2F2F4F10G4-A15B7E3G11<br>A3A14B2XXD1E2F2F4F10G4- | Does not apply | Invasive species | Anthropogenic activities or Climate change | Present and future pressure | Local knowledge/Field/ EO data |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | A15B7G11<br><br>A3A11B2XXD1E2F2F6F7G3F2F4F7 G4-A12B5E3F9G9F9G12<br><br>A1B1XXC1-B4-S1002W7<br><br>A2B1XXC2D3D9-B4C3C7C17D6-S13W7<br><br>A4B2B5C1D1D9-S0306X2<br><br>*Riparian - LCCS class undefined*<br><br>*Scrub Woodland thickets with Bamboo... LCCS class undefined* | | | | | |
| Disruption of plant and animal community structure | Change in dominance and evenness values | A12 | A3A10B2XXD1E1F2F6F7G3F1-B5E4F9G9<br><br>A3A10B2XXD1E1F2F6F7G3F1-F9<br><br>A3A11B2XXD1E2F2F6F7G3F2F4F7 G4-B7E3F9G9G11<br><br>A3A14B2XXD1E2F2F4F10G4-A15B7E3G11<br><br>A3A14B2XXD1E2F2F4F10G4-A15B7G11<br><br>A3A11B2XXD1E2F2F6F7G3F2F4F7 G4-A12B5E3F9G9F9G12<br><br>A3A10B2XXD1E2F2F6F7G3F1-B6F9G9<br><br>*Riparian - LCCS class undefined*<br><br>*Scrub Woodland thickets with Bamboo... LCCS class undefined* | Does not apply | NTFP Collection (eg. Phyllanthus,Lichen extraction, honey collection) | Anthropogenic pressures | Past, present and future pressure | Expert/field |
| Fine spatial scale pressures with large spatial impacts | Roads (light traffic) | | A3A10B2XXD1E1F2F6F7G3F1-B5E4F9G9<br><br>A3A10B2XXD1E1F2F6F7G3F1-F9<br><br>A3A11B2XXD1E2F2F6F7G3F2F4F7 G4-B7E3F9G9G11<br><br>A3A14B2XXD1E2F2F4F10G4-A15B7E3G11<br><br>A3A14B2XXD1E2F2F4F10G4-A15B7G11<br><br>A3A11B2XXD1E2F2F6F7G3F2F4F7 G4-A12B5E3F9G9F9G12<br><br>A3A10B2XXD1E2F2F6F7G3F1- | Does not apply | Anthropogenic activities | Anthropogenic pressures | Past, present and future pressure | EO data |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | B6F9G9<br>*Riparian – LCCS class undefined*<br>*Scrub Woodland thickets with Bamboo – LCCS class undefined* | | | | | |

## 4.6 Dutch site

### Table 13. Pressures in Dutch BIO_SOS site (NL1)

| Broad Categories of observed change | Specific types of change | Annex I | LCCS cat. | LCCS/GHC categories where this is likely to be an issue | Proximate pressures | Underlying factors | Past, Present and/or Future pressure | Types of data needed for identification and/or quantification |
|---|---|---|---|---|---|---|---|---|
| Land cover/habitat conversion | Broadleaved forest to recreation (Urban) | 9120, 9190 | A12 | A12/ A3.A10.B2.C1.D1.E2.F2.F6.F7.G3.F1-B5F9G8 | Urban & recreational pressure | Urban growth within the region. Especially city of Ede is expanding rapidly. Also the region is very attractive for tourism from everywhere, causing increase in tourism. | Past, Present and/or Future pressure. Pressure of growing population and tourism/recreation will continue to also due to aging population with more free time. | EO data |
| Land cover/habitat conversion | Coniferous forest to recreation (Urban) | - | A12 | A12 / A3.A10.B2.C1.D2.E1.F2.F6.F7.G3.F1-B5F9G8 | Urban & recreational pressure | Urban growth within the region. Especially city of Ede is expanding rapidly. Also the region is very attractive for tourism from everywhere, causing increase in tourism. | Past, Present and/or Future pressure. Pressure of growing population and tourism/recreation will continue to also due to aging population with more free time. | EO data |
| Land cover/habitat conversion | Arable land to recreation/industrial/construction sites/built-up (Urban) | - | A11 | A11 / (A3.)A4.B1.B5.C1.D1.D9-B4-S7, (A3.)A5.B1.B5.C1.D1.D9-B4-S4, (A3.)A5.B1.B5.C1.D1.D9-B4-S9, (A3.)A5.B1.B5.C1.D1.D9-B4-S3 | Urban & recreational pressure | Urban growth within the region. Especially city of Ede is expanding rapidly. Also the region is very attractive for tourism from everywhere, causing increase in tourism. | Past, Present and/or Future pressure. Pressure of growing population and tourism/recreation will continue to also due to aging population with more free time. | EO data |
| Land | Pastures to | - | A11 | A11 / | Urban & recreational | Urban growth within | Past, Present | EO data |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| cover/habitat conversion | recreation/industrial/construction sites/built-up (Urban) | | | (A3.)A4.B1.B5.C1D1.D9 | pressure | the region. Especially city of Ede is expanding rapidly. Also the region is very attractive for tourism from everywhere, causing increase in tourism. | and/or Future pressure. Pressure of growing population and tourism/recreation will continue to also due to aging population with more free time. | |
| Land cover/habitat conversion | Heathland to coniferous forest | 2310, 4030 | A12 | A12/ A4.A10.B3.C1.D1.E1.F1-B10 | Nitrogen deposition & changes land use management. Natural process of reforestation is being accelerated, and stimulates *tree encroachment* | Intensive agriculture in the surroundings are causing nitrogen deposition in natural areas. This stimulates tree encroachment. Abandonment grazing. Less nature management. Managed forest fires are not allowed anymore due to regulations | Past, Present and/or Future pressure. National and EU Legislation ask now to reduce N emissions. Emissions are reducing, which is a good, but N has already accumulated in natural areas causing encroachment problems. Current budget cuts nature management can increase natural encroachment | Field / EO data |
| Land cover/habitat conversion | Heathland to grassland | 2310, 4030 | A12 | A12/ A4.A10.B3.C1.D1.E1.F1-B10 | Nitrogen deposition. Heathland have to be nutrient-poor, but nitrogen deposition by intensive agriculture stimulates *grass encroachment.* | Intensive agriculture in the surroundings are causing nitrogen deposition in natural areas. This stimulates grass encroachment. Abandonment grazing. Less nature management. Managed forest fires are not allowed anymore due to regulations | Past, Present and/or Future pressure. National and EU Legislation ask now to reduce N emissions. Emissions are reducing, which is a good, but N has already accumulated in natural areas causing encroachment problems. Current budget cuts nature management can increase natural encroachment | Field / EO data |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Land cover/habitat conversion | Inland sand dunes to grassland | 2330 | B16, A12 | B16/A6 | Nitrogen deposition. Inland sand dunes have to be nutrient-poor, but nitrogen deposition by intensive agriculture stimulates *grass encroachment*. Dynamic process of drifting sands stops | Intensive agriculture in the surroundings are causing nitrogen deposition in natural areas. This stimulates grass encroachment. | Past, Present and/or Future pressure. National and EU Legislation ask now to reduce N emissions. Emissions are reducing, which is a good, but N has already accumulated in natural areas causing encroachment problems. Current budget cuts nature management can increase natural encroachment | Field / EO data |
| Land cover/habitat conversion | Inland sand dunes to mosses | 2330 | B16, A12 | B16/A6 | Nitrogen deposition. Inland sand dunes have to be nutrient-poor, but nitrogen deposition by intensive agriculture stimulates *moss encroachment*. Dynamic process of drifting sands stops | Intensive agriculture in the surroundings are causing nitrogen deposition in natural areas. This stimulates moss encroachment | Past, Present and/or Future pressure. National and EU Legislation ask now to reduce N emissions. Emissions are reducing, which is a good, but N has already accumulated in natural areas causing encroachment problems. Current budget cuts nature management can increase natural encroachment. | Field / EO data |
| Land cover/habitat conversion | Coniferous forest to heathland | - | A12 | A12 / A3.A10.B2.C1.D2.E1.F2.F6.F7.G3.F1-B5F9G8 | - Not a pressure, but due to nature management. | Nature management | Current/future | Field / EO data |
| Land cover/habitat conversion | Heathland to inland sand dunes | 2310, 4030 | A12 | A12/ A4.A10.B3.C1.D1.E1.F1-B10 | - Not a pressure, but due to nature management. | Nature management | Current/future | Field / EO data |
| Disruption / modification of ecological | Fresh water extraction for water | 6230? | B27, A12 | B27 / A1.B1C1.D1-A4 | Water extraction causes increase in drought / less | Population/land use management (e.g. construction polders | Past/current - in current and future situation | Expert / field / EO data |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| regimes | consumption | | | | seepage water and accelerates by changes in land use and climate. (Still much discussions about trends) | in the past had an influence on water regime ) | increasing soil moisture might also be problem for nutrient-poor habitats in the region. (Still much discussions about trends) | |
| Disruption / modification of ecological regimes | Pollution of surface water | | B27 | A1.B1C1.D1-A4 | | Agriculture | Past/current | Expert / field |
| Disruption / modification of ecological regimes | Soil disturbance | 2310, 4030 | | A12/ A4.A10.B3.C1.D1.E1.F1-B10 | Nature management tried to limit availability nutrients by sod cutting. New research of Alterra has indicated that destroyed soil profiles have a very negative impact on resilience of ecosystem. Especially in situations of heat stress. | Nature management has serious budget cuts (40%) at this moment | Past/current | Expert/field |
| Disruption / modification of ecological regimes | Forest Fires | 9120, 9190, 2310, 4030 | A12 | A12/ A3.A10.B2.C1.D1.E2.F2.F6.F7.G3.F1-B5F9G8, A3.A10.B2.C1.D2.E1.F2.F6.F7.G3.F1-B5F9G8, A4.A10.B3.C1.D1.E1.F1-B10 | Changes in climate and urban pressure | Population / Recreation. Most fires caused by humans | More problematic in future. However, managed forest fires can be a big advantage for heathland areas. But unfortunately, managed forest fires are not allowed anymore due to regulations (security) | Expert / field / EO data |
| Changes in species composition (flora) and structure | Changes in communities and structure | 2310, 2330, 4030, 6230, 9120, 9190 | A12 | A12 / A6.A10.B4.C1.XXXXF1-B12, A4.A10.B3.C1.D1.E1.F1-B10, A3.A10.B2.C1.D2.E1.F2.F6.F7.G3.F1-B5F9G8, A3.A10.B2.C1.D1.E2.F2.F6.F7.G3.F1-B5F9G8 | Nitrogen deposition and water extraction. Changes in land use management and climate. Invasive species of *Campylopus introflexus* causes moss encrachment | Changes in land use management | Past/current (in current and future situation | Expert / field / EO data |
| Disturbance population | Decreasing number of | | A12 | Most categories | Destruction habitat and loss of quality | Changes in land use management | Past/current (in current and future | Expert / field |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| dynamics (fauna) | species | | | | | | situation) | |
| Changes in spatial connectivity | Fragmentation | 2310, 4030, 9120, 9190? | A12 | Most categories | Construction new roads, artificial areas and fences | Increasing recreation / tourism and urban growth. | Past | Expert / field / EO data |
| Fine spatial scale pressures with large spatial impacts | New roads. Intensification of roads and bycicle and walking tracks. Also light pollution | 2310, 2330, 4030, 6230, 9120, 9190 | A12 | Most categories | Urban & recreational pressure | Increasing recreation / tourism | Past/current (in current and future situation) | Expert / field / EO data |
| Fine spatial scale pressures with large spatial impacts | New buildings | all | A12 | Most categories | Urban & recreational pressure | Population growth, tourism and agricultural activities | Past | Expert / field / EO data |

# 5. An operational contribution to the implementation of threat analysis

Literature surveys are described to see how EO data, GIS and modelling can be used to guide scenario development and analysis, with special reference to the types of pressures outlined in the BIO_SOS sites (see Section 3.6 to 3.11).

## 5.1 Land cover/habitat conversion

Change detection usually involves the analysis of two co-registered multi-spectral images acquired on the same geographical area at two different times. Such change detection can be very important to correlate with information on changes in species diversity, as for instance in assessments of deforestation rates in the UK, which have been related to changes in endemic bird diversity and distribution (Buchanan et al. 2008).

In literature, two different approaches for change detection are presented:

1. Direct comparison of the reflectance values of two multi-spectral images. Change Vector Analysis (CVA), Image Ratioing and Vegetation Index Differencing (Fung et. al 1990) are generally used. More recently, the comparison has been made between two images after their segmentation by traditional or advanced neural network (NN) clustering techniques (D'Addabbo et al., 2004). Classically, the analysis of a difference image is mainly based on histogram thresholding techniques by empirical strategies or trial-and-error procedures, but automatic techniques have been proposed in literature (Bruzzone et. al, 2000; Bovolo 2009). Change Vector Analysis (CVA) compares images (or image features) assuming that each pixel is a vector (each component of the vector being either a spectral band or a particular image feature as for instance spectral indices). The two dates are compared using a pixel-by-pixel vector difference. The resulting vector of differences gives information about the degree of change (magnitude of the vector) and also about the type of change (angle of the vector). However, the type of change may not have a straightforward interpretation in terms of semantic class transitions. In addition, relative radiometric calibration is needed before image comparison (Blonda et al. 2006).
   Due to cloud cover and system availability constraints, it may be difficult to obtain close similar dates, and as a consequence, the change detection approach may not be feasible using direct image-to-image comparison. Therefore several change detection strategies should be compared in Task 5.4.
2. Post-Classification Comparison (PCC) (Singh 1984; Congalton et al., 1994; Lu et al. 2004; Radke et al. 2005) which consists of performing the image classification for each date and then comparing the class labels for each pixel or region when classification is carried out. This gives information about the presence of change but also the specific class transition in terms of semantic label, such as forest land to barren land, barren land to agricultural area or to artificial structures, when a change has occurred. Relative calibration is not required since it is based on the result of independent classifications. The accuracy of the produced change image can be evaluated as the product of the overall accuracies relative to the two classified maps, since the maps are independently generated. As a consequence the final overall accuracy will always be lower than year-specific map accuracy values (Tarantino et al., 2007) and strongly dependent on the classification scheme adopted. When VHR imagery is used, beside thematic accuracy, spatial misregistration, fragmentation of the landscape, pixel size and grid origin (e.g. QuickBird, Worldview2 or IKONOS images), the different number of bands and their wavelengths (e.g. QuickBird and WorldView2) are additional factors that can introduce errors in change detection. The latter factors are very common when time series are needed and specific phenological constraints should be verified for LC/habitat class detection, as in the case of most BIO_SOS sites. Due to the lack of VHR image tasking of the same sensor (e.g. QuickBird) in the past, archive images from different sensors were only found and used for classification (e.g. classification of Le Cesine site in D5.2 and D5.3). As a consequence, although PCC approach to change detection is a well-known method, due to the underlined factors, its application to the overlay of final classification maps and/or intermediate output classification layers (e.g. comparison of vegetation strata only) from VHR imagery is still a matter of research.

In BIO_SOS, the PCC strategy to detect class transitions relies on two phases:

a) EODHaM-based generation of year-specific thematic maps and intermediate semantic layers (see D5.3), made from multi-temporal calibrated images. Outputs will be:
   - Thematic map images with crisp or fuzzy labels.
   - Thematic map confusion matrices, characterized by Overall Accuracy (OA) and error tolerance values
b) Comparison of thematic map pairs and or intermediate layers obtained at time $t_1$ and time $t_2$. Outputs will be:
   - Change images, characterized by their reliability value, as extracted from pairs of classified images at time $t_1$ and $t_2$.
   - Change matrices, extracted from pairs of thematic maps.
   - Class-transition probability estimates.
   - Temporal trends of class-specific occurrences

Due to the classification approach adopted in EODHaM system, with this being both object and expert knowledge based, object-based change detection will be investigated in preference to pixel-based change detection approach. Object-based approach to change detection is being explored increasingly in the literature (Chen et al. 2012) and reveals especially important when high spatial resolution images are used for change detection, as these provide more detail, but also make it likely that small areas of false change may be detected due to high spectral variability (Nagendra and Rocchini 2008, Wulder et al. 2008), as already explained above.

Within the EODHaM system, the baseline workflow defined currently uses 2 VHR satellite images, one in the pre-flush (i.e., early spring) and peak flush (i.e., mid to late summer) or just prior to and during the wet season (i.e., late dry and wet), cloud permitting.  Other images can also be acquired in transition periods, with these data often providing unique information for the discrimination of habitats and the plant communities/species contained. On this basis, the PCC approach can be applied in 2 different ways. The first would consist of comparing the 2 LCCS level 3 classifications of year N with those of year N+1 (e.g., spring with spring, summer with summer) and then analyzing the change in GHC and Annex 1 habitats, but only for the areas which have changed in terms of LCCS classes. The second approach is to compare the 2 final LC/LU (and /or habitat) classifications for each year but also measures (e.g., vegetation productivity, moisture content, amount of senescent materials) In order to monitor the test sites over a period of several years, the LC/LU and habitat maps need to be produced at regular intervals (e.g. annually).

Our preliminary suggestion is to investigate the 2 PCC approaches as well as the CVA applied on different sets of features (reflectances, spectral indices, etc.) and assess the advantages and disadvantages of each. The workflow could also be designed such that different approaches are combined in order to increase robustness.

The choice of the different approaches may depend on the relative date difference of the image acquisitions between the 2 years, but also in terms of data availability, as for instance the use of QuickBird imagery for one year and WorldView2 data for the other. Therefore, the BIO_SOS system is investigating the comparability of measures (e.g., photosynthetic fractions against vegetation indices), some of which require certain wavebands (e.g., the red edge) for derivation.

The detection of change will also depend on the processes that are occurring and the different rates. For example, in the Le Cesine Reserve, the *Cladium mariscus* communities (priority habitat 7210* according to the 92/43 EEC Directive) are particularly prone to wildfires spreading from the adjacent agricultural areas and from deliberate fires, such as those that occurred in 2007. Marine erosion has caused a progressive reduction of the sandbank separating the coastal lagoons from the sea. There has also been a progressive increase of the salinity of the lagoon water, with a corresponding spread of halophytic communities.

Once validated, the detected changes will be combined with other ancillary and in-field analyses through landscape modelling to produce early warning signals.

A specific deliverable, i.e. D5.6 due at the end of month 26, will provide a more detailed review on change detection techniques and description of the research work advancements in BIO_SOS.

## 5.2 Land cover degradation and habitat modification

Assessing the more cryptic and subtle process of habitat degradation is much more challenging than habitat mapping, often involving sub-canopy changes in biomass and/or structure that are difficult to detect (Ingram et al., 2005; Joseph et al., 2011). Yet, habitat modification and degradation tend to be much more widespread, even in seemingly intact landscapes. Therefore, the development of methods to map and monitor changes through habitat degradation are critical for adaptively managing protected areas. Despite widespread acknowledgement of this need, technological limitations of traditional medium to low-spatial resolution satellite imagery have hindered their use for the study of land degradation and habitat modification. In order to accurately identify and map fine scale, spectrally subtle changes in land surface that correspond to habitat degradation, such as changes in tree density, grass cover and bare soil, multi-temporal hyper-spatial and hyper-spectral imagery is required while LiDAR remote sensing can be very important for the tracking of three dimensional changes in forest structure (van Aardt et al. 2011).
Based on an examination of literature on remote sensing for conservation monitoring, there appear to be four commonly used approaches for the study of land cover degradation and habitat modification.

**Spectral Mixture Analysis**: Souza et al. (2003) used spectral mixture analysis (SMA) on a multi-spectral SPOT-4 scene to differentiate four categories of forest in the eastern Amazon: intact forest (mature undisturbed forest dominated by shade tolerant species); logged forest (moderately logged within a year, or heavily logged within the past 5 years with extensive damage), degraded forest (recently burned, heavily burned or heavily logged forests) and regenerating forest (regenerating areas which were once burned or heavily burned). Forest and non-forest pixels were first separated using unsupervised classification. Pure endmembers of shade, soil, green vegetation and non-photosynthetic vegetation (NPV) were defined and spectral mixture analysis used to estimate the proportion of sub-pixel cover for each end member within in each pixel. Ground truth data were collected for these four categories of forest, and the authors used exploratory data analysis procedures including box plots, scatter matrices and ternary diagrams to evaluate the scope of using these end member fractional images for separation of different categories of degradation. A hierarchical binary decision tree was then used to separate different classes using the fractional images, based on the proportion of green vegetation, NPV and shade (forest classes did not have any appreciable bare soil cover in this instance). A relatively high overall accuracy of 86 % was achieved using this approach, which is quite high considering the relatively moderate spatial (20 m pixel) and spectral (4 band) resolution of SPOT 4 imagery. The authors conclude that while this approach has been quite successful, the thresholds used to separate different degradation categories in the decision tree classifier are bound to be site specific. Further, they find that contrary to other studies that have relied on the percentage of bare soil to separate degraded forest classes, in this study area, the NPV endmember was the most critical to separate different types of degraded forest classes. Yet, they note significant challenges with identifying pure pixels for this category, because of its fragmented distribution as well as its similarity with bare soil. Results from an analysis by Asner et al. (2004), also in the eastern Amazon corroborate this, finding that sub-pixel fractions of photosynthetic and non-photosynthetic vegetation as well as bare soil derived from Landsat TM data can reliably map tree gaps caused by selective logging, and that this approach is much superior to previous attempts at mapping tree fall using spectral information or texture data.

Xian et al. (2012) have similarly used moderate resolution Landsat images to monitor changes in sagebrush ecosystems in South Western Wyoming, USA. Five components of sagebrush habitat were identified – bare ground, herbaceous, litter, sagebrush and shrub –and their spatial distribution estimated using field vegetation measurements coupled to high resolution Quickbird imagery in selected ground truth areas. Quickbird images were then rescaled to the resolution of Landsat imagery, and the proportion of each of the five sub-components within each pixel estimated using a regression tree algorithm. Landsat images of different dates were then processed using an image normalization algorithm, and the regression models developed were coupled with a change vector analysis to estimate

changes in percentage cover of all five components of sagebrush habitat between 1988 and 1996, using 2006 data as a baseline. The authors conclude that this approach can be very useful to accurately identify changes in density and area of cover of various sub-habitat components of sagebrush, which can be related to other time series data such as changes in wildlife populations to understand how habitat degradation can influence biodiversity. Such information can be very important for protected area managers. Similarly, in another recent study Van Aardt et al. (2011) have successfully used hyperspectral data collected using the Carnegie Airborne Observatory to map the fractional representation of bare soil, woody cover and grass across the Kruger National Park and its surrounding land uses. This approach of sub-pixel analysis and fractional cover mapping is being considered within BIO_SOS.

**Direct association with spectral bands and indices** -
Ingram et al. (2005) used information from Landsat ETM+ in conjunction with field measurements to predict tree basal area in tropical littoral forests in Madagascar, with the aim of associating this with human disturbance. Field data on basal area were significantly and strongly related to radiance values in bands 3, 4, 5 and 7 of Landsat ETM+, but not related to the NDVI. In contrast, stand density was only weakly and non-insignificantly related to spectral variables, but significantly correlated to stem density in a subset of the data representing extreme values. An Artificial Neural Network was used to predict basal area from the radiance values of bands 3, 4, 5 and 7 and found to be strongly related with field assessments of basal area (r=0.82).
Lu et al. (2002), using Landsat TM data, found that even though structural and textural signature are complementary to predict biomass, nevertheless biomass, and hence the relative predictive capabilities of these features, depends on vegetation growth rate and structural complexity - which in turn depend on a number of site variables (climate conditions, soil type and moisture content, and land use history - including silviculture and other kind of logging activities).
Palace et al. (2008) developed a novel automated tree crown analysis algorithm using 1-m panchromatic IKONOS satellite images, which allowed the analysis of varied crown shapes, sizes, and spacing inherent in old growth tropical forests. Despite the site-specificity of their approach, mostly owing to complexity of tropical forest structure and the inability to view understory trees in IKONOS images, the authors suggest that this technique might be useful for assessments over other areas of tropical forests where surveys are not possible.
The BIOASSESS project (Koch and Ivits 2003) has investigated the relationships between remote sensing and terrestrial derived biodiversity indicators. Remote sensing indicators (consisting of a range of features, focal, texture and spectral, as well as of a few patch level indices computed from classified images) were obtained from Landsat ETM and IRS-1D images processed by means of an adaptive fusion filter to aid object oriented classification, by enhancing the edges from the panchromatic higher resolution image, without transferring spectral information to the lower resolution image. Terrestrial biodiversity indicators consisted of species richness data on woody plants, birds and carabids. The results support the use of an object oriented approach to classification, and suggest that such an approach also has the potential to predict species diversity, particularly when applied to detailed landscape classifications. The study also finds that some taxa (e.g. birds) are more sensitive to the spatial resolution of grey value derivatives.
St-Louis et al. (2006) used image texture (14 first- and second-order texture measures in eight different window sizes) obtained from digital ortho-photographs as a predictor of bird species richness in a semi-arid landscape of New Mexico, by means of linear regression models. By combining multiple measures of texture or texture measures with other environmental attributes (e.g. elevation, coarse habitat type) they were able to increase the percentage of the variability in bird species richness explained by the model. This study thus confirms that image texture analysis has several advantages when compared to method based on image classification, and emerges as a very promising tool for characterizing habitat structure and predicting patterns of species richness in semi-arid ecosystems.
Costanza et al. (2011) investigated the relations between landscape heterogeneity, measured by means of a range of indicators of both abiotic environmental variables, productivity (NDVI) and land cover variables at four different scales, and local plant species richness. Their results highlight that different processes, described by the three classes of variables and which occur across different scales, are differently related to species richness.

In a hot desert in New Mexico, Muldavin et al. (2001) also used satellite reflectance values from Landsat TM data to develop regression models to predict the percentage of different groundcover components – perennial grass, shrub, litter and exposed soil. These values were used to develop a grassland biodiversity index, which increases as the percentage of perennial grass and litter goes up, and decreases as the percentage of shrub and exposed soil increases. This simple analysis was able to accurately identify grasslands with limited degradation and high conservation value, and can be used for monitoring. Their results suggested that traditionally used indices of vegetation, including the Normalised Difference Vegetation Index (NDVI) and tasselled-cap greenness, may be less useful in arid regions due to the increased component of senescent vegetation in such areas.

Vegetation indices derived from coarse spatial scale data, such as MODIS, but at fine temporal resolutions have also been used with success to map habitat degradation. In a semi-arid ecosystem in South Africa, Thompson et al. (2009) used a 19 month MODIS dataset with the maximum NDVI calculated for each pixel for a 16 day period, to capture various aspects of degradation – increased plant production in the growing season and decreased production in at the end of the dry season in degraded sites relative to intact sites, increased overall seasonal variability in plant production in degraded sites, and decreased variability in plant productivity in the spring in degraded sites, achieving a very high accuracy level of 86 %.

Hyperspectral imagery has also been used widely to assess habitat degradation, perhaps most commonly through assessments of habitat stress based on parameters such as nutrient deficiency (Joseph et al., 2011). Hyperspectral bands can enable the assessment of changes in chemical and structural traits including alterations in the level of chlorophyll, nitrogen, phosphorus and other foliage compounds, that can be linked with variations in enabling environmental factors such as soil quality (Townsend et al, 2008).

**Continuous assessments of change in landscape spatial pattern -**

Seixas (2000) used an index of local spatial autocorrelation, the g statistic, to compute local spatial autocorrelation across a landscape undergoing desertification in Portugal. The statistic was computed on a Landsat TM band4/band 3 ratio image, using a 3x3 pixel moving window. Over time, a clear pattern was observed – areas with increasing local variance expanded, while areas with decreasing local variance shrunk, indicating adverse environmental conditions of increasing drought, which have led to vegetation responses in terms of increased scrubby biomass. Pearson (2002) also used local spatial autocorrelation to identify changes in the fine scale distribution of tussocks and small patches of grass close to the ground, within areas that were classified as homogeneous "bare ground"., which is particularly important for species of granivorous birds. Kuemmerle et al. (2008) used measures of texture computed from Landsat TM bands, to distinguish farmland areas that were undergoing parcelization and fragmentation in Eastern Europe following the breakdown of the socialist regime.

**Active remote sensing including LiDAR** -

In contrast to passive remote sensing, active remote sensing such as LiDAR, with its ability to penetrate below the top vegetation canopy, can be very useful for monitoring habitat degradation, particularly where woody or tall herbaceous vegetation occurs. Lefsky et al. (1999) found that relationships between vertical distribution of canopy structure and stand basal area above ground biomass derived from field measurements could be related to canopy height profiles measured using SLICER scanning LiDAR system. This work encouraged a range of applications of LiDAR techniques to forestry (e.g., Lesky et al 2002, 2005, Koetz et al., 2006, Reitberger et al., 2008). More recently, in Pirotti (2011) the methods that have been used successfully for extracting key forest information from full-waveform (FW) LiDAR data. After describing FW characteristics and common pre-processing steps, he discusses tree-scale and plot-scale methods. This work highlights the potential of LiDAR for a number of applications related to forestry, which can be of interest for the assessment of changes in habitat internal conditions, in connection with human pressures including silviculture, and unplanned or illegal logging practices. As an example, pulse geolocation appears especially important for predicting single-tree metrics, while FW footprint size allows sampling of relatively large areas, thus increasing the probability of calculating accurate canopy height models. However, from this review it also appears that the application context (e.g., leaf-on vs. leaf off, plot vs. regional scale) might condition the applicability of certain models for the

evaluation of key characteristics (e.g. tree height distribution, crown diameter and relative structural tree parameters), and must be assessed before planning any such survey.
Graf et al. (2009) used LiDAR imagery to derive information on the horizontal and vertical stand structure in a forest reserve in central Europe, mapping habitat suitability for an endangered forest grouse species. Continuous metrics of horizontal and vertical strand structure were derived from LiDAR, and related with presence-absence data on grouse from the field using generalized linear models. Horizontal structure proved to be a better predictor of grouse habitat suitability than vertical structure. Waser et al. (2008) used a combination of tree mapping from very high spatial resolution airborne imagery and digital surface modelling from LiDAR data to create maps of fractional tree cover in a non-wooded mire habitat, to serve as an early warning signal of tree and shrub encroachment. Hyde et al. (2006) used a combination of LiDAR, SAR, Landsat and QuickBird to map wildlife habitat quality in the Sierra National Forest (Sierra Nevada, California), finding that the combination of LiDAR and ETM provided the best results, while incorporating QuickBird and InSAR/SAR resulted in marginal improvement. LiDAR was especially useful in estimating canopy height and biomass, two important indicators of habitat suitability in this ecosystem. Kuplich (2006) used a combination of Landsat and SAR to differentiate between Amazonian forest patches in different stages of regrowth. She found that the discrimination ability of SAR imagery could be limited, but this improved substantially when TM data was integrated. SAR data can also be used to indicate disturbance and deforestation patterns. Lucas et al. (2008) also established the use of ALOS PALSAR data in conjunction with Landsat-derived Foliage Projected Cover (FPC) for detecting dead standing trees and patterns of clearing in Queensland, Australia. Thus, it appears that the ability of active remote sensing data, especially LiDAR, can be very useful to map changes in the three-dimensional structure of vegetation. This can in turn be related to ecosystem simplification as a consequence of human disturbance through direct pressures such as logging or grazing. Whilst LiDAR and SAR requires considerable direct input from remote sensing analysts for accurate processing, techniques are advancing rapidly and the use of these data is encouraged.
An approach considered within BIO_SOS for the detection of change focuses on the use of the LCCS and GHC categories mapped using EO data. In particular, the LCCS categories are mapped by combining separate classifications of, for example, surface aspect, physical status and lifeform. As an example, forests are described on the basis of height, cover, leaf type and phenology whilst water is described by its flow (standing or flowing), sediment amounts, depth and salinity. Hence, changes in each of these components lead to an overall change in the LCCS category. Similar changes can be tracked using the GHC categories. In fact, both systems have been developed such that change can be detected. The advantage of the BIO_SOS approach is that many of these contributory layers are generated through consideration of indices or endmember fractions relating to, for example, the amount of green or dead/senescent vegetation and moisture content. Hence, changes in these 'biophysical' surrogates can similarly be used to establish the magnitude of change within a habitat, whether this leads to degradation, loss or regeneration or a transition to a different habitat. This approach to change detection is being evaluated as part of D5.6.

## 5.3 Disruption/modification of ecological regimes

### 1. Fire

Fire is an important driver of vegetation dynamics in many landscapes (Neary et al., 1999, Hudak et al., 2004). A number of different remote sensing datasets, ranging from coarse scale 1 km AVHRR and MODIS data to VHR images, have been employed to map fires (Kerr and Ostrovsky, 2003). Overall, the time of image acquisition appears to be more critical for fire studies than the spatial or spectral scale of imagery. MODIS has been widely used at regional scales for automated mapping of fires although the pixel size of 250-500 m renders these data less suitable for local scale studies but useful for longer term strategic regional planning (Lentile et al., 2006). Fire data derived from these sensors can, however, be used to provide a long-term view of fire dynamics, persistence and return periods and frequencies for landscapes which can be important when considering habitat degradation and recovery and impacts on flora and fauna. Ideally, such data should also be combined with those obtained with higher spatial resolution data which are acquired at lower frequency but can give information on burn scars.

Higher spatial resolution datasets offer greater utility for fire mapping. Using a national fire map derived from Landsat 5 TM images, Nunes et al. (2005) investigated the distribution of wildfires in a study area in Portugal, finding that fire tends to burn scrublands in preference to forest areas, and avoids agricultural areas, thus impacting the relative distribution of different land cover types. Siegert et al. (2001) used NOAA-AVHRR data to map the distribution of fire in East Kalimantan island in Borneo, but found this inadequate for assessment of the extent of fire impact. Change detection from images acquired using a high resolution (25 m) microwave SAR on board the ERS-2 satellite was used to penetrate haze due to fires, and cloud cover, and to map patterns of fire damage in forests in Indonesia, relating these to management. This analysis found a substantial increase in the intensity and scale of fire in this region compared to previous fires, and established a positive feedback between logging and susceptibility to fire, leading to an increased hazard of recurrent fires due to an altered fire regime.

**2. Changes in vegetational functional dynamics**

Changes in the spatial and temporal patterns of vegetation functioning can also be used to support the detection of habitat modification and landscape change. Thus, vegetation functional dynamics provides another very significant indicator for monitoring pressure in parks (Garbulsky and Paruelo, 2004). In the National Park network of Spain, NDVI derived from NOAA/AVHRR was used to assess changes between 1982 and 2006, tracking variations in the levels of overall photosynthetic activity and finding that the dates of maximum and minimum radiation interception have advanced, in addition to increased contrast between growing and non-growing seasons (Alcaraz-Segura et al. 2009). These trends can be linked to impacts on community and species population distributions, in particular with the advancement of the phenological cycle being known to impact the life cycle of migratory birds and insects.

Even if the coarse spatial resolution (typical of the high temporal resolution sensors required for detailed phenological studies) is not compatible with a local scale monitoring of individual habitat patches, these products may provide early warning of regional scale ecological change and support decision on the allocation of further resources for spatially more detailed assessments.

**3. Grazing**

Blanco et al. (2009) used Landsat TM to compare the impacts of continuous grazing against a rest-rotational system of grazing in a rangeland in Argentina. In Amazonia, the time-series classifications of Landsat sensor data enabled the reconstruction of fire and land-use history (Prates-Clark et al., 2009), with these collectively dictating the pathways of tropical forest regeneration and the capacity of these forests to recover biodiversity. Studies in Wales (Breyer, 2009) have suggested that the red edge wavebands are most sensitive to grass biomass and hence grazing levels and the availability of this waveband on several sensors (e.g., Worldview) may provide an opportunity for detecting grazing cycles and potential pressures.

**4. Sudden large scale disturbances**

For some kinds of disturbances that have an extremely short and focused temporal span, such as wildfires, cyclones or flash floods, high temporal resolution is required so that before and after studies of habitat distribution and condition can be conducted as close to the event as possible, for maximum information. Within the Wales BIO_SOS site, for instance, extensive flash flooding occurred in May, 2012, which led to considerable damage of property but also led to a large flush through the active bog. The impacts of such changes are being investigated by comparing July Worldview imagery acquired in 2011 and 2012, with the latter showing increased wetness in many areas surrounding the active raised bog as well as changes in the productivity of marginal habitats.

**5. Anticipating early stress signs**

Most of the studies discussed above deal with direct recognition of the present (at the moment of the survey) status of the landscape and habitat, and cannot alone recognize developing pressure before they are already showing their effects. In some cases it is possible to anticipate the

appearance of stress signs before they show their effects. These cases are relative to water availability as modified by runoff harvesting, soil erosion and sedimentation. Here, the techniques of image analysis must be coupled with specific software to transform land use changes into runoff/sediment distribution changes. The use of modelled estimates of water flow is, however, encouraged as part of the BIO_SOS system.

The probability that a given runoff/sediment amount produced at a given location can reach a downslope area that can be positively or negatively affected by, is called sediment/runoff connectivity. Connectivity describes the internal links between runoff and sediment sources in basin's upper parts and the corresponding sinks (Croke et al., 2005). The connectivity is direct when it occurs via channels or gullies, included newly formed gullies. It is diffuse when surface runoff reaches the stream network via overland flow (un-channelled) pathways.

Runoff and sediment production, transport and delivery to river channels downstream depends primarily on the overall catchment physiography, but also the spatial organization and the internal connectivity of various physiographic units can change it substantially (Hooke, 2003). Flow connectivity in a given catchment changes with 1) size and position in the catchment of whatever can impede water and sediment flow (e.g. wooded strips) and 2) with the processes that occur within the basin (Fryirs et al., 2007; De Vente and Poesen, 2005; Borselli et al., 2008).

Land use and management changes, both inside and around protected areas, can easily change flow connectivity. These effects are marginal if the protected areas are large, not interrupted and fragmented by human artefacts. Most of the European landscapes are strongly anthropic, dissected by villages and cultivated fields, while roads often cut them with a dense net. Besides, small reservoirs are often built to collect surface runoff.

Only a few events can connect large part of the slopes to the higher order streams or the local sinks. Decreasing the rainfall magnitude usually decreases the connectivity between areas, until the magnitude is so low that connection pathways are absent and sources reduced to a minimum. Interactions between climate change, habitat response and runoff/erosion processes complicate the issue opening to many feedbacks (e.g., changes in soil erodibility; Salvador et al., 2009, Borselli et al., 2012). Hence event magnitudes and a mixture of physically and biologically controlled thresholds have to be overcome to connect runoff generating areas to lower channel areas (Puigdefabregas et al., 1999; Cammeraat, 2002; Croke et al., 2005).

As a consequence of the issues discussed above, changes (e.g., of climate and land use) may divert water and sediment with changes of location where soil is eroded, sediment deposited and runoff harvested. Models, possibly more simple to handle than the classical runoff-erosion formulations, can help associating possible changes in surface water and sediment connectivity and in potential runoff and sediment harvesting locations to the detected land use and habitat changes.

## 5.4 Changes in spatial connectivity

As described in D6.2, direct human pressure on landscapes can manifest itself through quantifiable impacts on landscape pattern and landscape configuration (structure and composition). In addition, as the links between indicator species, biodiversity and critical ecosystem processes are not well established structure-based indicators (at both forest stand/plot level and landscape level) can provide a more viable alternative (Lindermayer et al., 2000a). For these reasons, substantial research effort has been devoted by landscape ecologists to the quantification of changes in landscape pattern by means of Landscape Pattern Analysis (LPA) techniques. In general, these can be divided into two basic groups of approach to the assessment of fragmentation/connectivity. Structural groups are where fragmentation and connectivity are measured entirely based on the spatial configuration of the landscape with no direct link to the behavioral attributes of any species. Functional groups are where connectivity measures consider the species' behavior to individual landscape elements alongside the structure of the landscape (Kindlmann and Burel 2008). In particular, structural connectivity measures are derived from physical attributes of landscape elements, such as size, shape and distances between habitat patches, whereas

functional connectivity measures combine these landscape structural attributes with information about dispersal ability, such as mean recapture distances from mark-recapture studies (Clark et al. 2001), and, explicitly take into account a heterogeneous landscape matrix (Petit and Burel, 1998, Lindenmayer et al 2000 a, b; Adriaensen et al., 2003; Ray, 2005), to quantify how connected a given landscape is for a given species. These approaches are complementary and can be used in conjunction with field data whenavailable.

Structural measures, as those derived from LPA, are meant to quantify tangible, topologically relevant landscape features. They are therefore better suited for the assessment of fragmentation (both at the habitat and landscape level) and for the quantitative evaluation of the spatial components of connectivity (connectedness). In particular, their use is indicated when assessing fast changes in landscape pattern over time as a response to pressures (e.g., anthropogenic driven change); especially those detectable by means of EO techniques at the most appropriate space and time scales – the purpose of this deliverable.

However, structural measures of fragmentation and connectivity can be supplementary to, but should not be used in place of landscape connectivity ones (i.e. functional) (Taylor et al. 2006 and literature cited). Attempts to combine structural measures, such as those derived by morphological spatial pattern analysis (MSPA, Vogt and Soille 2007), and connectivity indices originally devised for functional analysis, such as those derived by network analysis (Pascual Hortal and Suaura 2006, Saura et al., 2011) also recognize that such an approach can only return information on structural connectivity. Instead, functional (i.e. process related) inferences can be drawn when LPA is applied (e.g. for the derivation of independent variables) in connection to proxies of organisms' behavior (e.g. Jonsen and Taylor, 2000 a, b), in order to evaluate to what extent a land cover/land use change might affect landscape processes. A more advanced perspective in the use of structural measures of spatial variables which mediate biotic and abiotic mechanisms to understand the response of ecological systems (from species to ecosystems) to landscape and habitat pattern is proposed by Didham et al. (2011). This aims to use hierarchical causal models for the quantitative partitioning of direct vs. indirect effects of spatial variables, which are to be assessed empirically on a case-by-case basis. This approach is being considered within BIO_SOS. Functional measures, as also shown in recent comparative studies (Calabrese and Fagan 2004 and Kindlmann and Burel 2008), considering these more appropriate to generate information on process related landscape properties (e.g. connectivity), and thus recommending their use as guides in designing strategic conservation plans. However, as maintained by Saura et al. (2011) managers find it difficult to deal with the complexities brought about by a functionally oriented approach and thus, rather than not considering connectivity issues at all might be more willing to rely on more simplified approaches focused on structural connectivity, such as they suggest.

Both landscape connectivity and habitat amount and quality in the landscape affect species persistence (by affecting reproduction success and mortality). Thus, a conservation focus limited to connectivity alone is not sufficient (Stith et al. 1996, Keitt et al. 1997). Further, landscape fragmentation, through the disruption of habitat connectivity and the decrease in habitat quality, can impact species dispersion and habitat colonization, gene flows and population diversity, and species mortality and reproduction. For this reason, of the 22 biodiversity headline indicators internationally accepted (Strand et al., 2006) and adopted at an European level by the Streamlining European 2010 Biodiversity Indicators (SEBI 2010), observation data relevant to the structure of landscapes containing habitats of concern have been identified as critical for monitoring.

Thus, quantitative analyses of changes in landscape structure have been used to provide early warnings of habitat degradation. For instance, effective mesh size, which describes the probability that any two habitat patches are connected in a landscape, was used to compare the relative impacts of different types of land use disturbance such as roads and agriculture in California (Girvetz et al., 2008). A similar approach was also found to be useful to monitor anthropogenic and natural disturbance in the Swiss Monitoring System of Sustainable Development (Jaeger et al., 2008). Riitters et al. (2009 a) developed an additional indicator of landscape composition, the "landscape mosaic", which described the composition of the landscape locally adjacent to each pixel in terms of the amount of anthropogenically modified habitat and intensive development. They further used this to assess dominant drivers of disturbance and to identify vulnerable locations in the United States (Riitters et al. 2009 b), finding that

most of the natural grassland and forest habitat is not substantially threatened by habitat patch isolation, but does face pressure due to edge effects. Both of these approaches have been considered in BIO_SOS.

Nagendra et al. (2010) used Landsat TM and ETM+ imagery to assess fragmentation outside the Tadoba-Andhari Tiger Reserve in central India, finding a clear signal of forest fragmentation and deforestation at the periphery because of human pressure through activities such as bamboo and firewood extraction and grazing. Pôças et al. (2011) similarly applied landscape pattern analysis to a land cover time series derived from Landsat imagery, detecting an alarming trend in pressure leading to increased landscape fragmentation in high nature value mountain farmland on northern Portugal. In the Biological Dynamics of Forest Fragments Project (BDFFP; Laurance et al., 2011) in Amazonas State, Brazil, fragments of forest which were isolated during clearance operations were monitored using time-series of Landsat sensor data, and it was found that these rapidly became surrounded by secondary forests (Prates-Clarke et al., 2009). These regrowth forests facilitated movement of fauna and flora by providing connections between the fragments and the larger extent of undisturbed forests. Satellite sensor data can be used to better understand the impacts of the surrounding and changing landscape on their longer term role of forest fragments (e.g. Vogt et al., 2007). These data can also be used to identify events or processes that may be occurring before it is too late or expensive to undertake remediation measures. Thus it is clear that, even though EO techniques show an increasing potential to provide indirect measures on ecosystem functioning, such as those based on climate, topography, primary productivity, disturbance (Duro et al., 2007; Nagendra et al., 2012), baseline information on landscape configuration, in connection to information on landscape mosaic and habitat composition, is crucial for effective monitoring.

## 5.5 Disruption of animal and plant community structure

Pressures that cause disruptions in animal and plant community structure are much more cryptic and thus difficult to determine using EO data. So far, the greatest successes have been focused on the determination of invasive species (He et al. 2011). Sánchez-Azofeifa et al. (2011) used QuickBird imagery to map the distribution of a Tabebuia tree species in the Barro Colorado Island in Panama, relying on images covering a short 2-day span of synchronized flowering. They successfully detected flowering trees, but missed a large proportion of trees not flowering at the time of image acquisition. Although this species was not an invasive, the authors conclude that this type of approach can be adapted to identify the location of individuals of invasive species when they are flowering. Everitt et al. (2005) utilized QuickBird to map the distribution of invasive giant reed populations along the Rio Grande in Texas. This species was particularly easy to distinguish due to its characteristic association in large clumps, and they achieved very high accuracies of 86-100 %. Hall et al. (2011) employed QuickBird with success to derive relationships with fine-scale plant species diversity in a semi-natural grassland in Sweden, finding that species richness and species turnover were significantly associated with the NDVI, interestingly demonstrating a non-linear, U-shaped relationship. Of all image-derived variables, the spectral heterogeneity in the near-infrared band had the greatest explanatory power in this field context.

In a contrasting unsuccessful study, showing that very high spatial resolution imagery is not capable of successful detection of invasives across all locations, Fuller (2005) attempted to map *Melaleuca quinquenervia*, an invasive tree species in southern Florida, concluding that IKONOS imagery was unsuitable because of the very small pixel sizes, increasing the variability between different tree canopies and making it hard to identify the tree crowns of the species under study. Gillespie et al. (2008) reviewed a number of other studies that utilize VHR data to map specific tree species within temperate and mangrove forests, concluding that these datasets provided important information for managers on the distribution of selected species, and rates of tree mortality.

In contrast to very high spatial resolution imagery, He et al. (2011) conclude that hyperspectral images are particularly useful for mapping individual species when the invader is scattered at low density, where VHR datasets will fail to pick up on their occurrence (Fuller 2005). Collecting imagery that corresponds to unique phenological stages, such as flowering or senescence, increases the likelihood of accurate

identification. Hyperspectral information may also be useful in specific instances such as when studying foliage discolorations caused by specific pest attacks (Coops et al., 2007). Asner et al. (2008) additionally recommend the use of active remote sensing, combining this with airborne optical data to map five invasive plant species in Hawaii. This fusion of datasets enabled them to identify transformations in 3-dimensional forest structure due to invasives replacing native plants at mid-canopy, understory and ground levels.

In BIO_SOS sites in Portugal and India, invasive species represent important local pressures that require regular monitoring. In these locations, a combination of very spatial and spectral resolution datasets will be explored for such monitoring, along with the use of approaches such as Ecological Niche Modelling (D6.7).

## 5.6 Fine spatial scale pressures

VHR datasets can be very important to detect fine scale disturbances such as urbanization and human movement, mapping tree falls, and small scale pest attacks (Fuller, 2007). Allard (2003) used IKONOS data to map very fine scale impacts of grazing in a dry dwarf shrub heath in a mountainous landscape in Sweden, detecting erosion due to grazing at low levels that were easy to manage. Asner et al. (2002) used IKONOS to map the crown diameter of the largest trees in an Amazonian forest, as these trees were most commonly targeted by loggers. VHR datasets can also be very useful for studying fine scale pollution sources and their impact on wetlands and water bodies (e.g. Lee et al., 2010).

Remote sensing datasets of medium to fine spatial resolution can also provide important information on the “signature” of human use in and around protected areas such as logging roads and burn scars (Fuller, 2007). Ingram et al. (2005) used Landsat ETM+ imagery in conjunction with field plots to assess climatic and human pressures on forest biomass, relating the relatively low impact of a road bisecting the forest on basal area to the lack of mechanized logging in this forest.

# 6. Methodology to quantify pressures' impact on habitats

Table 14 below summarizes the (at this stage preliminary) information on impacts generated by anthropic pressures in different BIO_SOS sites provided in Table 7 (Italy), Table 8 (Greece), Table 9 (Wales), Tables 10 and 11 (two Portuguese sites), Table 12 (India), and Table 13 (The Netherlands). The table also discusses the possible types of determination using EO data – direct observation of the impact is largely possible for categories of land cover/habitat change, whereas indirect inference is required for most other categories of impact such as land cover/habitat modification, changes in spatial connectivity, or changes in species composition. Some types of impact (notably, those that involve subtle changes in plant or animal community composition, or changes due to almost unobservable, small scale spatial pressures such as those emanating from point pollution sources, or due to alterations in hunting and fishing regimes) may not be possible at all using EO data, and may require information solely generated from historical/existing GIS maps, expert input or field data. Yet for the most part, the vast majority of the impacts generated due to anthropic pressure described in most BIO_SOS sites appear capable of discrimination using EO data, which validates our confidence in the approach described. An attempt is also made to distinguish between the types of data (moderate, high and VHR spatial data, hyperspectral data, LiDAR, multi-season, and high temporal frequency) that may be required to delineate and map the spatial spread and intensity of each kind of impact, which is essential (as proposed in Section 5 above) for spatial mapping of impacts and pressures with respect to conservation targets.

We would like to stress here that hyperspectral and LIDAR data are expensive to acquire and so their use may be limited to contexts where other EO data are insufficient. Hyperspectral data are likely to provide options for mapping specific habitats (e.g., those that are rare) or facilitating better retrieval of endmember fractions, but for this they need to be acquired in a time-series at optimal times of year, at least two images are needed in many cases, and there is a need for extensive correction of these data before they can be used. Given these constraints, the approach investigated by BIO_SOS (D.5.3 and D5.4) finds that in general, time-series of spaceborne VHR data are likely to provide better or equivalent discrimination in most contexts.

LiDAR data are really recommended and investment in this together with VHR data is recommended. These provide considerably more information allowing the discrimination of habitats (e.g., forests) in terms of structure (and hence LCCS and GHCs). Classification and pressure/impact mapping can be undertaken without LiDAR, but the resultant maps may be much better in terms of detail and accuracy with LiDAR. Thus, although this may not be possible across all sites, our recommendation is to use these and acquire where possible, especially for extremely challenging environments with very low spectral heterogeneity or a high degree of variation in vertical stratification.

**Table 4. Synthesis of information on impacts generated by anthropic pressures on BIO_SOS sites in Italy, Greece, Wales, Portugal, India, and The Netherlands, also considering their possible modes of assessment using EO data, indicators from EO data, and required data resolutions.**

| Habitat type | Impact | BIO_SOS location | Type of assessment – Direct or Indirect | Indicator | EO Resolution |
|---|---|---|---|---|---|
| **Land Cover/Habitat Conversions** | | | | | |
| Forest | Conversion of forest to agriculture | Greece, India | Direct measure | Change in spatial coverage of LCCS/GHC category | High to VHR data, depending on spatial scale of change |
| Forest | Conversion of forest to (coffee) plantation | India | Direct measure | Change in spatial coverage of LCCS/GHC category | High to VHR data, depending on spatial scale of change |
| Forest | Conversion of forest to heathland | Netherlands | Direct measure | Change in spatial coverage of LCCS/GHC category | High to VHR data, depending on spatial scale of change |
| Forest | Conversion of forest | Netherland | Direct measure | Change in spatial | High to VHR data, |

| | | | | | |
|---|---|---|---|---|---|
| | to recreation | s | | coverage of LCCS/GHC category | depending on spatial scale of change, coupled with field data |
| Forest | Conversion of forest plantation to urban | Italy | Direct measure | Change in spatial coverage of LCCS/GHC category | VHR data, to identify buildings |
| Scrub | Conversion of scrub to forest | Portugal | Direct measure | Change in spatial coverage of LCCS/GHC category | High to VHR and possibly hyperspectral data, depending on spatial scale and degree of spectral change |
| Scrub | Conversion of scrub to woodland | Portugal | Direct measure | Change in spatial coverage of LCCS/GHC category | High to VHR and possibly hyperspectral data, depending on spatial scale and degree of spectral change |
| Scrub | Conversion of native scrub to patches of woody invaders | Portugal | Direct measure | Change in spatial coverage of LCCS/GHC category | High to VHR and possibly hyperspectral data, from multiple seasons within a year. Indirect measures should be used when hyperspectral data from multiple sensors are not available |
| Scrub | Conversion of scrub to perennial crops | Portugal | Direct measure | Change in spatial coverage of LCCS/GHC category | High to VHR and possibly hyperspectral data, depending on spatial scale and degree of spectral change |
| Agriculture | Conversion of agriculture to urban | Italy, Netherland s | Direct measure | Change in spatial coverage of LCCS/GHC category | High to VHR data, depending on spatial scale of change |
| Agriculture | Conversion of agriculture to forest | Portugal | Direct measure | Change in spatial coverage of LCCS/GHC category | High to VHR data, depending on spatial scale of change |
| Agriculture | Conversion of agriculture to scrub | Portugal | Direct measure | Change in spatial coverage of LCCS/GHC category | High to VHR data, depending on spatial scale and degree of spectral change |
| Agriculture | Conversion of annual crops to perennial grasslands and enclosed pastureland | Portugal | Direct measure | Change in spatial coverage of LCCS/GHC category | High to VHR data, for multiple seasons within a year |
| Agriculture | Conversion of annual crops to perennial crops | Portugal | Direct measure | Change in spatial coverage of LCCS/GHC category | VHR and hyperspectral data at multiple seasons within a year |
| Agriculture | Conversion of non-irrigated agriculture to irrigated agriculture | Italy | Direct measure | Change in spatial coverage of LCCS/GHC category | High to VHR data, to identify irrigated plantations. Possible fusion of High to VHR optical data and SAR data to identify irrigated plantations and precision farming. |

| | | | | | |
|---|---|---|---|---|---|
| Grassland | Conversion of grassland to forest plantation | Italy | Direct measure | Change in spatial coverage of LCCS/GHC category | High to VHR data, depending on spatial scale of change |
| Grassland | Conversion of grassland to urban | Italy, Netherlands | Direct measure | Changes in spatial coverage of LCCS/GHC category | VHR data to identify roads, wind/solar farms and quarries |
| Grassland | Conversion of grassland to agriculture | Italy | Direct measure | Changes in spatial coverage of LCCS/GHC category | VHR data at multiple seasons within a year |
| Grassland | Conversion of grassland to water body | Greece | Direct measure | Changes in spatial coverage of LCCS/GHC category | VHR data (e.g. specific water indices from WorldView-2?) acquired for multiple seasons within a year |
| Heathland | Conversion of heathland to coniferous forest | Netherlands | Direct measure | Changes in spatial coverage of LCCS/GHC category | High to VHR and possibly hyperspectral data, from multiple seasons within a year, coupled with field data |
| Heathland | Conversion of heathland to grassland | Netherlands | Direct measure | Changes in spatial coverage of LCCS/GHC category | High to VHR and possibly hyperspectral data, from multiple seasons within a year, coupled with field data |
| Heathland | Conversion of heathland to inland sand dunes | Netherlands | Direct measure | Changes in spatial coverage of LCCS/GHC category | High to VHR and possibly hyperspectral data, from multiple seasons within a year, coupled with field data |
| Salt marshes and other habitat types | Conversion of salt marshes and other habitat types to agriculture | Greece, Wales | Direct measure | Changes in spatial coverage of LCCS/GHC category | VHR data acquired for multiple seasons within a year |
| Communities with *Tamarix* sps | Conversion of communities with Tamarix sps to reed beds | Greece | Direct measure | Changes in spatial coverage of LCCS/GHC category | VHR data acquired for multiple seasons within a year |
| Almost bare saline land | Conversion of almost bare saline land to communities with *Tamarix* sps | Greece | Direct measure | Changes in spatial coverage of LCCS/GHC category | VHR data acquired for multiple seasons within a year |
| Beaches | Conversion of beaches to urban | Italy | Direct measure | Changes in spatial coverage of LCCS/GHC category | VHR data at multiple seasons within a year |
| Sand dunes | Conversion of inland sand dunes to heathland | Netherlands | Direct measure | Changes in spatial coverage of LCCS/GHC category | High to VHR and possibly hyperspectral data, from multiple seasons within a year, coupled with field data |
| Sand dunes | Conversion of inland sand dunes to mosses | Netherlands | Direct measure | Changes in spatial coverage of LCCS/GHC category | High to VHR and possibly hyperspectral data, from multiple seasons within a year, coupled with field data |

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| All terrestrial classes | Conversion of all terrestrial LCCS classes to water | Portugal | Direct measure | Changes in spatial coverage of LCCS/GHC category | High to VHR data, depending on spatial scale of change |
| **Land Cover/Habitat Modification** | | | | | |
| Forest | Loss in species diversity | Greece | Indirect measure | e.g. change in image texture, or vegetation index | High to VHR data, use of LiDAR and/or hyperspectral imagery (see D5.3 and D5.4) |
| Forest, Agriculture, Grazing land | Increase in vegetation due to abandonment | Italy | Indirect measure | e.g. change in vegetation index | High to VHR data, use of LiDAR and/or hyperspectral imagery (see D5.3 and D5.4) |
| Forest, Agriculture, Grazing land | Decrease in ground vegetation cover | Italy | Indirect measure | Change in vegetation indices, in image texture, or information from LiDAR | High to VHR data, use of LiDAR and/or hyperspectral imagery (see D5.3 and D5.4) |
| Forest | Scrub encroachment | Portugal | Indirect measure | Change in vegetation indices, in image texture, or information from LiDAR | High to VHR data, use of LiDAR and/or hyperspectral imagery (see D5.3 and D5.4) |
| Forests | Decrease in tree density due to grazing | India | Indirect measure | Change in vegetation indices, in image texture, or information from LiDAR | High to VHR data, use of LiDAR and/or hyperspectral imagery (see D5.3 and D5.4) |
| Agriculture | Changes in tree density | Greece | Direct measure | e.g. change in vegetation index,<br>counting of tree objects;<br>change in vegetation strata (class core) coverage with an increase of barren land strata (class context) coverage according to specific class description | High to VHR (pansharpened) and hyperspectral data, depending on degree of change in tree density and extent of canopy cover; subtle changes in density, and/or changes below the uppermost canopy of vegetation may benefit from hyperspectral imagery or LiDAR (see D5.3 and D5.4) |
| Agriculture | Soil erosion | Italy | Indirect measure | Changes in specific spectral indices/band combinations | May require VHR and hyperspectral data |
| Herbaceous grasslands | Encroachment of grass | Wales | Indirect measure | Changes in specific spectral indices/band combinations | May require VHR and hyperspectral data |
| Grasslands | Change in the structure and heterogeneity of grassland habitat | Portugal | Indirect measure | Changes in specific spectral indices/band combinations | May require VHR and hyperspectral data |
| Agriculture | Dumping of rubbish or toxic muds and radioactive substances | Italy | Indirect measure | Changes in specific spectral indices/band combinations | May require hyperspectral data |

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| Sand dunes | Denuded vegetation and sand dune collapse | Wales | Indirect measure | Changes in specific spectral indices/band combinations | May require hyperspectral data |
| Aquatic habitats | Eutrophication | Italy, India | Indirect measure | Changes in specific spectral indices/band combinations | May require VHR and hyperspectral data |
| Aquatic habitats | Acquaculture | Italy | Indirect measure | Changes in specific spectral indices/band combinations | May require VHR and hyperspectral data |
| River | Sand extraction from river bed | Italy | Indirect measure | Changes in specific spectral indices/band combinations | May require VHR and hyperspectral data |
| Beaches | Soil degradation | Italy | Indirect measure | Changes in specific spectral indices/band combinations | May require hyperspectral data |
| **Disruption/Modification of Ecological Regimes** | | | | | |
| Forest, Agriculture, Grassland and other terrestrial habitats | Altered fire regime | Italy, Greece, Portugal, India, Netherlands | Direct measure | Change in spatial coverage of fire scars; increase in scrub and wood encroachment | Moderate to high spatial resolution data, but needs to be acquired at high temporal frequency; coupled with expert assessments and field data |
| Scrub, grassland | Changed water and nutrient availability | Portugal | Indirect measure | Changes in specific spectral indices/band combinations | High and VHR spatial resolution data, as well as hyperspectral data |
| Agriculture, urban | Decreased fresh water availability | Italy | Indirect measure | Expansion of agricultural and urban land cover/land use | High to VHR data, depending on spatial scale of change |
| Forest, Agriculture, Grassland and other terrestrial habitats | Altered grazing patterns | Greece, India | Indirect measure | Changes in specific spectral indices/band combinations | High and VHR spatial resolution data, as well as hyperspectral data, needs to be acquired at high temporal frequency |
| Grassland, forest | Pressures due to tourism | Greece, India | Indirect measure | Changes in tourism infrastructure | VHR data |
| Grassland and coastal habitat | Sea level rise due to climate change | Greece | Indirect measure | Changes in areas covered or impacted by marine water | High and VHR spatial resolution data, as well as hyperspectral data, needs to be acquired at high temporal frequency |
| Various terrestrial and acquatic habitats | Altered hunting and fishing patterns | Greece, India | Indirect measure | Requires expert identification or through field data | Difficult to assess using EO data |
| Which types? | Soil disturbance | Netherlands | Indirect measure | Requires expert identification or through field data | Difficult to assess using EO data |

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| Bog | Drying out of bog surface | Wales | Indirect measure | Changes in specific spectral indices/band combinations | High and VHR spatial resolution data, as well as hyperspectral data |
| Active bog | Shrub encroachment, seawater intrusion, nitrogen deposition | Wales | Indirect measure | Changes in specific spectral indices/band combinations | High and VHR spatial resolution data, as well as hyperspectral data |
| Secondary bog | Ecological succession towards shrubs and woodland | Wales | Indirect measure | Changes in specific spectral indices/band combinations | High and VHR spatial resolution data, as well as hyperspectral data |
| Shallow perennial rivers and streams | Canalisation and diversion, land drainage | Wales | Indirect measure | Changes in specific spectral indices/band combinations | High and VHR spatial resolution data, as well as hyperspectral data |
| Which types? | Fresh water extraction for water consumption | Netherland s | Indirect measure | Changes in specific spectral indices/band combinations | High and VHR spatial resolution data, as well as hyperspectral data, in conjunction with expert identification and field data |
| Which types? | Pollution of surface water | Netherland s | Indirect measure | Requires expert identification or through field data | Difficult to assess using EO data |
| **Changes in Spatial Connectivity** | | | | | |
| Various land cover types/habit ats | Fragmentation | Greece, Portugal, India, Netherland s | Indirect measure | Changes in landscape pattern indicators | High to very high spatial resolution, depending on site-specific scale issues (see D6.3) |
| Various land cover types/habit ats | Decrease in patch size | Greece | Direct measure | Changes in patch size indices | High to very high spatial resolution, depending on site-specific scale issues (see D6.3) |
| Various land cover types/habit ats | Increase in inter-patch distance | Greece | Direct measure | Changes in metrics of inter-patch distance and connectivity | High to very high spatial resolution, depending on site-specific scale issues (see D6.3) |
| Various land cover types/habit ats | Landscape homogenization and increase of connectivity | Portugal | Indirect measure | e.g. changes in metrics of landscape diversity and spatial connectivity | High to very high spatial resolution, depending on site-specific scale issues (see D6.3) |
| Various land cover types/habit ats | Increased edge effects | Greece, Italy, India | Indirect measure | e.g. changes in edge metrics, used to infer impacts on species population and viability | High to very high spatial resolution, depending on site-specific scale issues (see D6.3) |
| **Disruption of Plant and Animal Community Structure** | | | | | |
| Various land cover types/habit ats | Change in species and community composition and structure, or dominance and evenness values | Italy, Greece, Portugal, India, Netherland s | Indirect measure | e.g. change in image texture, or spectral indices | High to VHR data, possible use of LiDAR and/or hyperspectral imagery (see D5.3 and D5.4), coupled with expert analysis and field data |
| Various land cover types/habit | Increase in spread and proportion of | Italy, Portugal, India, | Indirect measure | e.g. change in image texture, or | High to VHR data, possible use of LiDAR and/or hyperspectral imagery (see |

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| ats | invasive species | Netherlands | | spectral indices | D5.3 and D5.4), coupled with expert analysis and field data |
| Various land cover types/habitats | Decreasing number of species | Netherlands | Indirect measure | e.g. change in image texture, or spectral indices | Difficult to assess through EO data alone |
| **Fine Spatial Scale Pressures with Large Spatial Impacts** | | | | | |
| Various land cover types/habitats | Roads and trails | Greece, Portugal, India, Netherlands | Direct measure | Changes in road length | VHR data in conjunction with expert assessments and field data |
| Various land cover types/habitats | Buildings | India, Netherlands | Direct measure | Changes in building density, spread | VHR data in conjunction with expert assessments and field data |
| Various land cover types/habitats | Point pollution sources | Italy, Netherlands | Direct measure | Based on existing GIS maps or expert/field data | Difficult to map through EO data, , perhaps in conjunction with expert assessments and field data |
| Various land cover types/habitats | Point water uptake apparatus (e.g. wells, pumps) | Italy | Direct measure | Based on existing GIS maps or expert/field data | Perhaps through VHR data |

# 7. Conclusions and recommendations

In conclusion, a review of different approaches used by different conservation organizations for assessment of pressure/threats finds that the approach developed by IUCN/CMP (Salafsky et al. 2003, 2008) is the most widely used at the local level, and considered comprehensive as well as desirable because of many factors, including its hierarchical multi-level organization, flexibility, and emphasis on spatial mapping and monitoring. For BIO_SOS, while this approach has strength, it does not permit direct applicability for monitoring of local pressure through EO data. Instead we propose an approach that builds on this framework, but adapts it so that EO data are used instead to monitor *impacts* of pressure – on landscapes, land cover/habitat types, communities and species – which can then be used to infer pressure. We utilize this framework to describe impacts from local pressures that result in land cover/habitat conversion, land cover/habitat modification, disruption of ecological regimes, changes in spatial connectivity, disruption of community structure, and fine scale spatial pressures that result in large spatial scale impacts, finding the framework of utility in developing a better understanding of pressure-derived impacts at two levels of detail for BIO_SOS sites in six countries (Italy, Greece, Wales, Portugal, India and The Netherlands), and using an examination of peer-reviewed literature to describe the use of different types of EO data for examining pressures and impacts at various levels of detail in these different BIO_SOS sites.

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