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Report on criteria for selection of suitable EO datasets and identification of EO datasets with adequate range of spectral, spatial and temporal resolutions for each site

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Abstract	This report specifies criteria and outlines protocols for identifying EO datasets that are appropriate, in terms of their spatial, spectral and temporal characteristics, for discriminating, mapping and monitoring habitats and capturing the ecological scales of fragmentation, human

	pressures, and scales of impacts. It also recommends new data acquisitions to provide data that are considered to be best suited to support the BIO-SOS objectives for each of the eleven sites.
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Table of Contents

1. Executive summary....6
2. Introduction....8
3. Criteria for good indicators from EO datasets to satisfy monitoring requirements for Natura 2000 managers, EU Directives, and CBD 2020 Aichi Targets....10
3.1 Local (site) scale: Requirements of land managers....10
3.2 Regional (continental) scale: Requirements of EU Directives....10
3.3 Global scale: Requirements of CBD Aichi Targets for 2020....11
3.4 Criteria to specify good indicators of state of habitats and biodiversity....12
4. Factors determining the selection of EO datasets for monitoring habitats, species and threats....14
4.1 Considerations of habitat variability and scale (spatial, spectral, temporal, and radiometric) while selecting EO data for habitat mapping....14
4.2 Radiometric calibration requirements for optical EO data selection....17
4.3 EO data for monitoring threats to conservation....18
4.4 Selecting appropriate EO data for biodiversity observations and species monitoring....19
5. Identifying appropriate EO datasets for BIO_SOS sites....21
6. Appendix 1: Detailed assessment of EO data available and to be acquired for Dyfi catchment, including Cors Fochno training site....30
6.1 Introduction....30
6.2 Satellite sensor data....31
6.3 SPOT-5 High Resolution Geometric (HRG)....31
6.4 Landsat sensors....31
6.5 ASTER....32
6.6 Indian Remote Sensing Saellite (IRS)....33
6.7 VHR data 34
6.8 ALOS PALSAR....34
6.9 Aerial Imagery....35
6.10 Overview of satellite sensor data useful for Wales test sites....38
6.11 Habitat maps already produced in the framework of previous projects....39
7. Appendix 2: Italian training sites data....42
8. Appendix 3: Acronym List....48
9. References....49

1. Executive summary

The BIO_SOS project has the overarching goal of developing and providing a set of automated tools and models that will permit the consistent, effective and timely multi-annual monitoring of NATURA 2000 sites and their surroundings, which are exposed to a variety of human and natural pressures. For this purpose, the consortium has identified 10 test sites throughout Europe, and one site in the tropical rainforest of Brazil. Earth Observation (EO) datasets will be an integral part of this process, providing a powerful tool for the monitoring of habitats, biodiversity and disturbance. This report focuses on identifying new remote sensing data that needs to be collected to supplement existing ancillary, field based and remotely sensed datasets for monitoring of sites. First, we provide definitions of criteria and protocols for identifying EO datasets that are appropriate, in terms of their spatial, spectral and temporal characteristics, for discriminating, mapping and monitoring habitats and capturing the ecological scales of fragmentation and human pressures and scales of impacts. Next, based on these criteria and protocols, we identify new EO data acquisitions to provide data that are considered to be best suited to support the BIO-SOS objectives.

EO datasets have various requirements, to meet the local needs of managers, to meet regional requirements of the European Union Habitats Directive, and to meet global requirements of the Convention on Biological Diversity (CBD) 2020 Aichi targets. Based on this, the report outlines a set of criteria that meet the specifications for suitable indicators. These need to provide indicators of habitat state that allow the tracking of changes in habitat extent and detection of fine scale structure within habitat patches; enable measurement of changes in habitat condition through assessment of changes in vegetation biomass, seasonality, and vegetation damage or stress; permit measurements of changes in habitat structure and fragmentation; facilitate the direct monitoring of changes in the abundance and/or distribution of specific dominant, indicator, endangered or invasive species; and permit detection of human pressure through activities such as fire, urbanization, or agriculture.

Amongst the factors determining the selection of EO datasets for monitoring habitats, species and threats, considerations of habitat variability and scale (spatial, spectral, temporal, and radiometric) come foremost. The majority of EO studies focus on the mapping and delineation of land cover categories. Habitat mapping is much harder to undertake, as the correlation between land cover and habitat is far and the correlation between habitat and land cover is far from straightforward, and often requires a great deal of field information and interpretation by experts.

Habitat mapping has largely been addressed through mapping of one or a few dominant species in the upper canopy, or by establishing links with their broader biophysical characteristics (e.g., seasonal differences in the relative amounts of photosynthetic and/or non-photosynthetic components). The heterogeneity of the landscape also needs to be considered when mapping habitats. While agricultural and forest landscapes are relatively straightforward to delineate, in the majority of the Mediterranean BIO_SOS landscapes that are more heterogeneous and consist of a number of interlinked habitats at different scales (e.g., mountain, heath, bog and wetlands), habitat delineation is more difficult to achieve using EO data. In such cases, especially, issues of spatial, spectral, temporal and radiometric scale become predominant, and must be matched carefully to the type of habitats, species, and site characteristics and seasonality for specific locations.

While very high spatial resolution EO datasets are useful for fine scale observation of change, they are not sufficient and will need to be supplemented by data of medium spatial resolution, and hyperspectral datasets, with the maximum radiometric resolution available. As far as possible, the acquisition of data from multiple, phenologically characteristic seasons should also be explored. Recent hyperspatial satellites, especially WorldView 2, are opening out possibilities for high spatial and spectral resolution to be provided in one platform, and BIO_SOS should also explore the use of such datasets. Consideration should also be given to active remote sensing data as these provide information that is complementary but different to optical sensors. In particular, LiDAR and low frequency SAR (e.g., L-band) can be used to quantify the three dimensional structure and biomass of vegetation, particularly forests. X- and C-band data can also be used to discriminate non-woody vegetation based on differences in, for example, stem and/or leaf size and orientation. Moreover it must be highlighted that the use of SAR allows an observation that is independent of weather conditions. The value of these sensors is increased when

used in combination with optical remote sensing data in the framework of change detection.

This report summarizes aspects of the sites including the extent, types of land cover categories according to the CORINE taxonomy, which should be substituted with the LCCS taxonomy, according to the conclusions of D6.1, prominent habitat types, critical indicator species, and major types of pressures, which are important to consider when selecting the types of EO data sets for each location. A summary of existing ancillary and EO datasets, user requirements for temporal distinctions and other qualifications and a summary of spaceborne and airborne sensor datasets with actual and potential application to direct mapping of GHCs and Annex I habitats are given. Recommendations as to specific spaceborne and airborne remote sensing data for use at each of the study sites in BIO_SOS are provided.

2. Introduction

The BIO_SOS project has the overarching goal of developing and providing a set of automated tools and models that will permit the consistent, effective and timely multi-annual monitoring of NATURA 2000 sites and their surroundings, which are exposed to a variety of human and natural pressures.

Specifically, the project will:

1) Adopt and develop novel operational automatic EO data preprocessing and understanding techniques that utilise high spatial (HR), very high spatial resolution (VHR) and hyper-spectral resolution EO data to generate land cover maps and LC change maps that can be used for biodiversity monitoring. This is tantamount to saying that BIO_SOS is expected to provide improved operational core service products with respect to state-of-the-art satellite-based land cover (LC) and land cover change (LCC) mapping systems.

2) Develop a modelling framework (scenario analysis) to combine EO and on-site *in situ* data to support the automatic provision of biodiversity indicators and provide a deeper understanding, assessment and prediction of the impacts that human induced pressures may have on biodiversity. This means BIO_SOS aims *a* developping and integrating new and existing models able to evaluate and predict trends in biodiversity issues. This will lead to the development of *new downstream services* production.

Thus, a major focus of BIO_SOS is to test the integration of existing and new automatic EO data processing techniques to enable better use of observations over different scales, and link that with *in situ* information.

For this purpose, the consortium has identified eleven (11) test sites throughout Europe, belonging to the European Ecological Network Natura 2000. Of these, nine sites are located in the Mediterranean part of Europe. This is an important focus region for BIO_SOS because knowledge on biodiversity is relatively less developed in the Mediterranean as compared with other parts of Europe. Thus, there is an urgent requirement for automated processes of biodiversity monitoring that adequately capitalize on the information provided by EO data to provide information of direct management relevance for nature protection agencies in Mediterranean countries. There are 9 Mediterranean locations, with 4 sites in Italy, 3 in Greece, and 2 in Portugal. In addition, the BIO_SOS sites also include 2 locations in other parts of Europe, with 1 site in the Netherlands, and one set of two adjacent sites in Wales. Finally, in order to provide a contribution to global issues, the consortium has included a site in the tropical rainforest of Brazil, and some preliminary exploratory research is being undertaken s on a data-poor yet biodiverse and endangered sub-tropical protected national park in Goa, India. The approach to focus on protected sites is very complementary with many recent studies which despite the importance of effective data on habitat change, fragmentation and biodiversity in protected areas, find there is actually very little comparable data across such sites (Chape et al. 2005, Nagendra 2008).

EO datasets will form a very important component of BIO_SOS. EO data provide a spatial, synoptic and repeated view of changes in habitat extent, condition, fragmentation and the density and distribution of selected species (Nagendra 2001, Duro et al. 2007, Gilelspie et al. 2008). Although EO data cannot provide complete information on biodiversity change in isolation, when combined with detailed field inputs and ground truthing, EO datasets can prove to be a powerful tool for the monitoring of disturbance, enabling protected area managers to locate and address harmful processes quickly and effectively (Borre et al. 2011).

A large number of pre-existing datasets provide some information for several of the test sites, but other crucial information may be lacking at the relevant spatial and temporal scales. Thus, WP4 of BIO_SOS has three main goals:

1. To collect, harmonize and share pre-existing data on test sites relevant for habitat mapping by EO data processing. Spatial and alphanumerical datasets covering Natura 2000 sites are available at multiple spatial scales and contexts, and can be valuable to support and/or validate EO habitat maps resulting from other WPs in the project. Those datasets include *in situ* observational records and maps (e.g., local, regional, national or European surveys of habitats

and/or land cover), archive EO data and products, as well as many types of ancillary datasets (e.g., digital terrain models and cadastral data).

2. To plan new EO data acquisition for land cover and habitat maps production and updating.
3. To supplement existing datasets with new field data from on-site campaigns based on standard protocols and collect new in-situ data through on-field surveys.

This report is one of the WP outputs concerning the criteria for existing and new EO data selection. Within this objective, pre-existing datasets will be supplemented by new data on the spatial patterns of habitats and their biodiversity, collected on-site through the field application of standard protocols developed. In this deliverable, we provide definitions of criteria and protocols for identifying EO datasets that are appropriate, in terms of their spatial, spectral and temporal characteristics, for discriminating, mapping and monitoring habitats and capturing the ecological scales of fragmentation and human pressures and scales of impacts. This is being achieved through communications between consortium partners and sharing of datasets, methods and experiences with other projects. An archive of EO data exists for all the test sites, with varying degrees of holdings and availability. However, new EO data acquisitions are being planned to provide data that are considered to be best suited to support the BIO-SOS objectives.

The next section of this report discusses the various requirements of EO datasets to meet the local needs of Natura 2000 site managers, to meet regional requirements of the European Union Habitats Directive, and to meet global requirements of the Convention on Biological Diversity (CBD) 2020 Aichi targets. Based on this, a set of criteria that meet the specifications for suitable indicators as outlined in D 2.2 as well as the requirements for new EO data acquisition outlined are produced.

3. Criteria for good indicators from EO datasets to satisfy monitoring requirements for Natura 2000 managers, EU Directives, and CBD 2020 Aichi Targets

3.1 Local (site) scale: Requirements of land managers

The importance of EO data for monitoring habitats is recognized by a wide range of users worldwide. For example, in India, ATREE forest managers use processed remote sensing products routinely to track and manage incidences of fire. However, despite the level of remote sensing expertise in India, which is quite high compared to many developing countries, few use unprocessed data because of the lack of technical skills and challenges of time. A survey of 23 experts from the Bavarian State Forest Administration similarly indicated that they were keenly interested in local forest inventories, especially to assist them with the management of nature conservation (i.e. NATURA 2000) areas. However, only 10 % of the experts were willing to work with raw EO datasets, while over 66 % of the experts indicated that they preferred to have processed standardized spatial datasets generated routinely for use (Felbermeier et al. 2010).

Unfortunately, while it is widely recognized that EO data have great potential for habitat mapping, in practice the challenges of converting land cover maps to habitat information are quite difficult to overcome for forest managers (McDermid et al. 2005). A broader survey was conducted by Borre et al. (2011) who studied the processes used by the member states of the EU Habitat Directive to provide information on habitat change at the local scale. Out of 25 member states surveyed, as many as 18 had used remote sensing data, either alone or in conjunction with other approaches, to assess habitat area and conservation status. Yet, the methods they used were subjective and time consuming, with the majority of the cases where information was available indicating that they relied heavily on the visual interpretation of satellite imagery. Thus, the scope and the need for introducing automated approaches that can be quickly implemented, and that are not limited by the technical expertise of local managers, is extremely desirable. This is the gap area that BIO_SOS is attempting to fill.

Thus, looking at the experiences of both developing and developed countries, the process envisaged by BIO_SOS of providing automated, coordinated and repeated monitoring of NATURA 2000 sites for managers that utilizes EO datasets, but does not require direct processing of raw EO datasets by managers, seems to be well designed.

3.2 Regional (continental) scale: Requirements of EU Directives

The European Union has adopted two directives that are particularly of importance for biodiversity conservation - Council Directive 79/409/EEC of 2 April 1979 on the conservation of wild birds—the Birds Directive; and Council Directive 92/43/EEC of 21 May 1992—the Habitats Directive (Schmeller 2008). The Habitats Directive, which is of most relevance to BIO_SOS, asks EU member states to conserve rare and/or threatened habitats and species of "community Interest" that are listed in annexes to the Directive. Implementation has been difficult in large part because of a lack of baseline information on habitat distribution. Many sites have attempted to do this through intensive mapping programs that rely on expensive, time consuming and labour intensive field surveys – yet these are produced at varying levels of detail and different scales. A study by Lengyel et al. (2008) of 148 habitat monitoring initiatives across Europe found that the majority of the programs were launched to comply with the EU Directives, further underlining their major primacy in European assessments of habitat change.

In future stages of the directive, there is a call for member states to monitor changes in these habitats at six yearly intervals, and also take a further step by providing indications of changes in habitat condition or quality (Borre et al. 2011). As the number of advanced high spatial and spectral resolution satellites orbiting the Earth increases (Nagendra and Rocchini 2008), concurrent with technical advances in the capabilities of automated information extraction from these images, EO datasets are increasingly being

considered to offer the possibility for member states to satisfy their reporting obligations under the Habitats Directive (Borre et al. 2011). Previously, only about 15 % of habitat mapping studies in Europe have relied on remote sensing, with the remaining relying largely on field data collection, and selecting only specific habitats for monitoring. Thus there is significant scope for improvement on this count (Lengyel et al. 2008). Indeed, Jongman et al. (2006) propose a detailed approach for this, involving environmental stratification along with detailed sampling of selected sites, thus allowing for effective upscaling and downscaling of information. Such an approach can be very effectively developed using EO data in conjunction with GIS databases and modelling, which is an approach that is fundamental to the design of BIO_SOS.

Specifically, Articles 11 and 17 of the Directive require member states to report on changes in conservation status every six years, using four parameters of status – *area* covered by a habitat, *range* where the habitat is likely to occur, *specific structures and functions* that indicate changes in habitat quality and in typical species, and *future prospects* for the survival of the habitat (European Commission 2005 a; Borre et al. 2011). Approaches developed by BIO_SOS are easily capable of effective scaling up at the country level to provide data on all these aspects. It is essential to keep these in mind while selecting data at the site level.

Further, at the level of individual Natura 2000 sites, in order to actually conserve rare or threatened habitats and species, there is of course a need to go further than these country-level reporting obligations, and provide high quality, accurate, spatially explicit and repeated maps that show changes in the distribution of habitats and species, monitor changes in habitat quality, and track habitat fragmentation. This is also important for habitat patches located outside protected areas, but which provide important buffer areas for the conservation and maintenance of important species (Mücher et al. 2009). Thus, the procedure developed for selection of EO data in BIO_SOS will follow the requirements also outlined in the previous section.

3.3 Global scale: Requirements of CBD Aichi Targets for 2020

The overall vision of the CBD is that “By 2050, biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people.” Towards this, the tenth meeting of the Conference of the Parties, held in Nagoya, Aichi Prefecture, Japan in October 2010, adopted a revised and updated Strategic Plan for Biodiversity for the 2011-2020 period. The mission of the Strategic Plan is to “Take effective and urgent action to halt the loss of biodiversity in order to ensure that, by 2020, ecosystems are resilient and continue to provide essential services, thereby securing the planet’s variety of life, and contributing to human well-being, and poverty eradication. To ensure this, pressures on biodiversity are reduced, ecosystems are restored, biological resources are sustainably used and benefits arising out of utilization of genetic resources are shared in a fair and equitable manner; adequate financial resources are provided, capacities are enhanced, biodiversity issues and values mainstreamed, appropriate policies are effectively implemented, and decision-making is based on sound science and the precautionary approach.”

The Strategic Plan concludes that “The 2010 biodiversity target has inspired action at many levels. However, such actions have not been on a scale sufficient for addressing the pressures on biodiversity.“ Lack of scientific information is identified as one of the major obstacles that limited implementation of plans in the previous phase (Pereira and Cooper 2006). However, the Strategic Plan states that “scientific uncertainty should not be used as an excuse for inaction.” Thus the approach taken by BIO_SOS to provide accurate scientific information of use to managers is an important and critical one, which has significant potential for scaling up to the global scale eventually.

Two of the focal areas of the CBD are “Threats to Biodiversity” and “Status of Biodiversity”. The first focal area relates to Strategic Goal B, “Reduce the direct pressures on biodiversity and promote sustainable use”. Within this, BIO_SOS relates specifically to Target 5, “By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced”, and to Target 9, “By 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment.”

The second focal area relates to Strategic Goal C, “Improve the status of biodiversity by safeguarding ecosystems, species, and genetic diversity”. Within this, Target 12 is particularly relevant for BIO_SOS, stating that “By 2020 the extinction of known threatened species has been prevented and their conservation status, particularly of those most in decline, has been improved and sustained.”

While these targets were outlined relatively recently, and therefore indicators for measuring progress towards all targets are still being developed, the CBD Secretariat extended an invitation to GEO BON and its partners to convene a group of experts to prepare a report on existing observation capabilities as related to the Aichi targets, and to develop a draft assessment report, with the view towards providing possible inputs towards the definition of indicators. The discussion of Target 5 and Target 9 at this meeting, in particular, indicated that EO data plays a prominent role in providing information on habitat change, degradation and fragmentation as well as on the spread of invasive species, to monitor progress towards meeting these Targets. Thus, again, the approach taken by BIO_SOS in utilizing EO datasets for monitoring change in NATURA 2000 habitats is an important one, and fits well with international objectives. While selecting specific EO datasets, it is critical to keep these goals in mind, as the types of habitats and their correlation with land cover maps can influence the choice of remote sensing datasets (McDermind et al. 2005). Specifically, Target 5 indicates that we should ensure that the spatial, spectral and temporal resolution of these datasets enable the assessment of changes in habitat loss, degradation and fragmentation. Targets 9 and 12 indicate that EO datasets should also be used in conjunction with modelling and field information to predict changes in specific species of interest, including threatened species as well as invasive ones.

3.4 Criteria to specify good indicators of state of habitats and biodiversity

The discussion in Sections 3.1 to 3.3, as well as the observations provided in Report D2.1, can lead us to specify some criteria that EO-derived indicators of the state of the habitat and biodiversity within should satisfy. These are:

1. the indicator should represent some important aspect of the structure, compositional or functional attribute of the system;

2.it should be easy or cost effective to monitor;

3. Iit should be a direct measure of change, or an accurate, measurable proxy;

4. it should be possible to up-scale and downscale spatially;

5. it should be possible to relate this to the revised CBD 2020 targets;

6. accuracy of measurement should be high;

7. it should be possible to collect routinely to demonstrate changes over time – access to historical data is very useful ;

8. it should permit accurate identification and quantification of cause and response. At the minimum, it should enable users to differentiate between human and natural induced changes - so that scenarios can be developed based on this understanding.

Following this, the types of indicators that can be provided by EO data that broadly satisfy the above criteria can be broadly categorized into the following three categories:

<u>A. Indicators of Habitat State</u>

1. Tracking changes in habitat extent (indirectly, through linkages with land cover)
    a. Detection of habitats and patches
    b. Detection of fine scale structure within habitat patches
2. Measurement of changes in habitat condition through assessment of
    a. Changes in vegetation density, height or biomass (direct measurements)
    b. Changes in phenology and/or seasonality (direct over-time measurements)

c. Vegetation damage through pollution or stress (through a combination of GIS to identify vulnerable areas, and detailed EO derived maps in these areas)

3. Measurement of changes in habitat fragmentation

a. Indices of landscape and habitat fragmentation

b. Studies of within-patch structure for selected critical patches

B. Detection of Human Pressure

Urbanization and road construction, agriculture, mining, logging, landfills, fire, abandonment, pollution, etc.

C. Direct measurement of changes in the density of specific species

a. Abundance and distribution of widespread species/dominant life forms

b. Abundance and distribution of invasive species (through RS and GIS)

c. Occurrence, abundance and distribution of rare and endangered species

The criteria for selecting EO datasets for these three sets of indicators are discussed in further detail in the next section.

4. Factors determining the selection of EO datasets for monitoring habitats, species and threats

4.1 Considerations of habitat variability and scale (spatial, spectral, temporal, and radiometric) while selecting EO data for habitat mapping.

The majority of EO studies focus on the mapping and delineation of land cover categories. Habitat mapping is much harder to undertake, although has been achieved in a few studies, including at a national level (Lucas et al. 2011). One of the difficulties is that the correlation between land cover and habitat is far from straightforward, and often requires a great deal of field information and interpretation by experts (McDermid et al. 2005). Under the European Directive 92/43/EEC, habitats must be assessed as territorial entities, which exhibit some homogeneity in physical as well as biotic characteristics, at a scale that largely corresponds to that of direct human observation (Weiers et al. 2004; Varela et al. 2008).

Habitat mapping has largely been addressed through mapping of one or a few dominant species in the upper canopy (Nagendra 2001), or by establishing links with their broader biophysical characteristics (e.g., seasonal differences in the relative amounts of photosynthetic and/or non-photosynthetic components; Lucas et al. 2011). The heterogeneity of the landscape also needs to be considered when mapping habitats (Lucas et al. 2007). For example, many agricultural and forest landscapes are relatively straightforward to delineate, characterize and classify from EO data and mapped classes relate more to land cover; hence, mapping in Europe is quite advanced (Lengyel et al. 2008). However, where landscapes are more heterogeneous and consist of a number of interlinked habitats at different scales (e.g., mountain, heath, bog and wetlands), habitat delineation is more difficult to achieve using EO data (Varela et al. 2008).

Several of the Mediterranean ecosystems addressed by BIO_SOS will face this challenge. Some of these issues can be addressed by developing innovative approaches to automated classification, including fuzzy classification, object oriented methods, and the use of possibility theory to map patches (Bock et al. 2005, Förster and Kleinschmidt 2008, Comber et al. 2010; Lucas et al. 2011), which have been applied successfully in many NATURA 2000 areas. Fractional cover analysis is another approach that can help to create early warning signals of tree and shrub encroachment into non-wooded habitats such as mires (Waser et al. 2008). Combinations of optical and Synthetic Aperture Radar (SAR) data have also proved useful for discriminating scrub-like regrowth (Lucas et al., 2006) and macrophytes (Pope et al., 1997). Yet fundamentally, the choice of EO data will determine the amount of information that is available to map complex, fine scale, variable habitats to sufficient degrees of accuracy, and to monitor changes over time using automated processes.

Issues of scale are most critical to the selection of EO datasets for habitat mapping. Perhaps the most obvious and most discussed aspect of scale, certainly the one that comes to the mind of most users of EO data, is that of spatial scale. Spatial scale commonly has two components – extent and grain (Forman 1995). Extent refers to the spatial size of the study area under consideration. Thus, within the context of BIO_SOS, the extent of each study area is defined by the size of the protected NATURA 2000 site, as well as the surrounding area (e.g., the watershed) that impacts changes within the boundaries of the site. While the boundary of interest can in theory be extended to encompass a very large area, in practice most managers and end users will be interested in a relatively small buffer around the area within their purview, where they can receive scientific information that will have maximal impact on the effectiveness of their management strategies.

Grain refers to the size of the smallest unit for which EO data is available, and is the aspect of spatial scale that is most commonly discussed when deciding on the selection of EO data. Although there has been extensive discussion for decades on the need to match the spatial scale to the type of objects (habitats, species) of focal interest, there is a broad assumption in the ecological community that higher spatial resolution is automatically superior, and thus also an automatic preference for ordering very high resolution EO data whenever costs permit, and data coverage is available (Nagendra and Rocchini

2008). However, as a number of recent studies have demonstrated, there are tradeoffs in increasing the spatial resolution to levels that are much finer than the scale of the objects (such as trees, species assemblages or habitats) being studied. Very High Spatial Resolution (VHR) datasets such as Quickbird and IKONOS tend to create problems in areas of shadow caused by buildings, tree canopies, and other tall features, making it difficult to distinguish objects in shadow cast areas (Sawaya et al. 2003; Nagendra et al. 2010). In many cases, the use of high to moderate spatial resolution data may be sufficient to capture the broad extent of habitats but VHR data is then needed to focus on areas where change is difficult to resolve or where a particular species (e.g., indicator or invasive) or a point or line feature indicating pressure (e.g., point pollution source or road) needs to be identified.

Care should be taken to ensure that the spatial scale of EO data should at least match the spatial scale of ancillary environmental datasets. VHR Ancillary datasets on site conditions for the local scale for Natura 2000 habitats vary from 1:25,000 to 1:50,000 for some soil maps, to 1:1,000 to 1:5,000 for some field generated habitat maps (Weiers et al. 2004; Forster and Kleinschmit 2005; Bock et al. 2005). This indicates that a mix of VHR data (e.g., from IKONOS, Quickbird or Worldview), and medium to high spatial resolution data (e.g., from Landsat, ASTER or IRS) can be considered suitable for mapping. Ideally, the size of the pixel should be matched so that it is one quarter to one third of the size of the smallest patches of habitat, species assemblage, or individual plant/tree being mapped (Nagendra 2001). In practice, given that any area will be a heterogeneous mix of objects of different sizes, a multi-scaled analysis using different image datasets may be useful to map specific focal habitat types or species. For instance, some large scale habitats such as woodlands can be detected using Landsat at coarse segmentation scales, while other fine scale habitats such as hedgerows can be identified using QB and finer segmentation levels. The use of VHR datasets also permits the detection of within-habitat variations and ecotones. For instance, in a wetland NATURA 2000 habitat in northern Germany, object oriented classification of Quickbird could detect ecotone successional habitats such as bogs (Bock et al. 2005).

In a complex mountain landscape in the NW Iberian coast, Varela et al. (2008) were able to use Landsat TM imagery with a Digital Elevation Model (DEM) of 5 m resolution, and digitized aerial photographs of 20 m resolution, to produce a hierarchical habitat classification into 15 habitat classes including natural forest, plantations, different types of heathlands and bogs, bracken, grassland, agriculture, and urban areas. While habitat types such as Eucalyptus plantations were easily discerned, habitat differentiation of different types of heathland and complex agricultural mosaics was more challenging. The lessons from this study indicate that the low spatial and spectral resolution of Landsat TM imagery may not allow for complete discrimination of certain habitats at the required level of detail. In contrast, high resolution EO datasets can prove to be more useful. A recent study by Comber et al. (2010) showed how 1 m colour aerial photograph can be used to map ecotones and mixture areas in a landscape in Wales that contains a complex, fine scale mixture of acid grassland, scattered bracken and acid flush, by developing a new set of methods that incorporate a mix of object oriented classification techniques and the use of possibility theory.

Förster and Kleinschmit (2008) studied the applicability of Quickbird data and ancillary datasets on site conditions such as altitude, aspect, slope and soil type to classify forest habitats in a pre-alpine area in Bavaria. They document an increase in classification accuracy when ancillary information is applied. However, this effect is more pronounced for habitat types (as much as 13 % improvement in classification accuracy) that have distinct, defined ecological niches – such as alluvial forests – when compared with other habitats that have wide ecological niches (only improvement around 10 %). Similarly, those habitats that have a large variation in patch sizes and lack distinct boundaries cannot be identified with high accuracies using object oriented classification techniques on very high resolution Quickbird images. In these cases, the use of fuzzy classifications is more appropriate (Lucas et al., 2011). Habitats with clear boundearies (e.g., grassland and agriculture) are, by contrast, mapped with greater accuracy (Bock et al. 2005; Förster and Kleinschmit 2008).

Light altimetric data from directed remote sensing instruments (i.e. LiDAR), can prove very useful for mapping structurally compelx habitats. In order to assess tree and shrub encroachment in a sub-alpine mire in Switzerland, Waser et al. (2008) used 0.5 m aerial photographs in combination with digital surface models generated from LiDAR for fractional mapping, and demonstrated that they were

successfully able to detect small, sub-pixel levels of encroachment at early points in time when they could be addressed by managers. However, LiDAR is difficult to automate and requires significant input from remote sensing experts. Thus, while it can be extremely useful for monitoring complex habitats and assessing sub-canopy stratification and complexity, which are often useful indicators of habitat condition and quality, it may be difficult to use these at a large scale across all sites at this stage. However, selected use in specific locations, for certain habitats of special interest, may be considered. The LiDAR also provides a permanent record of vegetation structures within a landscape that can be used for detecting change.

Tradeoffs between spatial and spectral resolution also need to be kept in mind. The currently popular hyperspatial EO platforms of Quickbird, IKONOS and GeoEye lack sufficient resolution in the shortwave infrared and thermal infrared bands, which have proved to be of use for vegetation discrimination (e.g., using Landsat; Nagendra 2001). Thus, Gao (1999) found that 30 m Landsat data was more useful than 10 m SPOT data for discriminating mangrove forests in New Zealand, and concluded that this was because of the information contained in the coarse resolution, but spectrally important thermal infrared bands. Oldeland et al. (2010) use high spatial resolution HyMap hyperspectral data to map differences in vegetation within a semi-arid rangeland in central Namibia. Despite the challenges that are faced in mapping this habitat, where transitions between vegetation types are continuous rather than discrete, these authors were able to successfully use this dataset with a relatively small number of field data points from vegetation plots to map vegetation units, using a fuzzy approach, and achieving classification accuracies of 98%. The fact that the spatial resolution of this dataset was quite high, at 10 m, seems to have made this more feasible. Lucas et al. (2008a) were able to discriminate trees to species or genus by extracting spectra from the sunlit portion of crowns delineated within 1 m spatial resolution Compact Airborne Spectrographic Imager (CASI) data acquired in woodlands in semi-arid Australia. An improvement in classification accuracy was achieved by incorporating shortwave infrared data from co-registered 2.6 m resolution HyMap data acquired over a similar period.

Temporal scale can permit the accurate delineation of spectrally similar habitats if selected at critical stages that emphasize phenological differences between them (Nagendra 2001). Brown de Colstoun et al. (2003) map 11 different land cover types in a recreational park in the USA, and find that discrimination between different forest classes increases substantially when they use Landsat ETM+ images acquired at multiple seasons. Lucas et al. (2007) were also able to use multi-date Landsat TM imagery to successfully discriminate between urban areas and bare ground in cleared plantations, based on the fact that the bare ground habitat had a sparse ground cover of herbs in the summer months. Given the considerable challenges in detecting differences between bare ground and urban areas, which represent very different habitat types but are very similar spectrally, the use of multitemporal datasets has significant potential to discriminate between different, spectrally similar habitat types. However, acquiring different EO datasets at multiple, spectrally and phenologically important seasons poses a challenge, and it is not always possible to acquire cloud free, good quality data for the time periods of interest. The increase in classification accuracy achieved with multitemporal imagery is however not standard across all habitat types, and in fact tends to decrease for complex habitats (Lucas et al. 2007). Nevertheless, Lucas et al. (2011) established that many habitats in Wales could be discriminated using a combination of early spring (mid March) and mid summery (July) imagery, although an object-orientated approach that incorporated ecological rules (e.g., slope, proximity to water) was essential.

Finally, issues of radiometric resolution should be considered during EO data selection for habitat mapping. Rao et al (2007) observed a small increase in classification accuracy by using 12-bit over 7-bit data for land use/land cover classification (with homogeneous ground category. Similarly, Legleiter et al (2002) also obtained a slight improvement of the overall accuracy in the classification of in-stream habitats with 11-bit data when compared with 8-bit-data.

In conclusion, while VHR EO datasets are useful for fine scale observation of change, they are not sufficient and will need to be supplemented by class specific context-sensitive additional information in the second classification stage of the RS_IUS module of the BIO_SOS proposed system. Data of medium spatial resolution, and hyperspectral datasets, with the maximum radiometric resolution available. As far as possible, the acquisition of data from multiple, phenologically characteristic seasons should also be explored. Recent hyperspatial satellites, especially WorldView 2, are opening out

possibilities for high spatial and spectral resolution to be provided in one platform (Nagendra and Rocchini 2008), and BIO_SOS should also explore the use of such datasets. Consideration should also be given to active remote sensing data as these provide information that is complementary but different to optical sensors. In particular, LiDAR and low frequency SAR (e.g., L-band) can be used to quantify the three dimensional structure and biomass of vegetation; in particular, the polarimetric feature of ALOS allows distinguishing forests from other land covers based on colour (polarimetric band combination) and texture (Rahman et al, 2008) (Chen et al. 2009) (Karjalainen et al, 2008) . X- and C-band data can also be used to discriminate non-woody vegetation based on differences in, for example, stem and/or leaf size and orientation. Moreover the important archive of SAR data (in particular of the ESA ERS and ENVISAT missions) could be valuable for multi-temporal analysis and change detection.

4.2 Radiometric calibration requirements for optical EO data selection

By definition absolute radiometric calibration is the transformation of non-dimensional digital numbers (DNs) into a physical unit of measure, belonging to a community-agreed radiometric scale, based on radiometric calibration metadata files provided by the RS data provider.

The international Quality Assurance Framework for Earth Observation (QA4EO), led by the Committee of Earth Observations (CEOS) Working Group on Calibration and Validation (WGCV) in the context of the Global EO System of Systems (GEOSS) program, considers mandatory an appropriate coordinated program of calibration and validation (Cal/Val) activities throughout all stages of a spaceborne mission, from sensor building to end-of-life. This ensures the harmonization and interoperability of multi-source observational data and derived products. In spite of the QA4EO recommendations and although it is regarded as common knowledge in the RS community, radiometric calibration is often neglected in literature and surprisingly ignored by scientists, practitioners and institutions involved with RS common practice including large-scale spaceborne image mosaicking and mapping.

By making RS data well behaved and well understood, radiometric calibration not only ensures the harmonization and interoperability of multi-source observational data according to the international QA4EO guidelines, but is a necessary, although insufficient, condition for automating the quantitative analysis of EO data (Baraldi et al., 2009 and 2010).

In line with the aforementioned necessary condition for automating the quantitative analysis of EO data the automatic *Remote Sensing Image Understanding System* (RS_IUS) module of the *EO data for Habitat Monitoring* (EODHaM) system proposed by the BIO_SOS project requires as input multi-spectral (MS) images radiometrically calibrated into top-of-atmosphere reflectance (TOARF) or surface reflectance (SURF) values, the latter being an ideal (atmospheric noise-free) case of the former when atmospheric effects are removed or considered negligible.

This means that the proposed RS-IUS considers the inherently ill-posed and difficult-to-solve atmospheric correction of an input multi-spectral (MS) image as an optional rather than compulsory pre-processing stage.

In practice, by requiring as input MS image radiometrically calibrated into TOARF values the proposed RS-IUS is eligible for use with almost any of the existing or future planned spaceborne optical imaging sensors ranging from low (LR, > 30 m) to medium (MR, from 30 to 300 m), high (HR, from 3 to 30 m) and very high (VHR, < 3 m) spatial resolutions.

Exceptions to this general rule are those spaceborne sensors unable to provide RS imagery with radiometric calibration metadata files such as, for example, the KOrean MultiPurpose SATellite (KOMPSAT)-2, the China-Brazil Earth Resources Satellite (CBERS)-1 and -2, the Disaster Monitoring Constellation (DMC), etc.

In addition it is worth mentioning that, as underlined in (Baraldi et al., 2009 and 2010), the Satellite Pour l'Observation de la Terre (SPOT) sensor series, the Indian Remote sensing Satellite (IRS) sensor series and the RapidEye optical sensor constellation provide a band-specific radiometric calibration offset (bias) parameter always estimated as zero. It means that, in RS common practice, these MS images may require a relative calibration stage to be applied in series with an absolute radiometric correction pre-

processing step.

Unfortunately, to date, the aforementioned radiometric calibration issues cannot be considered either obvious or irrelevant as they are often ignored or neglected by the majority of the RS community.

4.3 EO data for monitoring threats to conservation

While there can be many types of threats to conservation depending on the landscape, context and time period of focus, this discussion will focus on some of the more common types of disturbance, including urbanization, road construction, mining, logging, agriculture, fire, hunting, grazing and drought.

EO datasets of medium to fine spatial resolution, such as Landsat, can provide important information on the "signature" of human use in other ways. Ingram et al. (2005) use Landsat EMT+ imagery in conjunction with field plots to derive maps of basal area in a forest in Madagascar. They find, as expected, that basal area increases within the interior of forest patches, and away from villages. Contrary to expectations, they do not find that a road bisecting the forest had any impact on basal area – this relates to the fact that logging in this forest is not mechanized but carried out by local people who carry the timber out on foot, and avoid the road as it is sunny and exposed.

VHR datasets will be important to detect fine scale disturbances, which can range from understanding the fine spatial scale impacts of urbanization and human movement on habitat fragmentation (by providing detailed information on settlements, roads and paths), to the mapping of tree falls, and small scale pest attacks. They 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). For some kinds of disturbances that have an extremely short and focused temporal span, such as fire, 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. Hyperspectral information is less often required for the study of disturbances and threats, but may be useful in specific instances such as when studying foliage discolourations caused by specific pest attacks (Coops et al. 2007).

SAR data can also be used to indicate disturbance and deforestation patterns. For example, Lucas et al. (2008b) established the use of ALOS PALSAR data and Landsat-derived Foliage Projected Cover (FPC) for mapping regrowth but also detecting dead standing trees and patterns of clearing in Queensland, Australia. In Amazonia, Prates et al. (2009) also demonstrated the benefits of using time-series classifications of Landsat sensor data to establish deforestation patterns, periods of active land use prior to regeneration of forests on previously deforested areas, frequency of regrowth clearance and the fire history. Such information was used to determine the pathways of forest regeneration in tropical regions, as defined by the species composition of the pioneer community, and their capacity to recover carbon stocks and biodiversity. The techniques applied in both studies may be applied to European as well as non-European sites.

Fire is an important driver of vegetation dynamics in many landscapes. Fire at low levels can be an important force in maintaining the ecological character of some successional communities. Severe burns can, however, completely change below and above ground ecological conditions, giving rise to long term impacts on vegetation (Neary et al. 1999). They can also have an impact on vegetation well beyond the boundaries of their occurrence, due to wind and rain events that carry ashes and charred soil to other areas (Hudak et al. 2004). The use of EO datasets to monitor fire has been widespread, across a number of continents and contexts. Overall, the time of image acquisition appears to be more critical for fire studies than the spatial or spectral scale of imagery. As directed acquisition of data for specific locations and time periods becomes more common, mapping and monitoring fire is becoming less of a challenge.

A number of different EO datasets, ranging from coarse scale 1 km AVHRR data to VHR images, have been employed to map fires. The choice of a particular spatial scale depends on the type of application. Although MODIS has been widely used at regional scales for automated mapping of fires, the pixel size of 250-500 m makes it unsuitable for local scale studies. For management applications, it is important to have detailed maps of locations where fire is ongoing, in order to manage and limit its spread. For longer term strategic planning, however, images of areas just before, and after burning can help to detect

possible spectral signatures of areas at high risk for burning, which can then be managed through specific, engineered interventions (Lentile et al. 2006). In North America, where studies of fire mapping have been most frequently conducted, Landsat and MODIS datasets are preferred. Yet, the additional spectral resolution provided by ASTER, with five short wave infra red bands compared to the one band of Landsat, and the increased spatial resolution provided by Quickbird and IKONOS, may make them more suitable for fire mapping. These can be investigated for the BIO_SOS sites where fire is or is anticipated to impact ecosystems.

Grazing can be investigated in reasonable detail using Landsat images. Blanco et al. (2009) demonstrated the use of TM datasets to compare the impacts of continuous grazing against a rest-rotational system of grazing in a rangeland in Argentina, concluding that this imagery can be used successfully to map spatial differences as well as temporal variations in vegetation productivity. 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, finding that this method was able to detect erosion due to grazing at a level when it was still easy to manage. The presence of the shortwave infrared band in AVHRR imagery, and therefore presumably also in Landsat data, is considered to be critical for identifying the impact of drought on vegetation (Boyd et al. 2002). Studies in Wales (Breyer, unpublished Ph.D. thesis) 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 levels. Combinations of visible, near infrared and shortwave infrared wavelength regions can also indicate grazing levels.

4.4 Selecting appropriate EO data for biodiversity observations and species monitoring

Invasions and modifications of habitat structure and condition by alien species present an urgent problem for managers of many nature reserves (Vicente et al. 2011). It is especially important to understand the distribution of many of these species at multiple scales for management. At the local scale, obtaining early warning signals of the occurrence and spread of an invasive species is critical for effective managers (He et al. 2011). At the regional scale, it is important to get a sense of the regional environmental factors (e.g., climate, topography, distance to water or transport networks) that may be limiting or enhancing the spread of specific species, in order to understand whether local efforts are of value, or whether the problem needs to be addressed through a larger focus (e.g. on climate change; Vicente et al. 2011). EO data provide an effective and natural way to address these issues at multiple scales, coupled with species modelling. In addition to invasive species, there is also a need for monitoring overall changes in biodiversity within protected areas (Chape et al. 2005), and to specifically focus on changes in species of interest, including threatened species, as mentioned in Target 12 of the CBD 2020's Aichi Targets. Thus, it is important to understand what characteristics of EO data are important for monitoring changes in overall biodiversity, as well as in specific species.

As with habitat mapping, VHR data is considered to be very useful for species mapping. Everitt et al. (2005) used QuickBird to map the distribution of invasive giant reed populations along the Rio Grande in Texas, and achieve very high accuracies of 86-100%, although they acknowledge that this particular species is very easy to distinguish due to its characteristic association in large clumps. Gillespie et al. (2008) review a number of other studies that utilize VHR data to map specific tree species within temperate and mangrove forests, concluding that these datasets provide important information for managers on aspects such as the distribution of selected species, and rates of tree mortality.

Sánchez-Azofeifa et al. (2011) use Quickbird imagery of selected dates to map the distribution of a *Tabebuia* tree species in the Barro Colorado island in Panama. The tree they select for mapping has a short 2-day span of synchronized flowering, which makes it ideal for detection using this approach. They find that they do successfully detect flowering trees, but miss a large proportion of trees belonging to the same species that did not flower due to the presence of lianas or other issues. However, this does indicate the location of individuals that are reproducing. Although this is not an invasive species, this type of approach can be adapted to assess reproducing invasive species if they exhibit synchronized flowering that can be detected from above the canopy.

In contrast to the conclusions of this study, Fuller (2005) attempted to map *Melaleuca quinquenervia*, an invasive tree species in southern Florida, but found that IKONOS imagery was unsuitable for this because the spatial resolution was too high, increasing the variability between different tree canopies and making it hard to identify the tree crowns of the species under study. Where within-habitat variability was low, with dense stands of this species, then they were easy to discriminate – but at the early stage of invasion where densities are low, and it is most useful for managers to be able to discriminate invasives, IKONOS was not very helpful. A study by Nagendra et al. (2010) established that Landsat sensor data were more suited to species mapping in a dry tropical Indian forest compared to IKONOS, because the latter lacked the shortwave infrared channel which is important for discriminating vegetation types. Similar results were also found by a number of other studies, as reviewed in He et al. (2011).

Nagendra and Rocchini (2008) and Lucas et al., (2008b) address some of the reasons behind these findings, pointing out the challenges of dealing with VHR data for discriminating individual plants and trees, as shadow effects caused by tree canopies begin to predominate. Additionally, a recent review by Rocchini et al. (2010) points out that there is a need for analysis at multiple spatial scales, as patterns that are hidden at some spatial scales may be revealed at others. For instance, a study by Kumar et al. (2009) finds that spatial heterogeneity, as assessed by the satellite image-derived Normalized Difference Vegetation Index (NDVI) strongly influenced butterfly species richness in a national park in the USA, but the strength of this relationship varied with spatial scale.

Several other studies have used LiDAR successfully to monitor specific bird species or, less often, mammal species by modeling species-habitat relationships, as reviewed in Vierling et al. (2008). Such approaches can be useful for BIO_SOS although they largely focus on a single species and there is a lack of research that uses laser altimetric data to study assemblages of species.

Spectral heterogeneity can also play a very important role in assessing biodiversity within habitats, and a number of studies have used spectral heterogeneity as a proxy for biodiversity, as summarized in a recent review by Rocchini et al. (2010). For instance, a study by Rocchini (2007) found that Landsat ETM+ and Quickbird imagery performed equally well in predicting species richness in a wetland habitat. While themajority of studies have attempted to use spectral heterogeneity as a proxy for species richness (e.g. Nagendra et al. 2010), Oldeland et al. (2010) found that there was added improvement in accuracy when species abundance information was taken into account, thus indicating the possibility of further utilization of hyperspectral datasets for monitoring changes in biodiversity levels within BIO_SOS.

Finally, timing the acquisition of remotely sensed datasets to coincide with critical phenological stages of flowering or leaf senescence can be very useful for mapping invasive species, as discussed in a recent review by He et al. (2011). For instance, Ramsey et al. (2005) demonstrate the use of space borne hyperspectral data from Hyperion to map an invasive tree, Chinese tallow (*Triadica sebifera*) in a coastal wetland in southwestern Louisiana to accuracy levels of 78%, based on its leaf phenology and using subpixel classification techniques. Andrew and Ustin (2008) provide nuance to our understanding of the challenges in mapping invasive species, through a study of invasive pepperweed in wetlands and riparian habitats in the USA. They found that 3 m 128 band airborne hyperspectral HyMap imagery was capable of successfully discriminating pepperweed in some landscapes, but failed to do so in others. They concluded that increases in the complexity of the habitat, in terms of the number of spectrally and structurally similar species, as well as overall habitat heterogeneity, made it difficult to map invasive species. Mapping was more achievable in simpler landscapes.

5. Identifying appropriate EO datasets for BIO_SOS sites

The following approach is utilized to identify appropriate EO datasets for each of the eleven BIO_SOS sites, based on the criteria for monitoring developed in previous sections. These general criteria should be adapted, not only to the ecological characteristics of each test site and the focal habitat types, but also in relation to the spatial and temporal scales of the specific processes of ecological change being evaluated in each site.

A. Monitoring habitats

1. Tracking changes in extent of habitat types

For each test site, a matrix of land cover and habitat categories will be developed and the following attributes determined. EO datasets will then be selected on the basis of these parameters.

a) Maximum extent.
b) Minimum spatial size.
c) Intra-year variability in relation to the timing of critical seasonal hydrological and phenological events.
d) Minimum inter-year interval between recordings and important reference years for monitoring (especially start year in relation to major policies).
e) Dates and spatial scale of existing maps and field datasets.
f) Important reference years for monitoring.
g) Dominant and important transformations between land cover types and habitats.

2. Tracking changes in habitat condition

For each test site, a set of habitats will be identified where changes in habitat condition need to be monitored. For this sub-set of habitats, the criteria listed above will similarly be considered. In addition, variables such as elevation (derived from DEMs) and climate (e.g., rainfall) will be tracked. Indirect measurements of species or biodiversity indicators (Griffiths and Li 2000; Waser et al. 2004; Duro et al. 2007; Phillips et al. 2008; Nagendra et al. 2010) could also be considered as this would improve the ability to track additional SEBI indicators (see Deliverables D2.1 and D2.2). Sites should be identified where there is a need to monitor changes in habitat condition, including in relation to sub-canopy species such as bushes and shrubs (for the use of LiDAR) or changes in life-form ratios relevant for vegetation processes and the condition of habitats .

3. Monitoring habitat fragmentation

For each land cover/habitat type, the spatial scale of the smallest patch of concern and spatial scale at which it is important to monitor finer within-patch spatial structure (if any) need to be identified. Identification of important linear elements or fine-scale point elements that may have a major disruptive (or positive) influence on connectivity also need to be considered and methods for assessing these quantified.

B. Detection of Human Pressure

We shall also list the human pressures important at each site, record the type of pressure (point, line, polygon) and the maximum and minimum sphere of influence of each type of pressure (if line or polygon), record the spatial scale and time period of any existing field datasets or maps on species abundance, distribution and ancillary information, and identify critical seasons when monitoring is essential.

Finally, the location of site will determine seasonality of habitats, and hence of imagery acquisition dates. For example, temperate regions with seasonality will typically require images from spring (March/April), and summer (July-September). Whilst images from winter (January-February) will also be useful, the sun angle will limit the potential for acquisition of such winter imagery. In tropical regions, persistent cloud cover will limit the ability to acquire cloud-free images and most data are likely to be acquired during the dry season (e.g., July to October in Brazil). In the Mediterranean regions, where most BIO_SOS sites are located, images will be required from spring (March-April), summer (July-September) and winter (January-February). Winter season imagery can also enable the separation of non-photosynthetic vegetation in the GHCs, especially facilitating the differentiation of habitats dominated by species such as bracken (*Pteridium aquilinum*) and purple moor grass (*Molinia caerulea*) that have a litter layer in winter as well as deciduous species with a cover of non-leafy branches (Lucas et al. 2011).

C. Direct measurement of species

Some assessments of species change can be undertaken by linking to changes in habitat quality, condition, density or fragmentation, as described in the preceding sections. For others, direct assessment of changes in species distributions and densities is possible through EO data coupled with ancillary GIS datasets. For this type of approach, within habitat types, sites should identify list important important animal and plant species (dominant, invasive, rare, threatened, indicator of stress etc), record the spatial scale and time period of any existing field datasets or maps on species abundance, distribution and ancillary information, identify critical seasons when monitoring is essential, and describe maximum and minimum size ranges. Predictive modelling supported by in situ species distribution data may be used in connection to direct EO detection in order to improve the overall ability to track changes in species distributions or abundances.

The next series of four tables provide assessments of EO datasets required for each site.

Table 1 summarizes aspects of the sites including the extent, types of CORINE land cover categories, prominent habitat types, critical indicator species, and major types of pressure, which are important to identify the types of EO datasets that may be required for each location. Table 2 considers the existing ancillary and EO datasets, and uses requirements of temporal distinctions and other qualifications to come up with some recommendations as to specific datasets for acquisition. Table 3 summarizes these recommendations as to provide an overview of the spaceborne and airborne remote sensing data considered optimal for each of the study sites considered in BIO_SOS. Finally, Table 4 provides a general summary of spaceborne and airborne sensor datasets with actual and potential application to direct mapping of habitats according to both GHCs and Annex I of the Directive that may be useful for other sites and projects.

Table 1 Site extent, types of CORINE and/or LCCS (if available) land cover categories, prominent habitat types, critical indicator species, and major pressures which are important to identify the types of EO datasets that may be required for each location.

Site Code	Name	Size (ha)	land cover classes: *Corine level 3 taxonomy* *LCCS taxonomy* where available	Important habitat types according to Habitats Directive	Important species	High intensity pressures
GR1	Kalamas River Delta	8481	112, 212, 213, 242, 243, 311, 321, 323, 331, 421, 521, 522	Habitat 1150 (coastal lagoons) is small – 4 ha – but a priority; riparian forests are important for diversity assessment	*Ruppia maritime, Phragmites australis, Cakile Maritima, Salicornia europea, Juncus maritimus, Sarcocornia fruiticosa, Elymus farctus, Salix alba, Populus alba, Euphorbia dendroides, Quercus macrolepis,Tamarix* spp.	Cultivation, grazing, animal breeding, burning, hunting, water pollution, erosion

GR2	Elos Kalodiki	845	211, 242, 243, 311, 323, 411	Habitat 7210 (calcareous ferns with *Cladium mariscus*) cover a small area, but are a priority habitat, rare at the national and European level. Other Mediterranean type ecosystems such as phrygana (5420) and macchia vegetation (934A) are abundant nationally but not widespread at the European level, hence important.	*Cladium mariscus, Salix alba, Salix fragilis, Tamarix* spp., *Quercus coccifera*	No high intensity pressures listed; cultivation is a medium intensity pressure; grazing and hunting are low intensity pressures
GR3	Stena Kalama	1867	243, 311, 312, 313, 321, 323, 324	Riparian forests (92C0) that cover a narrow strip of land parallel to river bed, *Salix alba* and *Populus alba* galleries (92A0), Mediterranean type ecosystems of macchia (934 A) and phrygana (5420) that are abundant nationally but not widespread at the European level, hence important.	*Salix alba, Populus alba, Potentilla caulescens, Quercus frainetto, Fagus sylvatica, Salix fragilis, Platanus orientalis, Quercus coccifera*	Cultivation, grazing, burning, hunting, erosion
NL	Ginkelse, Ederheide and WekeromseZand	1000 for Ginkelse and Ederheide	Not listed	Active inland sand dunes with open *Corynephorus* and *Agrostis* grasslands (2330), dry sand heaths with *Calluna* and *Genista* (2310), dry heaths (4030), species-rich *Nardus* grasslands on silicious substrates (6230), Atlantic acidophilous beech forests with *Ilex*(9120), old acidophilous oak woods with *Quercus robur* on sandy plains (9190)	*Campylopus introflexus, Polytrichem piliferum, Molinia caerulea, Deschampsia flexuosa, Agrostis vinealis, Festuca* spp., *Corynephorus cansecens, Carex pilulifera, Juncus squarrosus, Calluna vulgaris, Erica tetralix, Rubus fruiticoses, Pinus sylvestris, Betula pendula*	Loss of area, fragmentation, eutrophication, salinization, increasing soil moisture, pollution, soil, noise, light, visual, and mechanical disturbance
IT1	Valoni e steppe pedergarganiche	29817	121, 122, 131, 211, 212, 222, 223, 241, 311, 314, 321, 323, 324, 332, 333	Pseudo-steppe with grasses and annuals of the Thero-Brachypodietea (6220), eastern sub-Mediterranenan dry glasslands (62A0), calcareous rocky slopes with chasmophytic vegetation (8210), thermo-Mediterranean and pre-desert scrub (5330)	*Campanula garganica, Lomelosia crenata* subsp. *Dallaportae, Inula verbascifolia, Ephedra nebrodensis, Falco naumanni, Falco biarmicus feldeggi, Neophron percnopterus, Bubo bubo*	Ploughing, establishment of plantations, abandonment of agriculture, fire, quarrying, wind and solar farms, natural hazards
IT2	Zone umide della Capitanata-Paludi press oil Golfo di Manfredonia	14077 and 14437	422, 211, 212, 321, 511, 121, Other	Coastal lagoons (1150), Mediterranean salt steppes (1510), but additionally annual vegetation of drift lines (1210) is threatened because of coastal erosion, and *Salicornia* and other annuals colonizing mud or sand (1310) and Mediterranean and thermo-Atlantic halophilus scrub (1420) are threatened by existing agricultural practices	*Sarcocornietea fructicosae, Limonietalia* spp., *Thero-Salicornietea* spp., *Juncus maritimus, Juncus acutus, Carex* spp., *Phragmites australis*	Cultivation, continuous urbanization
IT3	Murgia Alta	125000	211, 321, 223, 311, 314, 312, 121, 313, 111, 222, Other *LCCS taxonomy:* B15/A4.A13.A14; B15/A4.A13.A16; B15/A4.A13.A17; B15/A3.A8; B15.A2.A6; A11/A.B2; A11/A2.B2-W7/A7.A10; A11/A2.B2-W8/A7.A10; A11/B1-W7/A7.A9.B4; A11(A1.B1.B5-W7/A8.A9.B3; A11/A5.B2.D3-W8; A12/A5.A10.B4/B12; A12/A3.A10.B2/B7; A12/A3.A10.B2/B7; A12/A6.A10.B4/B12; A12/A4.A10.B3/D1.E2	Priority habitat pseudo-steppe with grasses and annuals of the Thero-Brachypodietea (6220), and semi-natural dry grasslands and scrubland facies on calcareous substrates (6210) which form important orchid sites *Additional habitat non considered by Annex I can be found in Deliverable D6.1*	*Stipa austroitalica, Festuca circummediterranea, Thymus spinulosus, Koeleria splendens, Asphodelus ramosus, Aurinia saxatilis* subsp. *megalocarpa, Athamanta sicula, Linaria dalmatica, Linum tommasinii, Ornithalgum adalgisae, Cyclamino hederifolii, Quercetum ilicis,Euphorbio apii, Quercetum trojanae, Stipo bromoidis, Quercetum dalechampii, Falco naumanni, Falco biarmicus feldeggi*	Ploughing, abandonment of grazing, fire impact, forest wildfires
IT4	Le Cesine	2148 and 647	312, 323, 521, 324, 211, 223, 321, 421, 331, Other LCCS taxonomy: B15/A4.A12.A17; A11/A4.B2.C1.D1; A11/A5.B2.C2.D3; A11.B1.C1.D1-W8/A7.A9.B4; A11/a1.B1.B5-W7/A8.A9.B3; A12/A5.A10.B4/B12; A4.A10.B3/D1.E2.B9; A12.A4.A10.B3/B9; A12/A4.A10.B3/B9; A12/A4.A11.B3/B10; A12/ A5.A11.B4/A13.B13; A12/A6.A11.B4/A12.B12; A12/A6.A10.B4/A12.B11; A12/A2.A11.B4/A13.B13; A12.A2.A11.B4/A13.B13; A24/A2.A13.B4/A15.B13;	Coastal lagoons (1150), calcareous fens with *Cladium mariscus* and species of the *Carcion davallinae* (7210), Posidonia beds (1120), coastal dunes with *Juniperus* spp. (2250) and Mediterranean temporary ponds (3170). *Additional habitat non considered by Annex I can be found in Deliverable D6.1*	*Cladium mariscus, Pinus halpensis, Quercus ilex, Erica forskalii, Juniperus macrocarpa* subsp. *macrocarpa, Sarcocornetea fruticosi*	Continuous urbanisation, erosion

			A24/A6.A12.B4/B12; A24/A4.A12.B3/B10; A24/B4/B11; A24/A6.A12.B4/B12; A24/A2.A13.B4/A15.B12;			
PT1	Rios Sabor e Maçãs	53009	324, 321, 322, 243, 242, 223, 211, 241, 313, 312, 311, 222, 333, 334, 231, 221	Forests on slopes (9330, 9340 and 9560), riparian forests along river margins (91E0), relict *Buxus sempervirens* scrub (5110), annual and perennial dry grasslands (6220)	*Pinus pinaster, Cupressus lusitanica, Eucalyptus camaldulensis, Quercus suber, Quercus ilex* subsp. *rotundifolia, Retama sphaerocarpa, Cystisus multiflorus, Juniperus oxycedrus, Cistus ladanifer, Buxus sempervirens*	Construction of dams and reservoirs, plantation of non-autochthonous woods, succession due to grassland abandonment, succession due to the abandonment of grazing.
PT2	Peneda-Gerês	94480	333, 332, 322, 324, 321, 313, 243, 311, 231, 312, 512, 241, 211, 242, 112, 334, 131, 221	Wet heath (4020), acid grasslands (6230) and species rich riparian forests (91E0) are the main priority habitats, hay meadows (6510) and heath (4030) are declining due to post-abandonment succession, dry grasslands with dwarf chamaephytes (6160) and saxicolous habitats (8220, 8230) are rich in endemic plant species and also declining, mires and bogs (7140, 7150) are high conservation residual habitats, and oak forests on mesotrophic soils (9160) and laurel-leaved forests and scrublands (5230) are species rich, ecologically significant habitats in lowlands	*Quercus robur, Quercus pyrenaica, Betula celtiberica, Alnus glutinosa, Pinus pinaster, Pinus sylvestris, Chamaecyparis lawsoniana, Pseudotsuga menziesii, Eucalyptus globulus, Laurus nobilis, Prunus lusitanica,* invasive *Acacia dealbata*, invasive *Hakea sericea*, *Erica australis, Erica umbellata, Ulex europaeus, Cytisus striatus*, several species of perennial grasslands (e.g. *Arrhenatherum elatius*, *Molinia caerulea*, *Juncus effusus*, *Holcus lanatus*)	Forest wildfires, invasive species, succession due to grassland abandonment, succession due to the abandonment of grazing.
UK	Cors Fochno/Borth Bog	200	324, 331, 412, 421, 321, 423, 511, 512, 522, 523, 311, 312, 313, 322, 332, 333	Active raised bog vegetation (7110) is being replaced, and degraded raised bog vegetation (7120) is being actively restored; sand dune communities (2110, 2120, 2130, 2150 and 2190) and saltmarsh (1310, 1320, 1330 and 1340) are other important habitat types	*Sphagna* spp., *Erica tetralix, Andromeda polifolia, Eriophorum angustifolium, Calluna vulgaris, Rhynchospora alba, Myrica gale, Eriophorum vaginatum, Narthecium ossifragum, Drosera* spp., *Vaccinium oxycoccus, Menyanthes trifolia, Rhynchospora fusca, Molinea caerulea, Phragmites australis, Juncus maritimus, Schoenus nigricans*	Grazing, and changes in the hydrological regime
UK	Cors Caron/Tregaron Bog	330	324, 412, 511, 512, 311, 312, 313, 322, 332, 333	Active and degraded raised bogs, transition mires, quaking bogs	*Sphagna* spp., *Erica tetralix, Vaccinium oxycoccus, Andromeda polifolia,Menyanthes trifoliata, Eriophorum angustifolium, Calluna vulgaris, Rhynchospora alba, Myrica gale, Eriophorum vaginatum, Narthecium ossifragum, Drosera* spp., *Molinea caerulea, Phragmites australis, Phalaris arundinacea*	Grazing, and changes in the hydrological regime
BR	Flona Tapajos	545000	Not applicable	Not applicable – important habitat is dense evergreen forest	-	Agriculture, roads

Table 2 Existing ancillary and EO datasets, requirements of temporal distinctions and other qualifications that lead to recommendations of specific datasets for acquisition.

Site Code	Name	Resolution of ancillary datasets	Existing image datasets	Minimum spatial resolution of new EO data acquisition	Temporal distinctions required	LiDAR requirements, if any	Hyperspectral data requirements, if any	Summary of data required
GR1	Kalamas River Delta	Aerial photographs (scale 1:42000 to 1:3000)	IKONOS (multispectral and PAN), ASTER, Landsat MSS, TM, ETM+	Grain should be less than 3 m, especially to map changes in rare habitats, agriculture, fragmentation, complex distribution of habitat types, and small scale sources of disturbance	Aquatic land cover classes can be classified using imagery acquired at any time of the year. For vegetated and land cover classes, require multi-temporal images taken in Jan-Feb, April-May and August-September	Possible for assessing changes in riparian forest structure and diversity	Possible for assessing changes in riparian forest diversity, or separating spectrally similar GHCs	VHR data (IKONOS, Quickbird, GeoEye or Worldview II) for April-May, August-Sep 2011, and Jan-Feb 2011 or 2012, supplemented by HR data (ASTER, IRS or Landsat) for the same seasons. Explore possibilities of acquisition of LiDAR or hyperspectral data to assess riparian habitat, or classify spectrally similar GHCs
GR2	Elos Kalodiki	Not listed	Quickbird (multispectral and PAN), ASTER, Landsat MSS, TM and ETM+	Grain should be less than 3 m, especially to map changes in rare habitats, agriculture, fragmentation,	Aquatic land cover classes can be classified using imagery acquired at any time of the	Not required for this habitat as there is little structurally complex forest cover	Possible for separating spectrally similar GHCs	VHR data (IKONOS, Quickbird, GeoEye or Worldview II) for April-May August-Sep 2011, and Jan-Feb 2011 or 2012, supplemented by HR

				complex distribution of habitat types, and small scale sources of disturbance	year. For vegetated and land cover classes, require multi-temporal images taken in Jan-Feb, April-May and August-September			data (ASTER IRS or Landsat) for the same seasons. Explore possibilities of acquisition of hyperspectral data to assess riparian habitat, or classify spectrally similar GHCs
GR3	Stena Kalama	Not listed	ASTER, Landsat MSS, TM, ETM+	Grain should be less than 1 m, particularly to map elongated patches of riparian forests that are only a few meters wide	Requires multitemporal imagery	Possible for assessing changes in riparian forest structure and diversity, and changes in structure and diversity of other wooded habitats	Possible for assessing changes in riparian forest diversity, or separating spectrally similar GHCs	VHR data (IKONOS, Quickbird, GeoEye or Worldview II) for April-May 2011, Aug-Sep 2011, and Jan-Feb 2011/2012, supplemented by HR data (ASTER, IRS or Landsat) for the same seasons. Explore possibilities of acquisition of LiDAR or hyperspectral data to assess habitat condition of wooded habitats, and classify spectrally similar GHCs
NL	Ginkelse , Ederheide and Wekeromse Zand	Digital aerial photographs, land use databases (25-50 m), digital topographic maps (1:10,000), soil database (1:50,000), Dutch elevation models (precision 5-15 cm), vegetation and vegetation structure maps (1:10,000), management database (scale unspecified)	Airborne hyperspectral imagery (2.4 m), MODIS, Landsat	Grain should e about 1 m, with cartographic scales of 1:5000 to 1:10,000	Images required of mid-July (when vegetation reaches its maximum biomass), mid-August to mid-September (when heather is in blossom), and Jan-Feb (when some grasses are green, but deciduous forest is bare)	Required for assessing the structure (age) and composition of heathland vegetation	Possible for assessing grass encroachment	VHR data (IKONOS, Quickbird, GeoEye or Worldview II) for mid-July, August-Sep 2011, and Jan-Feb 2011 or 2012, supplemented by HR data (ASTER, IRS or Landsat) for the same seasons. Acquisition of LiDAR and hyperspectral data to assess habitat condition of heathland vegetation and map grass encroachment is recommended
IT1	Valoni e steppe pedergarganiche	1:5000 land use image, other ancillary datasets being collected from different bodies	Landsat TM, ETM+	Habitat maps at 1:5000, 1:10,000 and 1:25,000, grain scales of 1-30 m	One assessment between April and May for grasslands, one more in Jan-Feb to discriminate between deciduous and evergreen	May be useful for discriminating structure and condition of complex habitats such as wooded habitats	May be useful for discriminating species diversity and habitat condition of wooded habitats and grasslands	VHR data (IKONOS, Quickbird, GeoEye or Worldview II) for April-May 2011, summer 2011 and Jan-Feb 2011/2012, supplemented by HR data (ASTER, IRS or Landsat) for the same seasons. Acquisition of LiDAR and hyperspectral data to assess habitat condition and species diversity of grassland and forests may be useful
IT2	Zone umide della Capitanata-Paludi press oil Golfo di Manfredonia	1:5000 land use image, other ancillary datasets being collected from different bodies	Landsat TM, ETM+	Habitat maps at 1:5000, 1:10,000 and 1:25,000, grain scales of 1-30 m	Three periods of assessment in January-February (when plant communities have minimum biomass and coastal lagoons show maximum flooding), April-May (spring, when some vegetation communities peak), and August-September (late summer, when other vegetation communities show maximum biomass)	May be useful for discriminating structure and condition of complex habitats such as wooded habitats	May be useful for discriminating species diversity and habitat condition of wooded habitats and grasslands	VHR data (IKONOS, Quickbird, GeoEye or Worldview II) for April-May 2011, Aug-Sep 2011, and Jan-Feb 2011/2012 is essential, supplemented by HR data (ASTER, IRS or Landsat) for the same seasons. Acquisition of LiDAR and hyperspectral data to assess habitat condition and species diversity of grassland and forests may be useful
IT3	Murgia Alta	1:5000 land use image,	Landsat TM, ETM+	Habitat maps at 1:5000,	Two periods of assessment in	May be useful for	May be useful for discriminating	VHR data (IKONOS, Quickbird, GeoEye or

		other ancillary datasets being collected from different bodies		1:10,000 and 1:25,000, grain scales of 1-30 m	April-May (spring, when the dominant grassland reaches its phenological peak), and January-February (to separate deciduous, semi-deciduous and evergreen habitats)	discriminating structure and condition of complex habitats such as wooded habitats	species diversity and habitat condition of wooded habitats and grasslands	Worldview II) for April-May 2011, summer 2011, and Jan-Feb 2011/2012, supplemented by HR data (ASTER, IRS or Landsat) for the same seasons. Acquisition of LiDAR and hyperspectral data to assess habitat condition and species diversity of grassland and forests may be useful
IT4	Le Cesine	Habitat map, CLC map (scale unspecified)	Quickbird (multispectral and PAN), MIVIS, Worldview-2, Landsat TM, ETM+	Habitat maps at 1:5000 and 1:10,000, grain scales of 1-10 m	Three periods of assessment in January-February (when plant communities have minimum biomass and coastal lagoons show maximum flooding), April-May (spring, when some vegetation communities peak), and August-September (late summer, when other vegetation communities show maximum biomass)	May be useful for discriminating structure and condition of complex habitats such as wooded habitats	May be useful for discriminating species diversity and habitat condition of wooded habitats and grasslands	VHR data (IKONOS, Quickbird, GeEye or Worldview II) for April-May 2011, Aug-Sep 2011 and Jan-Feb 2011/2012, supplemented by HR data (ASTER, IRS or Landsat) for the same seasons. Acquisition of LiDAR and hyperspectral data to assess habitat condition and species diversity of grassland and forests may be useful
PT1	Rios Sabor e Maçãs	Land cover maps (1:25000) and other ancillary datasets (at different scales, from 1:10000 to 1:25000)	Landsat TM, ETM+ (30 m – MS)	Less than 1 m data required for some point habitats (like seasonal ponds) and linear habitats (like lines of trees), up to 10-30 m data for focal habitat types	Multiple seasonal imagery from April/May (when the dominant grassland reaches its phenological peak), mid summer (when other vegetation communities show maximum biomass), and mid autumn (October/November. to separate deciduous, semi-deciduous and evergreen habitats)	May be useful for discriminating structure and condition of complex habitats such as wooded habitats	May be useful for discriminating species diversity and habitat condition of wooded habitats and other complex habitat types	VHR data (IKONOS, Quickbird, GeoEye or Worldview II) for April-May 2011, August 2011, and Oct-Nov 2011, supplemented by HR data (ASTER, IRS or Landsat) for the same seasons. Acquisition of LiDAR and hyperspectral data to assess habitat condition and species diversity of grassland and forests may be useful
PT2	Peneda-Gerês	Land cover maps (1:25000) and other ancillary datasets (at different scales, from 1:10000 to 1:25000)	SPOT (10m – MS), Landsat TM, ETM+ (30m – MS), Orthoimagery (0.5 m)	Less than 1 m data required for some point habitats (like mires) and linear habitats (like lines of trees), up to 10-30 m data for focal habitat types	Multiple seasonal imagery from April/May (when the dominant grassland reaches its phenological peak), mid summer (when other vegetation communities show maximum biomass), and mid autumn (October/November, to separate deciduous, semi-deciduous and evergreen habitats)	May be useful for discriminating structure and condition of complex habitats such as wooded habitats	The use of hyperspectral imagery (integrated with aerial imagery) may be useful for discriminating species diversity and habitats condition, including the occurrence of invasion by alien species.	VHR data (IKONOS, Quickbird, GeoEye or Worldview II) for April-May 2011, August 2011, and Oct-Nov 2011, supplemented by HR data (ASTER, IRS or Landsat) for the same seasons. LiDAR may be useful to assess habitat condition. Hyperspectral data is recommended to assess habitat condition and map specific species, especially invasive species.
UK	Cors Fochno/ Borth Bog	Aerial photography, Daedalus airborne multispectral scanner, ordnance maps, historical scanned maps, digital habitat	Landsat MSS, TM, ETM+, ASTER, CASI, Airborne Thematic Mapper, Hyperspectral and LiDAR	To distinguish microtopographica features like hummocks and hollows within active raised bog, VHR data of 1 m is required	Multi seasonal imagery from late March (before leaf flush), mid summer (post leaf flush) and late September/early October (for some species groups like those	LiDAR and Synthetic Aperture LiDAR (SAR) useful for detecting habitat variability and assessment of species diversity, microtopography and habitat	Existing airborne multispectral data can be untegrated with hyperspectral data to develop detailed habitat maps, associated with assessments of species type and habitat condition	VHR data (IKONOS, Quickbird, GeoEye or Worldview II) for late March, late June and late September 2011, supplemented by HR data (ASTER, IRS or Landsat) for late March and late September 2011. Acquisition of LiDAR, SAR and hyperspectral data

		maps, digital vegetation classifications, NEXTMap Britain – topographic data			associated with active raised bogs)	structure and condition		strongly recommended for these habitat types.
UK	Cors Caron/Tregaron Bog	Aerial photography, Daedalus airborne multispectral scanner, ordnance maps, historical scanned maps, digital habitat maps, digital vegetation classifications, NEXTMap Britain – topographic data)	Landsat MSS, TM, ETM+, ASTER, CASI, Airborne Thematic Mapper, Hyperspectral and LiDAR	To distinguish microtopographica features like hummocks and hollows within active raised bog, VHR data of 1 m is required	Multi seasonal imagery from late March (before leaf flush), mid summer (post leaf flush) and late September/early October (for some species groups like those associated with active raised bogs)	LiDAR and Synthetic Aperture LiDAR (SAR) useful for detecting habitat variability and assessment of species diversity, microtopography and habitat structure and condition	Existing airborne multispectral data can be integrated with hyperspectral data to develop detailed habitat maps, associated with assessments of species type and habitat condition	VHR data (IKONOS, Quickbird, GeoEye or Worldview II) for late March, late June and late September 2011, supplemented by HR data (ASTER, IRS or Landsat) for the same seasons. Acquisition of LiDAR, SAR and hyperspectral data strongly recommended for these habitat type.
BR	Flona Tapajos	Ancillary datasets are being collected	Landsat and MODIS	VHR imagery of 1-3 m will be helpful to detect roads, logging, fire and agriculture	MODIS images of 15 day resolutions are useful to detect new hotspots of deforestation; multiseasonal imagery may be helpful but high and frequent cloud cover will determine seasonal availability in this location	LiDAR may be very useful in assessing changes in forest structure and habitat condition especially given the high cloud cover	Hyperspectral data can also be very useful in assessing species diversity and relating it to habitat condition and pressure, if data from cloud free periods is available	VHR data (IKONOS, Quickbird, GeoEye or or Worldview II) for at least three cloud free seasons, supplemented by HR data (ASTER, IRS or Landsat) for the same dates, and 15 day MODIS composites to assess hotspots of deforestation. Acquisition of LiDAR, SAR and hyperspectral data strongly recommended for this landscape.

Table 3 Summary of optimal periods for data acquisitions

Study site	Spaceborne Coarse	Spaceborne High Resolution (HR)		Spaceborne Very High Resolution (VHR)		Airborne		
	Multispectral[1]	Multispectral[2]	SAR[3]	Multispectral[4]	Hyperspectral[5]	Hyperspectral[6]	LiDAR[7]	Aerial photo[8]
GR1 - Kalamas River Delta		Apr/May, Aug/Sep, Jan/Feb		Apr/May, Aug/Sep, Jan/Feb	Apr/May	Apr/May	*	
GR2 - Elos Kalodiki		Apr/May, Aug/Sep, Jan/Feb		Apr/May, Aug/Sep, Jan/Feb	Apr/May	Apr/May	*	
GR3 - Stena Kalama		Apr/May, Aug/Sep, Jan/Feb		Apr/May, Aug/Sep, Jan/Feb	Apr/May	Apr/May	*	
NL - Ginkelse, Ederheide and WekeromseZand		Mid-July, Aug/Sep, Jan-Feb		Mid-July, Aug/Sep, Jan-Feb	Mid-July	Mid-July	*	
IT1 - Valoni e steppe pedergarganiche		Apr/May, Aug-Sep, Jan/Feb		Apr/May, Aug-Sep, Jan/Feb	Apr/May	Apr/May	*	
IT2 - Zone umide della Capitanata-Paludi press oil Golfo di Manfredonia		Apr/May, Aug-Sep, Jan/Feb		Apr/May, Aug-Sep, Jan/Feb	Apr/May	Apr/May	*	
IT3 - Murgia Alta		Apr/May, Aug-Sep, Jan/Feb		Apr/May, Aug-Sep, Jan/Feb	Apr/May	Apr/May	*	
IT4 - Le Cesine		Apr/May, June-Aug-Oct, Jan/Feb		Apr/May, June-Aug-Oct, Jan/Feb	Apr/May	Apr/May	*	
PT1 - Rios Sabor e Maçãs		Apr/May, Summer, Oct/Nov		Apr/May, Summer, Oct/Nov	Apr/May, Summer	Apr/May, Summer	*	
PT2 - Peneda-Gerês		Apr/May, Summer, Oct/Nov		Apr/May, Summer, Oct/Nov	Apr/May, Summer	Apr/May, Summer	*	
WL - Cors Fochno/ Cors Caron		Late March, Late June, Late Sep	Any	Late March, Late June, Late Sep	Late June	Late June	*	
BR - Flona Tapajos	Any; 15 days	Alternate cloud free months	Any	Alternate cloud free months	First post-monsoon cloud free month	First post-monsoon cloud free month	*	

[1]MODIS; [2]Landsat, IRS, ASTER, SPOT; M = Mid; L= Late; [3]X-band, C-band, L-band; [4]Quickbird, IKONOS, GeoEye; [5]Worldview; [6]CASI, EAGLEHAWK, HYMAP, MIVIS;[7]Discrete return/full waveform; [8]True colour/colour infrared

Table 4 Spaceborne and airborne sensor data with actual and potential application to direct mapping of GHCs.

GHC1	GHC2	GHC3	Existing data layers	Multispectral[2]	SAR[3]			MSI[4]	HS[5]	MS[6]	HS[7]	LiDAR[8]	Aerial photo[9]
					X	C	L						
URB	ART		≑					≑					≑
	NON		≑					≑					≑
	VEG		≑					≑					≑
	GRA		≑					≑					≑
	TRE		≑					≑	≑		≑		≑
CUL	SPA		≑	≑	≑	≑							≑
	CRC		≑	≑	≑	≑							≑
	WCC		≑	≑			≑	≑	≑				≑
SPV	SEA		≑	≑			≑						
	TID			≑	≑	≑	≑						
	AQU		≑	≑	≑	≑	≑						
	ICE			≑	≑	≑	≑						
	ROC			≑									
	BOU			≑			≑						
	STO			≑	≑	≑							
	GRY			≑	≑	≑							
	SAN			≑	≑	≑							
	EAR												
TRS	DCH			≑			≑					≑	
	SCH			≑	≑	≑						≑	
	LPH			≑	≑	≑						≑	
	MPH			≑	≑	≑	≑					≑	
	TPH			≑	≑	≑	≑					≑	
	FPH			≑	≑	≑	≑					≑	
	GPH			≑	≑	≑	≑					≑	
		DEC		≑S							≑		
		EVR		≑							≑		
		CON		≑							≑		
		NLE		≑							≑		
		SUM		≑S							≑		
SHY				≑	≑	≑							
EHY				≑	≑	≑	≑				≑		
HEL								≑	≑		≑		
LHE								≑	≑		≑		
CHE								≑	≑		≑		
THE								≑	≑		≑		
GEO								≑	≑		≑		
HCH								≑	≑		≑		
CRY								≑	≑		≑		

S = Seasonal imagery

6. Appendix 1: Detailed assessment of EO data available and to be acquired for Dyfi catchment, including Cors Fochno training site

6.1 Introduction

To support the BIO-SOS project, a large number of spaceborne and airborne datasets are available for the Dyfi catchment (including Cors Fochno) in mid Wales. Historical time-series of Landsat Multi-Spectral Scanner (MSS), Thematic Mapper (TM) and Enhanced TM (ETM+) data are available from the mid 1970s and continue to be acquired. These are complemented by data acquired by the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), Indian Remote Sensing Satellite (IRS) and SPOT sensors, including the higher resolution (10 m) SPOT-5 High Resolution Geometric (HRG). Very High Resolution (VHR) resolution KOMPSAT panchromatic/multispectral (1/4 m spatial resolution) and Worldview panchromatic data (50 cm) data have only recently been acquired (in 2010 and 2011 respectively in the framework of previous projects) and no Quickbird or IKONOS imagery have been identified. Spaceborne C- and X-band Synthetic Aperture Radar (SAR) data have been acquired although archives have not been searched. However, both Japanese Earth Resources Satellite (JERS-1) SAR and Advanced Land Observing Satellite (ALOS) Phased Arrayed L-band SAR (PALSAR) data are available for the Dyfi catchment. Airborne hyperspectral datasets have been acquired over Cors Fochno by the United Kingdom (UK) Natural Environment Research Council (NERC) in 2002 and 2009 and by the CASI and EAGLEHAWK sensors respectively. In the latter campaign, Light Detection and Ranging (LiDAR) data were also acquired together with digital photography. Airborne digital photography are also acquired on a near annual basis for all of Wales, including the Dyfi catchment. A summary of the available datasets and dates of acquisition are provided in Table 1, which also indicates which datasets have been obtained and which require purchase. It is worth noting that the RS_IUS Satellite Image Automatic Mapper™ (SIAM™) first stage can only accept as input RS images radiometrically calibrated into top-of-atmosphere (TOA) reflectance (TOARF) or surface reflectance (SURF) values, the latter being an ideal (atmospheric noise-free) case of the former when atmospheric effects are removed or considered negligible (Baraldi et al. 2009 and 2010). This means that, for example, RS images provided with no radiometric calibration metadata files such as Kompsat's, CBERS' and DMC's cannot be used in the BIO_SOS project, also refer to Section 4.2 .

Table 6.2.1. List of recent (from 2002 onwards) spaceborne and airborne sensor data acquired over the Dyfi catchment, including Cors Fochn

Sensor	Date
SPOT HRG	7th November 2006* 29th January, 2011† 2nd March, 2011†
Landsat TM	19th July, 2006*
Landsat ETM	17th April, 2010*
ASTER	18th October, 2004* 24th June, 2003* 1st June, 2003*
IRS	13th July 2006*
KOMSAT	8th October, 2010†
Worldview	26th March, 2011†
ALOS	9th June 2010*

Sensor	Date
ATM/CASI*	24th September 2002
EAGLE HAWK**	1st June, 2009
LIDAR**	1st June, 2009

* Available

** Becoming available

† Available for purchase

Tasking of high to very high resolution spaceborne datasets is considered essential in order to obtain sufficient data. Although cloud cover is persistent across Wales, there are known windows of opportunity particularly in March and early April, July and September/early October. Imagery acquired in the winter months (from mid November to late February) is compromised by the low sun angle, particularly in areas of relief. However, Cors Fochno is low lying and on level terrain and illumination effects are therefore comparatively minimal. The following sections provide illustrations and descriptions of available imagery and comment on their general utility for habitat mapping and monitoring. Examples of habitat maps available for Cors Fochno are also presented.

6.2 Satellite sensor data

Whilst single-date observations provide an opportunity to discriminate broad vegetation types (e.g., forests, grasslands), the use of multi-date observations over a season is considered necessary. Within regions with a greater occurrence of cloud cover, no single sensor provides observations throughout a season but the use of data acquired by different optical sensors allows the phenology of vegetation to be captured. The following provides a summary of the main datasets acquired over the Dyfi catchment and the particular benefits for land cover and habitat classification and monitoring.

6.3 SPOT-5 High Resolution Geometric (HRG)

The SPOT-5 HRG could be particularly useful for habitat mapping because the 10 m spatial resolution (in visible/near infrared wavebands) allows important features in the landscape (e.g., hedgerows, parkland trees) to be resolved. Higher resolution (2-5 m) products are also available. These data are also useful for segmenting the landscape into recognisable units, although this can be assisted with the use of digital cadastral data (e.g., representing field boundaries). The inclusion of the shortwave infrared data (at 20 m spatial resolution) is also beneficial for land cover and habitat discrimination.

In the framework of previous projects, for the Dyfi catchment, all of the SPOT-5 HRG images have been acquired in late autumn, winter or early spring (Figures 1 – 3), with the most recent being 3^{rd} March, 2011. With the exception of the low lying regions, including Cors Fochno, the imagery is of limited use for discriminating habitats in hilly terrain, even when topographic correction is applied. For this reason, targeted acquisition of SPOT-5 data in the early spring, mid summer and/or late autumn is recommended.

6.4 Landsat sensors

An extensive time-series of Landsat sensor data exists for the Dyfi catchment extending back to the 1975 and over a period of 35 years. The majority of data were acquired in the months of June and July and September. Examples of recent Landsat sensor data (2006 and 2010) are given in Figures 4 and 5. Whilst the spatial resolution of these data is too coarse to resolve some habitat classes (e.g., hedgerows, buildings), these data can be used to quantify seasonal changes in reflectance within pre-defined objects and can also be used to describe complex habitats (e.g., through use of fuzzy classifications). The inclusion of the blue waveband allows better detection of ploughed fields and discrimination from grazed pastures or crops at various stages of development.

Table 6.2.2. Landsat sensor data available for the Dyfi catchment, 1975 to 2010 (35 year period)

Scene name (USGS)	Path	Month	Year
LM22200231975159AAA05	8	June	1975
LT52040231984204AAA08	22	July	1984
LT52040231989041XXX06	10	February	1989
LE72040231999253EDC00	10	September	1999
LE72040232002085SGS00	26	March	2002
LE72040232002245EDC00	2	September	2002
LE72040232003296EDC01	23	October	2003
LT52040232003256MTI01	13	September	2003
LE72040232004059ASN01	28	February	2004
LE72040232004251EDC02	7	September	2004
LE72040232005317EDC00	13	November	2005
LT52040232006168KIS00	17	June	2006
LE72040232006160EDC00	9	June	2006
LT52040232006200KIS00	19	July	2006
LE72040232009152ASN00	1	June	2009
LE72040232010107ASN00	17	April	2010
LE72040232010171ASN00	20	June	2010

6.5 ASTER

The ASTER provides visible/near infrared and shortwave infrared data at 15 m and 30 m spatial resolution respectively. These visible/near infrared data are of sufficient spatial resolution for resolving many landscape features and the shortwave infrared wavebands (6 in total) are sensitive to moisture within the landscape and have proved useful for discriminating bog habitats (Lucas *et al*., 2011). These data can also provide input to algorithms for classifying complex landscapes (e.g, mosaics) and are a useful infill for when data from other sensors (e.g., Landsat) are not available. A number of ASTER scenes are available for Cors Fochno (Figure 6a-c), with these acquired over periods where discrimination of some habitats (e.g., raised bog habitats, marshy grasslands) from single-date imagery may be optimal.

6.6 Indian Remote Sensing Saellite (IRS).

The most recent IRS sensor, the Linear Imaging Self Scanning Sensor (LISS-3), provides three visible/near infrared and one shortwave infrared waveband, with all being of the same spatial resolution (23.5 m). This is in contrast to its predecessors (IRS 1C/D) in which SWIR data were acquired at 70.5 m spatial resolution. The IRS LISS-3 SWIR data are therefore more directly comparable to the VNIR data compared to ASTER and SPOT-5, although spatial resolution is often too coarse to resolve detail within the landscape. IRS data provide an additional source of spectral information that can be exploited for classifying land cover and habitats based on comparison of multi-temporal signatures and for describing complex mosaics. Imagery is available for Cors Fochno in the summer of 2006 (Figure 6d)

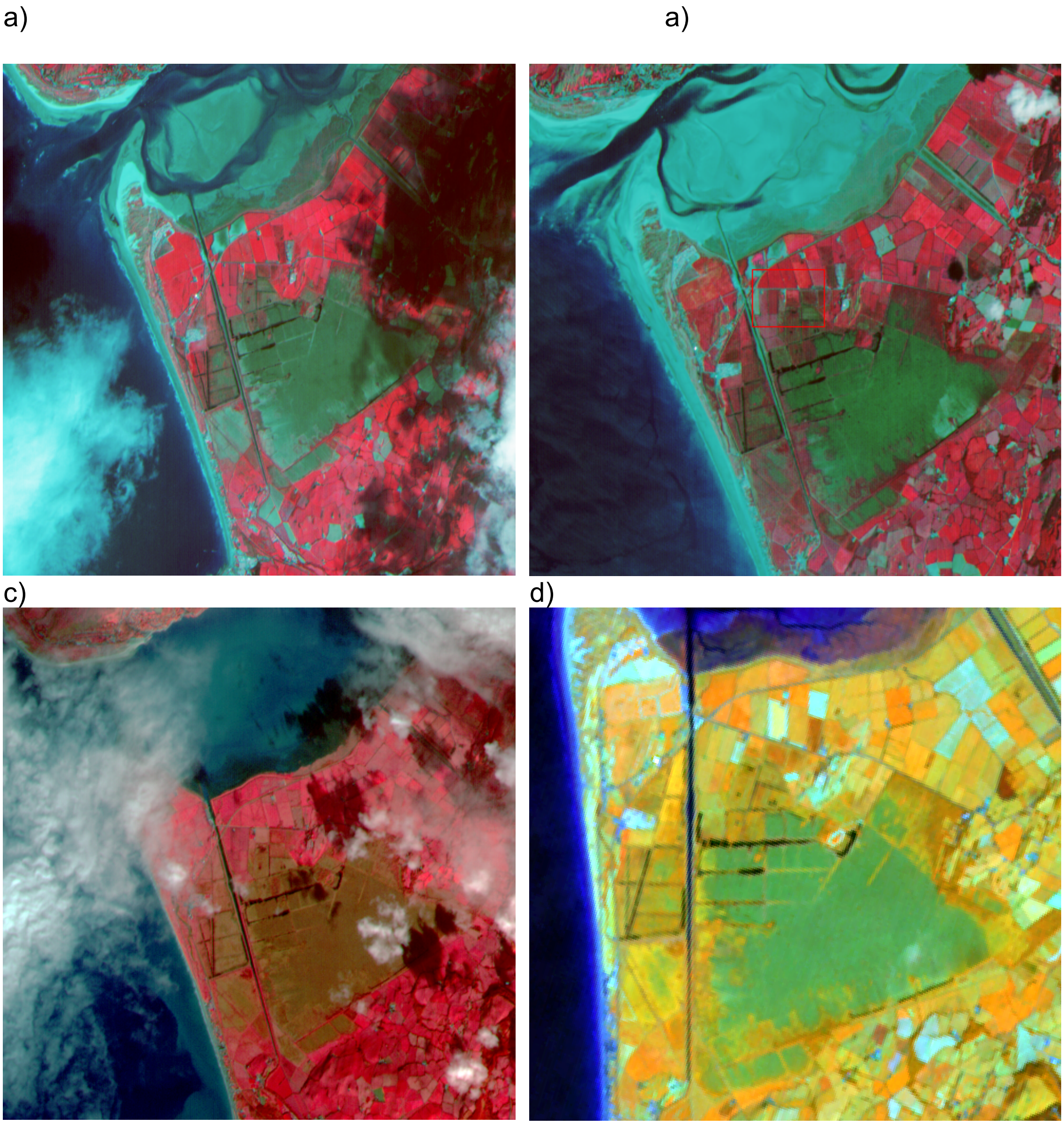


Figure 6.2.6. ASTER data (VNIR) acquired on 18th October, 2004, b) 24th June, 2003 and c) 1st June, 2003. d) IRS LISS-3 image (VNIR, SWIR) of Cors Fochno acquired on 13th July 2006

6.7 VHR data

VHR spaceborne datasets are fundamental to the BIO-SOS project in terms of identifying and monitoring indicators of change. Whilst most sensors operate in the VNIR regions and at spatial resolutions of 60 cm to 4 m (e.g., Quickbird, IKONOS), Worldview-2 is an exception as it acquires in 8 wavelength regions including the red edge which provides additional information for discriminating plant species or communities. Discrimination can also be enhanced by using time-series of VHR imagery, as phenological differences can be exploited. For Cors Fochno, KOMPSAT-2 acquired 1 m panchromatic and 4 m multi-spectral (red, green, blue and near infrared) data on 8th October, 2010 (image footprint of 15 x 15 km) in the framework of a previous project, although the latter were only for the western section (Figure 7). Worldview panchromatic data were acquired at a spatial resolution of 0.5 cm on the 26th March, 2011. KOMPSAT data will not be used within BIO_SOS. Whilst Worldview data can be calibrated, they are considered to provide no more information than the aerial photograph coverage available for the site. Additional multispectral bands will be acquired in the present BIO_SOS project.

a) b)

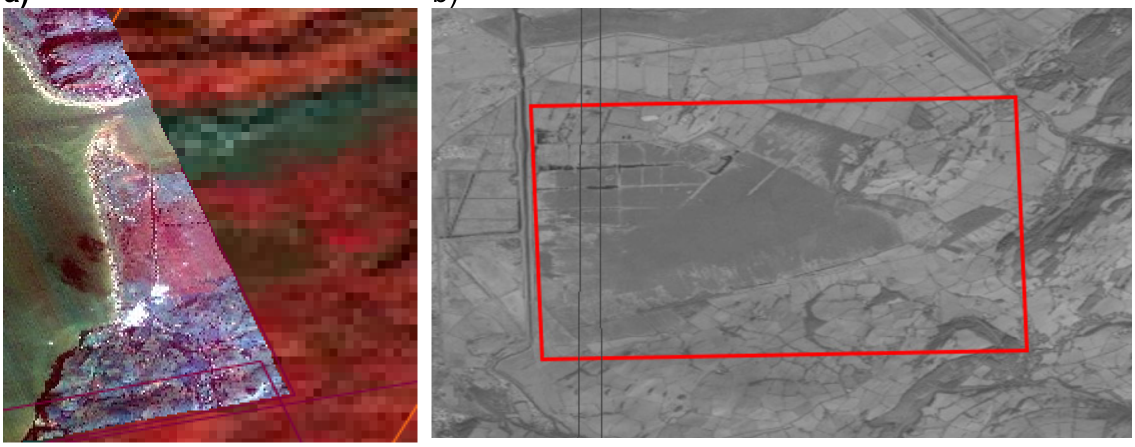


Figure 6.2.7a) KOMPSAT and b) Worldview data acquired on October, 2010 and 26th March, 2011 respectively

6.8 ALOS PALSAR

Advanced Land Observing Satellite (ALOS) Phased Arrayed L-band SAR (PALSAR) data are available for the Dyfi catchment, with several acquisitions per year in fine beam single (FBS; L-band HH), fine beam dual (FBD; HH and HV) and fully polarimetric (HH, VV and HV). L-band microwaves are sensitive to the woody components of vegetation and a large number of studies have established relationships between L-band HV and biomass and sensitivity to surface moisture is evident. For Cors Fochno, differences between raised bog and marshy grasslands are evident within the ALOS PALSAR FBD, with these attributed to contrasts in their 3D structure (Figure 8). Areas of woody vegetation, including scrub, are also discriminated providing potential for mapping of General Habitat Categories (GHCs).

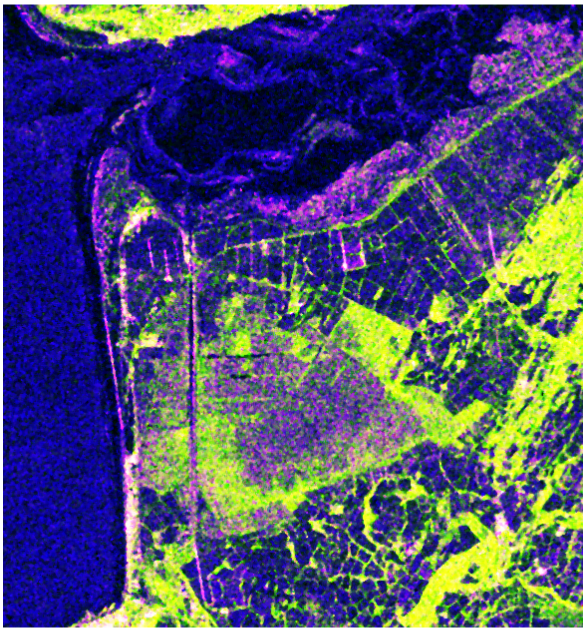


Figure 6.2.8. ALOS PALSAR FBD image acquired on 9th June 2006, with L-band HH, HV and the ratio of HH and HV in RGB respectively. Areas in yellow represent woody vegetation but also *Molinea*-dominated marshy grasslands. The extent of raised bog is well defined, with variations attributed to differences in structure and surface moisture conditions.

6.9 Aerial Imagery

For Cors Fochno and the Dyfi catchment, VEXCEL aerial photography were acquired in 2006, 2007 and 2009, an example of which is given in Figure 9. These data are not calibrated and, whilst digital, are largely used for interpretation and vector-based mapping. In September, 2002, a Natural Environment Research Council (NERC) airborne campaign was conducted, during which multi-spectral Airborne Thematic Mapper (ATM) and hypespectral Compact Airborne Spectrographic Imager (CASI) data were acquired (Figure 10). A subsequent NERC airborne campaign on 1st June, 2009, acquired hyperspectral EAGLEHAWK data (Figure 11), including in the short wave infrared, digital photography and Light Detection and Ranging (LiDAR) data (Figure 12). LiDAR data have also been acquired by the Environment Agency (EA).

Figure 6.2.9. Vexcel colour infrared aerial photography of Cors Fochno and surrounds. Coverage extends to the whole of Wales.

For generating a detailed spatial baseline of habitats and species distributions within Cors Fochno and the surrounding landscape and for detecting change, the use of the hyperspectral datasets acquired in 2002 and 2009 is considered essential, particulary as spaceborne sensor data have similarly been acquired over this time frame. The hyperspectral data allow better separation of vegeation types based on spectral differences alone but also derived information including endmember fractions (e.g., photosynthetic, non-photosynthetic vegetation, shade/moisture) and vegetation indices. Within the bog environment, in particular, microtopography is an important indicator of bog condition and the integration of LiDAR data (acquired in 2009) is considered beneficial for establishing a baseline although establishing the appropriateness of the post-spacing for detecting such differences requires further investigation

Figure 6.2.10. Airborne Thematic Mapper (ATM) data acquired over Cors Fochno on 24 September, 2002.

Figure 6.2.11. EAGLEHAWK data acquired over Cors Fochno on 1st June, 2009.

Figure 6.2.12. Airborne LiDAR data of Cors Fochno.

6.10 Overview of satellite sensor data useful for Wales test sites

With the exception of Landsat sensor data, all imagery has or can be obtained in Level 1A format such that they can be pre-processed within the BIO-SOS project. Orthorectification to a UTM projection (WGS 84) is required as a standard for all sites. To assist orthorectification of imagery acquired for the Dyfi catchment, Nextmap Britain Digital Elevation Model (DEM) data can be used, with this available at 5/10 m spatial resolution for the UK. High resolution aerial photography can be exploited for ground control point (GCP) collection where needed. Other DEMs may be available for European sites, with the Shuttle Radar Topographic Mission (SRTM; 90 m) and ASTER-derived (30 m) data provided free of change. Tandem-X DEM are anticipated to be available in the near future but the cost of DEMs of varying spatial resolution is currently uncertain.

Orthorectification options for several sensors (e.g., ASTER) are available within ENVI. Other software (e.g., the ERDAS/Leica Photogrammetry Suite (LPS) or SOCETSET) provides specific capability for orthorectification of SPOT, IRS, Landsat sensor and other high-resolution data. SAR data can be processed (orthorectified and calibrated) using software such as Gamma and SARScape and PolsarPro, which provides options for handling SAR data, with special capability for analysis of polarimetric data. Open source software associated with the Alaska SAR Facility and ESA) are also becoming increasingly available.

Partner 6 (PKI) and Partner 7 (ALTAMIRA) will apply the proposed BIO_SOS processing chain to the optical and SAR data of this site, respectively.

A summary of the data available over Cors Fochno is given in Table 3. Within the UK, most imagery is processed using the Ordnance Survey British National Grid and so data may be best processed using this projection, with output products then projected to UTM Zone 30 North. As satellite sensor data are acquired at different spatial resolutions, a ‘standard’ resolution (e.g., 10 m, even if for output products) should be defined within the BIO-SOS project rather than native resolutions maintained.

Table 6.2.3. Processing levels of imagery available for the Dyfi catchment

Sensor	Date	Processing Level		Source
SPOT HRG	7th November 2006*	Level 1A		SPOT Image
	29th January, 2011[†]	Level 1A		SPOT Image
	2nd March, 2011[†]	Level 1A		SPOT Image
Landsat TM	19th July, 2006*	Orthorectified	UTM Zone 30 North	USGS[1]
Landsat ETM	17th April, 2010*	Orthorectified	UTM Zone 30 North	USGS[1]
ASTER	18th October, 2004*	Level 1A		USGS[1]
	24th June, 2003*	Level 1A		USGS[1]
	1st June, 2003*	Level 1A		USGS[1]
IRS	13th July 2006*	Level 1A		Infoterra
KOMSAT	8th October, 2010[†]	-		SPOT Image
Worldview	26th March, 2011[†]	-		Geoimage
ALOS	9th June 2010*	Level 1.0		JAXA[2]

[1]Image search through the USGS Global Visualisation Viewer (GLOVIS); [2]Japanese Space Exploration Agency;

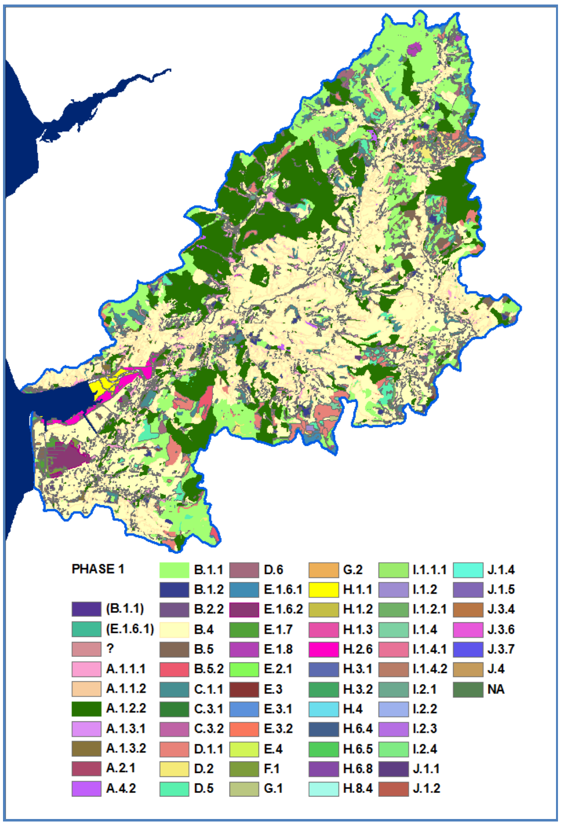
According to the requirements of the RS_IUS SIAM™ first stage (Baraldi et. al., 2009 and 2010), RS images provided with radiometric calibration metadata files exclusively can be adopted as input by the BIO_SOS project. The pre-processing chain, including topographic correction, will be carried out according to the RS_IUS chain.

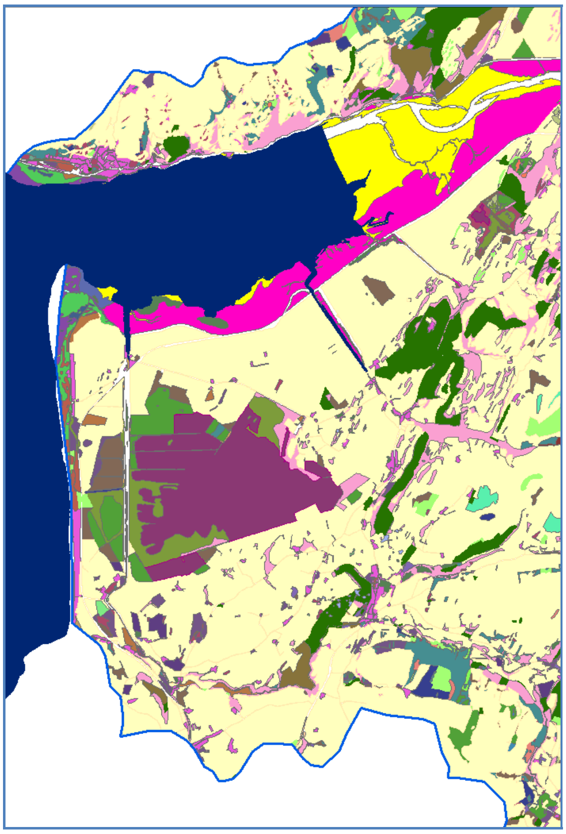
The cost of new VHR data may limit their use within the BIO-SOS project, however the GMES warehouse policy will be explored.

6.11 Habitat maps already produced in the framework of previous projects

For Cors Fochno, a number of habitat maps as opposed to land cover maps have been generated. The Phase 1 Habitat Survey commenced with the Upland Survey in 1979 followed by a lowland survey (completed in 1997). The survey has not been updated subsequently because of the costs associated with field data collection and analysis. A National Vegetation Classification has also been undertaken.

Satellite-based classifications of land cover have been generated as part of the UK Land Cover maps of 1990 and 2000. However, based on the method of Lucas et al. (2006), an object-orientated classification of sub-habitats across Wales has been generated recently using satellite sensor (SPOT, ASTER and IRS) data, and these are progressively been translated into Phase 1 habitats (Lucas et al., 2011) to generate a new and updatable national Phase 1 Survey map (for release in early 2012). Examples of the habitat classifications are provided in Figure 13 to 14.





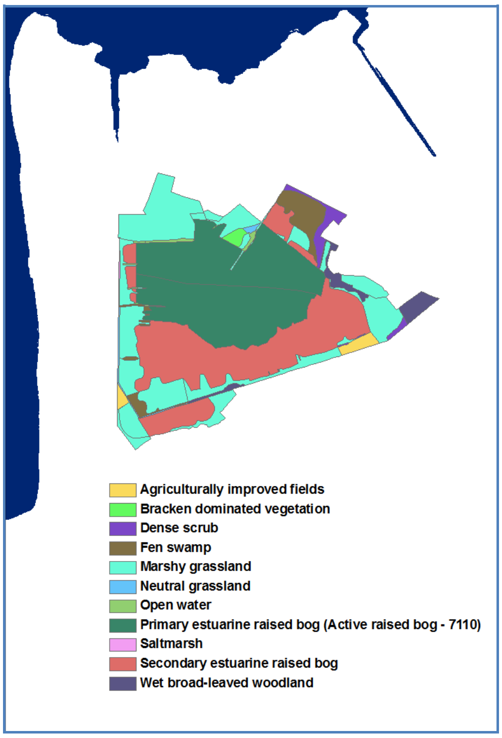


Figure 6.2.13. Phase 1 habitat maps for a) the Dyfi catchment and b) Cors Fochno and c) National Vegetation Classification (NVC) for Cors Fochno

a) b)

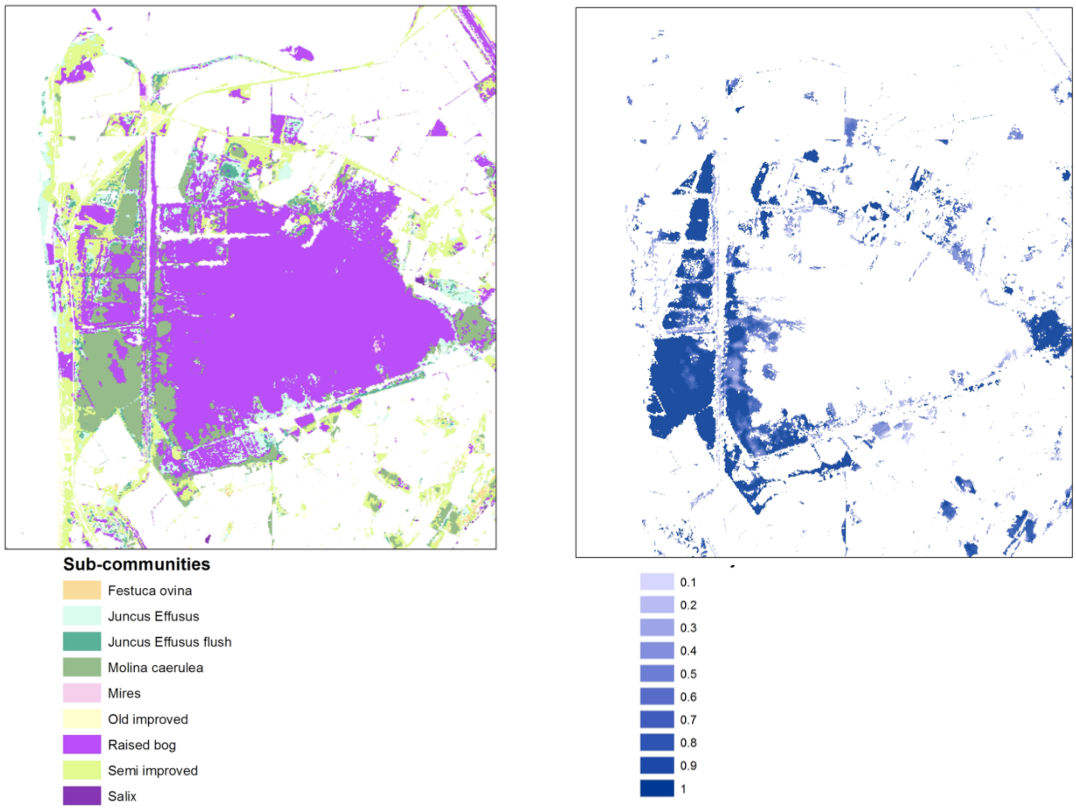


Figure 6.2.14. a) Revised habitat classification of Cors Fochno and surrounds achieved through object-based classification of SPOT and IRS data and b) class membership for *Molinea caerulea* based on fuzzy classification.

7. Appendix 2: Italian training sites data

The list of archive data available for two Italian training sites, i.e. Murgia Alta and Le Cesine, named as IT3 and IT4 in previous Deliverable 2.2 and Deliverable 6.1, respectively, is reported in the following two Tables.

Table 7.1 MURGIA ALTA, site IT3. List of VHR archive data.

Anno	Quickbird	Geoeye-1	Ikonos	Worldview-1	Worldview-2
2004			2004-03-29		
			2004-06-11		
2005			2005-03-18		
			2005-04-17		
			2005-04-23		
			2005-04-26		
			2005-04-28		
			2005-05-09		
2006	2006-10-26				
	2006-11-08				
2007	2007-07-18		2007-04-20	2007-11-03 2007-12-13	
			2007-04-23		
2008	2008-05-27			2008-01-03	
				2008-02-20	
				2008-02-24	
				2008-03-26	
	2008-06-01			2008-03-30	
				2008-04-25	
	2008-09-04			2008-08-23	
2009	2009-03-16	2009-07-31	2009-04-16	2009-03-24	
	2009-04-16	2009-11-21			
	2009-05-04				
	2009-05-09		2009-05-06	2009-07-13	
	2009-06-09				
2010		2010-04-21			2010-01-10
		2010-05-13			
		2010-05-18			
		2010-07-07			
		2010-09-05			
		2010-07-07			
		2010-09-05			

It is well known this target area is exposed to tremendous anthropic pressures. Priority habitats such as 6220 and 6210 are exposed to agricultural intensification/expansion based on grained soil.

LANDSAT images are already available at CNR. These are dated:1998-03-07;1999-09-26;2001-01-02; 2001-08-14; 2004-08-30; 2010-09-16. The IKONOS image dated 2009-04-15 has been recently bought.

The most recent Landsat image, dated 2010-09-16, has been analyzed by the RS_IUS SIAM™ first stage. This Landsat image together with its 7-band Landsat-like SIAM™ (L-SIAM™) preliminary spectral map at fine semantic granularity, featuring 92 output spectral categories, are depicted in Figure 7.1. .

Figure 7.1.1

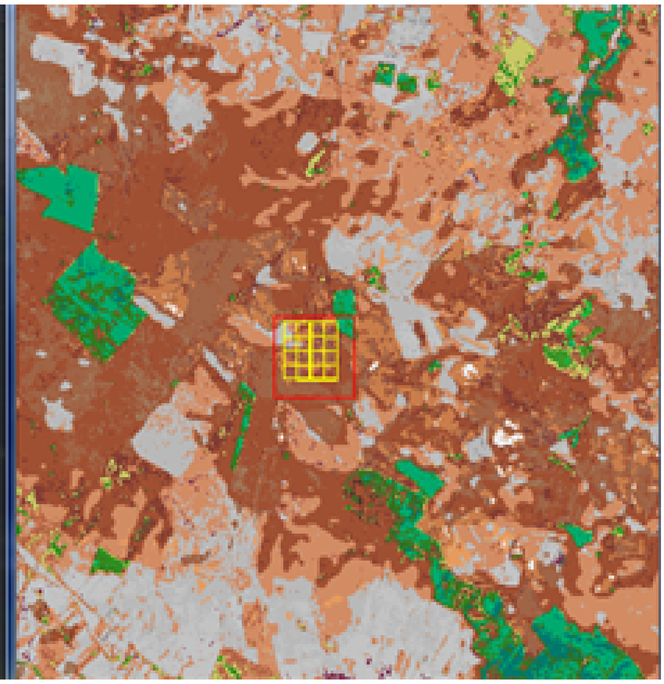


Figure 7.1.2

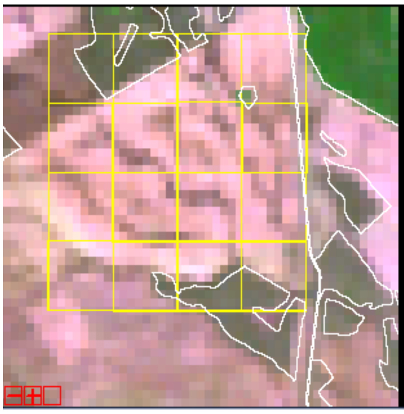


Figure 7.1.3

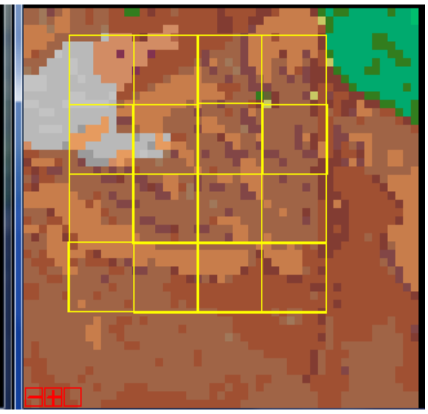


Figure 7.1.4

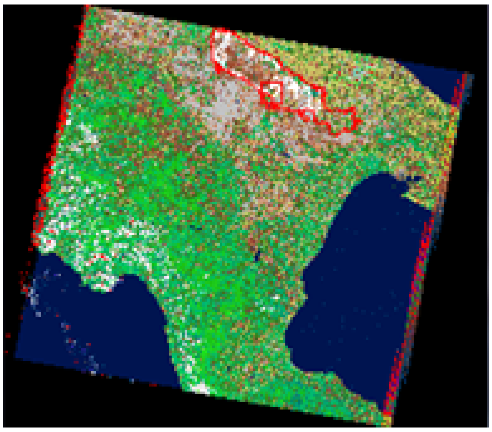


Figure 7.1.5

Figure 7.1. LANDSAT image dated 2010-09-16. The yellow grid corresponds to one of the 1km^2 sampling area for GHC training. An RGB=341 original band composition of a window and the zoomed area corresponding to the grid, is shown in Figure 7.1.1 and in Figure 7.1.3, respectively. The preliminary spectral output map obtained by the RS_IUS 7-band Landsat-like SIAM™ (L-SIAM™) first stage from the window, the zoomed area and the Landsat scene is shown in Figure 7.1.2, Figure 7.1.4 and Figure 7.1.5 respectively. The adopted 7-band L-SIAM™ map legend is shown in Figure 7.2.

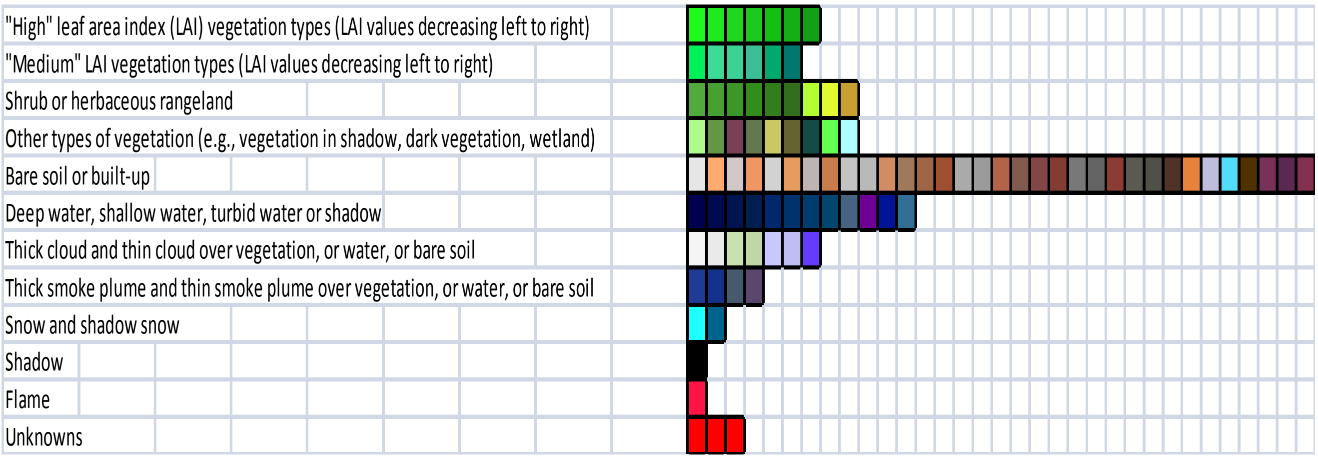


Figure 7.2. Landsat-like SIAM™ (L-SIAM™) map legend at fine semantic granularity featuring 92 spectral categories.

Table 7.2 Le Cesine, site IT4. List of VHR archive data

Anno	Quickbird	Geoeye-1	Ikonos	Worldview-1	Worldview-2
2005	2005-07-15				
	2005-06-09				
2006			2006-10-02		
2007	2007-07-08				
2009	2009-06-04			2009-08-12	
				2009-11-01	
2010		2010-04-21			2010-10-09
		2010-04-26			

For the Le Cesine study area, three images have been already pre-processed for radiometric and geometric corrections and analysed by the 4-band Ikonos-like SIAM™ (I-SIAM™) first stage of the proposed BIO_SOS RS-IUS system. The available set of very high resolution (VHR) images comprises two QuickBird images, dated 2005-07-15 and 2009-06-04, both bought in the framework of previous projects, and one WorldWiew-2 image dated 2010-10-09, refer to Figure 7.3. New acquisitions will be ordered according to the user requirements evidenced in D6.1 and reported in the present deliverable for better discrimination of habitats: June and August 2011, February and April 2012.

The QuickBird image acquired on 2005-07-15 and its 4-band I-SIAM™ preliminary map are depicted in Figure 7.3. The I-SAIM™ map legend at fine semantic granularity, featuring as output a finite and discrete set of 52 spectral categories, is shown in Fig. 7.4.

To provide field surveys in target geographic areas with prior knowledge about land cover types, SIAM™ preliminary classification maps were adopted during the GHC Training session held in Bari on 18-20 April 2011.

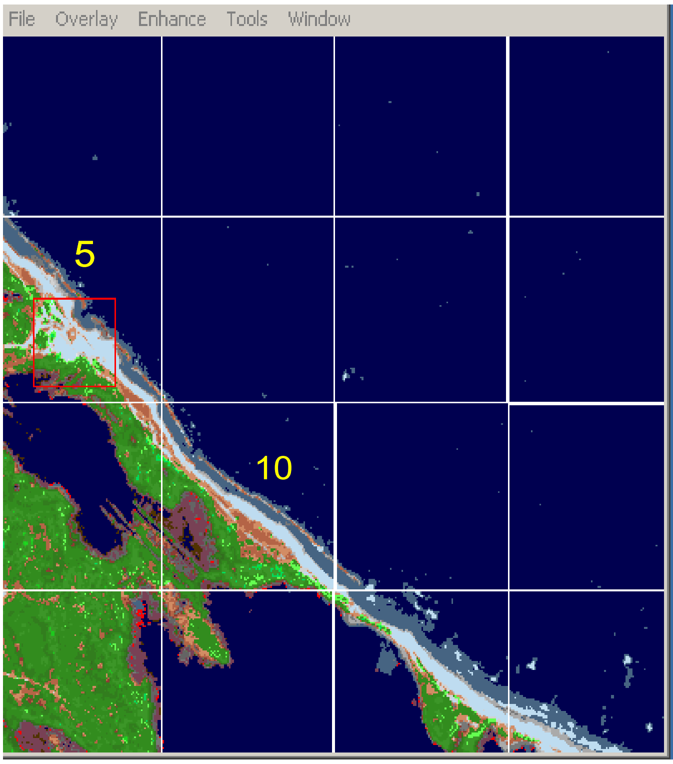


Figure 7.3.1

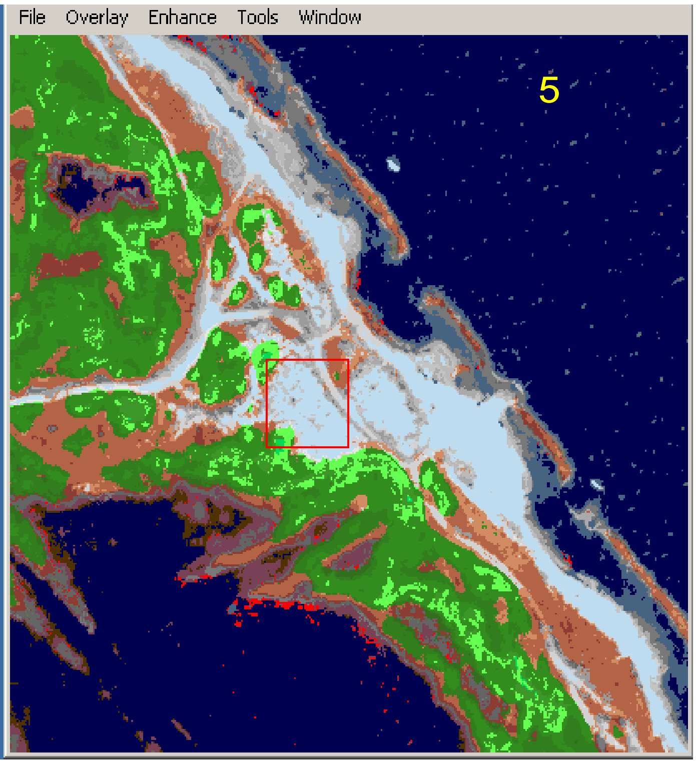


Figure 7.3.2

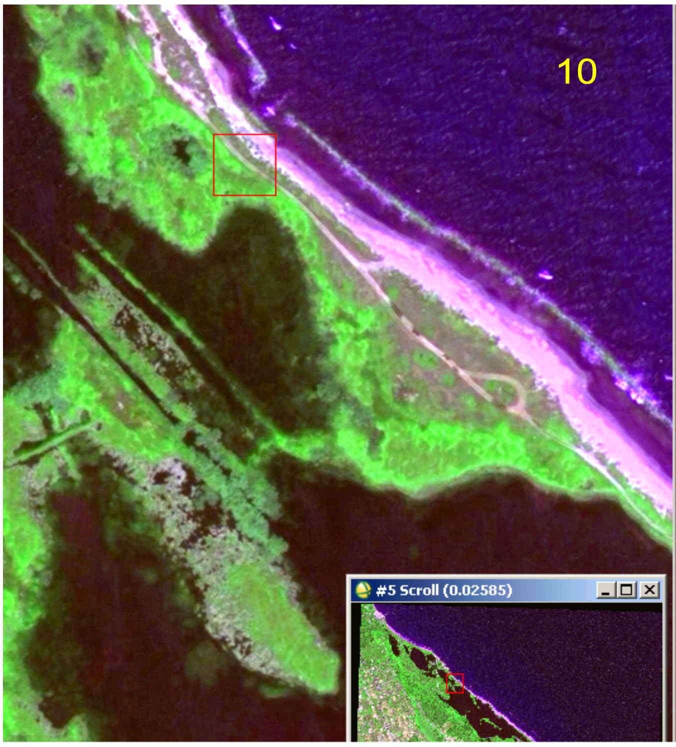


Figure 7.3.3

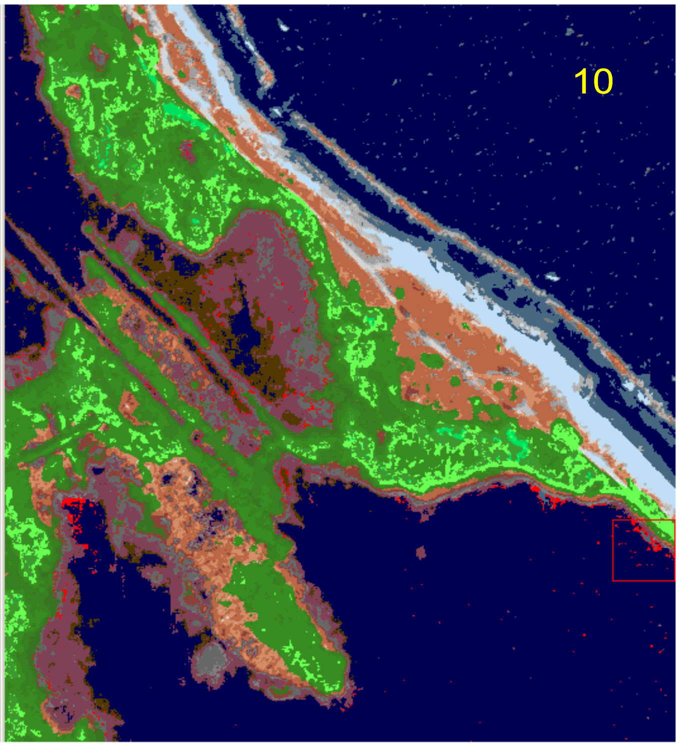


Figure 7.3.4

Figure 7.3. QuikBird image dated 2005-07-15: 1km^2 and vegetation sampling areas n. 5 and n.10 to be visited during the GHC training session. Figure 7.3.1: vegetation sampling areas n. 5,

preliminary spectral map obtained by the RS_IUS 4-band Ikonos-like SIAM™ (I-SIAM™) first stage at 2.4 m of spatial resolution; Figure 7.3.2: vegetation sampling area n.5, preliminary spectral map obtained by I-SIAM™ at 0.60 m of the panchromatic-sharpened QuickBird image; Figure 7.3.3: vegetation sampling areas n. 10, panchromatic-sharpened QuickBird image (RGB = band 3, 4, 1) at 0.60m resolution; Figure 7.3.4: vegetation sampling areas n. 10, prelimiminary spectral map obtained by I-SIAM™ from the panchromatic-sharpened QuickBird image at 0.60m resolution. The adopted 4-band Ikonos-like SIAM™ (I-SIAM™) map legend is shown in Figure 7.4.
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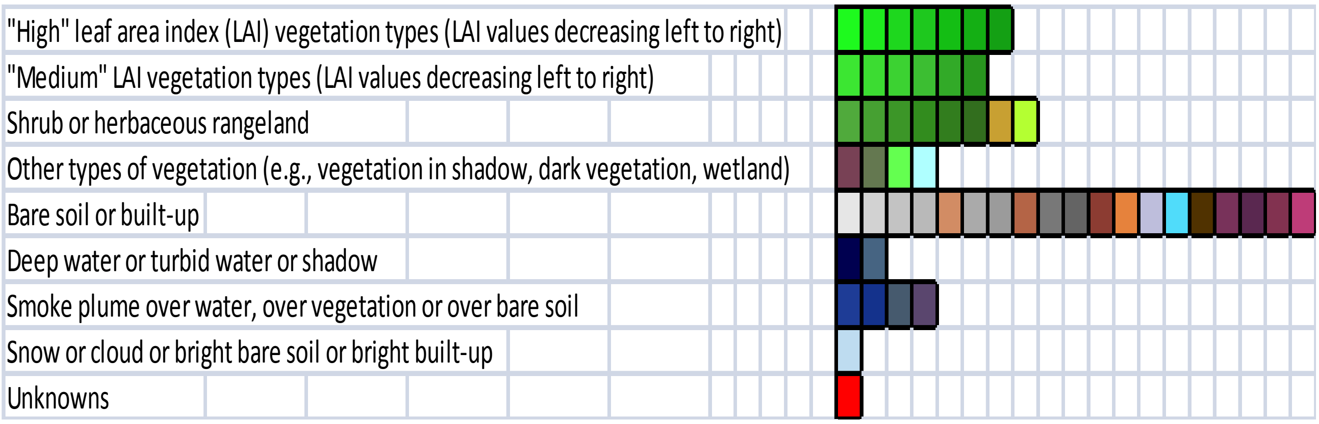

Figure 7.4. Ikonos-like SIAM™ (I-SIAM™) map legend at fine semantic granularity featuring 52 spectral categories.

8. Appendix 3: Acronym List

ABERY	University of Aberystwyth – Inst. of Geography And Earth Sciences
ALOS	Advanced Land Observing Satellite
ATREE	Ashoka Trust for Research in Ecology and the Environment – India
BIO_SOS	Biodiversity Multi-Source MOnitoring System: From Space To Species
CBD	Convention of Biological Diversity
CERTH	Informatics And Telematics Institute Of The Centre For Research And Technology – Greece
CIBIO	Centro de Investigação em Biodiversidade e Recursos Genéticos / ICETA - Portugal
CNR	Consiglio Nazionale delle Ricerche
EC	European Community
EO	Earth Observation
EU	European Union
GEO-BON	Group on Earth Observations Biodiversity Observation Network
GIS	Geographic Information System
HR	High Spatial Resolution
IRD	Institut de Récherche pour le Développement - France
JAXA	Japan Aerospace Exploration Agency
LC	Land Cover
LCC	Land Cover Change
PALSAR	Phase Array type L-band Synthetic Aperture Radar
SAR	Synthetic Aperture Radar
VHR	Very High spatial Resolution
WP	Work Package
WPL	Work Package Leader

9. References

Allard, A., 2003. Detection of vegetation degradation on Swedish mountainous heaths at an early stagby image interpretation. Ambio 32: 510-519.

Andrew, M.E., Ustin, S.L., 2008. The role of environmental context in mapping invasive plants with hyperspectral image data. Remote Sensing of Environment 112: 4301-4317.

A. Baraldi, L. Durieux, D. Simonetti, G. Conchedda, F. Holecz, and P. Blonda, 2010. Automatic spectral rule-based preliminary classification of radiometrically calibrated SPOT-4/-5/IRS, AVHRR/MSG, AATSR, IKONOS/QuickBird/OrbView/GeoEye and DMC/SPOT-1/-2 imagery – Part I: System design and implementation. IEEE Trans. Geosci. Remote Sensing 48: 1299 - 1325.

A. Baraldi, 2009. Impact of radiometric calibration and specifications of spaceborne optical imaging sensors on the development of operational automatic remote sensing image understanding systems. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing. 2: 104-134.

Blanco, L.J., Ferrando, C.A., Biurrun, F.N., 2009. Remote sensing of spatial and temporal vegetation patterns in two grazing systems. Rangeland Ecology and Management 62: 445-451.

Bock, M., Xofis, P., Mitchley, J., Rossner, G., Wissen, M., 2005. Object-oriented methods for habitat mapping at multiple scales – case studies from northern Europe and Wye Downs, UK. Journal for Nature Conservation 13: 75-89.

Borre, V. J., Paelinckx, D., Mücher, C.A., Kooistra, L., Haest. B., Blust, G.D., Schmidt, A.M., 2011. Integrating remote sensing in Natura 2000 habitat monitoring: Prospects on the way forward. Journal for Nature Conservation 19: 116-125.

Boyd, D.S., Phipps, P.C., Foody, G.M., Walsh, R.P.D., 2002. Exploring the utility of NOAA AVHRR middle reflectance to monitor the impacts of ENSO induced drought stress on Sabah rainforests. International Journal of Remote Sensing 23: 5141-5147.

Brown de Colstoun, E.C., Story, M.H., Thompson, C., Commisso, K., Smith, T.G. and Irons, J.R. 2003. National park vegetation mapping using multitemporal Landsat 7 data and a decision tree classifier. Remote Sensing of Environment 85: 316–27.

Chape, S., Harrison, J., Spalding, M., Lysenko, I., 2005. Measuring the extent and effectiveness of protected areas as an indicator for meeting global biodiversity targets. Philosophical Transactions of the Royal Society B 360_ 443-455.

Comber, A., Medcalf, K., Lucas, R., Bunting, P., Brown, A., Clewley, D., Breyer, J., Keyworth, S., 2010. Managing uncertainty when aggregating from pixels to objects: habitats, context-sensitive mapping and possibility theory. International Journal of Remote Sensing 31: 1061 — 1068

Coops, N., Wulder, M.A., White, J.C., 2007. Identifying and describing forest disturbance and spatial pattern: Data selection issues and methodological implications. In Wulder, M.S., Franklin, S.E. (eds.), Understanding forest disturbance and spatial pattern: Remote sensing and GIS approaches, CRC Press, Taylor and Francis Group, Boca Raton, Florida.

Duro, D.C., Coops, N.C., Wulder, M.A., et al, 2007. Development of a large area biodiversity monitoring system driven by remote sensing. Progress in Physical Geography 31:235–260.

Everitt, J.H., Yang, C., Deloach, C.J. Jr., 2005. Remote sensing of giant reed with QuickBird satellite imagery. Journal of Aquatic Plant Management 43: 81–85.

Felbermeier, B., Hahn, A., Schneider, T., 2010. Study on user requirements for remote sensing applications in forestry. In Wagner, W., Székely, B. (eds.). ISPRS TC VII Symposium – 100 Years ISPRS, Vienna, Austria, July 5-7, 2010, IAPRS, Vol. XXXVIII, Part 7B.

Forman, R.T.T., 1995. Land mosaics: The ecology of landscapes and regions. Cambridge University Press, Cambridge, 632 pp.

Förster, M., Kleinschmit, B., 2008 Object-based classification of Quickbird data using ancillary information for the detection of forest types and NATURA 2000 habitats. In Blaschke, T., Lang, S., Hay, G.J. (eds). Object-Based Image analysis: Spatial Concepts for Knowledge-Driven Remote Sensing Applications. Lecture Notes in Geoinformation and Cartography, Section 3, pp 275-290. Springer: Berlin.

Fuller, D.O., 2005. Remote detection of invasive Melaleuca trees (*Melaleuca quinquenervia*) in South Florida with multispectral IKONOS imagery. International Journal of Remote Sensing 26: 1057-1063.

Gao, J., 1999. A comparative study on spatial and spectral resolutions of satellite data in mapping mangrove forests. International Journal of Remote Sensing 20: 2823-2833.

Gillespie, T.W., Foody, G.M., Rocchini, D., Giorgi, A.P., Saatchi, S., 2008. Measuring and modeling biodiversity from space. Progress in Physical Geography 32: 203-221.

Griffiths, G.H., Lee, J., 2000. Landscape pattern and species richness; regional scale analysis from remote sensing. International Journal of Remote Sensing 21: 2685-2704.

He, K.S., Rocchini, D., Neteler, M., Nagendra, H., 2011. Benefits of hyperspectral remote sensing for tracking plant invasions. Diversity and Distributions 17: 381-392.

Hudak, A.T., Brockett, B.H., 2004. Mapping fire scars in a southern African savanna using Landsat imagery. International Journal of Remote Sensing 25: 3231-3243.

Ingram, J.C., Dawson, T.P., Whittaker, R.J., 2005. Mapping tropical forest structure in southeastern Madagascar using remote sensing and artificial neural networks. Remote Sensing of Environment 94: 491-507.

Jongman, R.H.G., Bunce, R.G.H., Metzger, M.J., Mücher, C.A., Howard, D.C., Mateus, V.L., 2006. Objectives and applications of a statistical environmental stratification of Europe. Landscape Ecology 21: 409-419.

Kumar, S., Simonson, S., Stohlgren, T.J., 2009. Effects of spatial heterogeneity on butterfly species richness in Rocky Mountain National Park, CO, USA. Biodiversity and Conservation 18: 739–763.

Lee, M., Park, G., Park, M., Park, J.Y., Lee, J.W., Kim, S.J., 2010. Evaluation of non-point source pollution reduction by applying Best Management Practices using a SWAT model and QuickBird high resolution satellite imagery. Journal of Environmental Sciences 22: 826-883.

Legleiter, C. J., Marcus, W.A., Lawrence, R.L., 2002. Effects of sensor resolution on mapping in-tream habitats. Photogrammetric Engineering and Remote Sensing, 68: 801-807.

Lengyel, S., Déri, E., Varga Z, Horváth, R., Tóthmérész, B., Henry, P-Y., Kobler, A., Kutnar, L., Babij, V., Seliškar, A., Christia, C., Papastergiadou, E., Gruber, B., Henle, K., 2008. Habitat monitoring in Europe: a description of current practices. Biodiversity and Conservation 17: 3327-3339.

Lentile, L.B., Holden, Z.A., Smith, A.M.S., Falkowski, M.J., Hudak, A.T., Morgan, P., Lewis, S.A., Gessler, P.E., Benson, N.C., 2006. Remote sensing techniques to assess active fire characteristics and post-fire effects. International Journal of Wildland Fire 15: 319-345.

Lucas, R., Rowlands, A., Brown, A., Keyworth, S., Bunting, P., 2007. Rule-based classification of multi-temporal satellite imagery for habitat and agricultural land cover mapping. ISPRS Journal of Photogrammetry and Remote Sensing 62: 165–185.

Lucas, R.M., Bunting, P., Paterson, M., Chisholm, M., 2008a. Classification of Australian Forest Communities Using Aerial Photography, CASI and HyMap Data. Remote Sensing of Environment 112: 2088-2103.

Lucas, R.M., Accad, A., Randall, L., Bunting, P., 2008b. Assessing human impacts on Australian forests through integration of airborne/spaceborne remote sensing data. In: Patterns and Processes in

Forest Landscapes: Multiple uses and sustainable management, pp. 213-240, Ed. R. Lafortezza, J. Chen, G. Sanesi and T.R. Crow, Springer.

Lucas, R.M., Medcalf, K., Brown, A., Bunting, P., Breyer, J., Clewley, D., Keyworth, S., Blackmore, P., 2011. Updating the Phase 1 habitat map of Wales, UK, using satellite sensor data. International Journal of Photogrammetry and Remote Sensing 66: 81–102.

McDermid, G.J., Franklin, S.E., LeDrew, E.F., 2005. Remote sensing for large-area habitat mapping. Progress in Physical Geography 29: 449-474.

Mücher, C.A., Hennekens, S.M., Bunce, R.G.H., Schaminée, J.H.J., Schaepman, M.E., 2009. Modelling the spatial distribution of Natura 2000 habitats across Europe. Landscape and Urban Planning 92, 148-159.

Nagendra, H., 2001. Using remote sensing to assess biodiversity. International Journal of Remote Sensing 22: 2377-2400.

Nagendra, H., 2008. Do parks work? Impact of protected areas on land cover clearing. Ambio 37:330-337.

Nagendra,H., Rocchini, D., 2008.High resolution satellite imagery for tropical biodiversity studies: The devil is in the detail. Biodiversity and Conservation 17: 3431−3442.

Nagendra, H., Rocchini, D., Ghate, R., Sharma, B., Pareeth, S., 2010. Assessing plant diversity in a dry tropical forest: Comparing the utility of Landsat and IKONOS satellite images. Remote Sensing 2: 478-496.

Neary, D.G., Klopatek, C.C., DeBano, L.F., Ffolliott, P.F., 1999. Fire effects on belowground sustainability: A review and synthesis. Forest Ecology and Management 122: 51-71.

Oldeland, J., Dorigo, W., Lieckfeld, L., Lucieer, A., Jürgens, N., 2010. Combining vegetation indices, constrained ordination and fuzzy classification for mapping semi-natural vegetation units from hyperspectral imagery. Remote Sensing of Environment 114: 1155-1166.

Pereira, H.M., Cooper, H.D., 2006. Towards the global monitoring of biodiversity change. Trends in Ecology and Evolution 21: 123-129.

Phillips, L.B., Hansen, A.J., Flather, C.H., 2008. Evaluating the species energy relationship with the newest measures of ecosystem energy: NDVI versus MODIS primary production. Remote Sensing of Environment 112: 3538-3549.

Prates-Clark, C.D., Lucas, R.M., dos Santos, J.R., 2009. Implications of land-use history for forest regeneration in the Brazilian Amazon. Canadian Journal of Remote Sensing 35: 534-553.

Ramsey, E., Rangoonwala, A., Nelson, G., Ehrlich, R., Martella, K. 2005. Generation and validation of characteristics spectra from EO1 Hyperion image data for detecting the occurrence of the invasive species, Chinese tallow. International Journal of Remote Sensing 26: 1611–36.

Rao, N.R., Garg, P.K., Ghosh, S.K., 2007. Evaluation of radiometric resolution on land use/land cover mapping in an agricultural area. International Journal of Remote Sensing 28: 443-450.

Rocchini, D., 2007. Effects of spatial and spectral resolution in estimating ecosystem alpha diversity by satellite imagery. Remote Sensing of Environment 111: 423–434.

Rocchini, D., Balkenhol, N., Carter, G.A., Foody, G.M., Gillespie, T.W., He, K.S., Kark, S., Levin, N., Lucas, K., Luoto, M., Nagendra, H., Oldeland, J., Ricotta, C., Southworth, J., Neteler, M., 2010. Remotely sensed spectral heterogeneity as a proxy of species diversity: recent advances and open challenges. Ecological Informatics 5: 318-329.

Sánchez-Azofeifa, A., Rivard, B., Wright, J., Feng, J-L., Li, P., Chong, M.M., Bohlman, S.A., 2011. Estimation of the distribution of *Tabebuia guayacan* (*Bignoniaceae*) using high-reloution remote sensing imagery.

Sawaya, K.E., Olmanson, L.G., Heinert, N.J., Brezonik, P.L., Bauer, M.E., 2003. Extending satellite remote sensing to local scales: land and water resource monitoring using high-resolution imagery. Remote Sensing of Environment 88: 144-156.

Schmeller, D.S., 2008. European species and habitat monitoring: where are we now? Biodiversity and Conservation 17: 3321-3326.

Varela, R.A.D., Rego, P.R., Iglesias, S.C., Sobrino, C.M., 2008. Automatic habitat classification methods based on satellite images: a practical assessment in the NW Iberia coastal mountains. Environmental Management 144: 229-250.

Vicente, J., Randin, C.F., Gonçalves, J., Metzger, M., Lomba, A., Honrado, J., Guisan, A., 2011. Where will conflicts between alien and rare species occur after climate and land-use change? A test with a novel combined modelling approach. Biological Invasions, DOI 10.1007/s10530-011-9952-7, published online 12 February 2011.

Vierling, W.A.G., Martinuzzi, S., Clawges, R.M., 2008. Lidar: Shedding new light on habitat characterization and modeling. Frontiers in Ecology and the Environment 6: 90-98.

Waser, L.T., Balstavias, E., Ecker, K., Eisenbeiss, H., Feldmeyer-Christe, E., Ginzler, C., Kuchler, M., Zhang, L., 2008. Assessing changes of forest area and shrub encroachment in a mire ecosystem using digital surface models and CIR aerial images. Remote Sensing of Environment 112: 1956-1968.

Weiers, S., Bock, M., Wissen, M., Rossner, G., 2004. Mapping and indicator approaches for the assessment of habitats at different scales using remote sensing and GIS methods. Landscape and Urban Planning 67: 43-65.