BIO_SOS

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Abstract	The main objective of D5.1 is to provide a significant proof of the feasibility of the EODHaM proposed modular system at both HR and VHR spatial resolution for the automatic mapping of LC/LU classes into GHC and Annex I habitats. The emphasis is on the feasibility to bridge LCCS and GHC taxonomies by integrating EO products with "on site" data through ecological modelling. A secondary objective is to solve the ambiguities among the different GHCs which can correspond to the same LCCS LC/LU class as an advancement of D6.10.
Keywords	Habitat mapping, LCCS, GHCs, Annex I, EUNIS, Semantic Networks

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1. Executive summary

D5.1, titled *Habitat Maps* is the first deliverable of WP5 and focuses on habitat mapping in continuity with WP6 D6.10 (Software for Habitat Maps Production from Land Cover/Use (LC/LU) Classes). D5.1 includes:

- An introduction to semantic nets as the framework to describe LC/LU and GHC classes of interest to the project.

- Two case studies with the instantiation of the mapping LCCS to GHC maps as an advancement of the work reported in D6.10. In particular, some of the ambiguities related to LCCS-GHC mapping are solved for two sites (i.e., Cors Fochno (Borth Bog and estuarine complex) in Wales (UK) and Le Cesine (IT4) in Italy) by using external information. For the first site, an LC/LU map in LCCS taxonomy was obtained by analyzing high resolution (HR) Earth Observation (EO) (i.e., Landsat and SPOT sensor) data, which was then translated into a map of GHCs. For the 2nd site (IT4), a pre-existing LC/LU map, derived from photo-interpretation of an ortophoto dated 2006 and in field campaigns dated 2007-2008 at 1:5000 scale was translated into a corresponding map of GHCs, since at this stage of the project the development of the 2nd EODHaM stage of the system for automatic VHR LC/LU maps production is still in progress.

- The mapping of LCCS/GHCs maps into Annex I habitats for the IT4 site. In addition, a key is proposed for non-Annex I habitat included in the IT4 Natura 2000 site, which are of great interest to the Users of Mediterranean sites.

2. Introduction

In the BIO_SOS project four main research activities can be identified:

1) The improvement of the SIAM™ spectral mapping algorithm within the 1st stage of the proposed EODHaM system to analyze multi-source and hyperspectral EO data.

2) The development of the 2nd stage of the EODHaM proposed system. The 2nd stage is based on the 1st stage EODHaM output map (i.e., a SIAM™ pre-classified map). The 2nd stage will provide, as output, a LC/LU map from multi-scale EO data and mainly VHR data. The FAO-LCCS taxonomy is to be used for LC/LU classes according to the analysis made in D6.1 because a more useful description of natural and semi-natural habitats is provided which relate to the Annex I habitat definition of the Directive. For LC/LU automatic mapping, the 2nd stage will be based on :

   o Semantic nets module development for the description of LC/LU classes.

   o A battery of feature-extraction modules.

   o Additional information (ancillary and on-site data)

   o Stratified land cover class-specific fuzzy rule-based classification modules

   o LC/LU change detection modules

3) The development of the 3rd stage of the EODHaM system, which includes:

   o The design and implementation of the algorithm for providing habitat maps from LC/LU maps.

   o The extraction of the biodiversity Indicators selected in D2.1 and their trends.

   o GHC change maps.

4) Modeling development and improvement for ecosystem state assessment and Biodiversity Indicator extraction within the EODHaM 3rd stage.

D3.1 provides more details on the EODHaM system.

The four research activities can run in parallel because of the high modularity of the proposed EODHaM system with a targeted convergence towards the end of the project. For this reason, D6.10 as well as the present D5.1 deal with habitat mapping even if the 2nd EODHaM stage output maps from VHR EO data are not yet available. In particular, D6.10 used, for each training site, a pre-existing reference LC/LU map whose LC/LU taxonomy was converted from CORINE into FAO-LCCS for habitat mapping, according to the findings of D6.1.

As already evidenced in the executive summary of D6.10, common approaches for habitat monitoring require definitions and rules that are harmonised continentally and globally. Habitat is a widely used term, but the content of the concept "habitat" remains diverse, ambiguous, and difficult to be used consistently in monitoring. The term "habitat", as used in the EBONE Manual [Bunce et al. 2011a] comes as an ecological refinement of land cover categorisation as developed by the FAO-Land Cover Classification Systems (LCCS) (see D6.1). To this end, D6.10 deliverable focused on the production of General Habitat Categories (GHC) maps [Bunce et al. 2011a] from LCCS maps.
The GHCs maps will be used further towards the production of Annex I habitat maps, using the rule based hierarchical Key developed within the EBONE [Bunce et al., 2011b] project. The Key is available as EBONE Deliverable 4.2 through www.ebone.wur.nl, whilst the Annex I of the EU Habitats and Species Directive is available at:
 http://ec.europa.eu/environment/nature/legislation/habitats directive/index_en.htm.

In the Mediterranean Natura 2000 sites selected for the BIO_SOS project several habitat types of ecological importance are not considered by Annex I of the EU Directive [see D6.1], even if functionally they link to habitats included in Annex I. For IT4 and IT3, such habitats are listed in Table IT4_1 and IT3_1 of D6.1 and evidenced by an X code in the Annex I column. These habitats are highly threatened by combined anthropic pressures and are exposed to reduction and high fragmentation processes. For these reasons, the Users who signed the SLA are particularly interested in their conservation.

In EBONE D4.2 [Bunce et al., 2011b], the Key for the mapping of these habitat types is obviously not available. Within BIO_SOS, which focuses mainly on Mediterranean Natura 2000 sites, a specific set of expert rules needs to be defined for the direct mapping of LCCS classes to both GHC and habitat types, as expressed by other habitats classification taxonomy (e.g., CORINE Biotopes or EUNIS).

As a main objective, D5.1 solves the ambiguities among the different GHCs which can correspond to the same LCCS LC/LU class by providing, at the same time, a significant proof of the feasibility of the EODHaM proposed modular system. Two training test sites (i.e., Cors Fochno (Borth Bog and estuarine complex) (UK) and the Italian site Le Cesine (IT4)) are considered. In the study cases analyzed, D5.1 identifies all the additional discriminating elements, such as LCCS environmental and site qualifiers, external information (e.g., cadastral maps) and EODHaM 1st stage outputs, such as the "water index", phenological information as well as specific LCCS and GHC class description features useful for discriminating similar GHCs. Some of attributes represented by these additional data (e.g. lithology, elevation) do not vary (at least not significantly) over time and provide baseline characteristics for sites; others are related to phenology whilst in-field measurements (e.g. water salinity) or other ancillary data (e.g., field boundaries) may be required. Such elements complement the description of GHC classes. GHC descriptions are provided in the EBONE handbook and appear ready for representation by means of semantic nets. However, for the training cases considered in the present deliverable, the description of both LC/LU classes and GHCs classes of interest is implicit in the implementation undertaken within eCognition software. These descriptions will be made explicit within *the semantic network framework* of Task 5.2 in WP5.

The present deliverable is organized as follows:

1. Section 3 focuses on semantic nets. The first part was fully developed by Partner 15.

2. Section 4 describes the state of research work within the Consortium of the LCCS to GHC mapping.

3. Section 5 describes the LCCS to GHC mapping in the UK (Welsh site) from HR (e.g. Landsat and Spot) data.

4. Section 6 describes the LCCS to GHC mapping in IT4 from a pre-existing LC/LU map. In addition, the mapping of GHC classes into Annex I and non-Annex I Habitats is provided for this Mediterranean site. A key for non-Annex I Habitats, which are coded with EUNIS taxonomy, is provided for translating GHC to non-Annex I Habitats and LCCS to Annex I and non-Annex I Habitats.

3.   Semantic Networks

3.1   Vision as an ill-posed image understanding problem

The main role of a biological or artificial visual system is to backproject the information in the (2-D) image domain to that in the (3-D) scene domain [Matsuyama & Shang-Shouq Hwang, 1990]. In greater detail, **the goal of a _visual system_ is to provide (one or multiple) plausible symbolic description(s) of the scene depicted in an image by finding associations between sub-symbolic (non-semantic, sensory, instantaneous, numerical, absolute, quantitative, varying, objective) (2-D) image features or sensations with symbolic (semantic, subjective, linguistic, qualitative, vague, abstract, persistent, stable) (3-D) objects (concepts or percepts) in the depicted 3-D scene (e.g., a building, a road, etc.).** Sub-symbolic (2-D) image features are either points or regions or, vice versa, region boundaries, i.e., edges, provided with no semantic meaning. In literature, (2-D) image regions are also called _segments_, _(2-D) objects_, _patches_, _parcels_, or _blobs_ [Baraldi et al., 2010a].

There is a well-known **_information gap_** between symbolic information in the (3-D) scene and sub-symbolic information in the (2-D) image, e.g., due to dimensionality reduction and occlusion phenomena [Matsuyama & Shang-Shouq Hwang, 1990]. This is called the **_intrinsic insufficiency_** of image features [Matsuyama & Shang-Shouq Hwang, 1990]. This information gap is also related to the inherent ill-posedness of inductive inference. It means that **the problem of image understanding is inherently ill-posed in the Hadamard sense**[1] and, consequently, very difficult to solve [Matsuyama & Shang-Shouq Hwang, 1990].

The aforementioned information gap coincides with the well-known _information gap_ existing between (sub-symbolic, sensory, quantitative, objective, varying) sensations and (symbolic, semantic, qualitative, subjective, stable) percepts (concepts, 3-D object-models), traditionally investigated in both philosophy and psychophysical studies of perception [Matsuyama & Shang-Shouq Hwang, 1990], also refer to Section 1.

In functional terms, biological vision combines preattentive (low-level) visual perception with an attentive (high-level) vision mechanism [Baraldi et al., 2010a].

> (1)   **_Preattentive (low-level) vision_** extracts picture primitives based on **general-purpose image processing criteria independent of the scene under analysis**. It acts in **parallel** on the entire image as a **rapid (< 50 ms) scanning system** to detect variations in simple visual properties. It is known that the human visual system employs at least four spatial scales of analysis. Marr calls the output of the low-level vision first stage _primal sketch_ or _preliminary map_ [Marr, 1982].

> (2)   **_Attentive (high-level) vision_** operates as a careful scanning system employing a **focus of attention mechanism**. Scene subsets, corresponding to a **narrow aperture of attention**, are looked at in sequence and each step is examined quickly (20–80 ms).

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[1]   [Online]. Available: http://en.wikipedia.org/wiki/Well-posed_problem. According to Jacques Hadamard, mathematical models of physical phenomena are defined well posed when they satisfy the following requirements: (1) a solution exists, (2) the solution is unique, and (3) the solution depends continuously on the input data, in some reasonable topology. Examples of archetypal well-posed problems include the heat equation with specified initial conditions. Problems that are not well-posed in the sense of Hadamard are termed ill-posed. Inverse problems are often ill-posed. For example, the inverse heat equation is not well-posed in that the deduced previous distribution of temperature is highly sensitive to changes in the final data. Even if a problem is well posed, it may still be ill-conditioned, meaning that a small error in the initial data can result in much larger errors in the answers. If the problem is well-posed, then it stands a good chance of solution on a computer using a stable algorithm. If it is not well-posed, it needs to be re-formulated for numerical treatment. Typically this involves including additional assumptions, e.g., smoothness of solution known as (Tikhonov) regularization.

Finally, it is worth mentioning that, according to Marr, "vision goes symbolic almost immediately, right at the level of zero-crossing (primal sketch)... without loss of information" [Marr, 1982] (p. 343). In practice, Marr suggests the following.

(a) The output of preattentive vision (primal sketch) is symbolic. This is tantamount to saying that:

- vision goes symbolic within the preattentive vision phase and

- the primal sketch is a preliminary semantic map whose symbolic labels belong to a finite and discrete set of 3-D object-classes or concepts in the real (3-D) world.

(b) The symbolic output of preattentive vision is lossless, i.e., when the input image is reconstructed from its semantic description then small, but genuine image details (high spatial frequency image components) must be well preserved.

It is also noteworthy that, in contradiction with his own computer vision (CV) system design intuitions, the CV system implemented by Marr is able to accomplish neither of the two aforementioned goals (a) and (b). For example, the Marr pre-attentive vision module consists of a contour detector (zero-crossing algorithm) whose output is a sub-symbolic primal sketch. This apparent contradiction between Marr's CV system design intuitions and his implementation solutions is not at all surprising. It accounts in general for the customary distinction between a model and the algorithm used to identify it [Baraldi et al., 2010b]. In particular, it accounts for the seminal nature of the work by Marr followed by his early dramatic death. To conclude, inspiration from Marr's work should stem from his CV system design principles (at the level of computational theory, considered the lynch-pin of success of any information processing system [Baraldi et al., 2010a]) rather than at the level of his CV system implementation solutions (e.g., a zero-crossing contour detector adopted at the first stage).

Adopted in the three-stage RS image mapping system proposed in the BIO-SOS project, the SIAM™ first stage of a two-stage stratified hierarchical RS image understanding system (RS-IUS) is a preliminary classifier in the Marr sense [Marr, 1982], i.e., SIAM™ is consistent with the physical constraints of preattentive (low-level) biological vision, namely, SIAM™ [Baraldi, 2011a], [Baraldi, 2011b]:

- extracts picture primitives based on general-purpose image processing criteria independent of the scene under analysis,

- acts in parallel on the entire image as a scanning system in near real time (e.g., the SIAM™ computation time is inferior to 5 minutes per spaceborne image of the Earth in a standard desktop computer, whereas the minimum inter-image acquisition time is 15 min for the geostationary Meteosat Second Generation spaceborne imaging sensor),

- in line with the Marr intuition ("vision goes symbolic almost immediately, right at the level of zero-crossings (primal sketch)… without loss of information" [Marr, 1982], p. 343), it does the following:

  o it provides as output a symbolic primal sketch of the depicted 3-D scene and

  o it avoids loss of information in the mapping (equivalent to a quantization into symbolic quantization levels) from sensory data to symbolic labels, see Figure 3.1 and Table 3.1.

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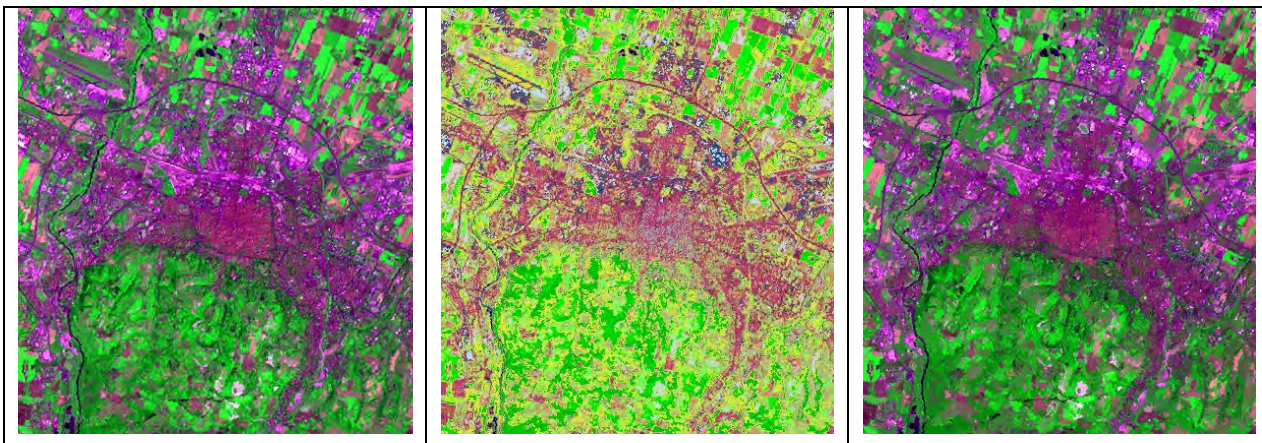
Figure 3.1(a). Zoomed image of the city of Bologna, Italy, extracted from a Landsat 7 ETM+ image (path 192, row 029, acquisition date: 2000-06-20), radiometrically calibrated into TOARF values and depicted in false colors (R: band TM5, G: band TM4, B: band TM1). Spatial resolution: 30 m.

Figure 3.1(b). Output map generated by SIAM™ from a synthetic IKONOS-like 4-band image obtained from a radiometrically calibrated Landsat 7 ETM+ image of the city of Bologna, Italy, depicted in Figure 3.1(a), where ETM+ bands 5 to 7 are removed. Output spectral categories are depicted in pseudo colors. Map legend shown in Table 3.1.

Figure 3.1(c). Piecewise constant approximation of Figure 3.1(a) based on segments extracted from the preliminary classification map shown in Figure 3.1(b), such that each segment is replaced with its mean reflectance value in the radiometrically calibrated input image domain. It is noteworthy that small but genuine image details appear well-preserved, i.e., SIAM™ performs as an edge-preserving smoothing filter. In addition, despite being pixel-based, SIAM™ does not appear to be affected by the traditional salt-and-pepper classification noise effect. In practice, SIAM™, which is capable of dealing with within-class variance, performs a context- (texture-) sensitive classification (e.g., see the image partition performed over urban areas, which are highly textured).

Figure 3.1(d). Transect extracted from the ETM+ Band 4 of Figure 3.1(a).

Figure 3.1(e). Piecewise constant approximation of Figure 3.1(a) based on segments extracted from the preliminary classification map shown in Figure 3.1(b), such that each segment is replaced with its mean reflectance value in the radiometrically calibrated input image domain. It is noteworthy that small but genuine image details appear well-preserved, i.e., SIAM™

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performs as an edge-preserving smoothing filter. In addition, despite being pixel-based, SIAM™ does not appear to be affected by the traditional salt-and-pepper classification noise effect. In practice, SIAM™, which is capable of dealing with within-class variance, performs a context- (texture-) sensitive classification (e.g., see the image partition performed over urban areas, which are highly textured).

Table 3.1. **Preliminary classification map legend adopted by SIAM™ when 4-band IKONOS-like images (consisting of bands visible blue, green, red and near infra-red) are mapped at fine semantic granularity. Pseudo-colors of the 52 spectral categories are gathered based on their spectral end member (e.g., 'bare soil or built-up') or parent spectral category (e.g., "high" leaf area index (LAI) vegetation types). The pseudo-color of a spectral category is chosen as to mimic natural colors of pixels belonging to that spectral category.**

"High" leaf area index (LAI) vegetation types (LAI values decreasing left to right)	
"Medium" LAI vegetation types (LAI values decreasing left to right)	
Shrub or herbaceous rangeland	
Other types of vegetation (e.g., vegetation in shadow, dark vegetation, wetland)	
Bare soil or built-up	
Deep water or turbid water or shadow	
Smoke plume over water, over vegetation or over bare soil	
Snow or cloud or bright bare soil or bright built-up	
Unknowns	

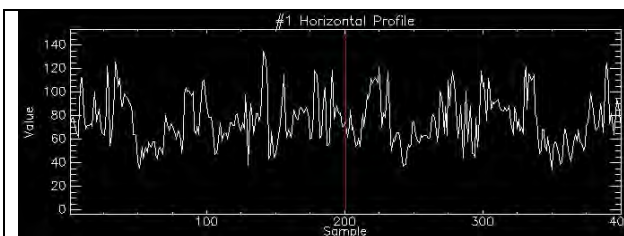## 3.2 A generic semantic network to represent a prior geospatial knowledge base for the interpretation of RS imagery.

Any **_prior geospatial knowledge base_** (which is, by definition, available before looking at the target 3-D scene, i.e., available before collecting the sensory (2-D) image data at hand) **_or ontology_** (consisting of a discrete and finite set of concepts and relations between concepts [Lüscher et al., 2007]) can be represented graphically with a **_semantic network_**.

Semantic networks are directed acyclic graphs whose structural primitives are *nodes* and *edges* in between nodes, such that both nodes and edges can be provided with nodes- and edge-specific attributes respectively, such that all network primitives (nodes, edges and attributes) belong to a community-agreed *network vocabulary*.

In other words, a semantic network is a graphical representation of an ontology (i.e., of a prior knowledge-based model of the world consisting of concepts and relations) according to a given network vocabulary consisting of network primitives such as nodes, arcs and attributes.

For example, in the BIO-SOS projects, semantic nets can be used to represent prior geospatial knowledge of the following categorical variables.

- 2nd-stage output LC class taxonomies (hierarchies, e.g., LCCS, CORINE, etc.) or ontologies, where the latter may include non-spatial relations, such as subset-of and part-of, together with spatial topological and non-topological relations among LC classes (e.g., a house always has one road connected to it).
- 3rd-stage output GHCs belonging to a known taxonomy (hierarchy) or ontology, which may include non-spatial relations, such as subset-of and part-of, together with spatial topological and non-topological relations among GHCs.

- ▪ Spatial topological, spatial non-topological and non-spatial (e.g., subset-of, part-of) relations between 2nd-stage LC classes and 3rd-stage GHCs.

It is noteworthy that in the framework of the three-stage EODHaM classifier developed by the BIO-SOS project, where categorical variables generated as output at each stage feature a level of abstraction (generalization) superior to that of categorical variables generated at previous stages, only spatial and non-spatial relationships as arcs between 2nd-stage semantic nets modelling LC classes and 3rd-stage semantic nets modelling GHCs are expected to date (until proved otherwise), as a practical example where lower level ontologies (LC classes) are combined into a superior-level ontology (GHCs).

In general, for 3-D scene reconstruction from (2-D) imagery (see Section 3.1), only visual (pictorial, appearance) properties of classes of 3-D geospatial objects and spatial and non-spatial (e.g., temporal) relationships between 3-D geospatial object-classes eligible for being observed by a generic imaging sensor located aboveground (!) and considered relevant by an expert photointepreter must be taken into consideration in the definition of a prior geospatial knowledge base (ontology of the world). For example, for a target olive grove to be described in pictorial and spatial terms, the internal chemical composition of the olive trees is irrelevant in the context of vision. Moreover, since the imaging sensor is assumed to observe the landscape from above, then some spatial relationships among 3-D objects in the world, like below or above, can be omitted in the adopted 3-D model (representation) of the world.
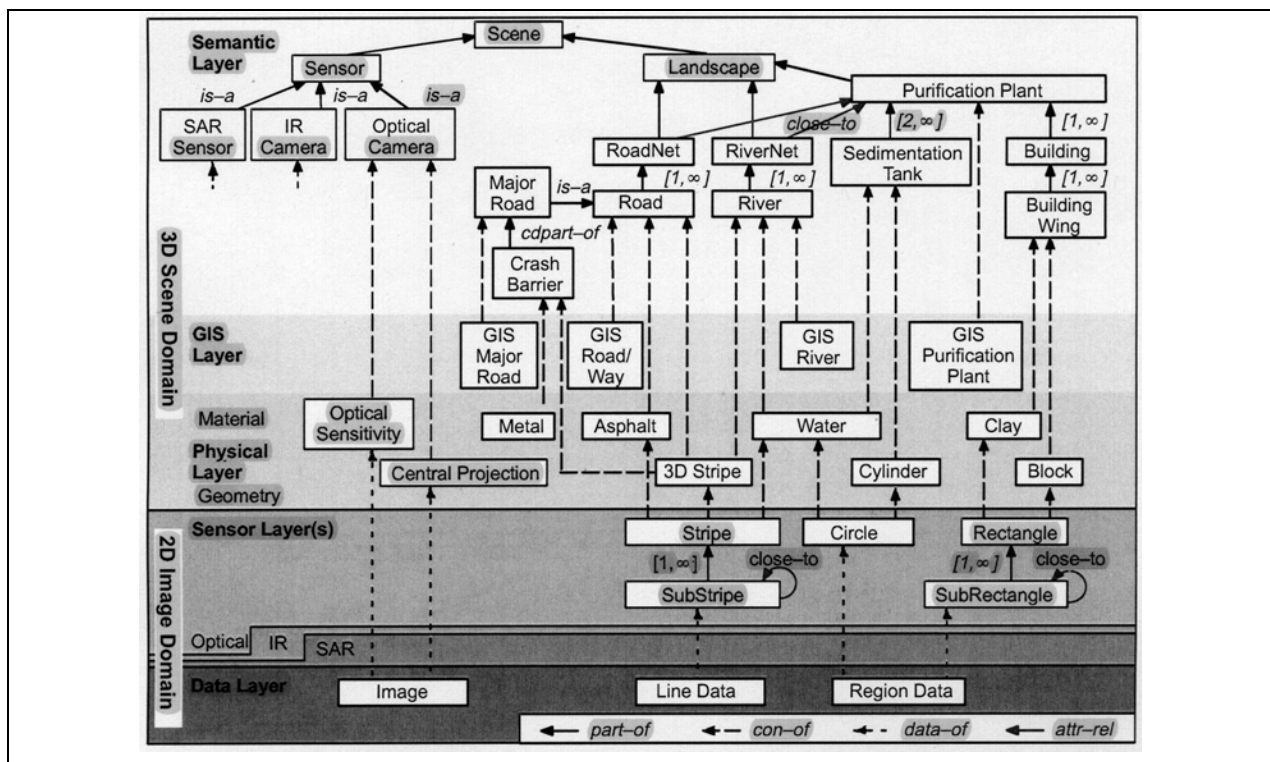

Figure 3.2. Taken from [Growe, 1999]. Semantic net representing a generic prior geospatial knowledge base for interpretation of RS imagery.

This prior knowledge base of the (3-D) real world in terms of classes of 3-D geospatial objects and their spatial (e.g., adjacency) and non-spatial (e.g., part-of) relationships is the so-called _**(3-D) world model**_ [Matsuyama & Shang-Shouq Hwang, 1990], required by any human or artificial vision system to fulfil its goal, namely, to construct one or more plausible symbolic structural descriptions of the (3-D) scene depicted in a (2-D) image by means of a combination of inductive (bottom-up, fine-to-coarse, data-driven, learning-by-example) and deductive (top-down, coarse-to-fine, model-driven, learning-by-rule) inference mechanisms (see Section 3.1).

It is important to stress that although it comprises visual (pictorial, appearance) properties of the (3-D) scene, **the world model is independent of the imaging sensor at hand once it is assumed the imaging sensor is viewing the landscape "from above".**

Hence, **the prior geospatial knowledge base consists exclusively of the following necessary and visible information.**

a) **Classes of 3-D geospatial objects in the (3-D) real world provided with visual (pictorial, appearance) attributes, including a geospatial position, once it is assumed the imaging sensor is viewing the target landscape "from above".**

b) **Spatial relationships between classes of 3-D geospatial objects.** They can be split as follows.

   a. **Topological** (e.g., adjacency, inclusion, etc. [Matsuyama & Shang-Shouq Hwang, 1990], [Pakzad, 1999]).

   b. **Non-topological** (e.g., distance, angle difference, etc. [Matsuyama & Shang-Shouq Hwang, 1990], [Pakzad, 1999])**)**

c) **Non-spatial relationships between classes of 3-D objects**(e.g., part-of, a-kind-of also called a-subset-of or is-a [Matsuyama & Shang-Shouq Hwang, 1990], [Pakzad, 1999], [Growe, 1999], temporal relationships, etc.)

A **_network vocabulary_** (see Section 3.3) is used to represent the prior geospatial knowledge base as a **_semantic network_, also called _concept network_ or _semantic graph_** [Baraldi et al., 2010b], which **is a generalization of the hierarchical decision-tree concept**. In other words (also refer to this text above), a **semantic network provides a graphical representation of a prior geospatial knowledge base (ontology of the 3-D world) according to a community-agreed network vocabulary**.

It means that **before** delivering any semantic network representation of a prior geospatial knowledge base (e.g., the semantic network representation of the definition of the LC class _olive grove_ in the Italian administrative region of Puglia, which may differ from the definition of the LC class _olive grove_ in the Italian administrative region of Umbria), **a community-agreed network vocabulary must be selected first.**

In Figure 3.2, a semantic network capable of representing a generic geospatial knowledge base for the interpretation of RS imagery is shown. This semantic network is divided into **_3-D and 2-D image domain_** defined as follows (also refer to Section 3.1) [Growe, 1999].

1. The 3-D scene domain, where the knowledge about inherent and sensor independent properties of 3-D objects in the (3-D) world is stored. It splits into:

   1.1 The _semantic layer_, represents the most abstract layer where the 3-D scene objects with their symbolic meanings are stored. As each transformation between the (2-D) image and the 3-D scene domain is determined by the sensor type and its projection parameters, these transformations are modelled explicitly in the semantic net by the concept _Sensor_ at the semantic layer and its specializations for the different sensor types. In addition to the concept _Sensor_, the root node of the concept net, _Scene_, comprises the concept _Landscape_, see Figure 3.2.

   1.2 The _geoinformation system (GIS) layer_, if any, consisting of symbolic (semantic) and vector geospatial information available before looking at the sub-symbolic (non-symbolic) raster sensory image at hand.

    1.3 The *physical layer* contains the geometric, morphological and radiometric properties as basis for the sensor specific projection. Hence, it forms the interface to the sensor layer(s).

2. The (2-D) image domain. For the objects of the 2D image domain, general knowledge about the sensors and methods for the extraction and grouping of image primitives like lines (edges, contours) and 2-D regions (segments or patches; it is noteworthy segment extraction is the dual task of contour detection) is needed. It splits into:

    2.1 The sensor layers, adapted to current sensors such as SAR, LIDAR or optical sensor. All information of the 2-D image domain is given related to the image coordinate system and the sensor type.

    2.2 The data layer. The image sub-symbolic primitives are extracted by image processing algorithms and they are stored in the semantic net as instances of the concepts *Line* (edge, contour) *Data* or *Region (segment) Data* respectively, where contour detection and segment detection are complementary tasks, both ill-posed in the Hadamard sense (refer to Section 3.1).

3.3   Semantic network representation of any prior geospatial knowledge base

According to Section 3.2 any prior geospatial knowledge base (i.e., geospatial knowledge of the 3-D world available before collecting the sensory (2-D) image data at hand) can be represented with a *semantic network* consisting of: (i) geospatial concepts as nodes, (ii) spatial and non-spatial relationships as arcs and (iii) node- and arc-specific attributes. Before delivering any semantic network representation of a prior geospatial knowledge base a community-agreed network vocabulary must be selected first.

For example, in the framework of the BIO-SOS project a community-agreed semantic network vocabulary should provide a set of graphical primitives sufficient to sketch the prior geospatial knowledge of human experts about: (a) second-stage LC classes, their spatial and non-spatial relationships and their geospatial and pictorial (visible) attributes, (b) third-stage GHCs, their spatial and non-spatial relationships and their geospatial and pictorial (visible) attributes, and (c) spatial and non-spatial relationships between second-stage LC classes and third-stage GHCs.

It is noteworthy that in the framework of the three-stage EODHaM classifier developed by the BIO-SOS project, where categorical variables generated as output at each stage feature a level of abstraction (generalization) superior to that of categorical variables generated at previous stages, only spatial and non-spatial relationships as arcs between 2nd-stage semantic nets modelling LC classes and 3rd-stage semantic nets modelling GHCs are expected to date (until proved otherwise), as a practicle example where lower level ontologies (LC classes) are combined into a superior-level ontology (GHCs).

According to the network vocabulary adopted in [Growe, 1999], components of a semantic net are described below (see Figure 3.3).

1. The ***nodes*** model the classes of 3-D objects, entities or concepts expected in the 3-D scene. Two classes of nodes are distinguished: the **concepts** are generic models of the 3-D objects and the **instances** are realizations of their corresponding concepts in the observed scene. In practice, the prior geospatial knowledge base is built out of concepts. During interpretation a symbolic scene reconstruction is generated consisting of instances of object classes. The object properties are described by **attribute values** attached to the nodes. In general, an attribute of an object-class is described as follows: (i) an attribute name or identifier, (ii) a physical unit of measure, if any, i.e., if this attribute is quantifiable, and (iii) a range of variation, also refer to point 3 below.

2. The ***edges*** (links, arcs) of the semantic net form the relations between these objects. A ***relation*** **between two classes of objects is defined as a subset of the cartesian product**

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(product set, direct product) between the two sets. In line with nodes, also arcs can be provided with attributes and properties as described hereafter, also refer to point 3 below**.**

- For the efficient representation of multiple relations (1-to-many, many-to-many, etc.), the minimum and maximum cardinality of an edge can be defined in the geospatial knowledge base, e.g., $[1, \infty]$. The minimum quantity describes the number of obligatory relations and the difference to the maximum quantity represents the number of optional relations between objects. In this way, it can be easily modelled that, for example, a crossroad consists of three up to five intersecting roads.

- For each edge a priority can be defined in order to realize an ordered evaluation of the relations. Edges with high priority are instantiated first.

- Some relations appear exclusively in certain domains. For example, roads have always a lane but they have pavements in urban areas only. This fact is taken into consideration by a domain dependent relationship in the generic model. Figure 3.3 shows a simple semantic net for a generic model of a *Road Net*, which is defined as a composition of at least one *Road*, illustrated by the set [1, 8]. A *Road* consists of one or two lanes. Its specialization *Major Road* inherits the properties of *Road* and possesses an additional *Crash Barrier*. For the part–of relation between pavement and road the domain *Urban Scene* is defined. Only in urban scenes this relation is valid and the system searches for pavements. All the initial objects (*Crash Barrier*, *Lane*, and *Pavement*) are represented by a *Stripe–Form* in the image.

- The following taxonomy of relations between geospatial concepts (nodes in the semantic net) is adopted (see Figure 3.3 to Figure 3.5).
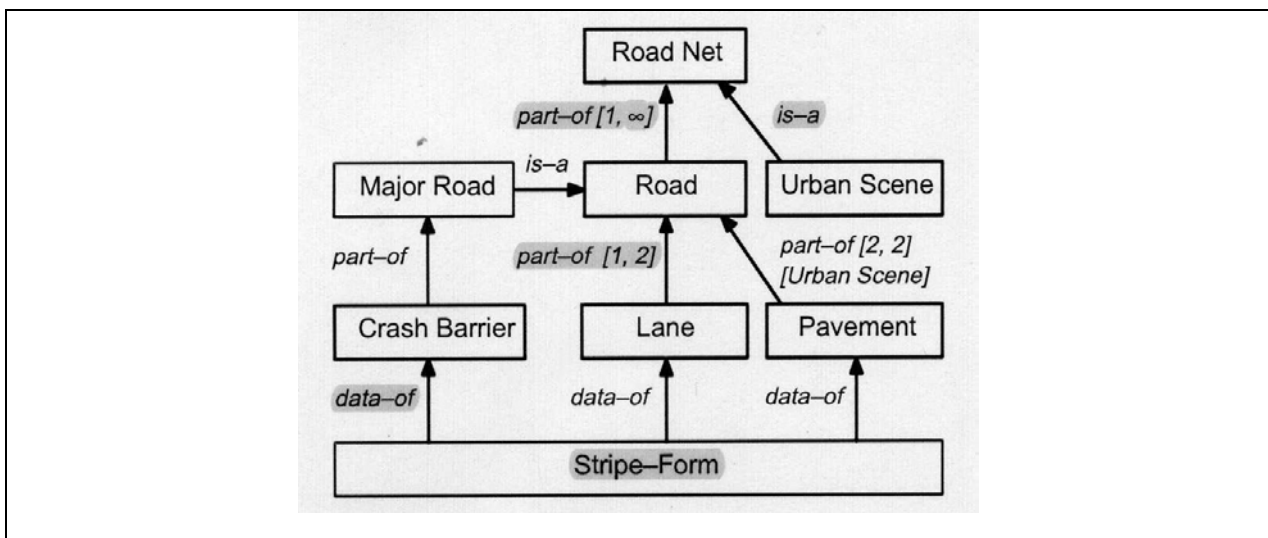

Figure 3.3. Taken from [Growe, 1999]. Example for a semantic net: The scene contains at least one Road. The Pavement is defined for the domain Urban Scene. The more special concept Major Road inherits the properties of Road. All objects are represented by a Stripe–Form in the image.
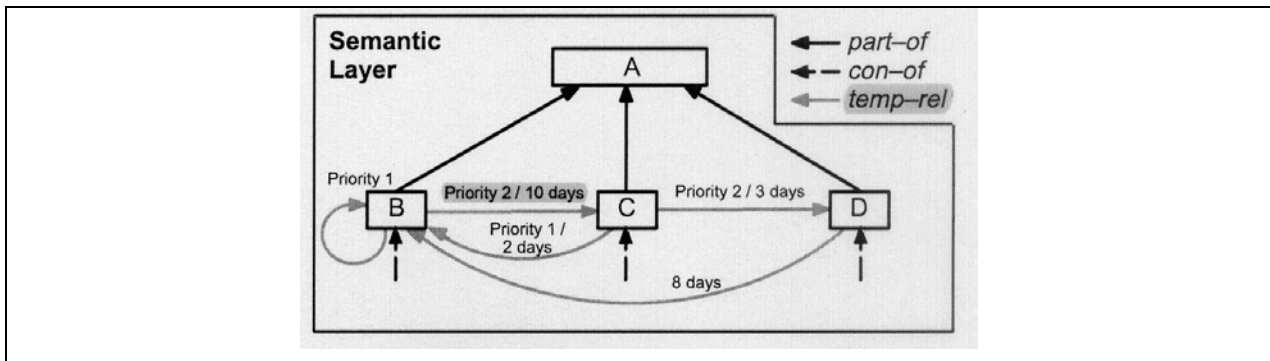
Figure 3.4. Taken from [Growe, 1999]. State transition graph represented by concepts of a semantic net. To each temporal relation a priority and a transition time can be assigned.
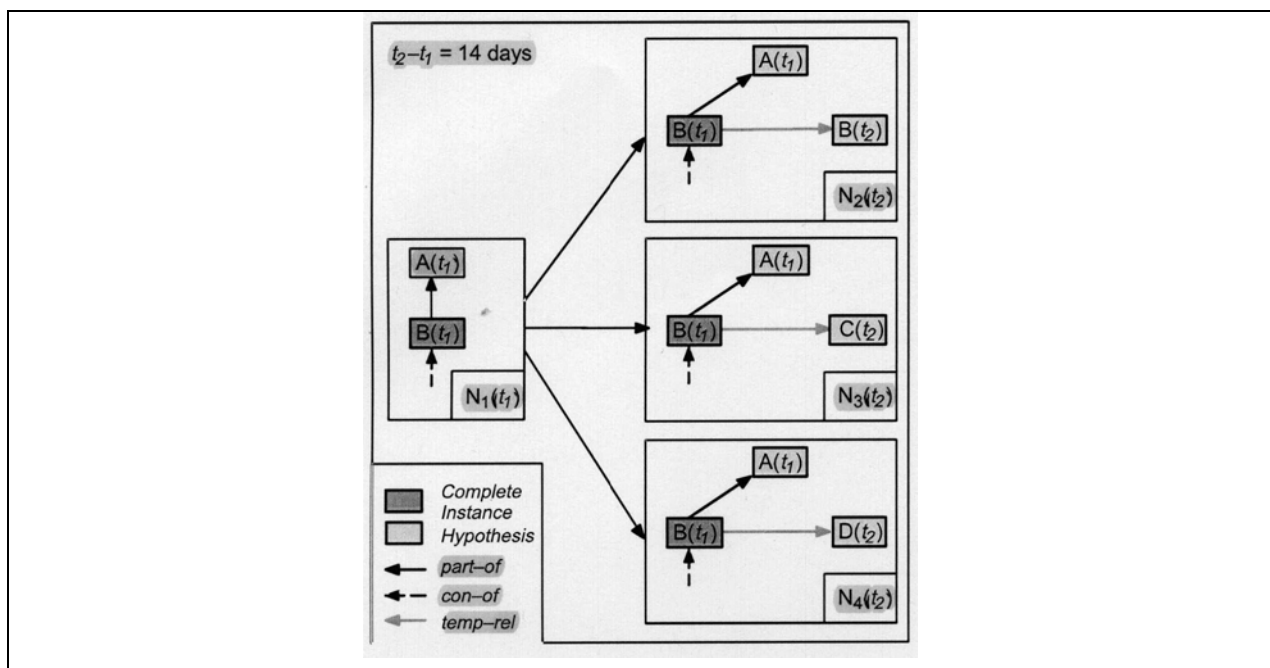
Figure 3.5. Taken from [Growe, 1999]. Search tree of the interpretation process according to the knowledge base in Figure 3.4: Assuming a time step of 14 days the possible successor states of *B* are *B, C,* or *D*. Hence, the search tree splits into three leaf nodes N2(*t2*) to N4(*t2*).

(i) The specialization of objects is described by the **is–a** (**subset-of**) relation introducing the concept of inheritance. **Along the is–a link, all attributes, edges and functions are inherited from the parent node to the more specialized (child) node.**

(ii) Objects are composed of parts represented by the **part–of** link. Thus, the detection of an object can be reduced to the detection of its parts. **These component parts inherit no property from their combination** (e.g., an instance of class *cars* consists of parts such as an engine, a car body and tires; these component parts inherit no property from their combination, namely, the car instance identified, say, by a car plate).

(iii) The transformation of an abstract description into its more concrete representation in the data is modelled by the hierarchical (oriented) relationship **concrete–of** relation, abbreviated **con–of** (**instance-of** [Matsuyama & Shang-Shouq Hwang, 1990]).

(iv) The initial concepts, which can be extracted directly from the data, are connected via the **data–of** link to the primitives segmented by image processing algorithms.

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(v) **Spatial relations**[2] provide information about the kind and the properties of neighbouring objects. Spatial relations are instantiated as soon as possible to realize a **spatial reasoning**. Spatial relations can be split as follows.

   a. **Topological spatial** relationships. For example:

   o adjacency,

   o inclusion.

   b. **Non-topological spatial** relationships, related to measures of distance and angles. For example:

   o close-to (distance-from).

   o in-between-angle.

Therefore, the class of **attributed relations** (**attr–rel**) is introduced in [Growe, 1999]. In contrast to other relations, this one has attributes, which can be used to constrain the properties of the connected nodes. For example, a non-topological relation close–to can be generated which restricts the position of an object to its immediate neighbourhood.

(vi) **Temporal relations**, see Figure 3.4 and Figure 3.5. Temporal changes can be formulated in a so called **state transition graph**, where the nodes represent the temporal states and the edges model the state transitions, to be integrated in a semantic net.

   ▪ For each temporal relation a priority can be defined in order to sort the possible successor states by decreasing probability (see Figure 3.4).

   ▪ As states can either be stable or transient, the corresponding state transitions differ in their transition time, which can be also specified in the temporal relation, (see Figure 3.4).

   ▪ In contrast to hierarchical relations such as part–of or con–of, the start and end node of temporal relations may be identical – forming a loop – to represent that the state stays unchanged over time (see Figure 3.4).

   ▪ Figure 3.5 shows a simple example of a state transition graph consisting of three alternative possible states. To exploit the temporal knowledge, a **time stamp is attached to each instance** of the semantic net, which documents the time of its instantiation.

During the interpretation process, the state transition diagram is used by a new inference rule. The possible successor states are sorted by decreasing priority so that the most probable state is investigated first. All hypotheses are treated as competing alternatives represented in separate leaf nodes of the search tree. Starting with the alternative of the highest priority, the hypotheses for the successor state are either verified or rejected in the interpretation of the (2-D) image at hand.

3. **Attributes** define the properties of nodes and edges. In general, a node- or edge-specific attribute is described as follows: (i) an attribute name or identifier, (ii) a physical unit of measure, if any, i.e., if this attribute is quantifiable, and (iii) a range of variation. For example, in the (2-D) image domain a typical list of 2-D object-class-specific attributes is provided below.

   • A hierarchical class index (numerical identifier).

   • A class name and/or acronym.

------

[2] See Appendix 1 for further details on spatial relations.

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- An unequivocal description/explanation/definition in terms of (3-D) surface properties in the real world. This description can be accomplished by a combination of surface type attributes (e.g., tree percent cover > 60% and tree height > 2 m and mixture of forest types none of which exceeds 60% of landscape).

- Pictorial (appearance, visual) properties in the 2-D image domain belonging to the following taxonomy

  I. Location (spatial) properties.

    a. Non-oriented Minimum Enclosing Rectangle (MER).

    b. Convex hull.

    c. Oriented MER (as a function of the convex hull), see Figure 3.6.
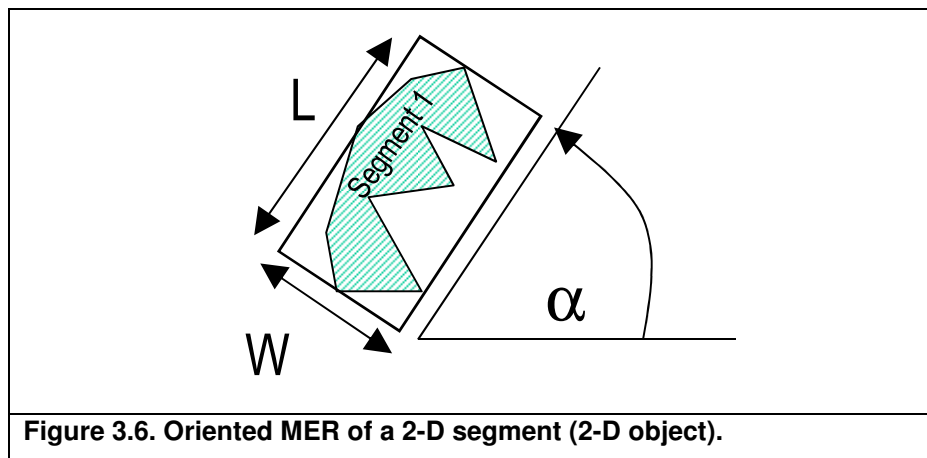
Figure 3.6. Oriented MER of a 2-D segment (2-D object).

  II. Photometric properties (chromatic and achromatic).

    a. Min, max, mean, standard deviation, etc.

    b. Average contrast of a region along its boundary.

    c. Semantic spectral category index according to SIAM.

  III. Geometric and shape properties.

    a. Area (A).

    b. Length (L) of the oriented MER.

    c. Width (W) of the oriented MER.

    d. Centroid.

    e. Perimeter length (PL) = 4-adjacency contour map, where each pixel contour value $\in \{0, 4\}$.

    f. Angle ($\alpha \in$ [0, 180) of the oriented MER.

    g. Compactness (C) = $((4 \times sqrt(A)) / PL) \in$ [0, 1]. This compactness value estimation is invariant to changes in scale [Nagao & Matsuyama, 1980].

    h. Rectangularity = $A / (L \times W) \in$ [0, 1] [Nagao & Matsuyama, 1980].

    i. Elongatedness = = $(L / W) \geq 1$ [Nagao & Matsuyama, 1980] or S = $(A / (D \times D))$, with D = number of shrinking steps to eliminate the region [Matsuyama & Shang-Shouq Hwang, 1990].

       j. Straightness of boundaries $\in$ [0, 1] [Nagao & Matsuyama, 1980].

       k. List of skeleton endpoints with attributes: position, angle, inter-endpoint distance [Shackelford and Davis, 2003].

IV. Morphological properties.

       a. Top-hat of opening (bright object over dark background) [Pesaresi, M., Benediktsson, 2001].

       b. Top-hat of closing (dark object over bright background) [Pesaresi, M., Benediktsson, 2001].

V. Textural properties. It is noteworthy that *texture* is defined as the visual effect generated from the spatial variation of gray tones. In general, textural properties can be parameterized in mathematical terms, e.g., the texture spatial period and the texture orientation, required to design banks of spatial filters (e.g., multi-scale wavelets) for image decomposition and texture detection [Baraldi & Parmiggiani, 1996].

       a. Texture properties (e.g., texture properties of class olive groves in VHR spaceborne imagery).

            i. Texture with structure, where the spatial organization of textons (texture elements) can be described in words of a natural language. It typically consists of foreground and background information.

- Foreground.
  - ✓ Texton (texture element) size in pixels (e.g., textons of class olive groves are the olive tree crowns).
  - ✓ Range of distances (in pixels) between textons.
  - ✓ Orientation of textons, if any.
  - ✓ Space period of the texture ≈ 3÷5 times the inter-texton distance.
  - ✓ Chromatic/achromatic properties of the textons.
- Background.
  - ✓ Chromatic/achromatic properties of the background.

            ii. Non-structured texture, where the spatial organization of textons (texture elements) cannot be described in words of a natural language, but in statistical terms exclusively. It Typically it cannot be split into foreground and background information.

- Texton size in pixels (in general, small).
- Inter-texton distance = 0 (there is no background, but only foreground).
- Orientation of texture, if any.
- Space period of the texture ≈ 3÷5 times the texton size.

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- Chromatic/achromatic properties of the texture.

b. Autocorrelation (e.g., estimated from a Differential Morphological Profile, DMP [Pesaresi, M., Benediktsson, 2001]).

As an example, the semantic net description of the LCCS class **A11/A1.B1.C1.D1.W8.A7.A9.B3,** (olive groves) is reported in Table 3.2 and Figure 3.7.

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Table 3.2. **Descriptions of LCCS class A11/A1.B1.C1.D1.W8.A7.A9.B3 (olive groves) in the 3-D world domain**

3-D LC/LU description/explanation/definition in terms of (3-D) appearance (visual, pictorial) properties in the 3-D world domain. Spatial units of measures: meters.   ***Semantic net is composed of:***   • ***nodes (e.g LCCS or GCH class, object composing the class) and edges (i.e. relations between objects)***   • ***relations: IS-A, PART-OF , DATA-OF, CON-OF***   • ***attributes: photometric, geometric, morphologic, texture***

NODE:
Monoculture field of rainfed broadleaved evergreen tree crops, orchard (olive groves)

EDGES:
Class IS A cultivated area
Class Foreground: olive tree crown (PART OF). Tree height range [1.5m, 4m]
Class Background: soil (PART OF) and, depending on seasonality (PART OF) , shadow (PART OF) as well as grass (PART OF), the latter depending also on agricultural practices (pesticide?)).
Temporal relation: (Class Phenology): perennial, evergreen (TEMPORAL RELATION)

Photometric: colour properties:
Background olive tree crown are green
Background soil colour ranges from maroon to very bright green due to soil graining procedures

Geometric (area, perimeter, compactness, straightness, elongation, rectangularity, no. of vertices)
Mean perimeter (P) of foreground (i.e. tree crown): 15m and 34m for young and old trees, respectively.
Mean area (A) of foreground: $18m^2$ and $34 \ m^2$ for young and old trees, respectively.

Compactness of foreground (P^2/A): 12,5
Shape: Tree crowns have a circular shape

Morphological attributes:
(a) dark object in a bright background: tree shadows
(b) bright object in a dark background: diameter (in m.) [4, 7] for medium aged trees
and [1.8, 3] for young olive trees

Textural attributes:
Periodicity: equivalent to the tree-to-tree average distance: range [10m, 20 m]
Oriented texture: generally Y, but not always (see Figure 1)
Number of directions: 2 generally orthogonal (but not always)

Spatial relations
Topological (e.g. adjacency, inclusion, right-of) properties:
Background shadow (in winter) is ADIACENT to foreground (tree crown)

Non-topological (e.g., close –to, distance-from, in-between- angle) topological attributes:
The distance between tree crowns for both medium aged olive trees and very young olive trees ranges in: [9m, 11m]
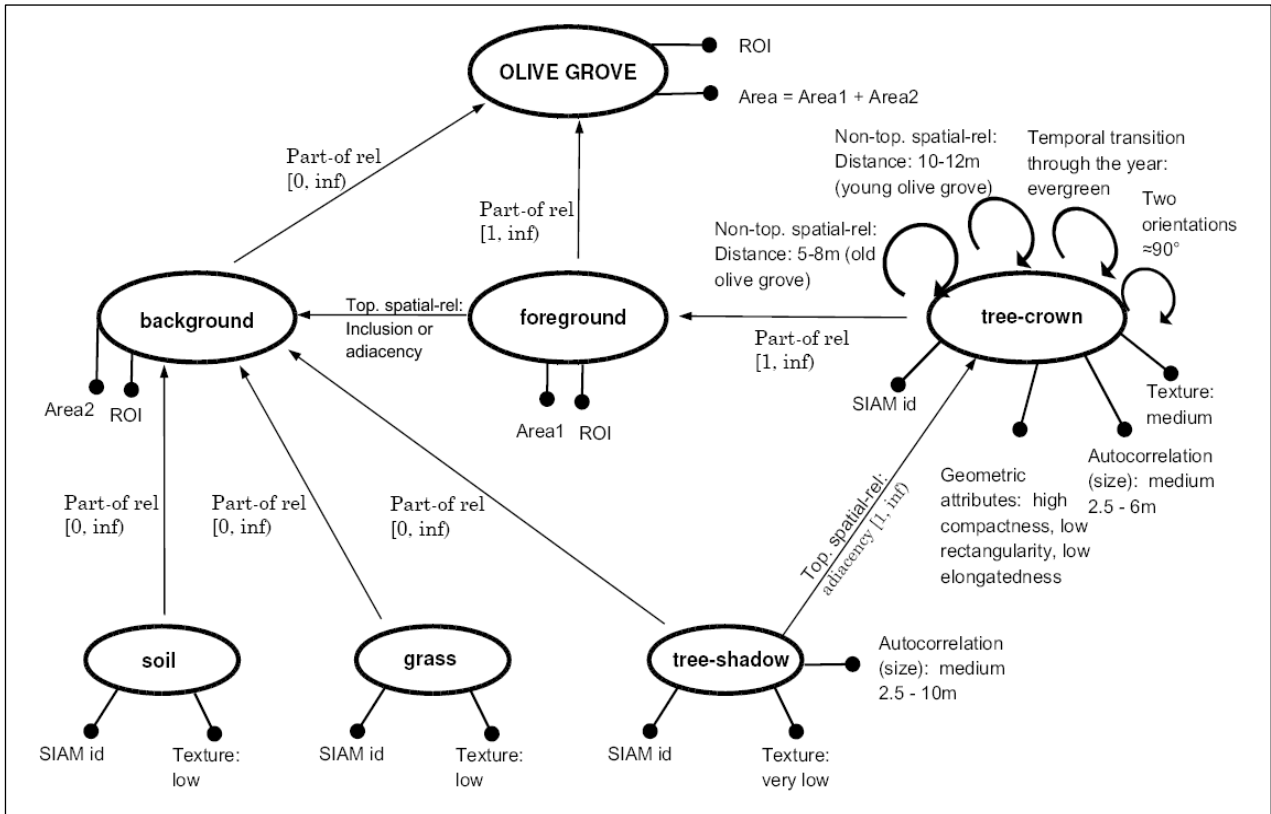
Figure 3.7. Semantic net representation of LCCS class A11/A1.B1.C1.D1.W8.A7.A9.B3 (olive groves)

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3.4 Semantic networks as ontologies to be combined at different levels of abstraction

According to Sections 3.2 and 3.3 a semantic network is a graph consisting of concepts (entities, classes of objects) as nodes and relationships as arcs. A relationship between two classes of objects is any subset of the cartesian product between the two sets (refer to Section 3.3).

In particular, a geospatial semantic network is a graphical representation of any prior knowledge of the 3-D world consisting of a taxonomy, namely, a discrete and finite set of geospatial concepts or classes of objects, and their spatial and non-spatial relationships.

On the other hand, "ontologies describe a set of concepts and relations between concepts" (Lüscher et al., 2007).

Thus, a semantic network, consisting of concepts as nodes and their relationships as arcs, is, *per se*, a graphical representation of an ontology, which is constructed based on expert (prior) knowledge and which can be integrated with higher-level ontologies at increasing levels of abstraction (generalization).

For example, in the context of the BIO-SOS projects the inference engine (namely, the three-stage EODHaM information processing system) starts from sensory data to gather symbolic (semantic) information at increasing level of abstractions, namely, 1st-stage spectral categories, 2nd-stage LC classes belonging to a discrete and finite LCCS taxonomy and, finally, 3rd-stage GHCs.

Basically, three types of ontologies can be differentiated according to the specialization of the represented concepts (Lüscher et al., 2007):

- Top-level ontologies define very general concepts such as space, time, matter, object, event and action. They are independent of a specific domain or problem. Examples of such ontologies are SNAP/SPAN and SWEET (Semantic Web for Earth and Environmental Terminology) ontologies.

- Domain ontologies describing the terminology of a certain domain or of a general task.

- Application ontologies describing the terms that are on the one hand dependent on a domain and on the other hand on a very specific task.

Concretely, domain ontologies should be built to define the concepts and relations to be used in the application ontologies, which would correspond to our low-level semantic nets. For example, identifying relevant concepts linked to the agriculture domain could be achieved using anan agricultural thesaurus such as AGROVOC proposed by the FAO. These concepts will then be included in the semantic nets in order to allow connections with high-level ontologies and consequently allow searching of inferences (e.g., spatial reasoning such that, for example, pictorial sub-symbolic features in a (2-D) image are matched with symbolic classes of 3-D geo-spatial objects in an ontology of the (3-D) world). As a concrete example of the need for using standard concepts, while building semantic nets (i.e. application ontologies), experts may define objects with terms such as "parcel", "cultivated land", "grove" or "meadow". Such terms actually refer to a same concept "field" that will be connected to other ontologies for further connections.

Domain ontologies should not only be used to define concepts but also relations. Specific ontologies should be built to describe spatial and temporal relations. This is a major issue of the BIO_SOS project since such relations are semantically vague. For instance, Shariff *et al.* (1998) proved that a same English term such as "goes to" might have different significations for describing the spatial relations between and object and a line. This implies that the construction of semantic nets, including spatial relations by experts, may be complicated. Moreover, according to (Egenhofer and Herring, 1991), three fundamental types of spatial relationships exist, the properties of which correspond to the three fundamental mathematical concepts topology, order and algebra.

i) Topological relationships are invariant under topological transformations, such as translation, scaling and rotation. Examples are concepts like neighbour and disjoint.

ii) Spatial order relationships rely upon the definition of order or strict order. In general, each order relation has a converse relationship. For example, behind is a spatial order based upon the order of preference (Freeman, 1975) with the converse relationship in-front.

iii) Metric relationships exploit the existence of measurements, such as distances and directions. For instance, "within 5 miles from the interstate highway" describes a corridor based upon a specific distance.

Such differences imply that spatial relations must be described differently. According to Shariff *et al.* (1998), topology is more critical for the semantics of spatial relations than metric. Metric can be used to specify the spatial relations when one term may be associated with various topological relations. Schwering and Raubal (Schwering, 2005) propose to define spatial relations as Booleans (a road is "adjacent to" a field or is not) or with ordinal attributes (a road is "close to" the field, with "close to" being characterized as near, very near, or low nearness).

To summarize, in BIO_SOS, we need to define ontology for spatial relations that would be relevant for describing 1) a 3-D scene with a clear enough semantic meaning, and 2) a 2-D scene with sufficient attributes to be mathematically modeled and then implemented on the image.

These issues introduced for spatial relations are also valid for temporal relations. Even more complicated is to link both spatial and temporal relations. For instance, Egenhofer and Al-Taha (1992) analyzed the gradual changes of spatial relations between two geographical objects, which properties (shape, size, locations…) are evolving in time. Semantic network integration with ontologies has to be undertaken within Task 5.2 of WP5.

4. LCCS to GHC mapping: state of art

The basis for the production of GHC maps from LCCS maps is the linking relations between the two taxonomies. These links represent the correspondence between the definitions and interpretations of the landscape according to the two classifications, forming the set of expert mapping rules, which are explicitly described in D6.10. In Figures 3.1-3.8, a tree-like structure is adopted to depict the latest version of the mapping rules that form the core of the algorithm for the production of LCCS maps into GHC maps.

Since, LCCS focuses on describing land cover whereas GHC also employs land use, many discrepancies can be found, mainly in the definitions of height and coverage of vegetation. These lead to one-to-many mapping relations (only 39 out of the total 87 mapping relations are one-to-one, as it can be easily derived by the Figs 3.1-3.8). Moreover, the one-to-many relationships between the two classification schemes are dependent upon the scale and hence, the spatial resolution of satellite or airborne systems. In particular, the linear elements, which are especially important to biodiversity in managed landscapes and would be recorded with additional qualifiers in the GHC, might be considered as a part of the adjacent classes in the LCCS classification. Additionally, several GHC classes can be contained within one LCCS class and therefore, it is difficult to relate the two classifications, even at the life form level.

Due to the discrepancies between the two taxonomies, a high level of uncertainty is imposed in the classification scheme; thus, sophisticated methods that take into consideration the reliability of the input data, the mapping rules and the classification process are used in the algorithm developed in Task 6.6. The mapping procedure can be further refined by the use of ancillary data and semantic nets in order to increase the classification accuracy in the output. The algorithm architecture (see Fig. 4-3 in D6.10) is such that it allows the future insertion of additional modules and data input towards the elaboration of the classification result. As new information is derived from interacting modules of the EODHaM system, new features will be incorporated in the algorithm to elaborate the produced habitat maps and minimize the classifying uncertainty.

Forthcoming improvements to the algorithm will include the incorporation of ancillary data, refinement of the existing expert rules and fuzzification of input data and expert rules.

The ancillary data may include:

- o Data from external sources, such as cadastral maps, digital elevation models, climatic conditions, etc, which could be included as an additional GIS layer, to discriminate between managed and natural areas or to exclude habitats that cannot occur (e.g. because of environmental conditions).

- o Semantic information from the EODHaM 2nd stage and the GHC definitions, which can reveal further information on the spatial and temporal relations between LC and GHC classes, or inherited properties from parental classes.

- o Data from previous stages of EODHaM. One of the structural features and advantages of the EODHaM system is the preservation of intermediate results, which might be useful in further processes. This mainly includes the output from the 1st stage, where spectral pixel-based information on the landscape is generated and can be further exploited (in certain cases) during the conversion from LC classes to habitats.

Based on a semantic net representing the GHC habitat properties, the existing mapping rules can be refined, with the incorporation of spatial and temporal correlations and scale issues, while the fuzzification of input data and expert rules will reduce uncertainty and improve the classification accuracy from LCCS to GHC classes.

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Figure 4.1: The mapping rules between the A11 LCCS super-category and the corresponded GHC classes.

Figure 4.2: The mapping rules between the A12 LCCS super-category and the corresponded GHC classes.

Figure 4.3: The mapping rules between the A23 LCCS super-category and the corresponded GHC classes.

Figure 4.4: The mapping rules between the A24 LCCS super-category and the corresponded GHC classes.
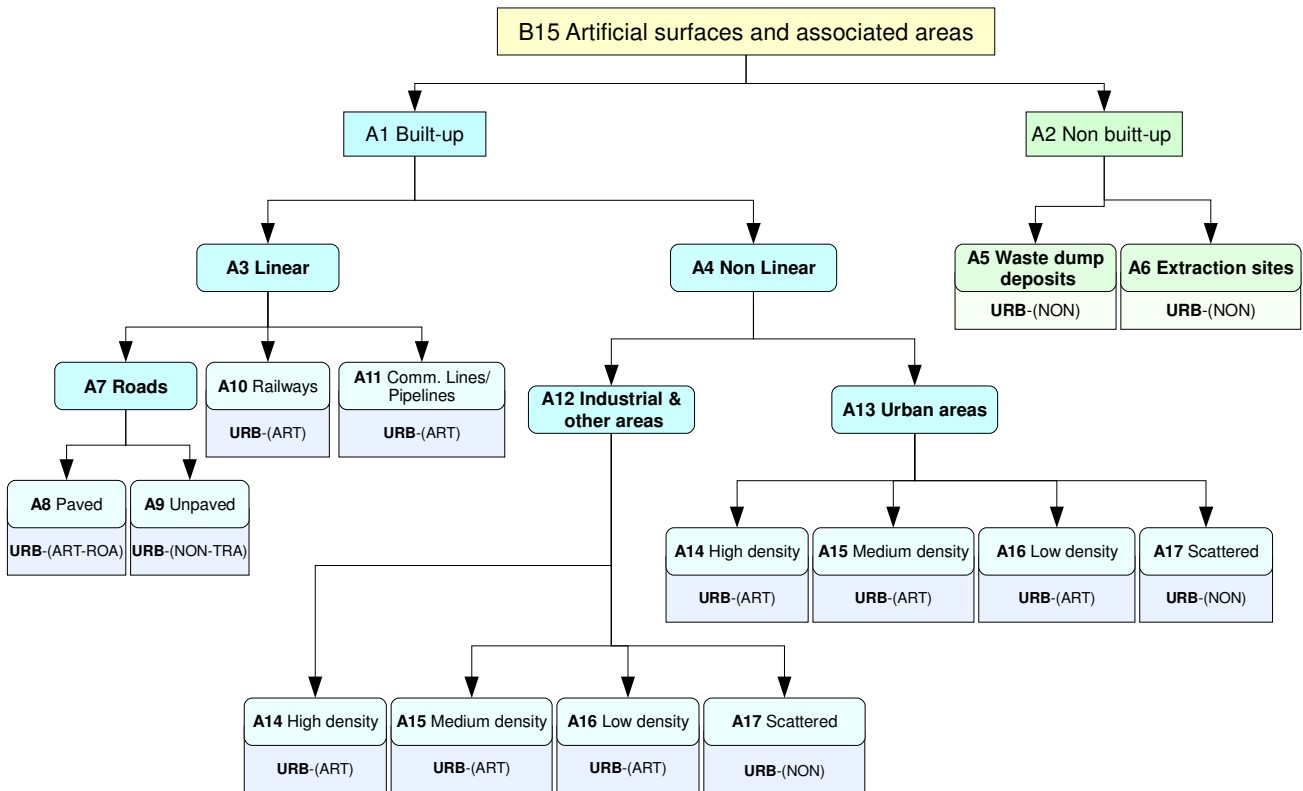
Figure 4.5: The mapping rules between the B15 LCCS super-category and the corresponded GHC classes.
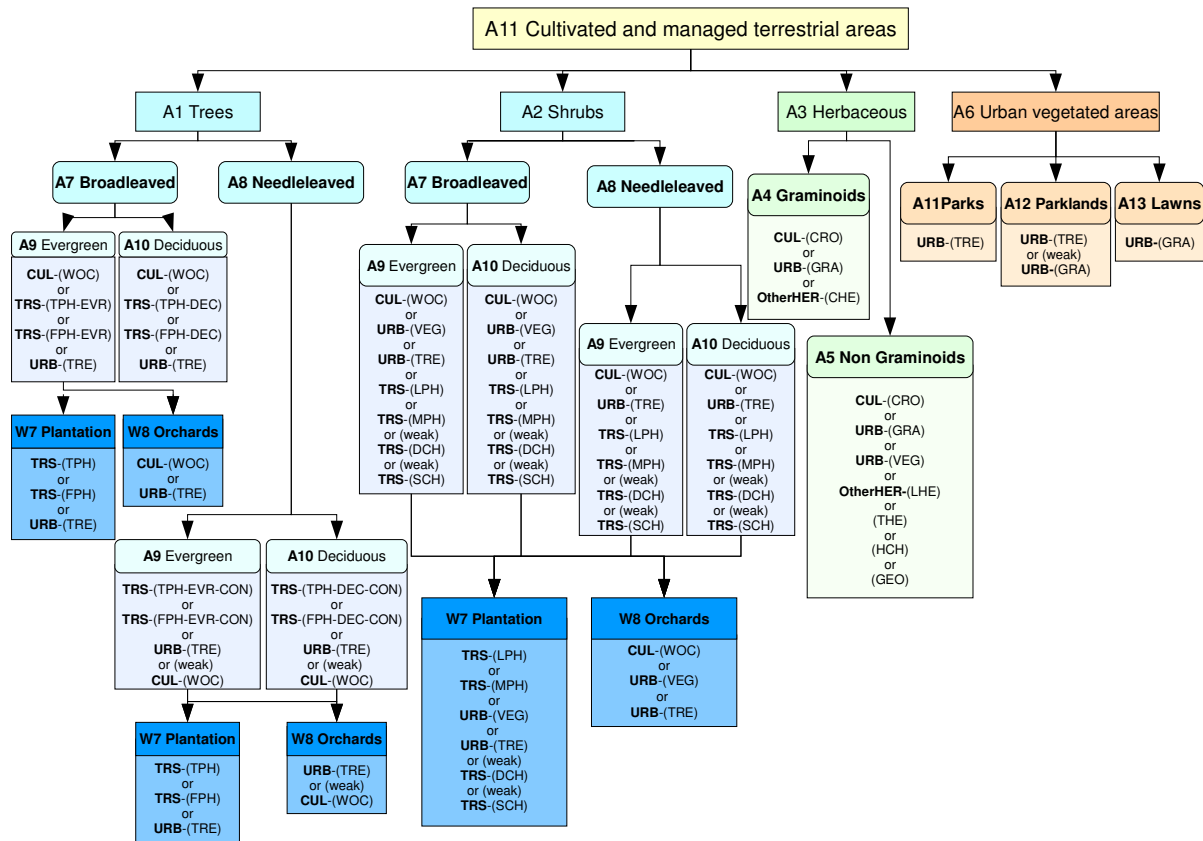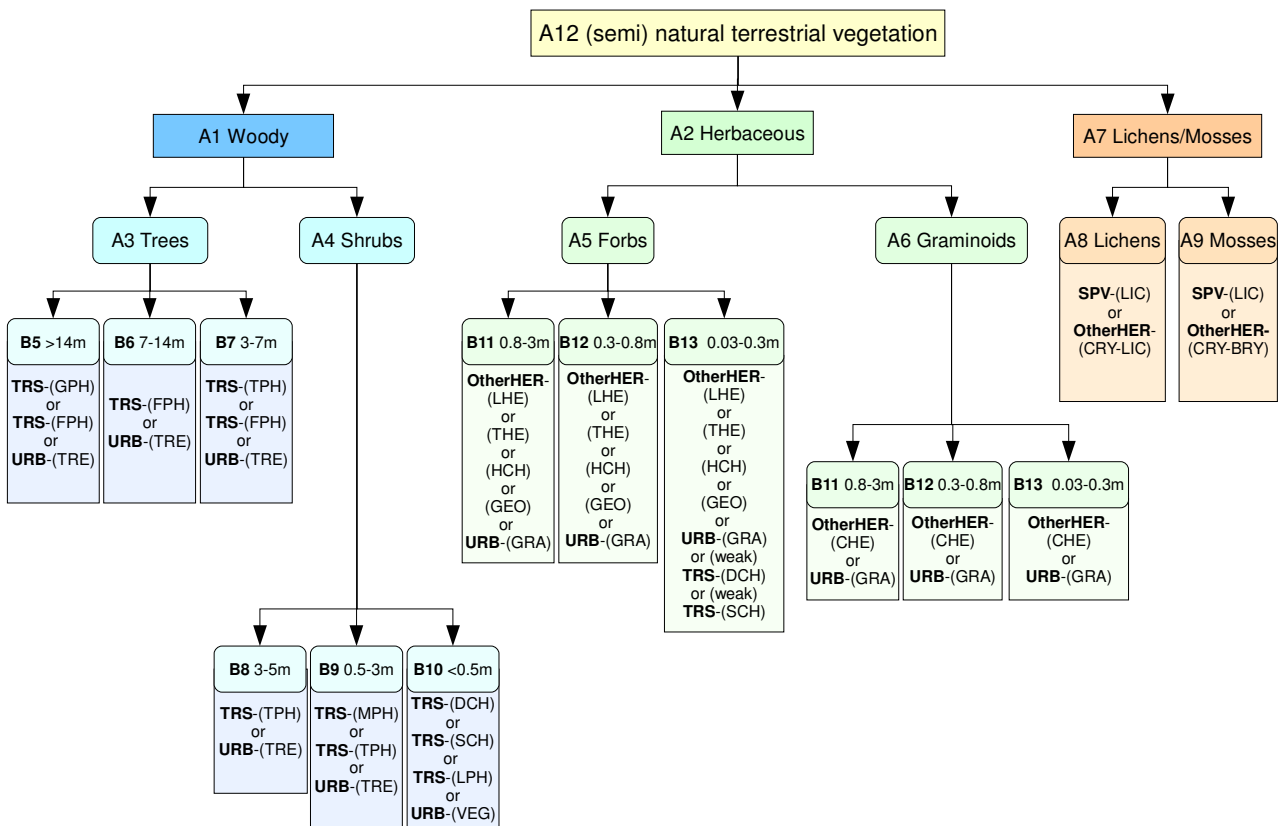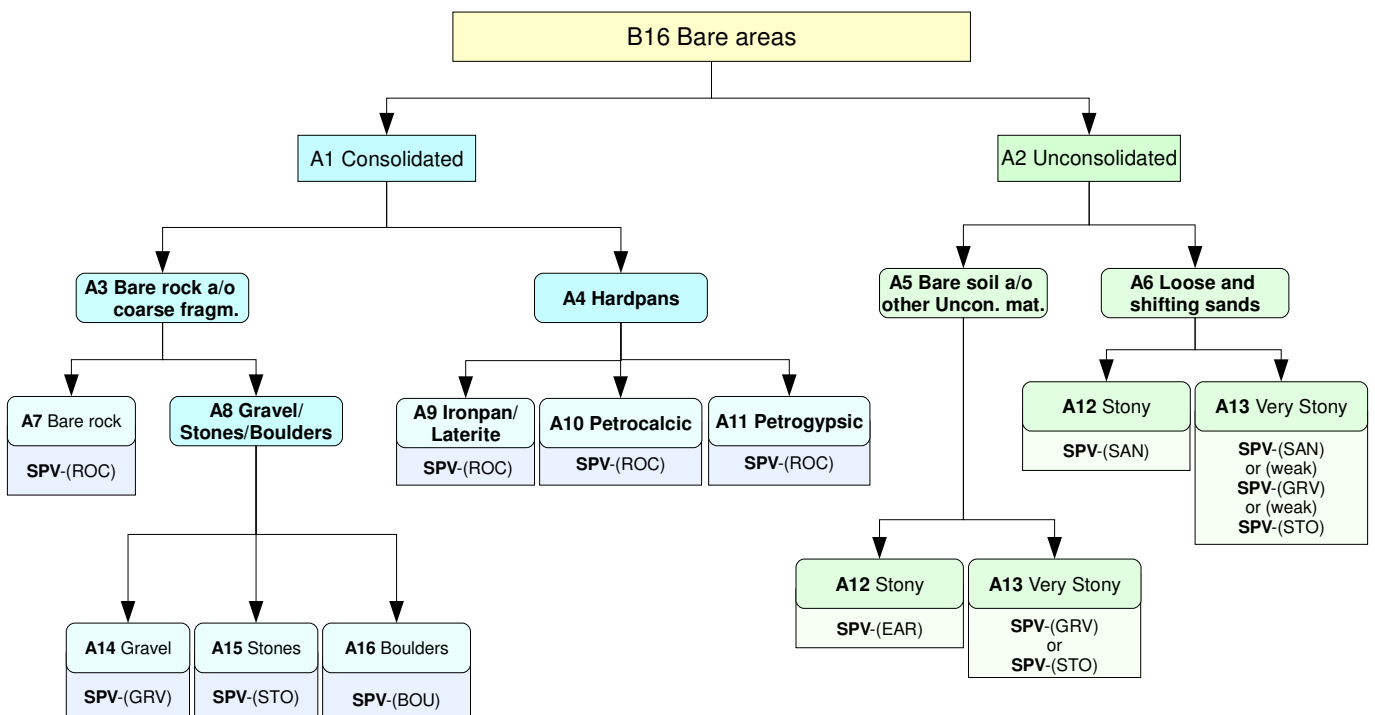

Figure 4.6: The mapping rules between the B16 LCCS super-category and the corresponded GHC classes.
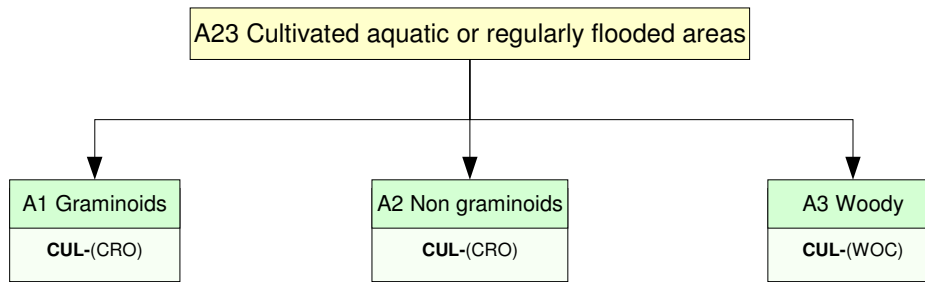
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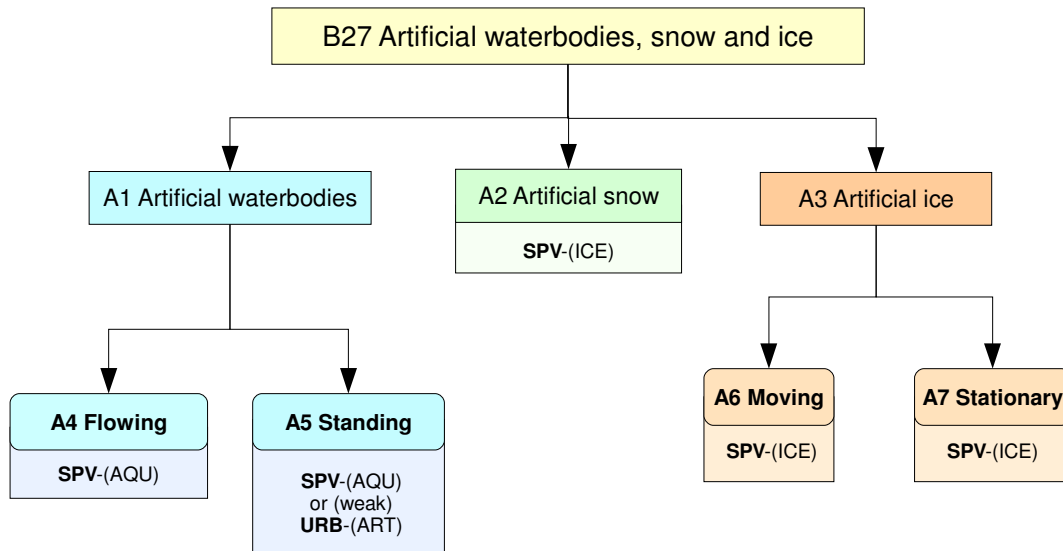
Figure 4.7: The mapping rules between the B27 LCCS super-category and the corresponded GHC classes.
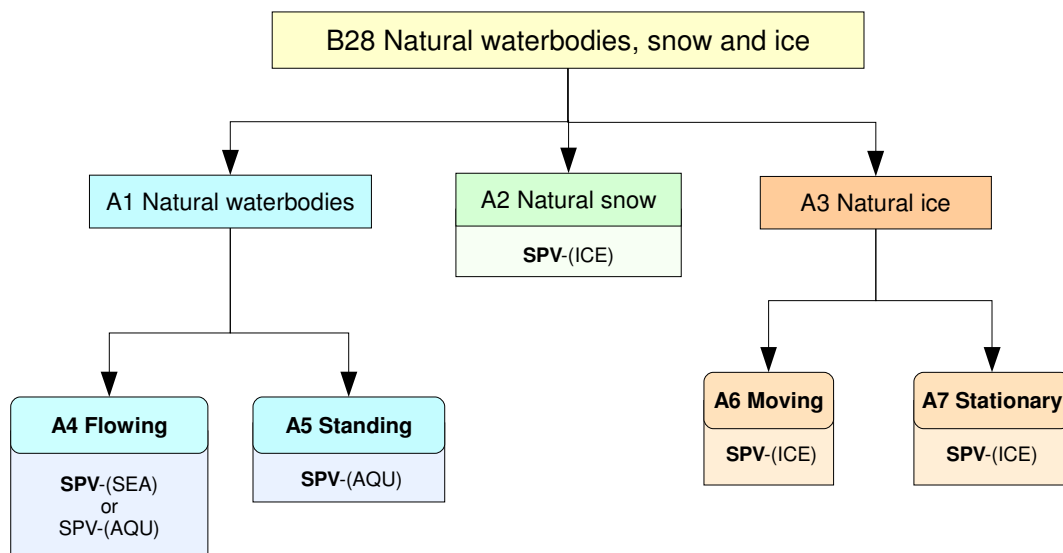
Figure 4.8: The mapping rules between the B28 LCCS super-category and the corresponded GHC classes.
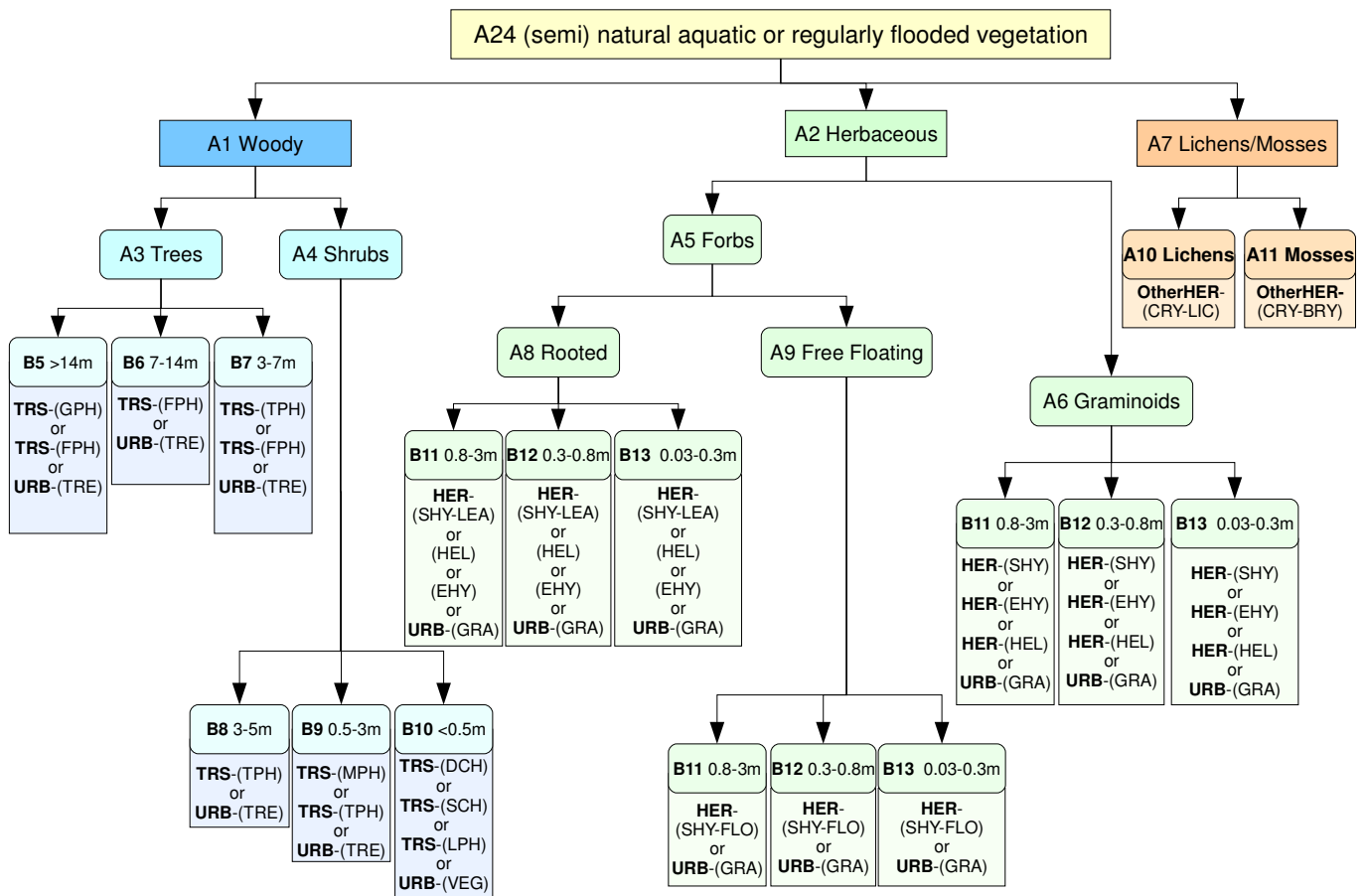
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5.   Test site in Wales

The Natura 2000 site includes the largest uncut area of lowland raised bog in the UK, Cors Fochno (Borth Bog), but also encompasses the estuarine complex located within the Dyfi catchment. Other habitats occurring within the area include sand dunes and salt marshes, a 'drying' estuary with both mud and sand flats, marshy grasslands, broadleaved woodlands and coniferous plantations, wet woodlands, scrub and improved/semi improved grasslands.

As with the whole of the UK, the land covers in the Dyfi catchment were classified in 2000 using a combination of Landsat sensor and Indian Remote Sensing Satellite (IRS) data as part of the UK Land Cover Map 2000 (LCM 2000). However, the BIO-SOS study seeks to classify the landscape according to the Food and Agriculture Organisation (FAO) Land Cover Classification System (LCCS) classes, primarily from spaceborne optical remote sensing data and based on SIAM™-derived spectral categories. These classes then need to be translated to General Habitat Categories (GHCs), which describe habitats rather than land covers, and subsequently to Annex I Habitat categories. The following provides a summary of the land covers and habitats occurring within the Natura 2000 site and Dyfi catchment before describing the approach to subsequent classification of land covers and habitats.

5.1   Land cover classification scheme: Welsh sites

5.1.1   Land Cover Map 2000 (LCM 2000).

The UK Land Cover Map (LCM 2000) is a classification of land covers that is aligned with the Corine Landcover Classification (CLC) scheme. The LCM 2000 classes identified for the Natura 2000 site are outlined in Table 5.1.

Table 5.1. UK Corine Landcover Classes present within the Natura 2000 site and the Dyfi catchment

Class	Equivalent Corine Landcover Class	Description	Cors Fochno	Dyfi
324	Broad-leaved/mixed woodland	Transitional woodland scrub	●	●
331	Supra-littoral rocks and sediments	Beaches, dunes, sands	●	●
412	Bog	Peat bogs	●	●
421	Littoral and supra-littoral rocks and sediments	Salt marshes	●	●
321	Neutral, acid and calcareous semi-improved and unimproved grasslands	Natural grassland	●	●
423	Littoral and supra-littoral rocks and sediments	Intertidal flats	●	●
511	Water (inland)	Water courses	●	●
512	Water (inland)	Water bodies	●	●
522	Sea / Estuary	Estuaries	●	●
523	Sea / Estuary	Sea and ocean	●	●
311	Broad-leaved/mixed woodland	Broad leaved forests		●
312	Coniferous woodland	Coniferous forest		●
313	Broad-leaved/mixed woodland	Mixed forest		●
322	Dwarf shrub heath (wet/dry)/Montane	Moors and heathland		●
332	Littoral and supra-littoral rocks and sediments	Bare rocks		●
333	Open spaces with little vegetation	Sparsely vegetated areas		●

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5.1.2 FAO LCCS

The FAO LCCS has not been applied previously to Welsh environments but has been undertaken as part of the BIOSOS project. As background, the LCCS first divides the landscape into areas that are primarily vegetated or non-vegetated (Figure 5.1). Each is then divided further according to whether it is terrestrial or aquatic or regularly flooded. Within the vegetated areas, areas that are cultivated or managed are separated from those that are semi-natural. Within the non-vegetated category, artificial surfaces and associated areas (primarily urban) are separated from bare areas and artificial and natural waterbodies are distinguished.
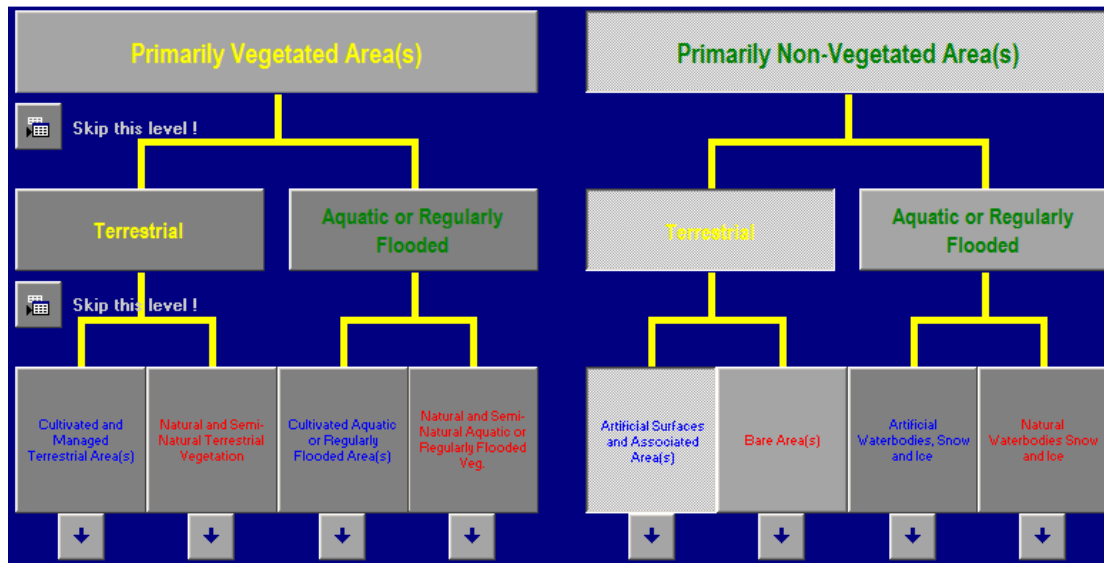
Figure 5.1. The FAO Land Cover Classification System, with dichotomous separation of primarily vegetated and non-vegetated areas.

The broad FAO LCCS classes occurring within the Natura 2000 site and the Dyfi catchment (*first three levels*) are listed in Table 5.2. All classes are present with the except
ion of Cultivated Aquatic or Regularly Flooded areas. Whilst the areas of saltmarsh along the Dyfi estuary are grazed by stock and could be regarded as 'managed', these were instead associated with the semi-natural aquatic/regularly flooded land cover category.

Table 5.2. LCCS classes (Level 3) located within the Natura 2000 site and the Dyfi catchment

PRIMARILY VEGETATED		PRIMARILY NON-VEGETATED	
A11	Cultivated and Managed Terrestrial	B15	Artificial surfaces and associated areas
A12	Natural and semi-natural primarily terrestrial vegetation	B16	Bare areas
A23	*Not present*	B27	Artificial waterbodies, snow and ice
A24	Natural and semi-natural aquatic or regularly flooded vegetation	B28	Natural waterbodies, snow and ice

Within the lower levels that deal with Life Forms, the 22 LCCS categories occurring within the Natura 2000 site and the Dyfi catchment are given in Table 5.5.3. A summary of each is provided in the following sections.

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Table 5.3. LCCS classes (Life Forms) occurring within The Natura 2000 site and the Dyfi catchment

Category	LCCS Code_Modifier	Description
A11	A3.A4.B1.B5.C1.D1.D9_B4	Permanently cropped area: Graminoid crops
A11	A1.B1.B5.C1.D1.D9_A8.B4	Permanently cropped area with rainfed needleleaved tree crops (plantations).
A11	A1.B1.B5.C1.D1.D9_A7.B4	Permanently cropped area with rainfed broadleaved tree crops (plantations).
A12	A1.A3.A10.B2.C2.D1.E2.B5	Broadleaved deciduous fragmented high trees
A12	A1.A4.A11.B3.C2.D1.E2.B14	Broadleaved deciduous medium to high shrubland
A12	A1.A4.A11.B3.C2.D1.E1	Broadleaved Evergreen Fragmented Shrubland single layer.Heathland (uplands)
A12	A2.A6.A10.B4.C1.E5_B12.E6	Closed Perennial Medium Tall Grassland (e.g., *Molinia/Juncus*)
A12	A2.A6.A11.B4.XX.E5_A12.B12.E6	Open ((70-60)-40 %) Perennial Medium Tall Grassland (e.g., *Eriophorum*)
A12	A2.A6.A10.B4.C2.E5_B13	Closed short grassland
A12	A2.A5.A10.B4_B11	Closed medium tall forbs (3.0-0.8 m)
A12	A2.A5.A10.B4_B12	Closed medium tall forbs (0.8-0.3 m)
A24	A1.A4.A20.B3.C1.D1.E1.F2.F4.F7.G4_C4	Closed to Open Broadleaved Evergreen Shrubs with Herbaceous Vegetation on Permanently Flooded Land (Persistent) (Active Bog)
A24	A2.A6.A12.B4.C1.E5_B11.C4.E6	Perennial closed tall grassland on permanently flooded land (persistent)
A24	A2.A6.A13.B4.C1_B13.C5	Open short grassland on permanently flooded land (with daily variations) (*Unmanaged Saltmarsh*)
B15	A3_A8	Paved road(s)
B15	A3_A10	Railway(s)
B15	A4_A13	Urban areas
B16	A3_A7	Bare rock
B16	A6.B6	Shifting Sands.Saturated Parabolic Dunes
B16	A6_A12	Stony loose and shifting sands

B16	A5_A13	Very stony bare soil and unconsolidated material(s)
B27	A1.B1.C2.D1.A5	Clear shallow artificial waterbody (Standing)
B27	A1.B1.C1_A4	Turbid Deep to Medium Deep Artificial Perennial waterbodies (Flowing)
B27	A1.B1.C1_A5	Deep to Medium Perennial Artificial Waterbodies (Standing)
B28	A1.B1.C1_A5	Deep to Medium Perennial Natural Waterbodies (Standing)
B28	A1.B3_A4.B6	Tidal Area (Flowing); Surface Aspect (sand)
B28	A1_A4	Natural waterbodies, flowing (ocean/sea)

A11. Permanently cropped area: Graminoid crops (A3.A4.B1.B5.C1.D1.D9_B4): The majority of intensive agriculture in Wales is associated with permanent pastures grazed primarily by sheep and cattle. As such, this LCCS class encompasses much of the landscape within the Dyfi catchment and surrounding The Natura 2000 site. Grassland categories are described primarily on the basis of cover and height. Cover is typically high (often > 95 %) but the height of the grasses varies considerable and largely as a function of grazing and cutting. These differences influence the reflectance characteristics of this land cover category, which are correspondingly diverse. In many managed areas, grasslands may contain swards dominated by grass species (typically *J. effuses* and *M. caerulea*), which are often associated with semi-natural vegetation.

A11. Continuous medium sized fields of needle leaved tree crops (plantations (A1.B1.B5.C1.D1.D9_A8.B4-W7) and continuous medium-sized fields of broad-leaved tree crops (plantations) (A1.B1.B5.C1.D1.D9_A7.B4-W7): Coniferous plantations are typically located in the uplands of Wales although smaller stands (with some exceptions) may occur in the lowlands. These stands are typically even-aged, of relatively uniform structure and species composition and typically located outside of the intensive agricultural areas. Broadleaved plantations are relatively scarce with most woodlands being semi-natural.

A12. Broadleaved deciduous fragmented high trees (A1.A4.A10.B2.C2.D1.E1.E2_B5): Broadleaved deciduous woodlands are widespread throughout the Dyfi catchment and are dominated by a range of species, primarily oak (*Quercus*), birch (*Betula*) and beech (*Fagus*). Many stands are relatively fragmented although more extensive stands may also occur.

A12. Broadleaved deciduous medium to high shrubland (A1.A4.A11.B3.C1.D1.E2_B14): Shrublands are either evergreen (e.g., gorse or *Ulex* species) or deciduous (e.g., blackthorn or *Prunus spinosa*). These shrublands typically occur in isolated clusters and the former are often associated with rock outcrops.

A12. Broadleaved evergreen fragmented shrubland single layer (A1.A4.A11.B3.C2.D1.E1): Heathlands occur largely in the uplands and in the margins of the catchment and are dominated by *Calluna*, *Erica* and *Vaccinium* species. These species are evergreen but experience a foliage flush in the spring (particularly *Vaccininum*).

A12. Closed Perennial Medium Tall Grassland (A2.A6.A10.B4.C1.E5_B12.E6): Much of the active bog is surrounded by tall grasslands, typically dominated by *Molinea* and *Juncus* species. These grass species also form extensive swards in the uplands. In the winter months, *Molinea*-dominated swards are characterised by a dense mat of dead material but in the summer months, these swards are moderately productive.

A12. Open ((70-60)-40 %) Perennial Medium Tall Grassland (e.g., Eriophorum/Juncus) (A2.A6.A11.B4.XX.E5_A12.B12.E6): Within some areas, grass swards dominated by, for example, *Eriophorum* and *Juncus* species, may occur with these are often interspersed with other grass species (including those on land that is managed). The active stand dune systems are stabilised by Marram grass (*Ammophia Arenaria*), which is variable in cover. Dune slacks are also present, with these often supporting short grassland (A6.A10.B4.C2.E5_B13).

A12. Closed short grasslands (A2.A6.A10.B4.C2.E5_B13): Grasslands that are relatively short include those associated with sand dunes and also terrain with relatively poor soils. The more extensive tracts are located in the uplands where several (e.g., *Festuca*) species dominate. Most are grazed by native mammals but are often diverse and regarded as semi-natural.

A12. *Closed medium tall forbs (A2.A5.A10.B4_B12 and _B11)*: Areas with extensive cover of closed medium tall forbs are dominated largely by bracken (*Pteridium aquilinum*). As with *Molinea*, stands are characterised by a dense mat of litter in the winter months, which are highly productive in the summer months. Stands can be relatively tall (up to 2 m) but the majority are < 1 m in height.

A24. Closed to Open Broadleaved Evergreen Shrubs with Herbaceous Vegetation on Permanently Flooded Land (Persistent) (shrubland) (A1.A4.A20.B3.C1.D1.E1.F2.F4.F7.G4_C4): The main habitat occurring within The Natura 2000 site is the active raised bog, which is comprised primarily of dwarf shrubs with these typically being in mosaics with graminoids, bryophtyes and lichens. The active bog is unique within the Dyfi catchment and the elevation of its surface is no higher than 6 m above mean sea level (msl).

A24. Perennial closed tall grassland on permanently flooded land (persistent) (A2.A6.A12.B4.C1.E5_B11.C4.E6): Within the Natura 2000 site, extensive areas *of Phragmites australis* occur, particularly along the margins of ditches but also the active bog.

A24. Open short grassland on permanently flooded land (with daily variations) (A2.A6.A13.B4.C1_B13.C5): Along the margins of the Dyfi estuary, saltmarshes are extensive and dominated by *Spartina* and *Salicornia* species. Large areas of the saltmarsh are grazed by horses. The elevation rarely exceeds 3 m above msl.

B15. Urban infrastructure: The main urban settlements (**A4.A13**), which often have terraced houses along roads, in the Dyfi catchment are Machynlleth and Borth and a number of small villages are scattered within the lowlands. Isolated farms and houses are located throughout the catchment. The main transport infrastructure is paved roads (**A3_A8**) and a single railway (**A4_A10**).

B16. Bare rock (A3.A7): Throughout the catchment, small areas of bare rock occur, primarily as outcrops.

B16. Shifting Sands.Saturated Parabolic Dunes (A6.B6): The main area of non-vegetated (bare ground) is the active sand dune system at the mouth of the River Dyfi.

B16. Stony loose and shifting sands (A6_A12): Towards the mouth of the estuary, stony loose and shifting sands occur as a minor component.

B16. Very stony bare soil and unconsolidated material(s) (A5_A13): Along the seaward coasts (particularly south of the estuary mouth) and inland of the sandflats, large unconsolidated stones (pebbles) occur in a narrow strip up to 20 m wide.

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B.27. Deep to Medium Perennial Artificial Waterbodies (Standing) (A1.B1.C1_A5): Artificial bodies of standing water are typically small (often < 1 ha) and typically consist of ponds, many of which are located within Cors Fochno. These have largely been created to restore and maintain the hydrological regime of the active bog. Several small reservoirs also occur in the uplands.

B.27. Turbid Deep to Medium Deep Artificial Perennial Waterbodies (Flowing) (A1.B1.C1_A4): Artificial bodies of flowing water consist largely of the River Leri, which is a straightened channel connecting to the main Dyfi estuary, and tributaries.

B.28. Deep to Medium Perennial Natural Waterbodies (Standing) (A1.B1.C1_A5): Isolated natural waterbodies occur in the uplands (e.g., Glaslyn Lake) and are rare in the lowlands.

B.28. Tidal Area (Flowing); Surface Aspect (sand) (A1.B3_A4.B6): Within the Dyfi estuary, extensive sand banks occur which are often covered at high tide.

B.28. Natural waterbodies, Flowing (ocean/sea) (A1_A4): The largest waterbody is the Irish Sea into which the Dyfi estuary flows. The tide range is large and, depending upon the date and time of the observation, the area potentially above to be classified as water is highly variable.

5.1.3 General Habitat Categories

Based on the conversion tables generated through the BIO-SOS project, General Habitat Categories (GHCs) were translated from LCCS (to Level 3) for the Dyfi catchment, including The Natura 2000 site (Table 5.4).

Table 5.4. General Habitat Categories present within the Dyfi catchment (including The Natura 2000 site) and their relationship with the FAO Land Cover Classification Scheme (LCCS) classes.

LCCS	Description	Potential GHC super categories
A11	Cultivated and Managed Terrestrial	CUL / URB (VEG-GRA-TRE) / TRS/Other HER
A12	Natural and semi-natural primarily terrestrial vegetation	SPV (LIC) / TRS / Other HER / URB (VEG-GRA-TRE)
A23	Cultivated Aquatic or regularly flooded areas	CUL (CRO)
A24	Natural and semi-natural aquatic or regularly flooded vegetation	HER / TRS / Other HER / URB(VEG-GRA-TRE)
B15	Artificial surfaces and associated areas	URB (ART-NON)
B16	Bare areas	SPV (ROC-BOU-STO-GRV-SAN-EAR)
B27	Artificial waterbodies, snow and ice	SPV (AQU-ICE)
B28	Natural waterbodies, snow and ice	SPV (SEA-AQU-ICE)

5.2 LCCS Classification based on remote sensing and ancillary data.

5.2.1 Satellite imagery

The classification of LCCS classes based on the spectral categories generated from the SIAM™ 1st stage spectral categories was first evaluated using time-series of Landsat sensor data, acquired on the 19th July, 2006, and 17th April, 2010, and a SPOT5 High Resolution Geometric (HRG) scene acquired in November, 2009. The Landsat scenes were obtained from the US Geological Survey (USGS) whilst the SPOT scene was obtained from SPOTimage. All data were converted to units of Top of Atmosphere Reflectance and run through the SIAM™ 1st stage

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classification. SIAM™ outputs included hierarchical layers of spectral categories (18, 47 and 95 respectively for Landsat TM/ETM+ and 15, 40 and 68 for SPOT HRG), associated segments (including the mean spectral values for each of the multispectral bands), urban and vegetation masks and greenness and brightness images. As an example, SIAM™ 1st stage classifications and the names associated with the spectral categories identified within the Natura 2000 site and Dyfi catchment are given in Figure 5.3 for the Landsat TM only.

5.2.2 Ancillary data

To reproduce the first three levels of the LCCS from these sensors, a number of additional data layers were needed, noting that these are themselves derived from high resolution remote sensing data (Table 5.1). Areas of vegetation were identified from the SIAM™ first stage classification, namely from the vegetation mask. The Ordnance Survey Mastermap provides vector layers relating to buildings and linear features, with this derived from aerial photograph interpretation. Similarly, the Land Parcel Information System (LPIS) vector layer representing field and other cadastral boundaries has been digitised manually from aerial photography. In both cases, similar datasets could be generated through manual interpretation of Very High Resolution (VHR) spaceborne data (e.g., IKONOS, Quickbird), although automated approaches would be preferable. The Nextmap Digital Terrain Model (DTM) provides information on elevation, slope and aspect and was derived from interferometric X-band SAR data. More detailed DTMs as well as Digital Surface Models (DSMs) have been generated from LiDAR, but only for the active bog and immediate surrounds.

5.2.3 Segmentation

Within eCognition, SIAM™-generated segments were translated into objects by first performing a chessboard (1 pixel per object). To incorporate existing information on infrastructure (buildings/roads), all pixels overlapping with the Ordnance Survey (OS) Mastermap layer of buildings and linear features were classified as a temporary 'urban' class. A spectral difference segmentation was then undertaken using the differences in the spectral classification (e.g., 95 classes) to ensure that segments exactly matched those generated by SIAM™. However, by incorporating Land Parcel Information System (LPIS) data into the segmentation process, some segments were split to product objects that conformed to the boundaries of cultivated or managed areas. In all cases, the original spectral class allocations were retained.

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a)
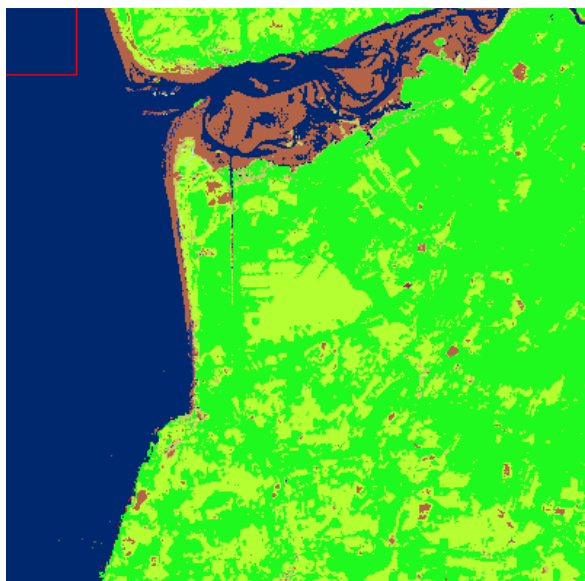
b)
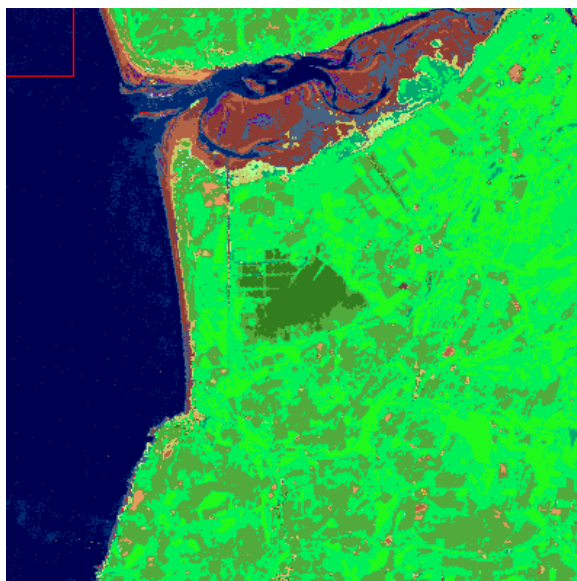
c)
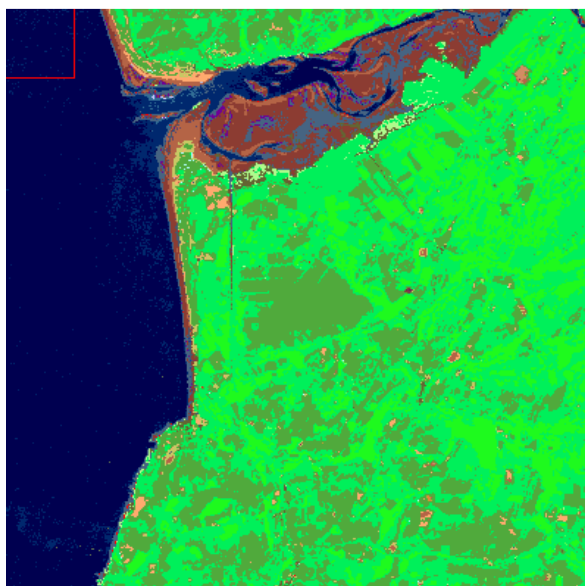
Figure 5.2. Preliminary outputs of the SIAM™ classification for Landsat TM data with a) 18, b) 47 and c) 95 spectral categories.

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a)

- V
- SHV
- R
- WR
- PB
- GH
- BB
- SHB
- WASH
- CL
- SMKPLM
- TNCL°SHRBR°HRBCR°BB
- SN
- SHSN
- SH
- UN
- BA
- FLAME

b)

- Unclassified
- SVHNIR
- SVLNIR
- AVHNIR
- AVLNIR
- WV
- SHV
- SHRBRHNIR
- SHRBRLNIR
- HRBCR
- WR
- PB
- GH
- VBBB
- BBB
- SBB
- ABB
- DBB
- WBBorSHB
- NIRPBB
- BA
- DPWASH
- SLWASH
- TWASH
- SASLWA
- CL
- SMKPLM
- TNCLV
- TNCLWA°BB
- SN
- SHSN
- SH
- FLAME
- UN

c)

- Unclassified
- SV
- AV
- WV
- SHRWE
- SHV
- SSHRBR
- ASHRBR
- SHR
- AHRBCR
- WR
- WEDR
- CNFRSTSN
- PB
- GH
- BBB°VBBB
- SBB
- ABB
- DBB
- WBB
- NIRPBB
- NIRPSABA
- SHB
- RBA
- BSFAFS
- OBA
- BSFS
- DPWASH
- SLWASH
- TWA
- SASLWA
- CRCL
- TKCL
- SMKPLMWA
- SMKPLMV
- SMKPLMBB
- TNCLV°SHRBR°HRBCR
- TNCLWA°BB
- SN
- SHSN
- SH1
- VDTWASH
- DTWASH
- VTNCLWA
- FLAME
- UN1
- UN2
- UN3

Figure 5.3. Spectral categories and associated names identified within the Dyfi catchment (based on the SIAM™ outputs from Landsat sensor data).

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Table 5.5. Ancillary datasets available to support the classification of landscapes according to the FAO LCCS.

Data layer	Information content	Use within LCCS classification
Vegetation mask (SIAM™)	Extent of vegetation	Differentiation of vegetated and non-vegetated surfaces
OS Mastermap	Buildings and linear features	Identification of non-vegetated artificial surfaces (B15)
Land Parcel Information Systems (LPIS)	Field boundaries	Identification of cultivated and managed terrestrial or aquatic or regularly flooded areas
Nextmap Digital Terrain Model (DTM)	Elevation, slope and aspect	Separation of terrestrial or regularly flooded areas

a)   b)   c)
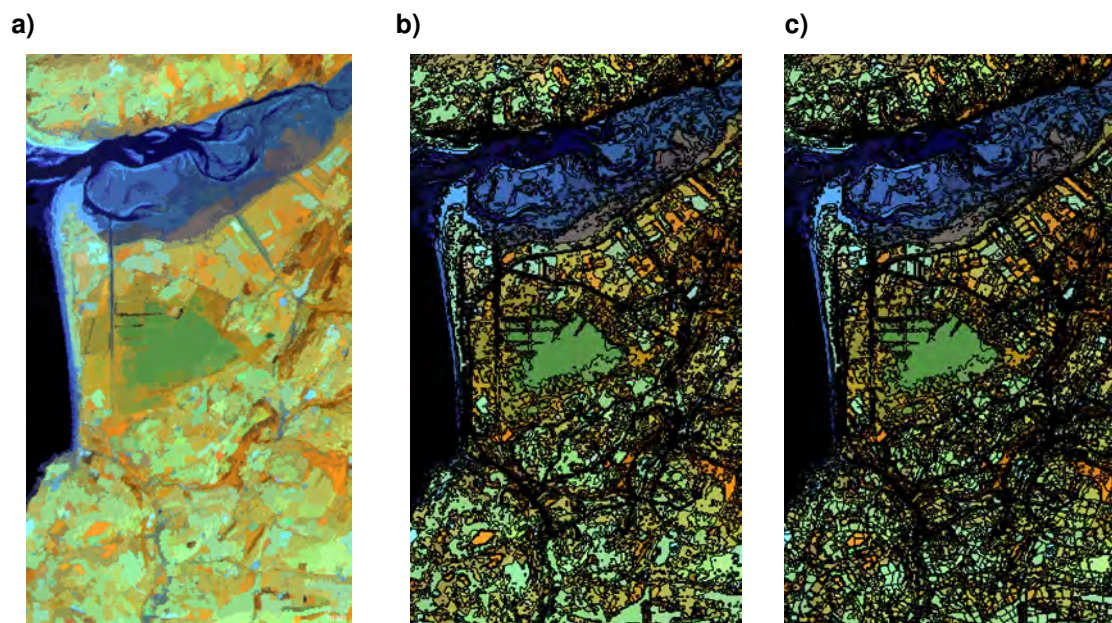
Figure 5.4. a) Landsat TM image acquired on 17th April, 2010, b) SIAM™-derived segments (based on 95 spectral categories) and c) SIAM™-derived segments divided by LPIS field boundaries (note that values for these segments do not change).

a)   b)
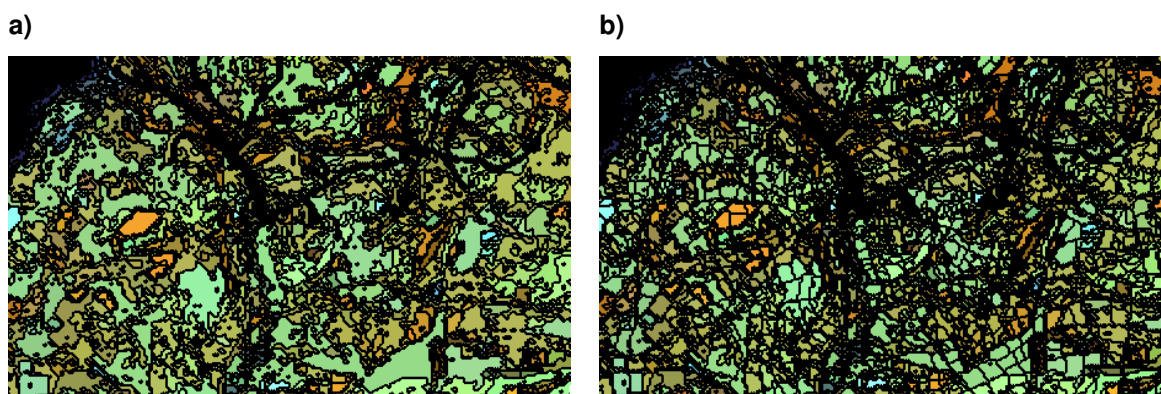
Figure 5.5. Close ups of Figure 5.1b) and c) highlighting the benefits of integrating LPIS vector data Pixels associated with pre-existing information on urban areas, derived from OS Mastermap, are also identified and merged into objects

5.2.4 1st stage classification of Landsat sensor data (July, 2006).

Initially, the Landsat TM data acquired in July, 2006, were considered for classification into the 2nd stage, with this undertaken within eCognition. The Landsat ETM+ data from April, 2006, were subsequently classified independently and then in combination with the TM data to establish potential of data acquired in different seasons for improving the classification of LCCS classes. The SPOT-HRG data were then classified to establish the benefits of using finer (10 m) spatial resolution data for mapping LCCS classes.

Of the top 18 spectral categories generated in the 1st stage classification of the Landsat TM data using SIAM™, 5 were prominent within the Natura 2000 site (Figure 5.6a; Table 5.6) and identified all vegetated areas (whether heavily (1) or with less dense vegetation with non-photosynthetic or short components (2)). Three categories were associated with coastal margins (3) or non vegetated areas (primarily coastal, estuarine and lakes (4, 5)). The next level within the classification identified 47 spectral categories (Figure 5.6b), with these giving more detail within the vegetated and non-vegetated components of the landscape (Table 5.6b). In many cases, these spectral categories could be used in the 2nd stage classification of LCCS classes to Levels 1-3, although the more detailed layer (i.e., 95 spectral categories) was needed in some cases. In many cases, a one-to-one correspondence between the SIAM™ 1st stage and the LCCS was not observed.

a)   **b)**
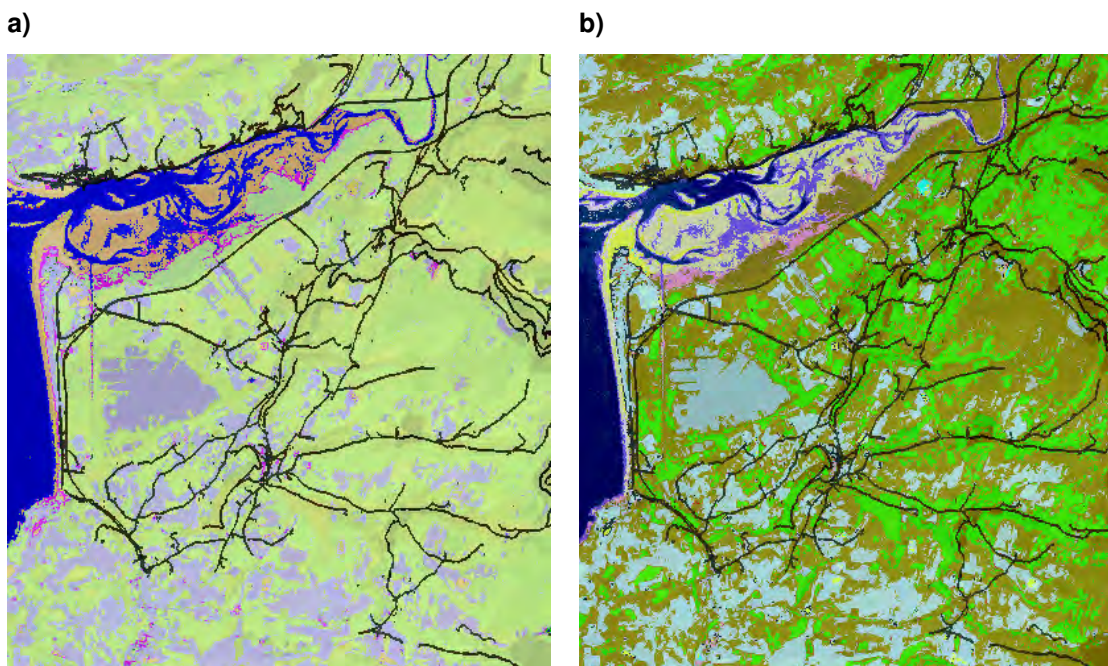
Figure 5.6. SIAM™ classification of Landsat Thematic Mapper (TM) data acquired over The Natura 2000 site and the Lower Dyfi catchment with a) 18 and b) 47 spectral classes.   The legend for a) and b) is provided in Tables 5.6a and 5.6b respectively, with these based on an interpretation of VEXCEL aerial photography and user knowledge.

Table 5.6a. Spectral classes based on Landsat TM data.

SC18	CODE	Description	LCCS
1		All heavily vegetated areas (excluding bogs)	A1: Veg
3		Vegetated (Bogs short vegetation, conifer)	A1: Veg
4		Coastal margins (saltmarsh, dunes and minor urban)	A1: Veg
7		Estuarine/lake sediments and sand/bare earth	B2: Non-veg.aqu.
9		Water (sea, reservoirs)	B2: Non-veg.aqu.
11		Sand (tidal)	B1: Non-veg.aqu.

Table 5.6b. Spectral classes based on Landsat TM data.

SC18		CODE	Description
1			Productive grasslands and woodlands
2			Less productive grasslands, shrubs and scrub, conifer
3			Saltmarsh and open water
5			Open water
7			Less productive vegetation, often short (e.g., grass)
10			Bare ground and urban
11			Saltmarsh, bare ground and urban
15			Less productive vegetation, very short or bare ground
16			Short vegetation
17			Sand (dry) and bare ground (e.g., ploughed earth)
18			Sand (moist)
27			Open water
28			Open water
29			Marine/estuarine sediments

5.2.5 2nd stage classification to FAO LCCS (Landsat TM data)

5.2.5.1   Level 1: Vegetated (A) and non-vegetated (B) categories

The vegetation mask generated from the SIAM™ 1st stage classification was considered suitable for separating vegetated from non-vegetated surfaces (Figure 5.7). The latter were then combined with the urban areas identified previously from the existing OS Mastermap vectors relating to infrastructure. The inclusion of this layer was necessary because urban infrastructure was not easily resolved within the coarse spatial resolution Landsat sensor data.

◼ Vegetated (A)
◻ Non-vegetated (B)

Figure 5.7. Initial classification of LCCS categories into vegetated and non-vegetated undertaken using the SIAM™ vegetation mask.

5.2.5.2   Level 2: Terrestrial (A1/B1) and Aquatic or regularly flooded (A2/B2)

The 2nd level of LCCS classification divides the primarily vegetated and non vegetated areas into those that are terrestrial or aquatic or regularly flooded (Figure 5.8).
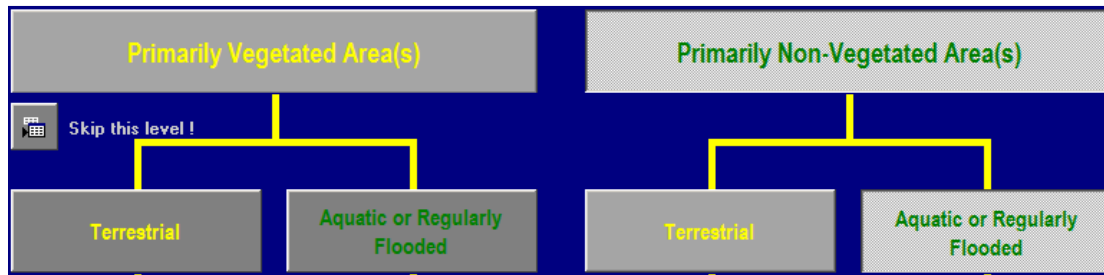
Figure 5.8. 2nd level split within the LCCS

The Dyfi catchment has extensive coastal landscapes and, as all vegetated and non-vegetated areas below an elevation of 3 m are likely to be influenced by tidal flows, these can be regarded as Aquatic or Regularly Flooded (A2 or B2), although primarily by saline water. All other vegetated and non-vegetated surfaces (i.e., above 3 m) can conversely be regarded as terrestrial (A1 or B1; with the exception of freshwater wetlands). The elevation threshold is based on the maximum tidal range.

When the DTM was used to define the elevation threshold of 3 m, some estuarine sediments were classified as non-vegetated terrestrial (B1) rather than non-vegetated aquatic (B2), largely because the elevation of sand banks within the estuarine complex was over 3 m (particularly in the upper reaches). Indeed, one characteristic of the upper reaches of the estuary is that the elevation is naturally above that of the surrounding low lying terrain. The classification was, however, improved using the following Spectral Categories (18):

- AVVHNIR (primarily associated with open water)
- SVVLNIR (estuarine and lacustrine sediments)
- AVNMIR (estuarine and lacustrine sediments)

The AVVHNIR (open water) was assigned directly to the Non-Vegetated Aquatic (B2) category. Where SVVLNIR and AVNMIR categories were located in areas with an elevation of < 3 m (i.e., within the estuary), these were assigned as Non-Vegetated Aquatic (i.e., estuarine; B2) but otherwise Non-Vegetated Terrestrial (B1). Both classes were grown by initially locating those segments that were next to the open water and expanding these iteratively until the mean elevation exceeded 3 m. The resulting classification is given in Figure 5.9.

■ Vegetated Terrestrial (A1)
■ Vegetated Aquatic (A2)
■ Non-vegetated Terrestrial (B1)
■ Non-vegetated Aquatic (B2)

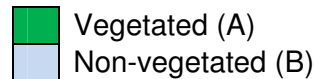**Figure 5.9. Initial classification of LCCS categories into vegetated and non-vegetated undertaken using the SIAM™ vegetation mask**.

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5.2.5.3 Level 3a: Cultivated/Managed versus Semi-Natural (A11/A12 and A23/A24)

At the 3rd level, the LCCS divides both terrestrial and aquatic/regularly flooded areas into Cultivated and Managed (A11 or A23) or Semi-natural (A12 or A24) (Figure 5.10). In Wales, actual cultivation is relatively rare with most fields being in permanent pasture and used to graze sheep, cattle or horses. Such areas can be identified as they are typically bordered (on at least one side) by a hedgerow, ditch or track. However, within Landsat sensor data, such features are difficult to resolve because of the coarse spatial resolution. An alternative was to use the LPIS units, which have been digitised from aerial photography and represent the extent of managed landscapes. Within the Dyfi catchment, intensive management and/or cultivation typically occurs within the smaller LPIS units, with these determined as being < ~ 20 ha (Figure 5.11a). In the larger units, management of the coniferous and broadleaved plantations occurs and hence these are also regarded as Cultivated and Managed terrestrial vegetation (A11). Some semi-natural vegetation within the LPIS area is also managed but can be placed within the category Semi-Natural Terrestrial (A12). All other areas can be regarded as Semi-Natural Terrestrial (A12) or Aquatic/Regularly flooded (A24). On this basis, any Cultivated and Managed areas (A11) were associated with LPIS polygons with an area of < 20 ha, recognising that some semi-natural vegetation (e.g., bracken) may still occur within these areas (Figure 5.11b). All coniferous plantations were included, with these identified as belonging to Spectral Categories (98) 11 and 12. Whilst coniferous forests shared the same spectral category as saltmarsh, this latter land cover had been identified previously as aquatic vegetation and so confusion was avoided. Most broadleaved forests are semi-natural and distinguishing plantations, which are comparatively few in area, could not be achieved because of similarities in spectral response.
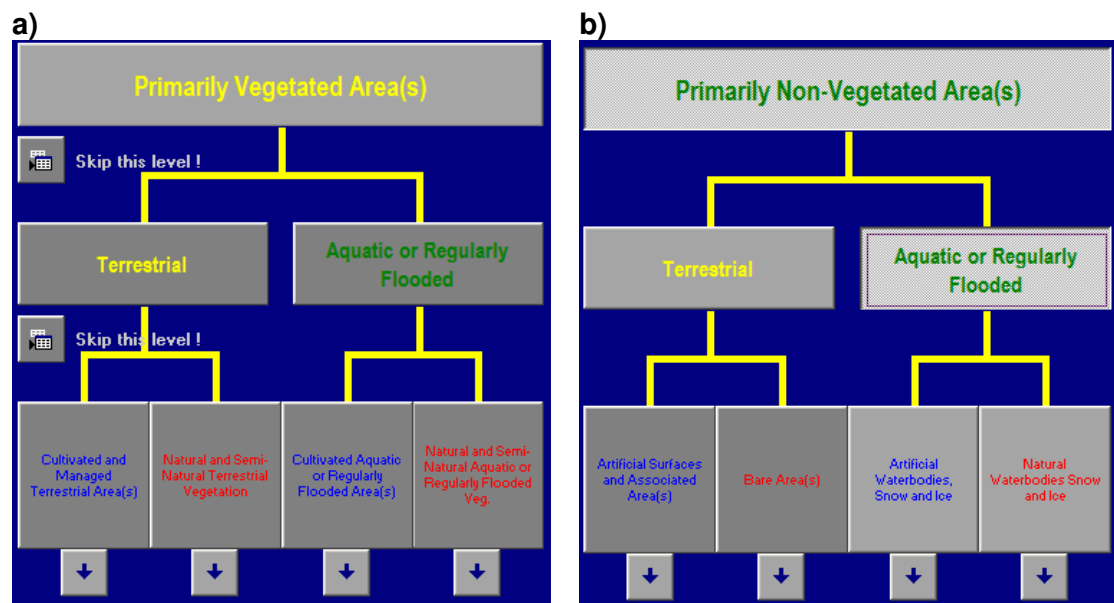
Figure 5.10. Level 3 split into Cultivated and Managed (A11/A23) and Natural or Semi-natural (A12/A24) landscapes and b) Artificial surfaces (B15), Bare areas (B16) and both Artificial (B27) and Natural (B28) waterbodies, snow and ice.

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a)

b)
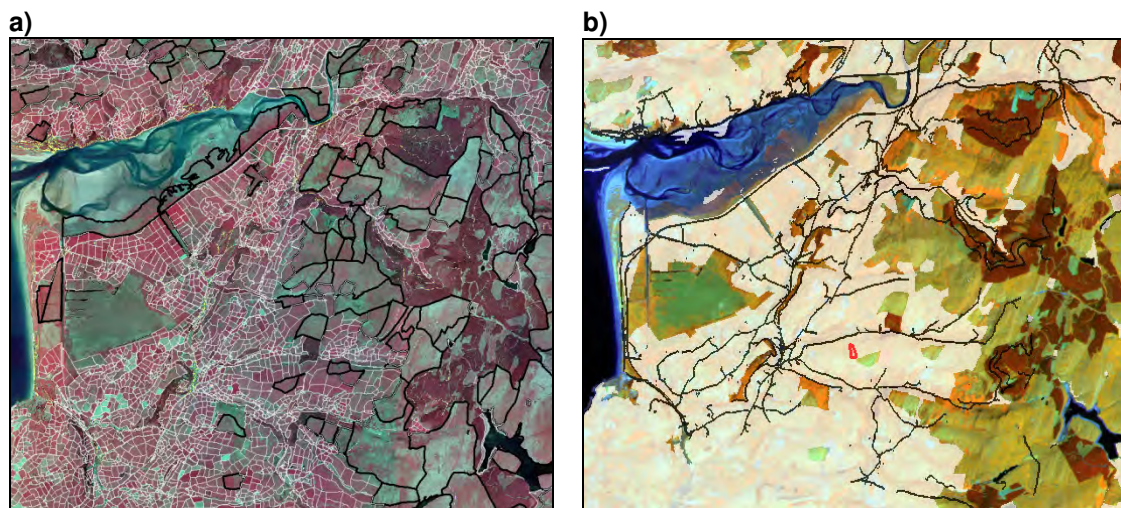
Figure 5.11. a) VEXCEL colour infrared image of The Natura 2000 site and the lower Dyfi catchment with Land Parcel Information System (LPIS) boundaries (< 20 ha in white and black otherwise) and urban layers (yellow) overlain. b) Landsat-5 TM image (NIR, SWIR and R in RGB) showing the extent of cultivated and managed land (transparent white) and semi-natural vegetation.

As the SIAM™ segments were split by the LPIS vectors, each object generated within eCognition also conformed to the parcel boundaries. Therefore, the resulting classifications aligned with the field patterns observed in the landscape. All areas outside both the LPIS boundaries (>= 20 ha) and the area of coniferous plantation were defined as (A12) Semi-Natural Vegetation. No areas of Cultivated and Managed Aquatic (A23) occur within the Dyfi catchment, although these could be identified in other areas through reference to ancillary datasets such as the LPIS if available. The resulting classification is given in Figure 5.12.

Cultivated and managed Terrestrial (A11)

Semi-natural vegetation (A12)

Cultivated and managed Aquatic (A23) – *not occurring*

Semi-natural Aquatic (A24)

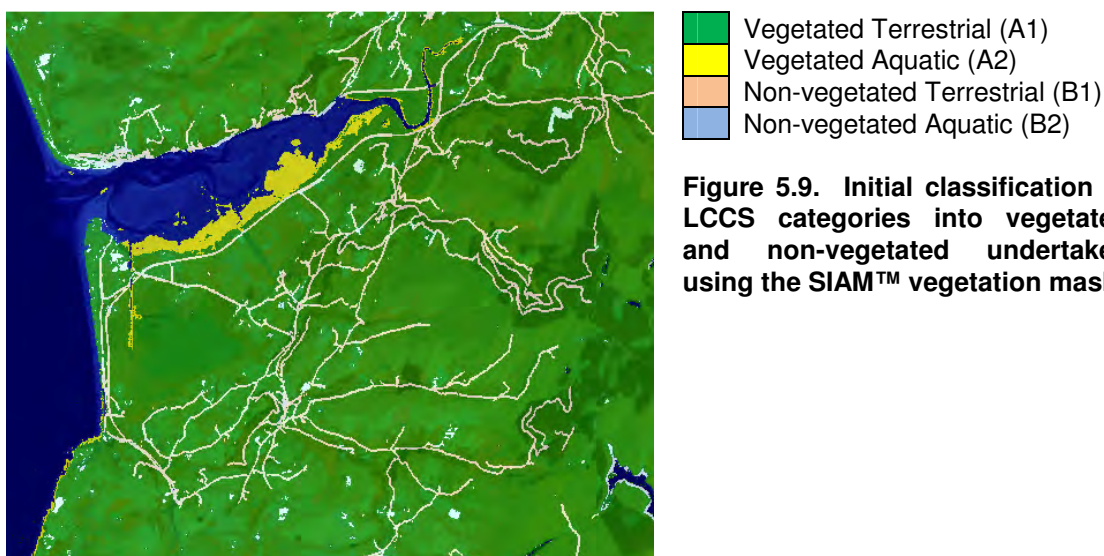Non-vegetated Terrestrial (B1)

Non-vegetated Aquatic (B2)
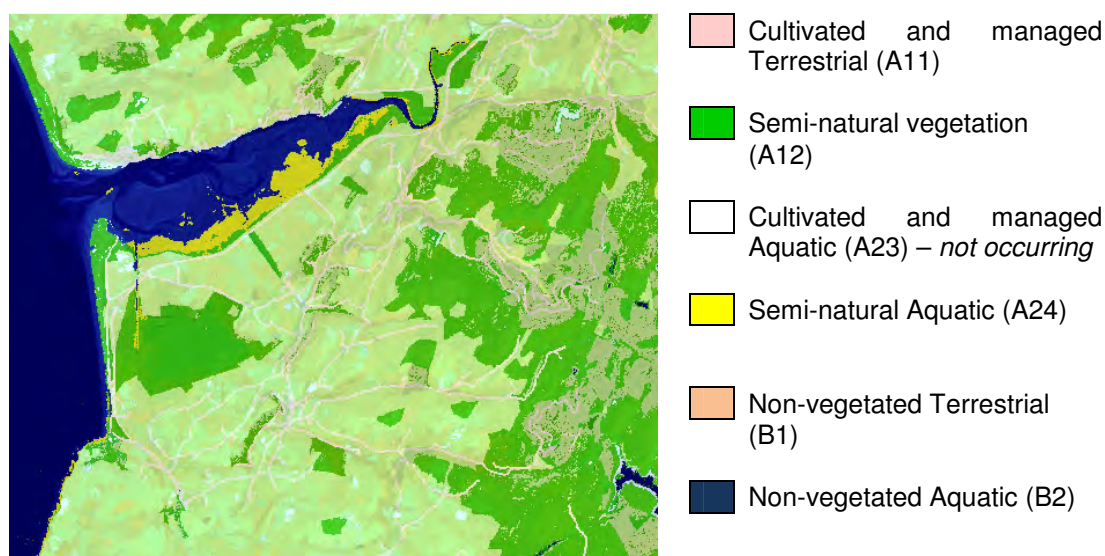
Figure 5.12. Initial classification of LCCS categories into vegetated and non-vegetated undertaken using the SIAM™ vegetation mask.

5.2.5.4   Level 3b: Artificial, bare and natural non-vegetated surfaces (B15/B16 and B27/B28)

The division of non-vegetated terrestrial and aquatic landscapes into artificial, bare and natural surfaces also occurs in Level 3 of the LCCS. Artificial Surfaces (B15) were associated with objects overlapping the OS Mastermap units (defined at the pixel level). All remaining Terrestrial areas were then assigned to Bare Areas (e.g. ploughed fields). The division of the Non-Vegetated

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Aquatic category (B2) into artificial or natural subcategories was difficult to achieve. Even in the field, this distinction may prove difficult. For example, the river Leri is an artificial channel which connects to the main Dyfi estuary and contains brackish water. Pools within the active raised bog in Cors Fochno have been artificially constructed to recreate and restore this habitat. With few exceptions, most of waterbodies located above 3 m in elevation are artificial and hence an elevation threshold was used to distinguish these. In VHR imagery, reservoirs could be better identified because of the presence of a dam wall at one end but such differentiation is less easy within moderate resolution data such as those provided by the Landsat sensors. However, many reservoirs also have a 'border' of bare areas at relatively low water, which can be used to establish (in some cases) whether these are artificial. Further differentiation can be achieved as the OS Mastermap contains information on many of the structures associated with the dams and where mapped areas of water are adjacent to these, they can be defined as artificial. Reference to existing water bodies masks may be an option, particularly as the status of reservoirs and lakes is well known in many countries. The resulting classification of the non-vegetated surfaces is provided in Figure 5.13.
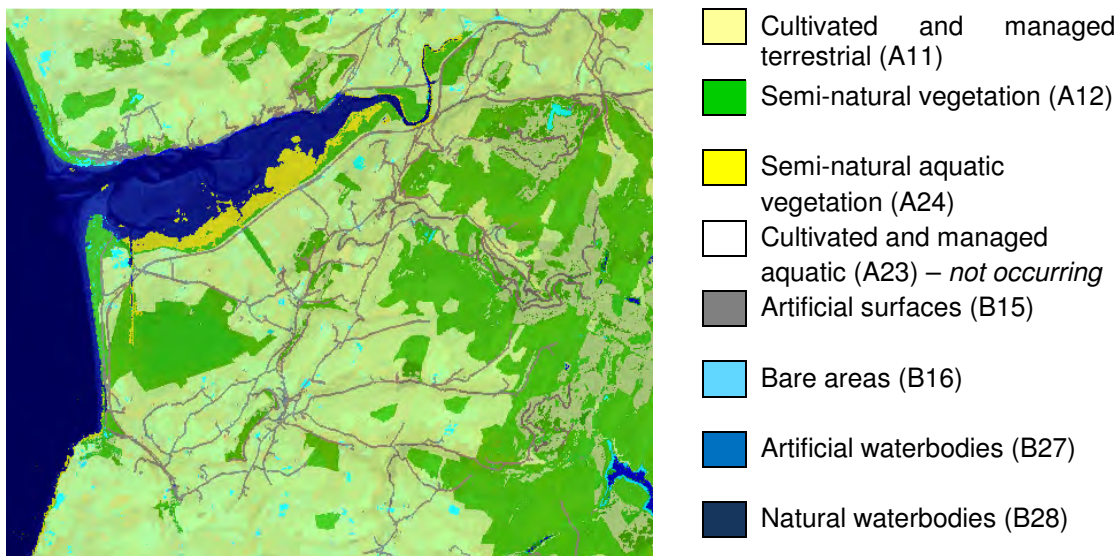
Figure 5.13. Initial classification of LCCS classes into vegetated and non-vegetated categories.

5.2.6 Life form classifications (Landsat TM)

Within the Dyfi catchment, the list of Life Forms identified at the scale of the Landsat TM is given in Table 5.3. The classification of life forms was undertaken in the same sequence as defined in the LCCS hierarchy (Level 3) and outlined in the following sections.

5.2.6.1 Vegetated cultivated or managed (A11)

Coniferous and broadleaved plantations: Within areas identified as A11, coniferous plantations were associated with SC95 11 and 12 (SC47 2) and broadleaved with SC95 3 and 4 (SC47 1) (Tables 5.7 and 5.8). In most cases, these were located outside of the LPIS but within the area considered as cultivated and managed (see Section 2.5.3). Indeed, the same rules for identifying this Level 3 category were used. Discriminating plantation and semi-natural broadleaved plantations could not be achieved, although textural differences may be evident particularly within higher resolution imagery.

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Table 5.7. List of spectral categories associated with coniferous and broadleaved plantations present within the lower Dyfi catchment and descriptions.

SC47	CODE	Description	SC95	CODE	Description
Primarily coniferous					
2	AV.SC	Average vegetation SC	11	AVMNIR.LSC	Strong vegetation with medium NIR LSC
			12	AVLNIR.LSC	Average vegetation with low NIR LSC
Primarily broadleaved					
1	SV.SC	Strong vegetation SC	3	SVVHNIR.LSC	Strong vegetation with very high NIR LSC
			4	SVHNIR.LSC	Strong vegetation with high NIR LSC

Table 5.8. List of spectral categories (SCs18, 47 and 95) used in the classification of LCCS classes associated with coniferous and broadleaved plantations.

LCCS	SC18	SC47	SC95	LCCS.LF
A11	1	2	11	Continuous medium sized fields of needle leaved tree crops (plantations)
			12	
		1	3	Continuous medium-sized fields of broad-leaved tree crops (plantations)
			4	

Grasslands: The majority of grasslands within the Dyfi catchment consist of graminoid crops, which were classified primarily based on SC95. A wide range of spectral categories was needed to define this category (Table 5.9 and 5.10) because of the diversity of spectral signatures associated with grazing, cutting and different levels of fertiliser application. Different management regimes could also be identified based on the different spectral signatures. In addition to permanent graminoid crops, closed medium tall grassland was identified within the cultivated/managed area, with this associated primarily with stands of common reed (*Juncus effuses*). This species occurs in many fields used for grazing stock and is often associated with poor drainage. Where identified, such classes were reassigned to a semi-natural category.

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Table 5.9. List of spectral categories associated with cultivated/managed grassland present within the lower Dyfi catchment and descriptions.

SC47	CODE	Description	SC95	CODE	Description
1	SV.SC	Strong vegetation SC	1	SVVH2NIR.LSC	Strong vegetation with very high2 NIR LSC
			2	SVVH1NIR.LSC	Strong vegetation with very high1 NIR LSC
			3	SVVHNIR.LSC	Strong vegetation with very high NIR LSC
			7	SVVLNIR.LSC	Strong vegetation with very low NIR LSC
2	AV.SC	Average vegetation SC	8	AVVH1NIR.LSC	Average vegetation with very high1 NIR LSC
			9	AVVHNIR.LSC	Average vegetation with very high NIR LSC
			10	AVHNIR.LSC	Average vegetation with high NIR LSC
			11	AVMNIR.LSC	Strong vegetation with medium NIR LSC
7	ASR.SC	Average shrub rangeland SC	20 21	ASRVHNIR.LSC	Average shrub rangeland with very high1 NIR LSC
				ASRHNIR.LSC	Average shrub rangeland with high NIR LSC
10	WR.LSC	Weak rangeland leaf	27	WR.LSC	Weak rangeland leaf SC

Table 5.10. List of spectral categories (SCs18, 47 and 95) used in the classification of grasslands and bracken.

LCCS	SC18	SC47	LCCS.LF	SC95	LCCS.LF
A11	1	1		1[1] 2[1] 3	Permanently cropped area: Graminoid crops.
		2		8 9 10	
	3	7	Closed short grassland	20 21	
	4	10		27	
	1	2		10 11	Closed Perennial Medium Tall Grassland
	1	1		1	Closed medium tall forbs (*primarily bracken*)

[1]Slope ≤ 10°

5.2.6.2   Semi-natural vegetation (A12 and A24)

Semi-natural woodlands: The majority of semi-natural woodlands are broadleaved although many contain variable proportions of coniferous species, with yew (*Taxus baccata*) and Scots Pine (*Pinus sylvestris*) being the primary native species. As with broadleaved plantations, the same spectral categories listed in Tables 5.6 and 5.7 were used, with these applied outside of the area defined as cultivated or managed (A12).   No extensive areas of semi-natural coniferous species were identified.

Grasslands: The majority of grasslands outside of the cultivated and managed areas consisted of closed short and medium tall grasslands. The short grasslands included those dominated by species such as *Festuca*, *Nardus* and *Agrostis* species which, although not actively managed,

were nevertheless grazed by sheep. The taller grasslands were dominated largely by *Molinea* and *Juncus* species. Perennial closed tall grassland on permanently flooded land (persistent; primarily *Phragmites*) were unable to be distinguished from *Molinea*-dominated grasslands. The spectral categories and rules used in the classification are listed in Tables 5.11 and 5.12.

Table 5.11. List of spectral categories associated with semi-natural grasslands within the lower Dyfi catchment and descriptions.

SC47	CODE	Description	SC95	CODE	Description
1			2	SVVH1NIR.LSC	Strong vegetation with very high1 NIR LSC
			3	SVVHNIR.LSC	Strong vegetation with very high NIR LSC
2			9	AVVHNIR.LSC	Average vegetation with very high NIR LSC
			10	AVHNIR.LSC	Average vegetation with high NIR LSC
			11	AVMNIR.LSC	Strong vegetation with medium NIR LSC
7	ASR.SC	Average shrub rangeland SC			

Table 5.12. List of spectral categories (18, 47 and 95) used in the classification of semi-natural grasslands

LCCS	SC18	SC47	SC95	
A11	3	7		Closed short grassland
A12	1	1	2	Closed Perennial Medium tall grassland
			3	
		2	9	
			10	
			11(DEM<20)	

Dune grasslands: Vegetated dunes were identified based on two spectral classes (ASR.SC and WR.LSC) (Tables 5.13 and 5.14). However, to avoid confusion with other land covers, objects had to be adjacent to those classified previously as Shifting Sands/Saturated Parabolic Dunes or Tidal Area with sand.

Table 5.13. List of spectral categories associated with vegetated dunes within the lower Dyfi catchment and descriptions.

SC47	SC95	CODE	Description
7	21	ASR.SC	Average shrub rangelands SC
10	27	WR.LSC	Weak rangeland Leaf SC

Table 5.14. List of spectral categories (18, 47 and 95) used in the classification of vegetated dunes

	SC18	SC47	SC95	
A12	3	7	21	Open ((70-60)-40 %)
	4	10	27	Perennial Medium Tall Grassland

Bracken: Bracken (*Pteridium aquilinum*) is extensive throughout the Dyfi catchment and occurs within cultivated and managed (where regarded as semi-natural) as well as semi-natural

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landscapes.   In the summer months, and when single date imagery is used, spectral confusion occurs between highly productive grasslands and bracken as both support a closed canopy cover with a high leaf area index (LAI).   However, bracken occurs primarily on well-drained soils on sloping ground (typically $> 10^{o}$) whilst many of the more productive grasslands are located in more level ground in the lowlands. Hence, this rule was necessary to distinguish bracken.   However, better discrimination can be achieved using multi-temporal imagery (see later sections). Within the cultivated and managed as well as the semi-natural areas, bracken was associated with SVVH2NIR in the summer months and was located where slopes exceeded 10°. Some areas were also associated with SVVH1NIR (Table 5.15), with these considered to be more scattered in their distribution.

Table 5.15. List of spectral categories (18, 47 and 95) used in the classification of bracken

	SC18	SC47	SC95	
A12	1	1	1	Closed medium tall forbs
			2	

Saltmarsh: Extensive tracts of saltmarsh occur within the Dyfi estuary and were associated with SC47 3 and also SC95 11 and 12 (SC47 2).   Spectral confusion with coniferous forests also occurred but these had been classified previously within Cultivated or Managed (A11) and hence the sequence of processing assisted the classification of saltmarshes. Confusion with surfaces within shadow (e.g., sea cliffs) was also noted but as saltmarshes occur on level ground, a slope threshold of $< 0.5^{o}$ was used to isolate this land cover class from areas of topographic shadow. Using the SC47 categories (3 and 11), marginal areas of saltmarsh were identified first. However, saltmarsh was also associated with SC95 11 and 12. To assign these spectral categories to saltmarsh, a region growing approach was adopted such that they would only be classified if they had a border with objects classified previously as saltmarsh. The spectral categories used for classifying saltmarsh are listed in Tables 5.16 and 5.17.

Table 5.16. List of spectral categories associated with saltmarshes within the lower Dyfi catchment and descriptions.

SC47	CODE	Description	SC95	CODE	Description
2	AV.SC	Average vegetation	11	AVMNIR.LSC	Strong vegetation with medium NIR LSC
			12	AVLNIR.LSC	Average vegetation with low NIR LSC
3	WV.SC	Weak vegetation	15	WVLNIR.LSC	Weak Vegetation with HNIR LSC
11	WEDR.LSC	Wetland or dark rangeland leaf SC	28	WEDR.LSC	Wetland or dark rangeland leaf SC

Table 5.17. List of spectral categories (18, 47 and 95) used in the classification of saltmarshes

LCCS	SC18	SC47	LCCSLF	SC95	LCCS.LF
A12	1	3	Open short grassland on permanently flooded land (with daily variations) (*saltmarsh*)	15	
	4	11		28	
	1	2		11	Open short grassland on permanently flooded land (with daily variations) (*saltmarsh*)
				12	

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Active raised bog: The active raised bog was identified using SC.95 22 and 23 (Tables 5.18 and 5.19) and necessarily assumed that the elevation was < 5.5 m to avoid confusion with other surface covers. Some areas that had previously been cultivated and managed had been restored to bog and hence the classification was applied within both the A11 and A12 categories.

Table 5.18. List of spectral categories associated with the active raised bog

SC47	CODE	Description	SC95	CODE	Description
7	ASR.SC	Average shrub rangeland SC	22	ASRMNIR.LSC	Average shrub rangeland with medium NIR LSC
			23	ASRLNIR.LSC	Average shrub rangeland with low NIR LSC

Table 5.19. List of spectral categories (18, 47 and 95) used in the classification of the active raised bog.

LCCS	SC18	SC47	SC95	LCCS.LF
A12	3	7	23 DEM 5.5 m 22	Open (70-60 – 40 %) dwarf shrubs (shrubland)

5.2.6.3 Non-vegetated artificial (B15)

The main distinction within the non-vegetated artificial surfaces was between buildings and linear features (roads and railways). Within this category, thematic codes relating to buildings and roads/railways were used to distinguish the two categories. Spectral categories were not used as these were unable to be resolved within the relative coarse spatial resolution Landsat data.

5.2.6.4 Non-vegetated bare (B16)

Bare areas were associated with the sand dunes occurring at the mouth of the Dyfi catchment, which were classified as SC.47 17 (Tables 5.20 and 5.21). Some confusion with sand flats within the estuary that were not submerged and hence relatively dry at the time of the satellite data acquisition was evident.

Table 5.20. List of spectral categories (47; based on Landsat) present within the lower Dyfi catchment and descriptions.

SC47	CODE	Description
17	ABB.SC	Average barren land or built-up SC – mixed pixels

Table 5.21. List of spectral categories (SCs 18, 47 and 95) used in the classification of non-vegetated natural/semi-natural land surfaces from Landsat sensor data.

	SC18	SC47	LCCS.LF	SC95
B16	7	17	Shifting Sands.Saturated Parabolic Dunes	49

5.2.6.5 *Artificial and natural waterbodies (B27 and B28)*

Natural waterbodies (flowing) consisted primarily of the ocean and tidal area within the Dyfi estuary and were associated with SC47 27, 28 and 42 (Table 5.22 and 5.23). Within the tidal area, sand is the predominant sediment and was captured using spectral SC47 18 and 29.

Table 5.22. List of spectral categories (47; based on Landsat) present within the lower Dyfi catchment and descriptions.

SC47	CODE	Description
27	DPWASH.SC	Deep Water or Shadow SC
28	SLWASH.SC	Shallow water or shadow
42	VDTWASH.LSC	Very deep turbid water or shadow LSC
18	DBB.SC	Dark barren land or built up SC
29	TWA.LSC	Turbid water LSC

Table 5.23. List of spectral categories (SCs 18, 47 and 95) used in the classification of non-vegetated natural/semi-natural land surfaces from Landsat sensor data.

Sequence of classification	LCCS	SC18	SC47	LCCS.LF	SC95
1	B28	9	27 28 42	Natural waterbodies, flowing	68 72 90
2	B28	7 9	18 29	(Tidal Area (Flowing); Surface Aspect (sand)	55 74

The final classification of LCCS life forms is shown in Figure 5.14 and provides a realistic representation of land cover distributions within the Dyfi catchment. Within the lowlands, key land covers are the saltmarshes on the southern margins of the estuary and the sand dune complex toward the river mouth. The active bog is well represented, with both the distribution of shrublands and medium tall grasslands aligning with existing Phase 1 Habitat Survey mapping. Extensive areas of the uplands are occupied by medium tall grasslands, particularly *Molinea*. The majority of the landscape is covered by cultivated or managed vegetation, with coniferous forests and permanent pastures being prominent.

5.2.7 Classification using Landsat sensor data (April, 2010).

In the classification of the single-date Landsat ETM+ data from April 2010, the same ruleset was applied and the LCCS classification (up to Level 3) was generally consistent. However, the extensive area of non-photosynthetic grasslands (e.g., *Molinea*-dominated medium tall grasslands) in the uplands and margins of the active bog as well as tall closed medium tall forbs (primarily bracken-dominated) were associated with spectral categories akin to bare ground (B16). Hence, the vegetation mask produced by SIAM™ was added to such that these areas were included.

The broad sequence in the classification of LCCS categories is given in Figure 5.15. Whilst a general correspondence was observed with the classification of the July image, several differences were noted:

a) The extent of coniferous forest and also perennial medium tall grasslands were better separated from other land cover classes (with the exception of bracken).

b) Within the terrestrial vegetated category, closed medium tall forbs (primarily bracken) could not be distinguished from open perennial medium tall grassland (primarily *Molinea* species) as both presented a dense surface layer of non-photosynthetic vegetation.

c) Different spectral categories were needed to classify vegetation with seasonal changes in foliage cover (e.g., semi-natural broadleaved woodlands).

d) The closed to open broadleaved evergreen shrubs and herbaceous vegetation associated with the active raised bog were less well-defined using the spectral categories.

e) At the time of the satellite data acquisition, a mid-tide was observed so extensive areas of saltmarsh were inundated and not observed. Hence, the extent was reduced compared to the previous image.

5.2.8 Classification using Landsat sensor data from both dates.

Whilst classifications of land covers can be generated using single-date imagery, the use of at least dual-season imagery is advocated, particularly given that some land cover categories were better identified in either the April or July image.   For this reason, the rule-set from both classifications was combined and amended to allow better discrimination of land covers known to have a strong seasonal variation in reflectance.   The classification was undertaken by considering changes in spectral categories from one image to the next, with examples indicated in Table 5.24. In some cases, the change in spectral category (as indicated) led to better identification of some LCCS classes (e.g., closed medium tall forbs, primarily bracken and broadleaved deciduous forests). However, in the case of categories associated with, for example, the active raised bog and grass pastures, a large number of transitions were observed and classification was simpler to achieve using single date imagery. The sequence of classification is illustrated in Figure 5.16.
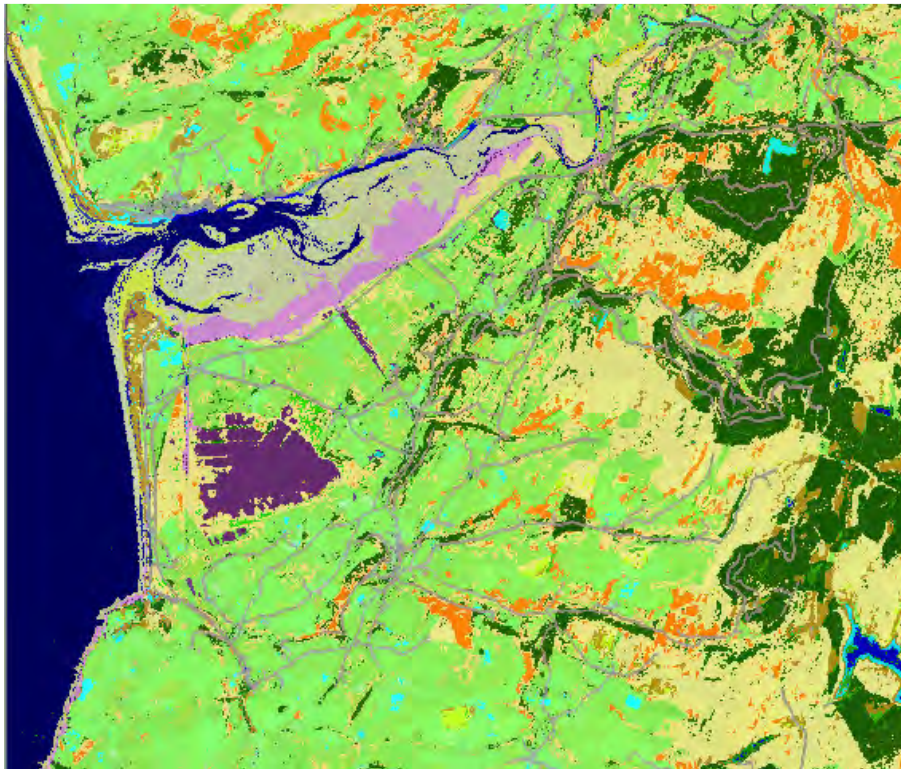
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LCCS		LCCS Code_Modifier	Description
A11		A3.A4.B1.B5.C1.D1.D9.B4	Permanently cropped area: Graminoid crops
A11		A1.B1.B5.C1.D1.D9.A8.B4-W7	Permanently cropped needleleaved trees
A11		A1.B1.B5.C1.D1.D9.A7.B4-W7	Permanently cropped broadleaved trees
A12		A1.A3.A10.B2.C2.D1.E2.B5	Broadleaved deciduous trees
A12		A1.A4.A11.B3.C2.D1.E2.B14	Broadleaved shrubland
A12		A1.A4.A11.B3.C2.D1.E1	Broadleaved evergreen shrubland (heath)
A12		A2.A6.A10.B4.C1.E5.B12.E6	Closed perennial medium tall grassland
A12		A2.A6.A11.B4.XX.E5.A12.B12.E6	Open medium tall grassland
A12		A2.A6.A10.B4.C2.E5.B13	Closed short grassland
A12		A2.A5.A10.B4.B12/B13	Closed medium tall forbs (3.0-0.8/0.8-0.3 m)
A24		A1.A4.A20.B3.C1.D1.E1.F2. F4.F7.G4.C4	Broadleaved evergreen shrubs flooded (bog)
A24		A2.A6.A12.B4.C1.E5.B11.C4.E6	Perennial closed tall grassland on permanently flooded land (persistent)
A24		A2.A6.A13.B4.C1.B13.C5	Open short grassland (saltmarsh)
B15		A3.A8	Paved road(s)
B15		A3.A10	Railway(s)
B15		A4.A13	Urban areas
B16		A3.A7	Bare rock
B16		A6.B6	Shifting Sands. Saturated Parabolic Dunes
B16		A6.A12	Stony loose and shifting sands
B16		A5.A13	Very stony and unconsolidated material(s)
B27		A1.B1.C2.D1.A5	Clear shallow artificial waterbody (standing)
B27		A1.B1.C1.A4	Turbid artificial waterbody(flowing)
B27		A1.B1.C1.A5	Deep/medium artificial waterbody (standing)
B28		A1.B1.C1.A5	Deep/medium natural waterbody (standing)
B28		A1.B3.A4.B6	Tidal area (flowing); surface aspect (sand)
B28		A1.A4	Natural waterbody, flowing (ocean/sea)

Figure 5.14- Classifications of LCCS based on Landsat TM data from July, 2006. LCCS classes not able to be classified are in white in the legend below.

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a)

b)

c)

d)
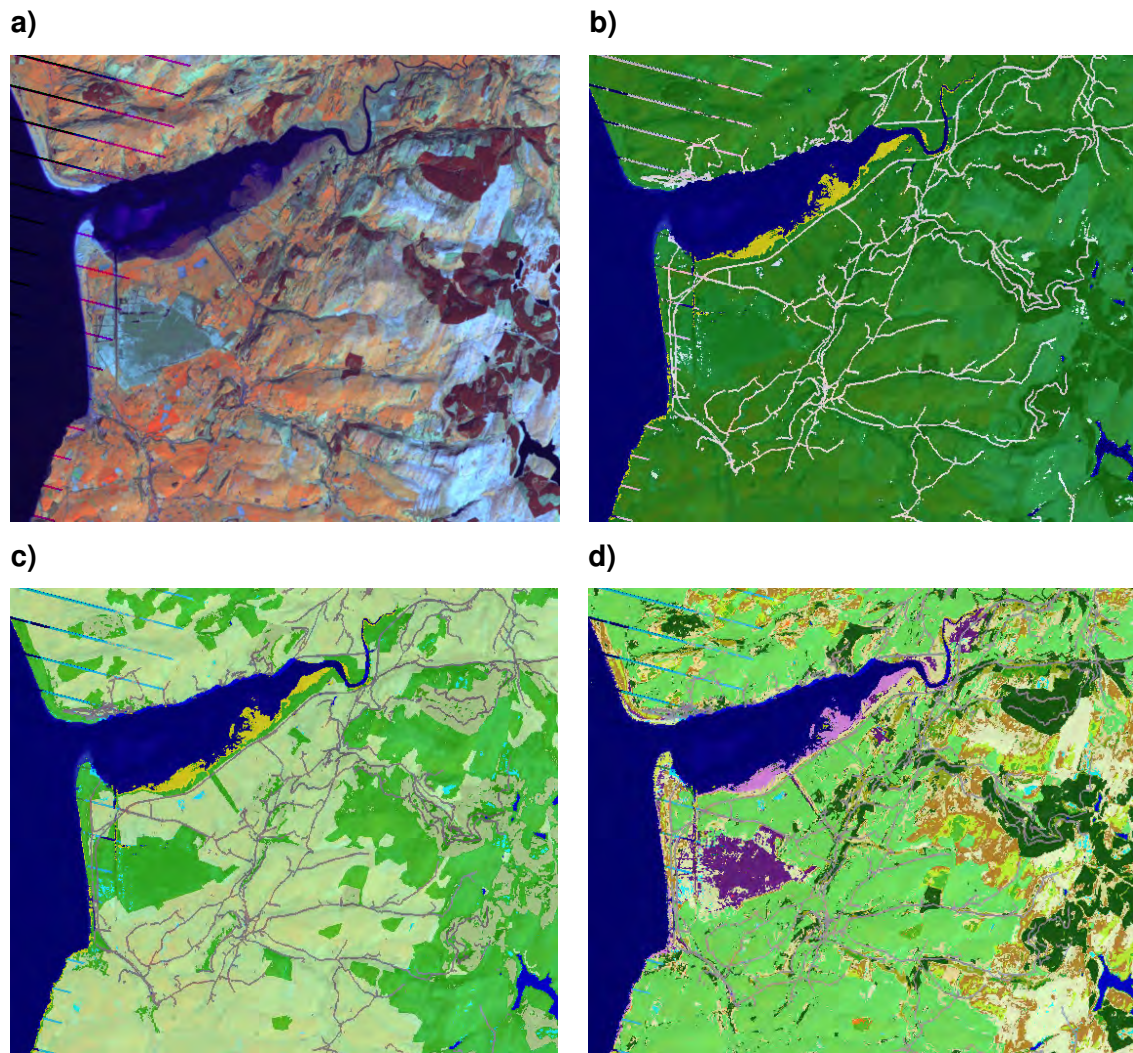
Figure 5.15. a) Landsat ETM+ image acquired on 19th July, 2006 (NIR, SWIR and Red in RGB), b) classification of vegetated and non-vegetated (terrestrial and aquatic) (see Figure 5.9 for legend), c) classification of cultivated and semi-natural categories (see Figure 5.13) and d) LCCS categories (see Figure 5.14 for legend).

Table 5.24. Examples of changes (or otherwise) in spectral categories between dates reflecting variations (or otherwise) in seasonal phenology.

Description	April	July	Description	April	July
Permanently cropped area: Graminoid crops	Variable		Closed to Open Broadleaved Evergreen Shrubs with Herbaceous Vegetation on Permanently Flooded Land (Persistent) (*Active Bog*)	3,7,23 7,17,51	3,7,23 3,7,22
Permanently cropped area with rainfed needleleaved tree crops (plantations).	1,2,12 1,2,11	1,2,11/1,2,12 1,2,11/1,2,12/ 1,1,3/1,1,4	Open short grassland on permanently flooded land (with daily variations) (*Unmanaged Saltmarsh*)	1,2,12 Variable because of tidal condition	1,2,11
Permanently cropped area with rainfed broadleaved tree crops (plantations).	3,7,23	1,1,4/1,2,10	Shifting Sands. Saturated Parabolic Dunes	7,17,49	7,17,49
Broadleaved deciduous fragmented high trees	3,7,23	1,1,4/1,2,10	Deep to Medium Perennial Artificial Waterbodies (Standing)	9,28	9,28
Closed Perennial Medium Tall Grassland (e.g., *Molinia/Juncus*)	12,36,83 7,15,39	1,1,3 1,1,3	Natural waterbodies, flowing (ocean/sea)	9,27,66	9,27,68
Closed medium tall forbs (3.0-0.8 m)	3,7,20 3,7,21 3,7,22	1,1,1 1,1,1 1,1,2			
Closed medium tall forbs (0.8-0.3 m)					

a)

b)

c)
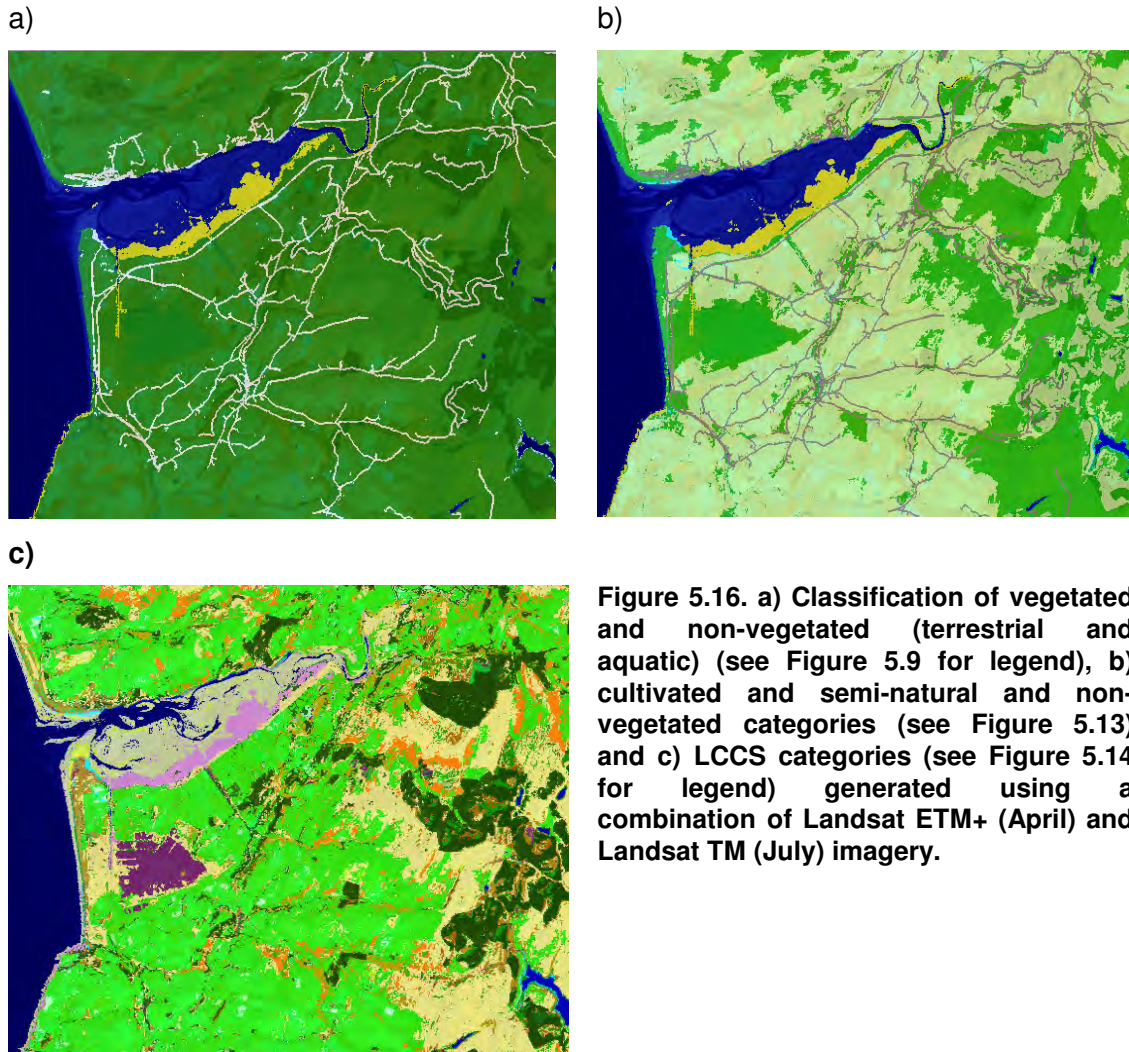
Figure 5.16. a) Classification of vegetated and non-vegetated (terrestrial and aquatic) (see Figure 5.9 for legend), b) cultivated and semi-natural and non-vegetated categories (see Figure 5.13) and c) LCCS categories (see Figure 5.14 for legend) generated using a combination of Landsat ETM+ (April) and Landsat TM (July) imagery.

5.2.9 Classification using SPOT sensor data.

The SPOT HRG image available for The Natura 2000 site was acquired in November, 2010. Whilst many of the more hilly regions were affected by terrain shadows, most of the Natura 2000 site was unaffected because of the lack of significant topography. In the classification, a similar ruleset as that applied to the Landsat sensor data was used although the spectral categories selected differed for several LCCS classes partly because of the lower number of spectral categories available. The main similarities and differences from the Landsat-based classification are outlined in the following sections.

5.2.9.1   Classification of LCCS to Level 2.

Using the same procedures as for the Landsat, LCCS classes to Level 2 were mapped as these were based on the vegetation mask (generated from SIAM™), elevation data and urban layers. The extensive areas of *marram* grass on the coastal sand dunes were classified as non-vegetated and so were reassigned to vegetated. Whilst attempts were made to map urban areas from spectral categories themselves, this was difficult to achieve consistently because of the large number of categories involved. Therefore, the urban mask generated using the OS Mastermap layer was used, recognising that a similar product is anticipated from the very high resolution (VHR) data to be acquired over the site. The region-growing rules used to identify A24 (Aquatic semi-natural vegetated or saltmarsh areas) were similarly employed. The resulting classification is shown in Figure 5.17.

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Figure 5.17. **Classification of LCCS classes (to Level 2) based on SPOT HRG-derived vegetation mask, elevation data and an urban mask.**

5.2.9.2   *Classification of A11: Cultivated and Managed Terrestrial*

In defining the extent of cultivation within the Landsat sensor data, the use of the LPIS data was considered essential for classifying cultivated and managed terrestrial land covers, particularly as field boundaries were difficult to delineate at this relatively coarse spatial resolution. Whilst the same approach was successful using the SPOT imagery, an alternative was considered. Here, the spectral categories associated with features bounding agricultural fields (primarily hedges, ditches, walls) were first identified and merged. Then, any feature with a spectral category associated with grazed pastures and with a border to these bounding features was classified as the LCCS class "Permanently cropped area: Graminoid crops". This process was iterative and allowed progressive classification of the agricultural (cultivated/managed) areas. However, the method was less successful in hilly terrain where spectral confusion between boundary features and shadowed terrain occurred but is expected to perform well with appropriate topographic correction and when imagery outside of the period between mid-November and mid-March is used. The area mapped as (A11) Cultivated and Managed Terrestrial is shown in Figure 5.18. The LPIS field boundaries are overlain for comparison. Where agricultural areas were not classified, LPIS data were necessarily used to correct for this.   All remaining Level 3 classes were mapped using rules similar to those applied to the Landsat sensor data.

Figure 5.18. Initial classification of vegetated and non-vegetated categories based on SPOT HRG data.

5.2.9.3 Classification of Level 4 categories

Using the SPOT-5 HRG-derived spectral categories, classification to LCCS life form was achieved, with the distribution of most categories being similar to that generated using Landsat sensor data (Figure 5.19). Whilst spectral rules were used, several context-based rules were also considered including the area of Closed Perennial Medium Tall Grassland surrounding the active bog and within the sand dune complex, which was classified using adjacency rules and saltmarsh, which was expanded based on rules relating to adjacency to water.

Figure 5.19.   Classification of LCCS classes, lower Dyfi catchment (including The Natura 2000 site)

5.2.10 Use of semantic features.

Within the classification, a number of semantic rules were used, examples of which are listed in Table 5.2. Most were based on adjacency to classes or the elevation or slope information derived from the DTM.

Table 5.25.   Semantic rules used in the classification of LCCS

LCCS	Adjacency to	Elevation	Slope
Saltmarsh	Open water	< 3 m	
Medium tall grasslands (dune vegetation)	Open sand		
Artificial waterbodies	Urban infrastructure	> 10 m	
Sea cliffs	sea		>10°
Active raised bog		< 6 m	
Bracken			< 10°

5.3   Overview of procedures

Using the SIAM™ 1st stage spectral categories from both Landsat and SPOT sensor data within eCognition together with ancillary data layers, a classification of LCCS categories (to Life Form) has been achieved for the Lower Dyfi catchment, including the Natura 2000 site. The classification follows the dichotomous key that is characteristic of the LCCS and thematic layers relating to the following divisions can be progressively generated:

- Vegetated (A) and no-vegetated (B) categories
- Terrestrial (A1/B1) and Aquatic or regularly flooded (A2/B2)

- Cultivated/Managed versus Semi-Natural (A11/A12 and A23/A24)
- Artificial, bare and natural non-vegetated surfaces (B15/B16)

In undertaking the classification, ancillary data layers were necessarily used with these being:

- A digital terrain model (DTM) to provide measures of elevation and slope.
- Land Parcel Information System (LPIS) boundaries
- OS Mastermap urban layer.

The SIAM™ first stage vegetation mask was essential for differentiating between vegetated and non-vegetated areas.   In the case of pre-flush or post-senescence observations, areas of non-photosynthetic vegetation (e.g., grasslands dominated by Molinea or bracken) need to be assigned to a vegetation category at Level 1. In the classification of LCCS categories up to Level 3, the use of ancillary data led to a robust and reproducible approach that could be applicable across a range of sites, as long as these data are available.

Whilst a number of spectral categories were identified, these were lower than the number potentially available. Some land covers (e.g., water) were identified using either SC.40 or 47 alone but many required SC.68 or 95. For some classes (e.g., saltmarsh), region growing was necessary to avoid confusion with spectrally similar categories (e.g., active bog, coniferous forest). Rules relating to adjacency (e.g., to open water, sand flats) were required for the classification of vegetated dunes.   Elevation and slope rules were also needed to constrain the classification of some categories (e.g., shrublands on the active raised bog and bracken).   As many categories were spectrally similar within the July image, the use of ancillary data was essential for classification of LCCS classes.

5.4   Translating LCCS to General Habitat Categories (GHCs)

In the translation of LCCS (Level 3) to GHCs, the scheme outlined in Table 5.26 was used. The GHC maps generated from the LCCS classification of Landsat sensor data are presented in Figure 5.20.   Further translation of LCCS to GHCs based on the life forms observed within the Dyfi catchment is discussed in the following sections.

Table 5.26. Conversion from LCCS to GHCs (super-categories)

LCCS Code	Description	Potential GHC super-categories
A11	Cultivated and managed terrestrial areas	CUL(CRO/WOC) URB (VEG/GRA/TRE) TRS
A12	Natural and semi-natural terrestrial vegetation	TRS HER URB(VEG/GRA/TRE)
A23	Cultivated aquatic or regularly flooded areas	CUL (CRO)
A24	Natural and semi-natural aquatic or regularly flooded vegetation	HER/TRS
B15	Artificial surfaces and associated areas	URB (ART/NON)
B16	Bare areas	SPV (STO/GRV/SAN)
B27	Artificial waterbodies, snow and ice	SPV (AQU)
B28	Natural waterbodies, snow and ice	SPV (SEA/AQU)

CUL(CRO/WOC)
URB (VEG/GRA/TRE)
TRS

TRS
HER
URB(VEG/GRA/TRE)

HER/TRS

CUL (CRO)
not occurring
URB (ART/NON)

SPV (STO/GRV/SAN)

SPV (AQU)

SPV (SEA/AQU)
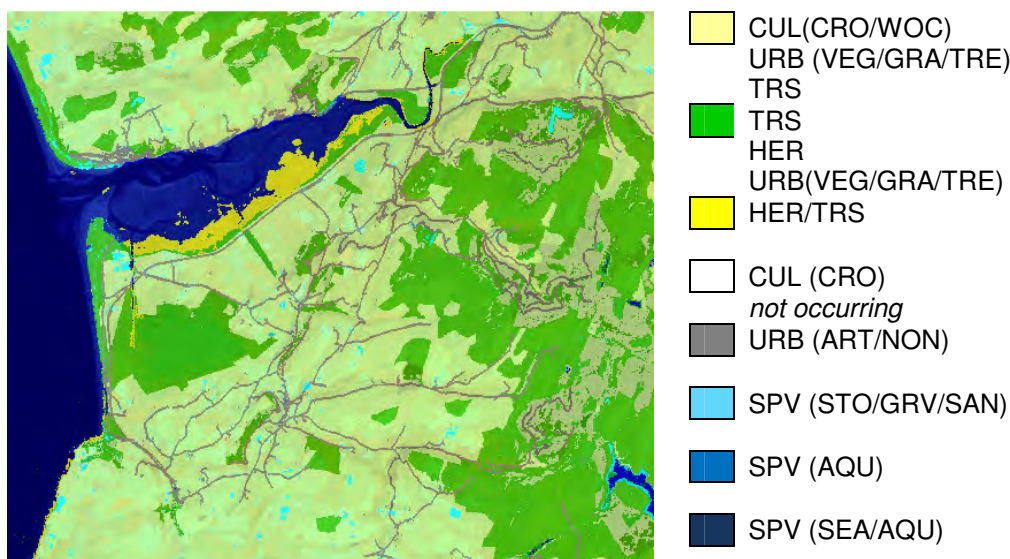
Figure 5.20. Map of GHCs based on translation from LCCS categories (Level 3) derived from Landsat sensor data.

5.4.1 Cultivated and managed terrestrial areas (A11)

Within A11, all cultivated and managed terrestrial areas are associated with grasslands and forest plantations (WOC), with these being primarily coniferous (CON) evergreen (EVR) (Table 5.23). However, plantations of coniferous deciduous (DEC) forest are also widespread, with these dominated by Larch (*Larix* sp.). Broadleaved plantations occur but are difficult to distinguish from semi-natural broadleaved forests with Landsat and SPOT data without reference to management data. Textural information within VHR imagery is anticipated to assist discrimination, particularly if plantations are even-aged and consist of only a few species. Whilst a number of texture measures based on the greenness and/or brightness images were considered (e.g., entropy, homogeneity), confusion with other categories was evident.

The majority of grasslands are used for grazing stock (primarily cattle, sheep and horses). However, considerable variability in their spectral response occurs as a function of grazing (e.g., grass amount, length) and levels of improvement, with this ranging from highly improved (e.g., fertilised with one species dominant) to semi-improved (not fertilised but multiple species). These grasslands are combined into a single LCCS class (A4.B1.B5.C1.D1.D9_B4) and GHC category (CRO/GRA). Using the Landsat and/or SPOT sensor data, the LCCS classes listed in Table 5.27 were mapped and associated with a corresponding GHC class. Urban categories with vegetation (Table 5.28) were unable to be discerned within the SPOT-5 data largely because of their small size and dominance of ribbon development but would be visible within VHR datasets. Descriptions of the GHCs are given in Table 5.29.

5.4.2 Natural and semi-natural terrestrial vegetation (A12)

Within the Dyfi catchment, a diversity of semi-natural vegetation exists, with this defined as vegetation not planted by humans but influenced by human actions. In terms of GHCs, all vegetated tree/shrub (TRS) and herbaceous (HER) categories are present with the exception of therophytes (THE), with these being annual plants that survive as seeds during unfavourable seasons and are more typical to deserts. The GHC categories that correspond to the LCCS categories mapped from Landsat and SPOT sensor data are identified in Table 5.30 and these are associated with a) bracken (vegetated herbaceous) and grasslands (three main types), b) dwarf

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shrublands (within the active raised bog and moorlands in the uplands) and c) semi-natural broadleaved woodlands (vegetated tree/shrub).

Table 5.27. Description of GHCs associated with A11 and present within The Natura 2000 site.

LCCS Code_Modifier	Description	GHCs	GHC (lowest)
A3.A4.B1.B5.C1.D1.D9.B4	Permanently cropped area: Graminoid crops	CUL(CRO) URB(GRA)	CRO/GRA
A1.B1.B5.C1.D1.D9.A8.B4	Permanently cropped area with rainfed needleleaved tree crops (plantations).	CUL(WOC) /URB(TRE)/TRS (TPH/FPH)	WOC/ TRE/TPH/FPH-CON(EVR)
		CUL(WOC) URB(TRE)/TRS (TPH/FPH)	WOC/ TRE/TPH/FPH-CON(DEC)
A1.B1.B5.C1.D1.D9.A7.B4	Permanently cropped area with rainfed broadleaved tree crops (plantations).	CUL(WOC) URB(TRE)/TRS (TPH/FPH)	WOC/ TRE/TPH/FPH-(DEC)

[1]A6.A10.B4.XX.E5_B12.E6 (Closed perennial medium tall grassland) does exist but is more associated with a semi-natural category.   The GHCs are the same as permanently cropped area of graminoid crops.

Table 5.28. Description of GHCs associated with A11, present within The Natura 2000 site but unable to be adequately discerned using the available Landsat and SPOT-5 data.

LCCS Code_Modifier	Description	GHCs	GHC (lowest)
A6.A11	Urban-parks	URB(GRA/TRE)	GRA/TRE
A6.A13	Urban-lawns		GRA
		URB(GRA)	

Table 5.29. Description of GHCs associated with A11 and present within The Natura 2000 site.

Class1	Class2	Description 1	Description2	Description3
CUL	CRO	Crops	Cultivated herbaceous crops	
	WOC		Woody crops	
URB	GRA	Urban	Herbaceous	
	TRE		Woody	Trees
	VEG		Vegetables	
TRS	TPH		Tall Phanerophytes	
	FPH		Forest Phanerophytes	

5.4.2.1   Vegetated herbaceous

At resolutions of 10-30 m, bracken (*Pteridium aquilinum*) is the only broadleaved herbaceous species (LHE) or forbs that can be mapped within confidence as it occupies large and contiguous areas and favours dry ground (e.g., moderate slopes). Even so, classification is best achieved using multi-temporal data because the transition from entirely non-photosynthetic to photosynthetic vegetation can be captured. Single-date summer imagery can also be used but other information (e.g., slope derived from DEMs) is needed. Grassland categories can be distinguished as these consist primarily of closed medium tall grasslands dominated mainly by *Molinea caerulea* (CHE), open medium tall grasslands dominated by *Eriophorum* species (with these favouring the

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waterlogged conditions on the active raised bog; HEL) and closed short grasslands which are common in the uplands and often grazed by sheep. Dominant species include *Festuca* (CHE) and *Nardus*, with the latter typically more tussock-like.

5.4.2.2   Vegetated trees/shrubs

In the uplands, heaths are generally dominated *Calluna*, *Erica* and *Vaccinium* species. Woody scrub is often associated with low phanerophytes (LPH; 0.3 – 0.6 m) to tall phanerophytes (TPH; 2.0 – 5.0 m) and *Ulex* and *Myrica* species are examples. The taller communities are also linked with successional (e.g., *Betula*) or regrowth communities (e.g., regenerating oak forest) and have the potential to develop into a forest phanerophyte (FPH; > 5 m). On this basis, most uplands heaths were classified as dwarf or shrubby chaemophytes (DCH/SCH), although often these were interspersed with grasses and sedges (CHE).   All scrub mapped as the category A4.A11.B3.XXD1.E2_A13B14 (Broadleaved deciduous (40-(20-10)|%) Medium to high shrubland) can be associated with the GHCs ranging from LPH to TPH (< 5 m). All LCCS categories above 5m can be translated to the GHC category FPH, with further assignment based on seasonal information. Many forests are also contiguous and of similar height and cover because of historical planting regimes. All broadleaved forests (TRS/FPH) are winter deciduous (DEC) with no semi-natural coniferous forests occurring and therefore the mapping of the LCCS and also the equivalent GHC is straightforward. At 10-30 m spatial resolution, mapping of broad LCCS classes (to life form) can be achieved as most forests are relatively structurally homogeneous with closed canopy cover and occur in discrete fragments.

Table 5.30. Description of GHCs associated with A12 and present within the UK site

LCCS Code_Modifier	Description	GHCs	GHC Lowest
A1.A3.A10.B2.C2.D1.E2.B5	Broadleaved deciduous fragmented high trees	TRS(TPH/FPH) URB(TRE)	TRE/TPH/FPH-DEC
A1.A4.A11.B3.XXD1.E2 .A13.B14	Broadleaved deciduous (40-(20-10)|%) Medium to high shrubland	TRS(MPH/TPH) URB(VEG/TRE)	VEG/TRE/MPH/TPH
A1.A4.A11.B3.C2.D1.E1	Broadleaved Evergreen Fragmented Shrubland single layer.Heathland (uplands)	TRS	SCH/DEC/EVR
A2.A6.A10.B4.C1.E5.B12.E6	Closed Perennial Medium Tall Grassland (e.g., *Molinia/Juncus*)	HER	CHE
A2.A6.A11.B4.XX.E5.A12.B12.E6	Open ((70-60)-40 %) Perennial Medium Tall Grassland (e.g., *Eriophorum*)	HER	CHE HEL
A2.A6.A10.B4.C2.E5.B13	Closed short grassland	HER	CHE
A2.A5.A10.B4.B11	Closed medium tall forbs (3.0-0.8 m)	HER	LHE
A2.A5.A10.B4.B12	Closed medium tall forbs (0.8-0.3 m)	HER	LHE

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5.4.2.3   *Cultivated aquatic or regularly flooded areas*

These do not occur within the Dyfi catchment.

5.4.3 Natural and semi-aquatic or regularly flooded vegetation (A24)

Within the Dyfi catchment, open dwarf shrubs (shrublands) are associated with the active raised bog at Cors Fochno (where *Myrica*, *Calluna* and *Erica* dominate). As with the uplands, the shrubs are often in mosaics with grass species (as listed above) and hence can be regarded as open ((70-60) – 40 %) when observed at 10-30 m spatial resolution.   At these spatial resolutions, discrimination between GHCs (i.e., DCH, SCH, LPH and MPH) is difficult to achieve, particularly given the lack of height information necessary for reliable classification and the complexity of the mosaics occurring.   As illustration, the active raised bog (LCCS category A4.A20.B3.C1.D1.E1.F2.F4.F7.G4_C4) is associated with and classified on the basis of two spectral categories.   However, at 10-30 m spatial resolution, bog contains a combination of shrubs (i.e., TRS (DCH/SCH/LPH and MPH)) and herbaceous vegetation (including grasses) favouring waterlogged conditions (i.e., HER (SHY/EHHY/HEL/LEA) and HER (EHY-FLO)). Hence, in terms of GHCs, translation to three categories from a single mapped LCCS class is necessary (Table 5.31).   Areas dominated by *Phragmites* were primarily associated with the category HEL(EHY) The saltmarshes on the Dyfi are comprised primarily of the introduced grass species *Spartina* although the halophyte *Salicornia* is widespread.   In both cases, these can be regarded as helophytes (HEL) occurring within the intertidal region (Tables 5.31 and 5.32).   These species typically occur in combination and hence there is a direct translation from the LCCS class.

Table 5.31. Description of GHCs associated with A24 and present within the Dyfi Estuary.

LCCS Code_Modifier	Description	GHCs	GHC (lowest)
A1.A4.A20.B3.C1.D1.E1.F2.F4.F7.G4.C4	Closed to Open Broadleaved Evergreen Shrubs with Herbaceous Vegetation on Permanently Flooded Land (Persistent) (*Active Bog*)	TRS(DCH/SCH/LPH/MPH) HER(SHY/EHY/HEL/LEA) HER(EHY-FLO)	TRS(DCH/SCH/LPH/MPH) HER(SHY/EHY/HEL/LEA) HER(EHY-FLO)
		HEL(EHY)	HEL(EHY)
A2.A6.A13.B4.C1.B13.C5	Open short grassland on permanently flooded land (with daily variations) (*Unmanaged Saltmarsh*)	HER	HEL

Table 5.32. Description of GHCs associated with A24 and present within the Dyfi catchment.

C1	C2	Description 1	Description2	Example
HER	HEL	Herbaceous	Helophytes	*Spartina* *Saliconria*

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5.4.4 Artificial surfaces and associated areas (B15)

The translation from the LCCS categories to GHCs for artificial surfaces and associated areas is given in Tables 5.33 and 5.34.

Table 5.33. Description of GHCs associated with B15 and present within the Dyfi Estuary.

LCCS Code_Modifier	Description	GHCs	GHC (lowest)
A3.A8	Paved road(s)	URB(ART)	ART/
A3.A10	Railway(s)	URB(ART)	ART
A4.A13	Urban areas	URB-(ART/NON)	ART/NON

Table 5.34. Description of GHCs associated with B15 and present within the Dyfi catchment.

Class1	Class1	Description 1	Description2
URB	ART	Urban	Artificial
	NON		Non-vegetated

5.4.5 Bare areas (B16)

The majority of bare areas occur on the coastal margins and within the estuarine complex. Most of the LCCS classes can be translated to GHCs, although this depends upon the tidal state and the extent of deposits. For example, unconsolidated rounded stones above the strandline are present along the seaward facing beach whilst smaller stones and gravels occur at the mouth of the Dyfi estuary.   Whilst discernible within aerial photography at VHR, these areas are less easily detected using Landsat and SPOT sensor data as they form a narrow band running generally parallel to the water.

Table 5.35. Description of GHCs associated with B16 and present within the Dyfi Estuary.

LCCS Code_Modifier	Description	GHC	GHC (lowest)
A3.A7	Bare rock	SPV(ROC)	ROC
A6.B6	Shifting Sands.Saturated Parabolic Dunes	SPV (STO/SAN)	SAN
A6.A12	Stony loose and shifting sands	SPV (STO/SAN)	STO
A5.A13	Very stony bare soil and unconsolidated material(s)	SPV(STO/GRV)	STO/GRV

Table 5.36. Description of GHCs associated with B16 and present within the Dyfi Estuary.

C1	C2	Description 1	Description 2
SPV	ROC	Sparsely	Rock
SPV	STO	vegetated	Stones
	GRV		Gravel
	SAN		Sand

5.4.6 Artificial waterbodies (B27)

The main artificial waterbodies (Table 5.37) are the shallow pools formed to restore or enhance the active raised bog (Figure 5.20) as well as the straightened channels leading to the Dyfi Estuary. The former waterbodies are typically smaller in area that the Landsat and often SPOT spatial resolution but can be identified in some cases. The deeper artificial waterbodies are represented by the larger water reservoirs in the uplands. A direct translation from the LCCS to a

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single GHC category (AQU) can be achieved (Table 5.38), with this indicating that the surface is covered in water over 70 % of the time. Salinity indicators can also be used to indicate whether saline, brackish or freshwater or acid, neutral or basic, with these based on Ellenberg values.

Table 5.37. Description of GHCs associated with B27 and present within the Dyfi Estuary.

LCCS Code_Modifier	Description	GHC	GHC (lowest)
A1.B1.C2.A5	Clear Shallow Artificial Perennial Waterbodies (Standing)	SPV(AQU)	AQU
A1.B1.C1.A4	Turbid Deep to Medium Deep Artificial Perennial waterbodies (Flowing)	SPV(AQU)	AQU
A1.B1.C1.A5	Deep to Medium Perennial Artificial Waterbodies (Standing)	SPV(AQU)	AQU

Table 5.38. Description of GHCs associated with B27 and present within the Dyfi Estuary.

C1	C2	Description 1	Description 2
SPV	AQU		Aquatic

Figure 5.20. Open water (AQU), Cors Fochno. Whilst these pools are artificial, they have been created to maintain and restore the raised bog.

5.4.7 Natural waterbodies (B28)

In terms of area, the majority of the waterbodies are natural (Table 5.39 and 5.40), with these comprised of the sea (SEA-AQU) and the estuary (SAN/AQU). A direct translation from the LCCS classes can be achieved, with both assumed to be flowing.   Several deep to medium perennial natural waterbodies in the uplands can be classified as AQU.

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Table 5.39. Description of GHCs associated with B28 and present within the Dyfi Estuary.

LCCS Code_Modifier	Description	GHC	GHC (lowest)
A1.B1.C1.A5	Deep to Medium Perennial Natural Waterbodies (Standing)	SPV(AQU)	AQU
A1.B3.A4.B6	Tidal Area (Flowing); Surface Aspect (sand)	SPV(SEA/AQU) TID	TID(AQU)
A1.A4	Natural waterbodies, flowing (ocean/sea)	SPV(SEA/AQU)	SEA(AQU)

Table 5.40. Description of GHCs associated with B28 and present within the Dyfi Estuary.

C1	C2	Description 1	Description 2
SPV	SEA	Sparsely vegetated	Sea
	TID		Tidal
	AQU		Aquatic

5.4.8 Improving classification of GHCs

Whilst LCCS categories can be translated into GHCs, these are often quite broad and a more detailed classification is needed. A list of GHCs associated with vegetation and occurring within the Dyfi catchment (including The Natura 2000 site) is given in Table 5.41 and illustrative examples from Cors Fochno are provided in Figures 5.21 to 5.24. The translation from LCCS is likely to be problematic in many cases, particularly where combinations of these occur (e.g., in complex vegetation mosaics). Direct mapping of GHCs may therefore be a more viable option if suitable datasets are available, with these including:

a) Higher resolution data to discriminate between herbaceous categories (e.g., SHY, EHY, HEL, LEA), with hyperspectral data likely to prove useful.
b) Seasonal data to separate broadleaved from coniferous (evergreen and deciduous) and non-leafy evergreen vegetation (DEC, EVR, NLE, CON)
c) Vegetation height data obtained directly from LiDAR or indirectly from SAR or optical texture measures to differentiate between DCH, SCH, LPH, MPH, TPH and FPH.

Illustrations of maps of GHCs generated from a combination of LiDAR and aerial photography are provided in Deliverable D4.3.

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Table 5.41. Description of GHCs associated with A11 and present within the Dyfi catchment. Many of these categories can only be reliably separated using higher spatial resolution data.

C1	C2	C3	Description 1	Description2	Description3	Example
HER	SHY	FLO LEA	Herbaceous	Submerged hydrophytes	Floating plants Plants with floating leaves	*Sphagnum*
	EHY	FLO LEA		Emergent hydrophytes		*Scirpus* *Phragmites*
	HEL	FLO LEA		Helophytes		*Eriophorum* *Rhynchospora*
	LHE			Leafy hemicryptophytes		*Chamaenerion* *Pteridium*
	CHE			Caespitose hemicryptophytes		*Festuca* *Luzula*
		TUS			Tussock grasses	*Molinia* *Nardus*
	THE			Therophytes		n/a
	GEO			Geophytes		*Iris*
	HCH			Herbaceous chaemophytes		*Saxifraga*
	CRY	BRY LIC		Cryptograms	Bryophytes Lichens	*Hymnoptera* *Cladonium*
TRS	DCH	DEC EVR NLE	Tree/shrub	Dwarf chamaephytes (< 5 cm)	Deciduous Evergreen Non-leafy evergreen	*Erica* *Ulex galliei*
	SCH	DEC		Shrubby chamaephytes (5 - 30 cm)	Deciduous	*Vaccinium*
		EVR			Evergreen	*Calluna* *Erica, Myrica*
		NLE			Non-leafy evergreen	*Ulex*
	LPH	DEC		Low phanerophytes (0.3 – 0.6 m)	Deciduous	*Vaccinium* *Myrica*
		EVR			Evergreen	*Calluna*
		NLE			Non-leafy evergreen	*Ulex*
	MPH	DEC EVR CON		Medium phanerophytes (0.6 – 2 m)	Deciduous Evergreen Non-leafy evergreen	*Myrica* *Rhododendron* *Ulex*
	TPH	DEC EVR CON		Tall phanerophytes (2 - 5 m)	Deciduous Evergreen Coniferous	*Betula* *Rhododendron* *Pinus* (regrowth)
	FPH	DEC CON		Forest phanerophytes (> 5 m)	Deciduous Coniferous	*Quercus* *Pinus* (regrowth to mature)
URB	VEG TRE		Urban	Vegetables Woody		*Prunus*

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Sphagnum (SHY)

Molinea (CHE)

Chamaenerion (LHE)

Eriophorum (HEL)
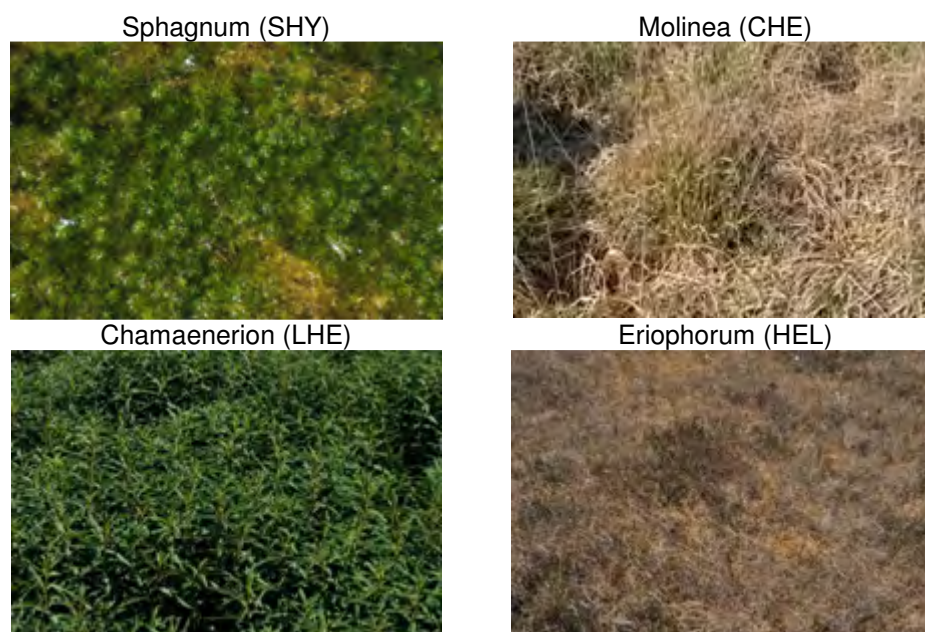
Figure 5.21. Examples of Life Forms, Cors Fochno

HEL-SCH(EVR)

HEL-CHE

HEL-DCH/DEC-CHE-LHE

LHE

LHE-CHE
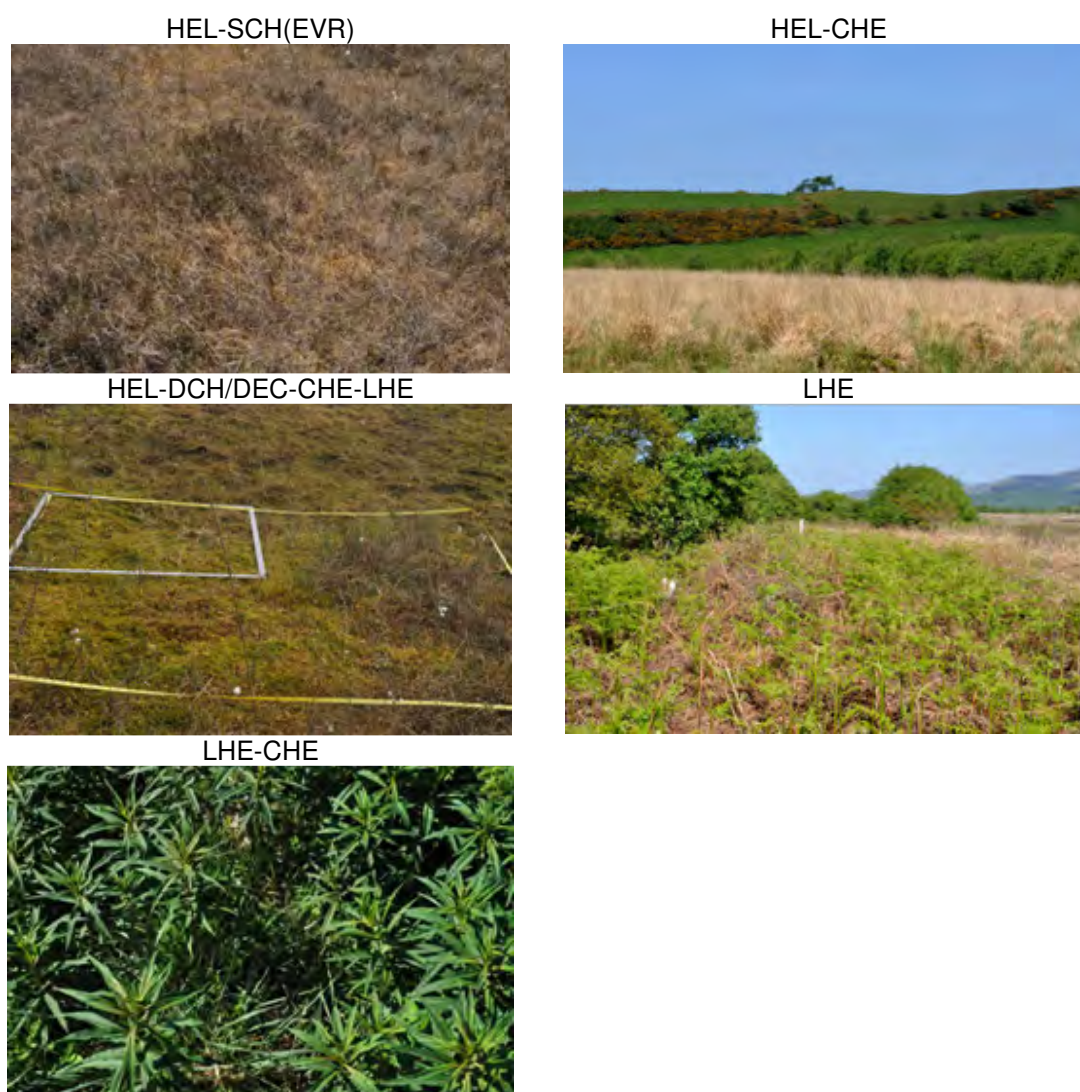
Figure 5.22. Examples of combinations of GHCs, Cors Fochno.

DCH/DEC/-CHE

LPH-CRY

SCH/EVR/-HEL

SCH-CHE

LPH-CHE-SCH-CRY

SCH/LPH-CHE

Figure 5.23. Examples of GHC combinations, Cors Fochno

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MPH/DEC

MPH/DEC-SCH/EVR-HEL

FPH-TPH-MPH-CHE
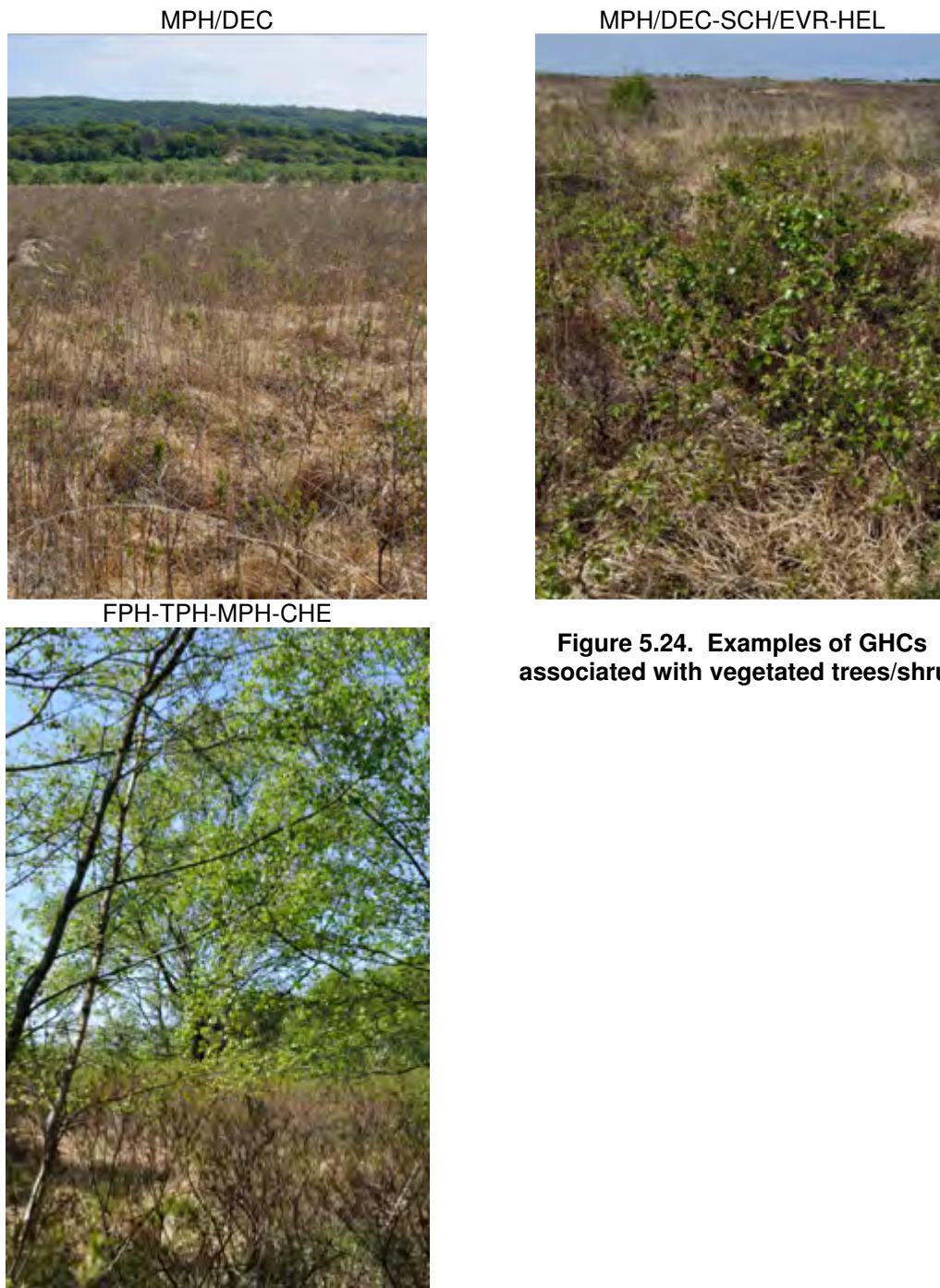
Figure 5.24. Examples of GHCs associated with vegetated trees/shrub

5.4.9 Overview of GHC classifications.

For the lower Dyfi catchment, including the Natura 2000 sites, GHC maps generated using Landsat sensor data, either from one or two dates, are shown in Figure 5.25 with these directly translated from the LCCS. In the dual season case, focus was on refining the classification for vegetation with strong seasonal phenology (e.g., bracken, semi-natural broadleaved forests). In each case, the distribution of many habitats varies for the following reasons

a) The extent of open water and saltmarsh varies as a function of tidal state
b) Artificial waterbodies (reservoirs) contract during the summer months.
c) The active bog varies in extent because of changes in phenology within the diverse vegetation communities occurring leading to confusion with other vegetation types (e.g., broadleaved deciduous forests in April).

d) Bracken is not classified within the April nor November SPOT imagery because of spectral similarity with other categories (primarily medium to tall grasslands).

a)
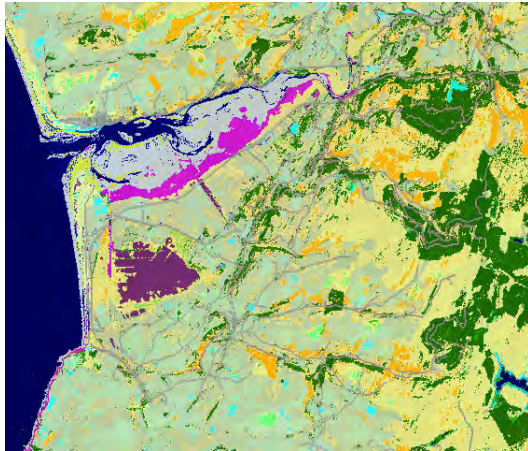
b)
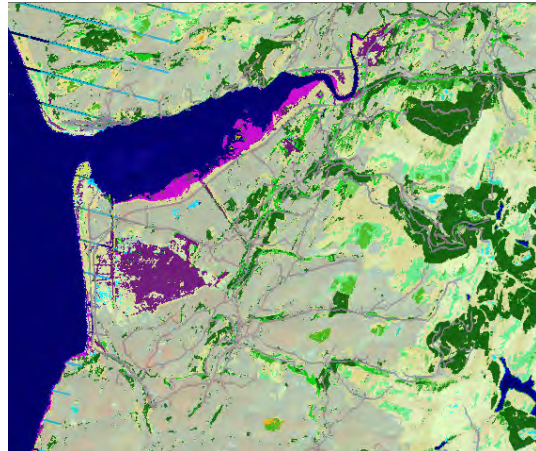
c)
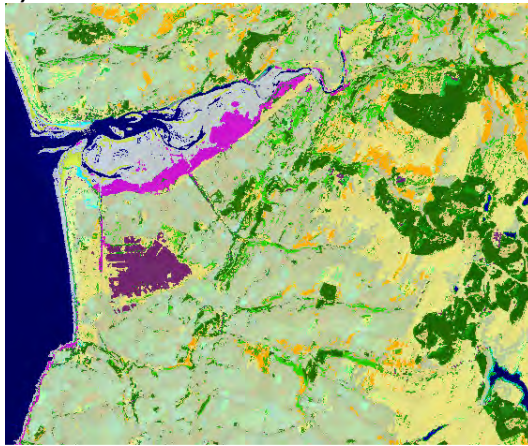
Figure 5.25. Classifications of GHCs based on a) Landsat TM data (July), b) Landsat ETM+ data (April) and c) combinations of both.

LCCS		LCCS Code_Modifier	Description
A11		A3.A4.B1.B5.C1.D1.D9.B4	CRO/GRA
A11		A1.B1.B5.C1.D1.D9.A8.B4	WOC/ TRE/TPH/FPH-CON(EVR/DEC)
A11		A1.B1.B5.C1.D1.D9.A7.B4	WOC(DEC)
A12		A1.A3.A10.B2.C2.D1.E2	TRE/TPH/FPH-DEC
A12		A1.A4.A11.B3.C2.D1.E2.B14	VEG/TRE/MPH/TPH
A12		A1.A4.A11.B3.C2.D1.E1	SCH/DEC/EVR
A12		A2.A6.A10.B4.C1.E5.B12.E6	CHE
A12		A2.A6.A11.B4.XX.E5.A12.B12.E6	CHE
A12		A2.A6.A10.B4.C2.E5.B13	CHE
A12		A2.A5.A10.B4.B12/B13	LHE
A24		A1.A4.A20.B3.C1.D1.E1.F2. F4.F7.G4.C4	TRS(DCH/SCH/LPH/MPH) HER(SHY/EHY/HEL/LEA) HER(EHY-FLO)
A24		A2.A6.A12.B4.C1.E5.B11.C4.E6	HEL(EHY)
A24		A2.A6.A13.B4.C1.B13.C5	HEL
B15		A3.A8	ART
B15		A3.A10	ART
B15		A4.A13	ART/NON
B16		A3.A7	ROC
B16		A6.B6	SAN
B16		A6.A12	STO
B16		A5.A13	STO/GRV
B27		A1.B1.C2.D1.A5	AQU
B27		A1.B1.C1.A4	AQU
B27		A1.B1.C1.A5	AQU
B28		A1.B1.C1.A5	AQU
B28		A1.B3.A4.B6	AQU(TID)
B28		A1.A4	AQU(SEA)

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Whilst similar classes were generated using the SPOT HRG data, a more detailed map of their distribution was provided (Figure 5.26). The use of dual season SPOT HRG or, ideally, VHR data is anticipated to provide a much improved classification of habitats for the Natura 2000 site and immediate surrounds.
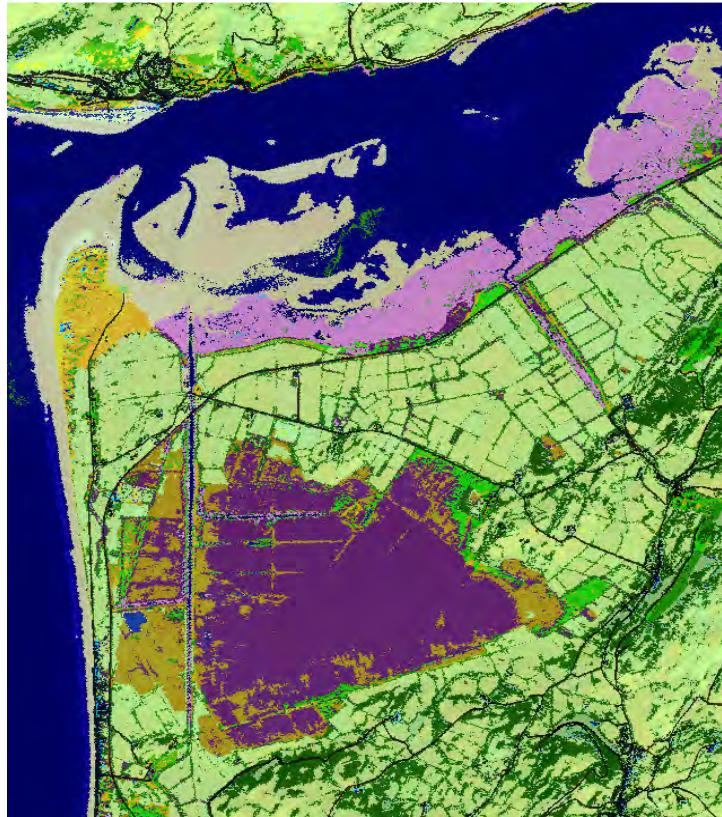
Figure 5.26. Map of GHCs translated from LCCS classes.

LCCS		LCCS Code_Modifier	Description
A11		A3.A4.B1.B5.C1.D1.D9.B4	CRO/GRA
A11		A1.B1.B5.C1.D1.D9.A8.B4	WOC/ TRE/TPH/FPH-CON(EVR/DEC)
A11		A1.B1.B5.C1.D1.D9.A7.B4	WOC(DEC)
A12		A1.A3.A10.B2.C2.D1.E2	TRE/TPH/FPH-DEC
A12		A1.A4.A11.B3.C2.D1.E2.B14	VEG/TRE/MPH/TPH
A12		A1.A4.A11.B3.C2.D1.E1	SCH/DEC/EVR
A12		A2.A6.A10.B4.C1.E5_B12.E6	CHE
A12		A2.A6.A11.B4.XX.E5.A12.B12.E6	CHE
A12		A2.A6.A10.B4.C2.E5.B13	CHE
A12		A2.A5.A10.B4.B12/B13	LHE
A24		A1.A4.A20.B3.C1.D1.E1.F2.F4.F7.G4.C4	TRS(DCH/SCH/LPH/MPH) HER(SHY/EHY/HEL/LEA) HER(EHY-FLO)
A24			HER(EHY)
A24		A2.A6.A13.B4.C1.B13.C5	HEL
B15		A3.A8	ART
B15		A3.A10	ART
B15		A4.A13	ART/NON
B16		A3.A7	ROC
B16		A6.B6	SAN
B16		A6.A12	STO
B16		A5.A13	STO/GRV
B27		A1.B1.C2.D1.A5	AQU
B27		A1.B1.C1.A4	AQU
B27		A1.B1.C1.A5	AQU
B28		A1.B1.C1.A5	AQU
B28		A1.B3.A4.B6	AQU(TID)
B28		A1.A4	AQU(SEA)

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5.5 Accuracy assessment

As indicated in Deliverable D4.3, field survey data relating to GHCs are being acquired between July and September, 2011 for up to 30 km^2 locations distributed throughout the Dyfi catchment but including the area within and outside the Natura 2000 site. Within each km^2 and across the range of GHCs occurring, point, linear and aerial plots are being located and descriptions of the vegetation communities provided. For each 1 km^2, maps of GHCs will be generated. This comprehensive dataset will be used to:

a) quantify the accuracy in the classification of LCCS (through translation of GHCs) generated from sensors ranging from Landsat through to VHR.
b) support the classification of GHCs from a combination of LiDAR and hyperspectral data as well as aerial photography.

5.6 Translation to ANNEX I

Using the GHC maps presented in Figures 5.25 and 5.26 and to be generated using VHR and hyperspectral data, translation to ANNEX I categories will be undertaken. For the Dyfi catchment, the list of ANNEX I categories is given in Tables 5.42 to 5.44. In many cases, a direct translation from the LCCS classes and GHCs can be used to identify these habitats. However, some require more detailed classification including annual vegetation of drift lines and Atlantic salt meadows (*Glauco-Puccinellietalia maritimae*). Further detail in the classification of dune habitats is needed as embryonic shifting, white, grey and decalcified fixed dunes and dune slacks occur and VHR or hyperspectral data will be needed. Some differentiation of degraded raised bogs still capable of regeneration and depressions on peat substrates of the *Rhynchosporium* is also necessary.

Table 5.42. UK Annex I Categories present within the Dyfi catchment (including the Natura 2000 site).

Class	Description
1110	Sandbanks which are slightly covered by sea water all the time
1130	Estuaries
1140	Mudflats and sandflats not covered by seawater at low tide
1210	Annual vegetation of drift lines
1310	*Salicornia* and other annuals colonizing mud and sand
1320	Spartina swards (*Spartinion maritimae*)
1330	Atlantic salt meadows (*Glauco-Puccinellietalia maritimae*)
2110	Embryonic shifting dunes
2120	Shifting dunes along the shoreline with *Ammophila arenaria* ("white dunes")
2130	Fixed coastal dunes with herbaceous vegetation ("grey dunes")
2150	Atlantic decalcified fixed dunes (*Calluno-Ulicetea*)
2190	Humid dune slacks
6410	*Molinia* meadows on calcareous, peaty or clayey-silt-laden soils (*Molinion caeruleae*)
7110	Active raised bogs
7120	Degraded raised bogs still capable of natural regeneration
91D0	Bog woodland

Table 5.43. UK Additional Annex I Categories present within the Dyfi (including The Natura 2000 site) catchment.

Class	Description
1230	Vegetated sea cliffs of the Atlantic Coasts
3130	Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or *Isoë* to *Nano juncetea*
3160	Natural dystrophic lakes and ponds
4010	Northern Atlantic wet heaths with *Erica tetralix*
7130	Blanket bogs (* if active bog)
91A0	Old sessile oak woods with *Ilex* and *Blechnum* in the British Isles
3260	Water courses of plain to montane levels with the *Ranunculion fluitantis* and *Callitricho-Batrachion* vegetation

Table 5.44. UK Non-Annex I Categories present within the Dyfi (including CorsFochno) watershed.

Class	Description
1020	Cultivated land
1021	Anthropogenic vegetation
1050	Settlements
5150	*Pteridium aquilinum* stands
72A0	Reed thickets (*Phragmites australis*)

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6.   Test site in Italy

The work described hereafter corresponds to the advancement of the work carried out in both WP5 and WP6 on LC/LU to habitat mapping for IT4 site. Habitats are mapped according to the GHC methodology and translated to the Annex I taxonomy of the Habitat Directive (92/43/EEC). The complete architecture of the LC to habitat conversion module of the EODHaM 3rd stage is shown in Figure 4.3 of D6.10 and is copied in Figure 6.1 below.
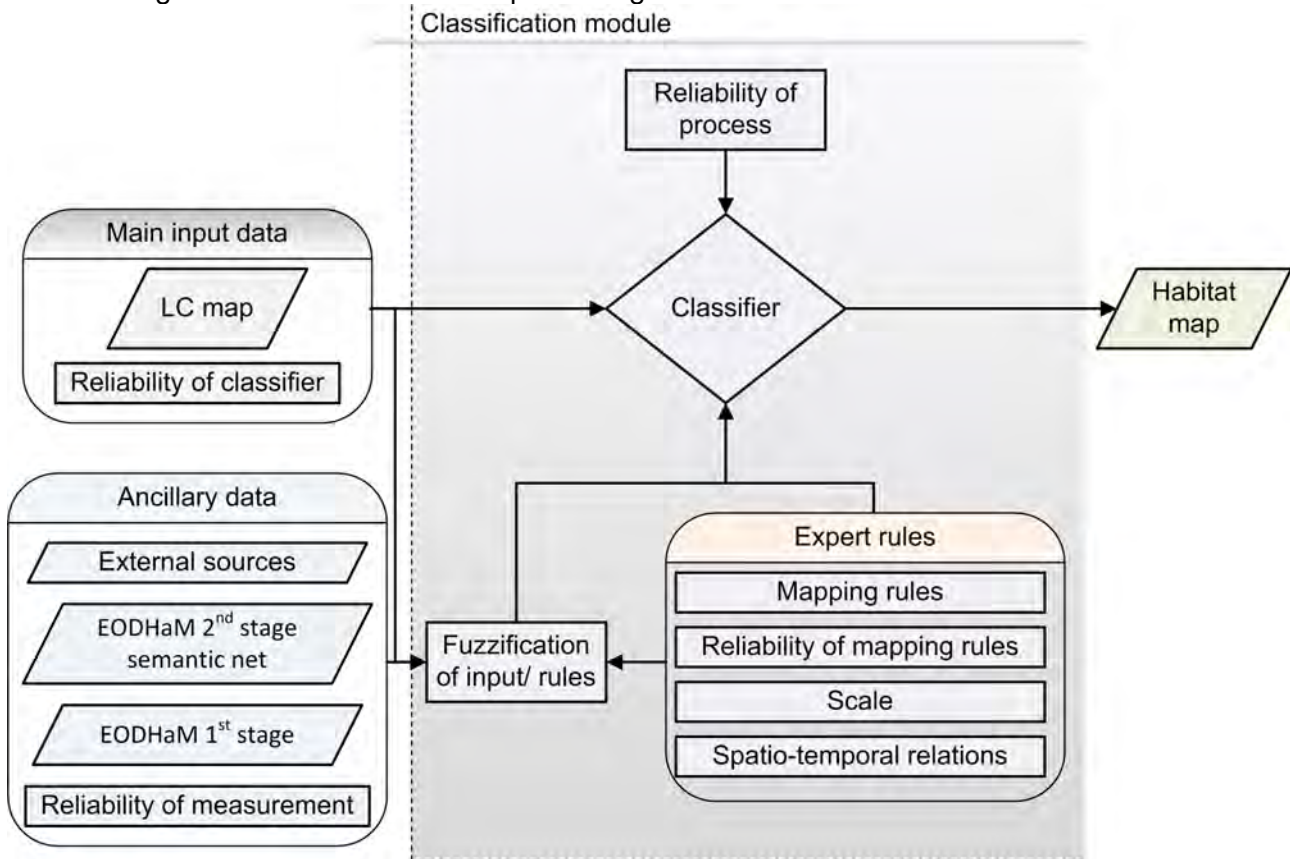
Figure 6.1. Classification module for the production of habitat maps from LC maps (from D6.10)

As stated in D6.10, *"to a certain degree, the refinement of the algorithm for GHC mapping will proceed in parallel with the evolution and refinement of the EODHaM 2nd stage, where the algorithm will take its main input from. The more semantic the information, including contextual and temporal, generated from the 2nd stage, the more additional data will be available for the refinement of the algorithm. In addition, the system will be further trained to include additional information from external sources and incorporate supplementary mapping and classifying rules. In a further level the accuracy of both input data and expert rules will be questioned and fuzzy classification schemes will be adopted to improve the resulting habitat maps."*

At this stage of the project, and for IT4 site, two summer QuickBird images and one Worldview2 autumn image are available. One QuickBird image dated July 2005 has been pre-processed and pre-classified within the EODHaM 1st stage by the SIAM™ module, but further research work is required to produce a LC map derived from VHR imagery according to the automatic methodology proposed for the development of the EODHaM system 2nd stage. In both D6.10 and this WP (D5.1), a pre-existing map produced for IT4 site and validated (OA = 95% with an error tolerance = 2%.) within a previous European Project Interreg III-A Greece - Italy 2000-2006 (code I3101001 project) is used as a base for GHC mapping. The scale of the LC/LU map is 1:5000, which is quite

compatible with VHR image spatial resolution of about 1.27m. The map was produced by photo-interpretation of a 2006 ortho-photo and in-field campaigns undertaken in 2007-2008. Even though the scale of the pre-existing map (i.e., 1:5000) is compatible with the spatial resolution of the three images and no reduction of the number NC of classes is needed, there are differences in the dates of acquisition and map production. For this reason, and before selecting the LC/LU classes to be considered within the pre-existing map, there was a need to verify that each strata (class) of the pre-existing map (and its label) was visible on the VHR image July QuikBird image. For this purpose, the preliminary SIAM™ spectral output map from the 1st EODHaM stage was used for selecting and excluding strata in the pre-existing map. As described in D3.1, the SIAM™-derived map can provide non-overlapping semantic strata (e.g., barren land or built up, vegetation, water, etc.) that could assist in identifying strata (class) changes between the pre-existing map and the actual VHR image and/or errors. As an example, in the QUICKBIRD image acquired in 2005 some strata (e.g. rivers covered by vegetation) evident in the pre-existing map were not visible in the image and/or were erroneously labeled when compared with the Quickbird pre-classified SIAM™ map (e.g. classified as soil instead of vegetation).

As a result of LC/LU selection, the list of LCCS classes considered for this site, both within and outside the Natura 2000 designation, are listed in Table 6.1(a, b and c) with their LCCS code and LCCS class description. It is worth noting that there is an inconsistency in the association of E6 and E7 alphanumeric codes to annual and perennial vegetation belonging to A12 and A24 classes between the LCCS software output code and the description reported in Appendix C of the FAO-LCCS manual [Di Gregorio, 2005]. In the present deliverable, the class description obtained by running the software, version 2, is adopted, i.e. E6 stands for perennial and E7 for annual.

The last column of Table 6.1 includes the Annex I or EUNIS habitats associated to each LC/LU class. Only the first 18 classes listed in Table 6.1 are located within the Natura 2000 site which is covered by the pre-existing LC/LU map. When the LCCS map will be produced from EO imagery, the GHC mapping will be undertaken also in the surrounding area of the site.

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Table 6.1a List of 3-D LC classes in LCCS taxonomy for the IT4 test site: A12

Class Counter	2° class counter		LCCS class code	LCCS class description	ANNEX I / EUNIS code
1		A12 Natural and seminatural terrestrial vegetation	A2.A5.A10.B4.E5.B12.E7	Closed annual medium/tall forbs	X / E1.6
2		A12	A1.A4.A10.B3.D1.E2.B9	Broadleaved deciduous medium/high closed shrubland (thickets)	X / F5.51
3		A12	A1.A4.A10.B3.D2.E1.B9	Needleaved evergreen medium/high closed shrubland (thickets)	2250 / B1.63
4		A12	A1.A4.A11.B3.D1.E1.B10	Broadleaved evergreen open dwarf shrublands	X / F6.2C
5	5.1	A12	A1.A4.A10.B3.D1.E1.B9 **+** topology+other attributes	Broadleaved evergreen medium/high closed shrubland (thickets)	5330 /F5.55
	5.2				X / F5.514
6		A12	A2.A5.A11.B4.E5.B13.E7	Open annual short forbs	1210 / B1.1
7		A12	A2.A6.A11.B4.E5.B12.E6	Open perennial medium-tall grasslands	2110 / B1.31
8	8.1	A12	A2.A5.A11.B4.E5.A13.B13.E7	Open (40-(20-10)%) annual short herbaceous vegetation	2230 / B1.48
	8.2				6220 / E1.313

Table 6.1b List of 3-D LC classes in LCCS taxonomy for the IT4 test site: A24, A11

Class counter	2º class counter		LCCS class code	LCCS class description	ANNEX I / EUNIS code
9	9.1	A24	A2.A5.A13.B4.C2.E5.B13.E7 +topology+other attributes	Open annual short herbaceous vegetation on temporarily flooded land	3170 / C3.421
	9.2	Natural and seminatural aquatic or regularly flooded vegetation			1310 / A2.51
	9.3				1310 / A2.55
10		A24	A1.A4.A12.B3.C2.D3.B10	Aphyllous closed dwarf shrubs on temporarily flooded land	1420 / A2.526
11	11.1	A24	A2.A6.A12.B4.C2.E5.B11.E6 +other technical attributes (species)	Perennial closed tall (3-0.8m) grasslands on temporarily flooded land	1410 / A2.522
	11.2				7210 / D5.24
	11.3				X / D5.1
	11.4				X / D5.2
12		A24	A2.A6.A12.B4.C2.E5.B12.E6	Perennial closed medium-tall (0.8-0.3m) grasslands on temporarily flooded land	X / C2
13		A24	A2.A5.A16.B4.C1.E5.A15.B12.E6	Perennial sparse medium tall herbaceous vegetation on permanently flooded land	1150 / X03
14		A11 Cultivated and managed	A3	Herbaceous crops	X / I1
15		A11	A1.B1.C1.D1.W8.A7.A9.B3	Monoculture fields of rainfed broadleaved evergreen tree crops orchards (olive groves)	X / G2.91
16		A11	A1.B1.C1.D1.W7.A8.A9.B3	Monoculture fields of rainfed needleleaved evergreen tree crops plantations	X /G3.F1

Table 6.1c List of 3-D LC classes in LCCS taxonomy for the IT4 test site: B15

Class counter	2° class counter		LCCS class code	LCCS class description	ANNEX I / EUNIS code
17		**B15** **Artificial surfaces**	A1.A4.A12.A17	Scattered industrial or other areas	X / J2.1
18		**B15**	A1.A3.A7.A8	Paved roads	X / J4.2
19		**B28**	A1.B1	Perennial natural waterbodies	X / A7.3

The preliminary GHC map of IT4 site provided in D6.10 was based on only four out of eight top LCCS classes, which are shown in Figure 6.3. A translation was attempted into the potential GHCs super-categories for each class. Four different combinations of possible GHC super-categories were created as a result, namely:

i.   Urban or cultivated or other herbaceous or tree and shrub areas,
ii. Herbaceous wetlands or other herbaceous vegetation or trees and shrubs or urban areas,
iii. Urban or sparsely vegetated areas or other herbaceous vegetation or trees and shrubs, and
iv. Urban areas.

Figures 6.4 and 6.5 evidence the ambiguity among potential GHC output super-categories.

Figure 6.3 (Equivalent to Figure 5.1 of D6.10). IT4. Pre-existing LC/LU map converted in LCCS taxonomy.

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CUL (CRO) or URB (VEG/GRA) or Other HER (LHE/THE/GEO/HCH/CRY)
CUL (WOC) or URB (TRE) or TRS
HER
HER or Other HER (CRY) or TRS or URB (VEG/GRA/TRE)
Other HER (CHE) or URB (GRA)
Other HER (HCH/LHE/CHE/THE/GEO) or URB (VEG/GRA) or TRS (DCH/SCH)
Other HER (HCH/LHE/THE/GEO) or URB (VEG/GRA) or TRS (DCH/SCH)
TRS (DCH/SCH/LPH/MPH/TPH) or URB (VEG/TRE)
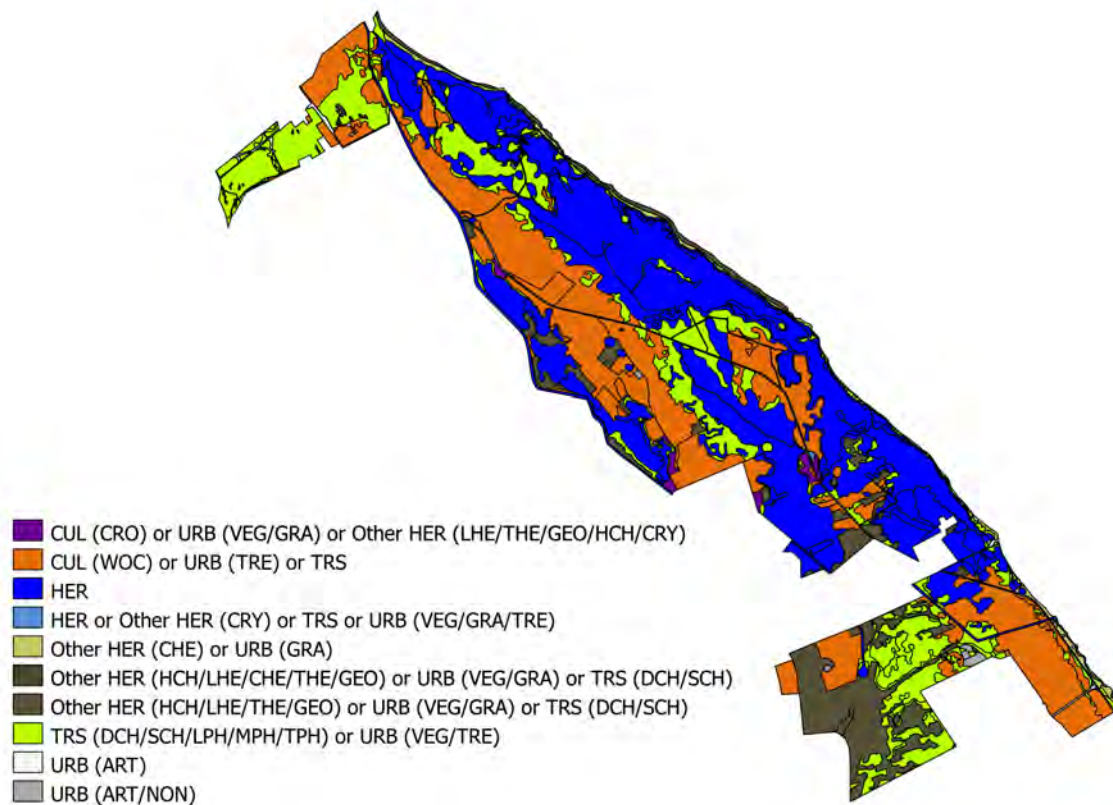URB (ART)
URB (ART/NON)

Figure 6.4 (Equivalent to Figure 5.4 of D6.10). GHC super-categories and potential LFs and NLFs categories extracted from the LCCS top classes and life form classifiers for (IT4).
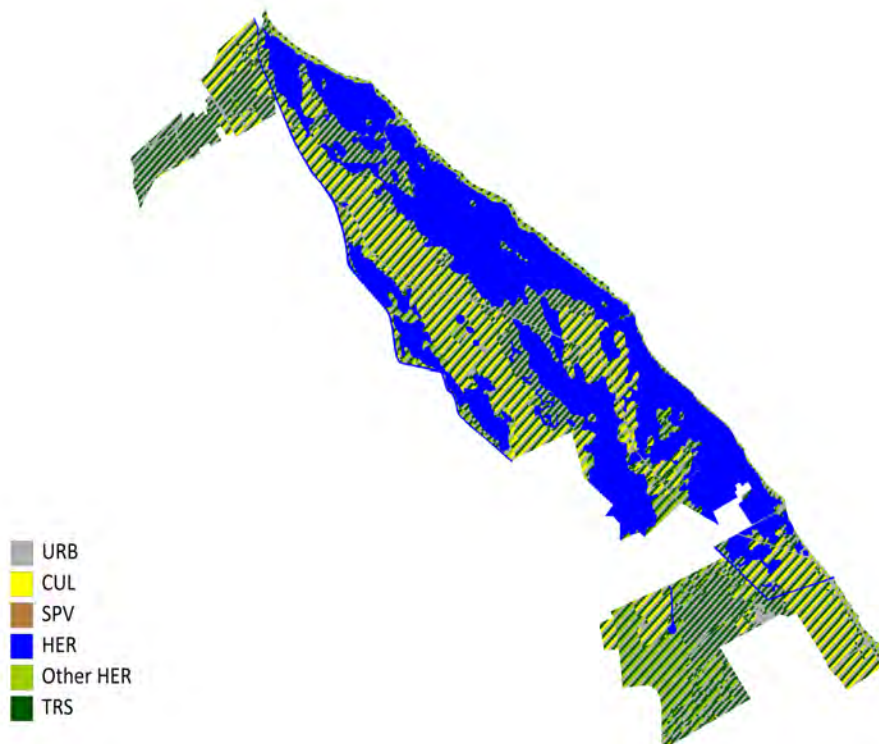

URB
CUL
SPV
HER
Other HER
TRS

Figure 6.5 (Equivalent to Figure 5.5 of D6.10). GHC super-categories included for each combination for Le Cesine

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As an advancement on previous work undertaken in D6.10, this deliverable describes the effort to differentiate GHCs within IT4 and is based mainly on:

- The use of *additional LCCS attributes* characterizing class description in LCCS taxonomy. The LCCS class distribution in the IT4 site is shown in Figure 6.6; for each class, the alphanumeric codes useful for GHC discrimination are evidenced in bold. Such subset of alphanumeric codes is used in Table 6.2, second column, for listing LCCS classes. The potential associated GHCs codes are also reported in Table 6.2, first column (see Section 6.1).

- *Topological relationships.* LCCS taxonomy does not allow an exhaustive translation of class description from the 3-D real world domain to the 2-D image domain. On the contrary, LC/LU class description based on semantic nets (see Section 3) offers this opportunity because, as explained previously in Section 2, relationships between classes of 3-D objects can be handled, including both spatial topological and non-topological relationships and non-spatial relationships. In addition, semantic nets potentially provide the opportunity for the description of GHCs classes, which are currently listed in the EBONE handbook, and also the rules for translating LCCS to GHC. At this stage of the work, the semantic net description of LCCs to GHC mapping is implicit in the eCognition projects used for GHC mapping in IT4 as well as in the UK (Welsh site). Topological relationships were used to disambiguate potential GHC output classes that could be activated by a specific LCCS class.

- Textural *attributes* related to the description of some GHCs. These were used to discriminate habitats within two height categories (i.e., greater or lower than 2.0 m). The Entropy texture feature, extracted from the occurrence matrix (with a 3x3 kernel) of the calibrated QuickBird Green band 2 (520-600 nm) was used (Figure 6.6b) to accomplish height discrimination. As already evidenced in D6.10, there is a limited correspondence between the height ranges considered in GHC and LCCS taxonomies. LIDAR data should be used for height discrimination but such data are not available on IT4.

- The introduction of *external source of information,* such as Cadastral information (i.e., the 1:5000 CTR map provided by the Puglia Region) to extract field boundaries. As a result, a LCCS segment labelled with a specific LCCS code was decomposed in its different sub-areas (fields) according to the cadastral limits of each field. Each field has the same label of the original segment in the LCCS map.

- The outputs of the SIAM™ 1st EODHaM can be either categorical (e.g., the preliminary image spectral map) or continuous variables (e.g., soil, vegetation and water indices). In particular, for discriminating emergent hydrophytes (i.e. HER/EHY)) from submerged hydrophytes (i.e., HER/SHY), the water index (i.e., *fRatioWaterIndex*) output map obtained by the SIAM™ processing of the Quickbird July image at 2.4 m. resolution was used. Verification was undertaken by analysing the *fRatioWaterIndex* values within Region of Interest (ROIs) in the *fRatioWaterIndex map* corresponding to the LCCS classes, which themselves related to HER(EHY/SHY/HEL) categories (i.e., classes 9 and 13). Emergent hydrophytes HER(EHY) and helophytes HER(HEL) areas were characterized by a low *fRatioWaterIndex* value whereas submerged hydrophytes areas (i.e., HER(SHY)) were characterized by a high *fRatioWaterIndex* value in July. This is highlighted in Figure 6.6.d and 6.6.e., the latter being a close up of the former image. In particular, a threshold *fRatioWaterIndex* value was set equal to 1.05 since the range of low water index was [0,2; 0.9] with mean value 0,4 and StDev= 0,1 and the range of high water index value was [1,3; 3,7] with mean value 2,65 and StDev= 0,2.

  Additional information related to the topological relations between HER (EHY/SHY/HEL) and HEL on the ground were used to discriminate HEL from EHY. Both HEL and EHY classes were characterized by a low *fRatioWaterIndex* value, but the former should be not close to SHY. In fact, according to the domain expert (i.e., V. Tomaselli CNR-IGV), in the description of such GHCs, when habitats are in an ideal 'good' conservation status, these

three GHCs should be arranged according to a concentric geometric pattern with SHY, EHY and HEL occurring from the inner to outer part of the pattern. More details are provided in the Section below.

6.1 LCCS to GHC mapping

The potential GHCs in IT4 are listed in Table 6.2, with this based on Table 6.1 and Figures 4.1 to 4.8 of Section 4 of the present deliverable.

The following premises are made:

a) LCCS to GHC mapping is mainly a many to many mapping.

b) The topological relation *close-to* is interpreted as *adjacency.*

c) No species information in the technical attribute has been used.

d) LIDAR data were not available on this site. Therefore, plant height could not be quantified directly as in Wales (see Section 5 of the present deliverable and D4.3). The following GHC categories have therefore been fused: TRS (TPH) and TRS (FPH), which are described as GHC categories characterized by an height value greater than 2 m; TRS (LPH) and TRS (MPH), which are described as trees with an height lower than 2 m. The two height ranges (greater or lower than 2 m.) can be discriminated based on textural information extracted from the summer QuickBird image. First, the Entropy values of the occurrence matrix with a 3x3 kernel window were computed for each band of the calibrated image. Then, the Entropy values of the green band were selected based on separability measures. A crisp threshold was empirically defined for height discrimination by a thresholding procedure.

e) Only area units in the LCCS map were considered and labelled even if their areal size was lower than 400m^2. At the end of the mapping process, adjacent fields labelled with the same GHC were grouped. GHC areal units below 400m^2 were coloured in red and considered as point elements in the GHC map.

On this basis and considering Table 6.2, the mapping LCCS to GHC can be described as follows:

- According to the schemes reported in Section 4, for each GHC in Table 6.2 the full set of LCCS classes that can generate that specific GHC is reported in the 3rd column. This means that LCCS classes not included in IT4 are also considered with the aim to extend the discrimination of that GHC to other sites. For each LCCS class, only the alphanumeric codes useful for GHC discrimination are considered and reported in the 3rd column of Table 6.2, with these including those that align with the corresponding LCCS full class code. As an example, Class 15 of Table 6.1 has the LCCS class code A11/A1.B1.C1.D1.W8.A7.A9.B; however, only the subset A11/A1.W8 seemed useful for GHC discrimination. The remaining alphanumeric codes, with these including broadleaved (A7) and evergreen (A8) attributes, should be used only for the detection of LCCS classes when EO images will be classified to provide LC/LU maps. As a result, only a subset of the original class codes was used in the mapping procedure.

  As evidenced in D6.10 and in Section 4 of the present deliverable, often LCCS to GHC mapping is a many to many mapping. To solve the ambiguities among the different GHCs, which can correspond to the same LCCS LC/LU class, a number of semantic rules are required. This means that for identifying a specific GHC (among those listed in the first column of Table 6.2) in the output GHC map, the LCCS classes of the input LC/LU map that might translate to that GHC (as listed in the 3rd column of Table 6.2) must satisfy the semantic rules listed in the last three columns of Table 6.2. If a rule can be developed there, one to one mapping is possible.

- The categories belonging to the URB super-category were first identified, except URB/RO) because attention was focused on areal elements; URB/ART and URB/NON were first mapped by just relabeling the LCCS classes corresponding to the ones in the 3rd column

of Table 6., with these corresponding to each of the two cited GHC classes. These two GHC categories are needed to apply the topological rule most frequently used in the table (see fourth column; i.e. *close to* URB/ART or URB/NON categories) for discriminating other GHCs. Herein, *close to* was interpreted as *adjacent to*. Then, URB/VEG and URB/GRA categories were identified by relabeling LCCS class objects (segments) in the LC/LU map as URB/VEG and URB/GRA in the output GHC map if:

- o close to URB/ART or URB/NON and
- o texture values were very low or low for URB/VEG and URB/GRA respectively.

Further refinements are required because of the lack of LIDAR data.

- CUL/WOC and CUL/CRO NLFs were identified by labeling all the LCCS segments of the input LC/LU map only when the field (i.e. LCCS class segment) was *close* neither to URB/ART nor to URB/NON categories (*not close* condition in Table 6.3)

- HER/EHY, HER/SHY and HER/HEL were identified by considering A24/A2 LCCS class segments in the LC/LU input map only when they satisfied specific topological relations and showed either a low or high water index (*fRatioWaterIndex*) value. As already mentioned in the introduction, both HER/HEL and HER/EHY classes are characterized by a low *fRatioWaterIndex* value. The differentiation between these two GHC classes depends on their relative position with respect to HER/SHY), i.e. the former class should *not be   close* to the HER/SHY category. When the habitats are in an ideal conservation status, the three GHCs should be arranged in a concentric geometric pattern with HER(SHY), HER(EHY) and HER(HEL) being located from the inner to the outer part of the zonation.

- Other Herbaceous O. HER/THE and O.HER/CHE were identified mainly on the basis of topological relations such as closeness *to* URB/ART or URB/NON (*not close).*

- All TRS categories were identified by the set of LCCS classes that could have activated those categories which met both the topological relations reported in the 4th and 5th columns of Table 6.2 and displayed either a low or high texture value, as indicated in the 6th column of Table 6.2. In order to identify the TRS(SCH/NLE) category, the two LCCS classes, among those associated to the TRS category (Table 6.2, 3rd column) should be *close to* either HER(SHY), HER(EHY) or HER(HEL).

The GHC map will be validated in September during a new field data collection session in the field.

Figure 6.8 shows the GHC map as obtained without integrating the information provided by the cadastral map. Figure 6.9, instead, shows the GHC map after integration with the information of the cadastral map. This information was very useful since it reduced the extension of URB/TRE while extending that of CUL/WOC in relation to the land functional use. This difference between the two maps can be appreciated by comparing the GHC map in Figure 6.8 with the one in Figure 6.9 (a) and (b). The Figures 6.9(a) and (b) report the final GHC map with and without the QuickBird image in the background, respectively.

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- **A1.A3.A7.A8**
- **A1.A4.A12.A17**
- **A1.A4**.A10.B3.**D1.E1**.B9
- **A1.A4**.A10.B3.**D1.E2**.B9
- **A1.A4**.A10.B3.**D2.E1**.B9
- **A1.A4**.A11.B3.**D1.E1**.B10
- **A1.A4**.A12.B3.C2.**D3**.B10
- **A1**.B1.C1.D1.**W7.A8**.**A9**.B3
- **A1**.B1.C1.D1.**W8.A7**.**A9**.B3
- **A2.A5**.A10.B4.E5.B12.**E7**
- **A2.A5**.A11.B4.E5.B13.**E7**
- **A2.A5**.A13.B4.C2.E5.B13.**E7**
- **A2.A5**.A16.B4.C1.E5.A15.B12.**E6**
- **A2.A6**.A11.B4.E5.B12.**E6**
- **A2.A6**.A12.B4.C2.E5.B11.**E6**
- **A2.A6**.A12.B4.C2.E5.B12.**E6**
- **A3.A5**.B2.C2.D3
- **A2.A5**.A11.B4.E5.A13.B13.**E7**
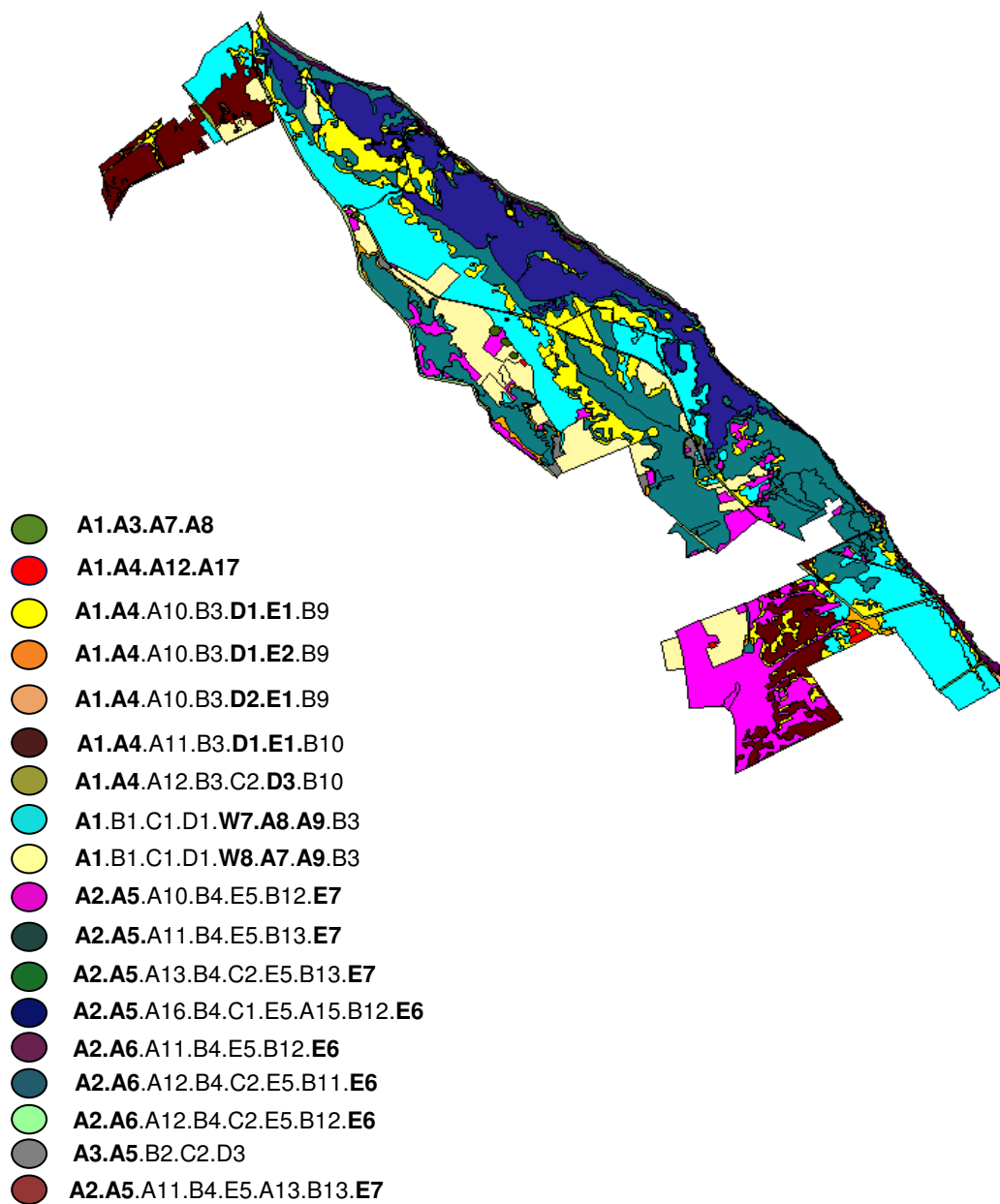
Figure 6.6 LCCS classes in IT4. The alphanumeric codes useful for GHC discrimination in LCCS to GHC mapping are evidenced in bold.

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Table 6.2. LCCS to GHC mapping. 1st column: list of potential GHC categories; 2nd column: LCCS class counter from Table 6.1; 3rd column: all the LCCS classes (including classes not present in IT4) that could activate, according to Figures 4.1 to 4.8 of Section 4, the specific GHC category in the first column; no index in the 2nd column indicates the absence of a specific LCCS class in IT4 site. Fourth to sixth column: additional semantic rules (conditions) to be satisfied to solve LCCS to GHCs mapping ambiguities; no rule means that the mapping is one to one. Please note that * means that a specific LCCS class requires additional explanation for its final translation into a GHC category, as in the case of A11/ A3.A5*.

GHC categories	LCCS class counter	Associated LCCS Code	Rule 1	Rule 2	Rule 3
URB(ART/ROA)	18	B15/ A1.A3.A7.A8			
URB(ART)		B15/ A1.A4.A13. (A14 OR A15 OR A16)			
		B15/ A1.A4.A12. (A14 OR A15 OR A16)			
		B15/ A1.A3.A10			
		B15/ A1.A3.A11			
		B27/ A1.A5			
URB(NON)	17	B15/ A1.A4.A12.A17			
		B15/ A1.A4.A13.A17			
		B15/ A2			
URB(VEG)		A11/ A2	Close to URB(ART) or URB(NON)		Low Entropy value
	2/3/4/5	A12/ A1.A4			
	10	A24/ A1.A4			
	14	A11/ A3.A5*			
URB(GRA)		A11/ A6. (A12 or A13)	Close to URB(ART) or URB(NON)		Low Entropy value
	14	A11/ A3.A4			
	1/6/8	A12/ A2.A5			
	7	A12/ A2.A6			
	9/13	A24/ A2.A5			
	11/12	A24/ A2.A6			
	14	A11/ A3.A5*			
URB(TRE)	16	A11/ A1.W7	Close to URB(ART) or URB(NON)		High Entropy value
	15	A11/ A1.W8			
		A11/ A6. (A11 OR A12)			
		A11/ A2			
		A24/ A1.A3			
	10	A24/ A1.A4			
		A12/ A1.A3			

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	2/3/4/5	A12/ A1.A4			
CUL(WOC)	15	A11/ A1.W8	Not close to URB(ART) and URB(NON)		
		A11/ A2.W8			
		A23/ A3			
CUL(CRO)	14	A11/ A3	Not close to URB(ART) and URB(NON)		
		A23/ A1			
		A23/ A2			
HER(EHY)	9/11/12/13	A24/ A2	Not close to URB(ART) and URB(NON)		Low *fRatioWaterIndex* value in summer
HER(SHY)	9/11/12/13	A24/A2	Not close to URB(ART) and URB(NON)		High *fRatioWaterIndex* value in summer
HER(HEL)	9/11/12/13	A24/ A2	Not close to URB(ART) and URB(NON)	Not close to HER(SHY)	Low *fRatioWaterIndex* value in summer
O.HER(THE)	1/6/8	A12/ A2.A5.E7	Not close to URB(ART) and URB(NON)		
O.HER(CHE)	7	A12/ A2.A6.E6	Not close to URB(ART) and URB(NON)		
TRS(SCH/NLE)		A12/ A1.A4.D3.E1	Not close to URB(ART) and URB(NON)	Close to HER(SHY) or HER(EHY) or HER(HEL)	
	10	A24/ A1.A4.D3.E1			
TRS(MPH/DEC)	2	A12/ A1.A4.D1.E2	Not close to URB(ART) and URB(NON)		Low Entropy value
		A24/ A1.A4.D1.E2			
TRS(LPH/NLE)		A12/ A1.A4.D3.E1	Not close to URB(ART) and URB(NON)		Low Entropy value
	10	A24/ A1.A4.D3.E1			

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TRS(LPH/EVR) OR TRS(MPH/EVR)	4/5	A12/ A1.A4.D1.E1	Not close to URB(ART) and URB(NON)		Low Entropy value
		A24/ A1.A4.D1.E1			
		A11/ A2.A7.A9.W7			
TRS(MPH/CON)	3	A12/ A1.A4.D2.E1	Not close to URB(ART) and URB(NON)		Low Entropy value
		A24/ A1.A4.D2.E1			
TRS(TPH/EVR)		A12/ A1.A3.D1.E1	Not close to URB(ART) and URB(NON)		High Entropy value
	4/5	A12/ A1.A4.D1.E1			
		A11/ A1.A7.A9.W7			
		A24/ A1.A3.D1.E1			
		A24/ A1.A4.D1.E1			
TRS(TPH/CON-EVR) OR TRS(FPH/CON-EVR)	3	A12/ A1.A4.D2.E1	Not close to URB(ART) and URB(NON)		High Entropy value
		A12/ A1.A3.D2.E1			
	16	A11/ A1.A8.A9.W7			
		A24/ A1.A4.D2.E1			
		A24/ A1.A3.D2.E1			

(a)

(b)

(c)

(d)

(e)
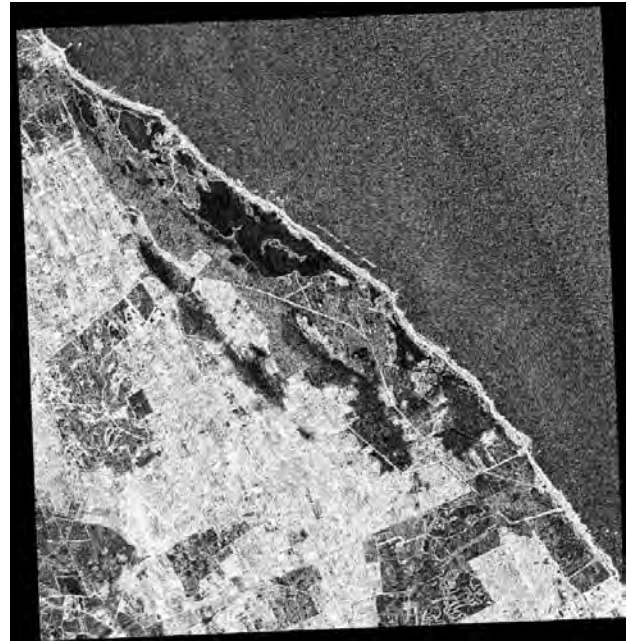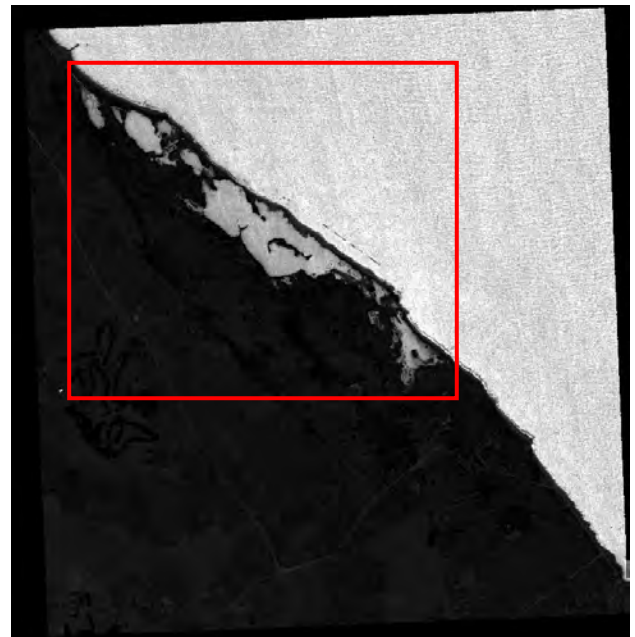
Figure 6.7. (a) July QuickBird image. RGB: 341 false colour. (b) Entropy image extracted from (green) Band 2 by a (3x3) window, range values [0, 2.2], mean value 1,0 and StDev 0.6. (c) 1ˢᵗ-stage SIAM^{TM} pre-classified map. (d) *fRatioWaterIndex map,* range values [1,10], mean value 1,4 and StDev 1,4. (e) ROI for aquatic and terrestrial areas used for *fRatioWaterIndex* thresholding in a window of the image shown in (d).

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● TRS(LPH) or TRS(MPH)	● CUL(CRO)
● TRS(LPH/EVR) or TRS(MPH/EVR)	● CUL(WOC)
● TRS(LPH/NLE)	
● TRS(MPH/CON)	● URB(ART)
● TRS(MPH/DEC)	● URB(ART/ROA)
● TRS(SCH/NLE)	● URB(GRA)
● TRS(TPH/CON-EVR) OR TRS(FPH/CON-EVR)	● URB(NON)
● TRS(TPH/EVR)	● URB(TRE)
	● URB(VEG)
● OTHER HER (CHE)	
● OTHER HER(THE)	● HER(EHY)
	● HER(HEL)
● GHC_MIN_400MQ	● HER(SHY)
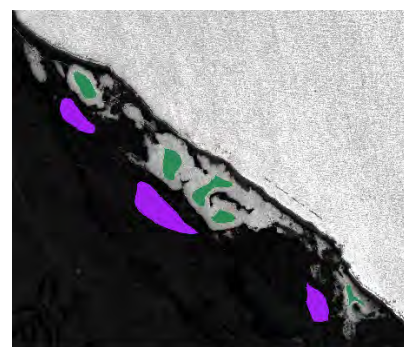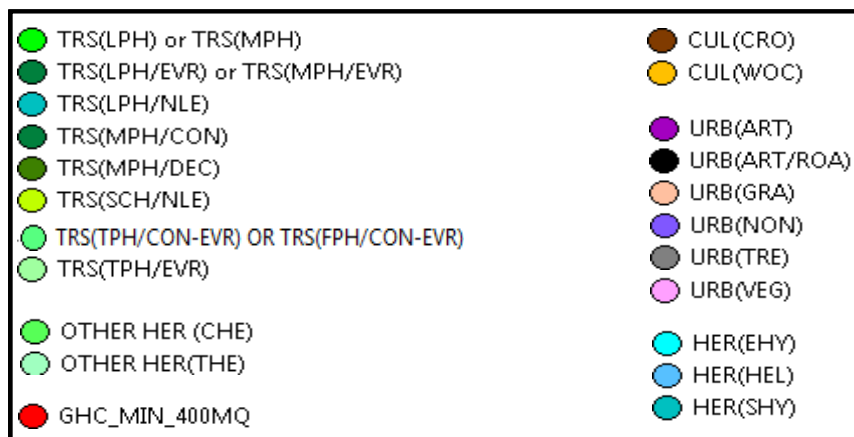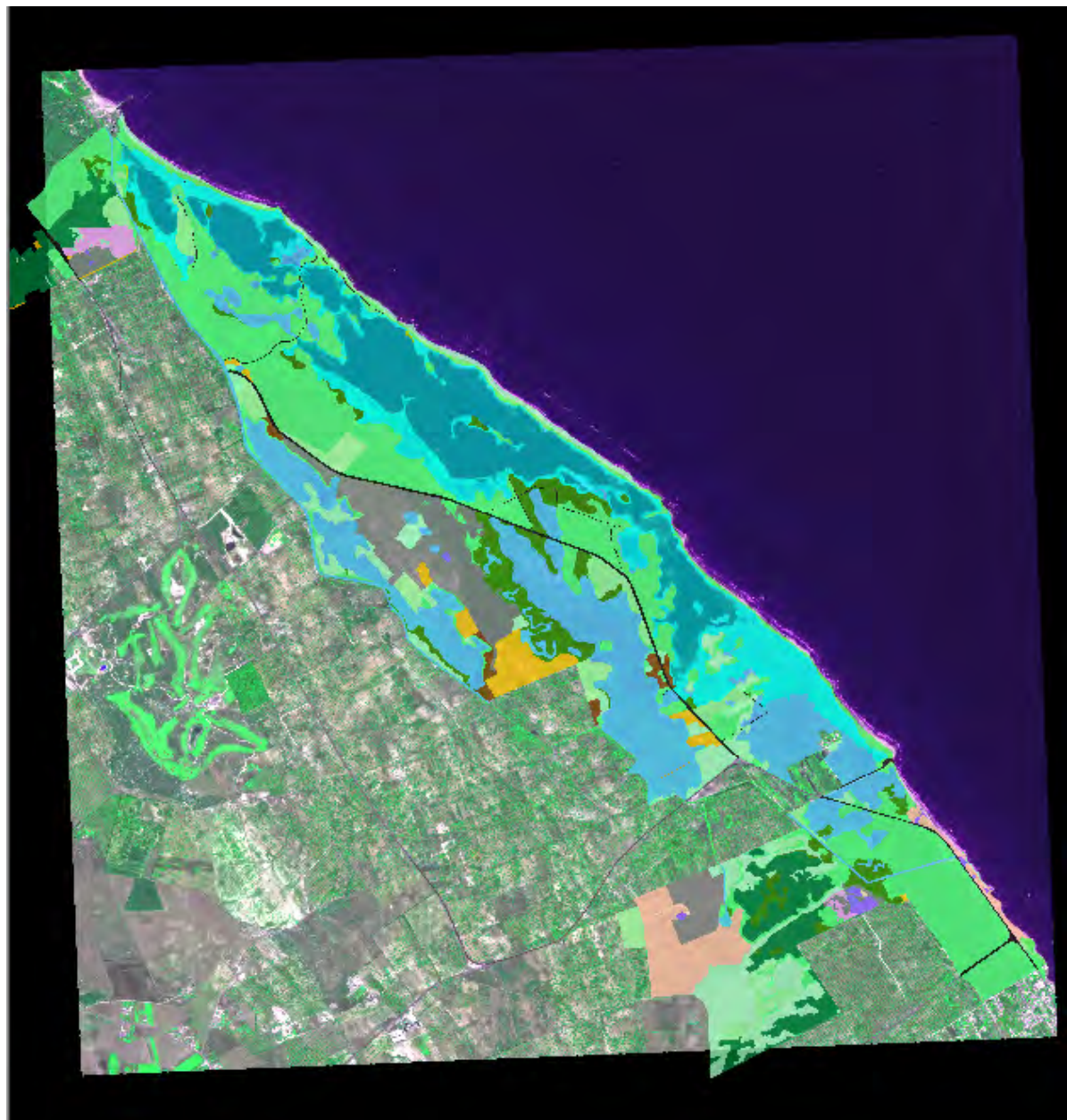
Figure 6.8 GHC map overlaid to the EO Quickbird calibrated MS image, RGB= 341. The map was obtained from the pre-existing LCCS shown in Figure 6.2 without considering the cadastral map.

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(a)

🟢 TRS(LPH) or TRS(MPH)		🟤 CUL(CRO)
🟢 TRS(LPH/EVR) or TRS(MPH/EVR)		🟠 CUL(WOC)
🔵 TRS(LPH/NLE)		
🟢 TRS(MPH/CON)		🟣 URB(ART)
🟢 TRS(MPH/DEC)		⚫ URB(ART/ROA)
🟡 TRS(SCH/NLE)		🟤 URB(GRA)
🟢 TRS(TPH/CON-EVR) OR TRS(FPH/CON-EVR)		🔵 URB(NON)
		⚫ URB(TRE)
🟢 TRS(TPH/EVR)		🟣 URB(VEG)
🟢 OTHER HER (CHE)		🔵 HER(EHY)
🟢 OTHER HER(THE)		🔵 HER(HEL)
🔴 GHC_MIN_400MQ		🔵 HER(SHY)
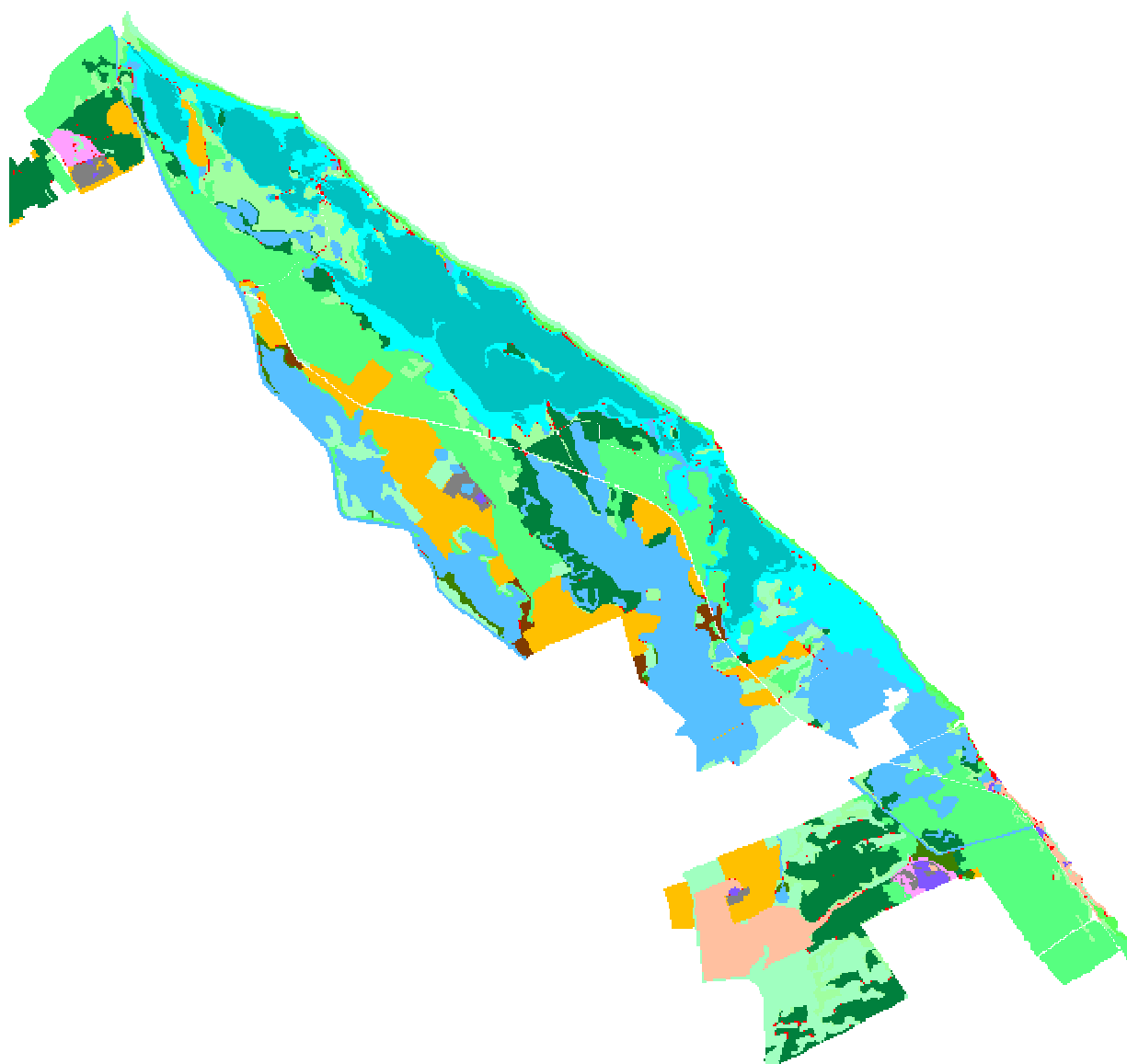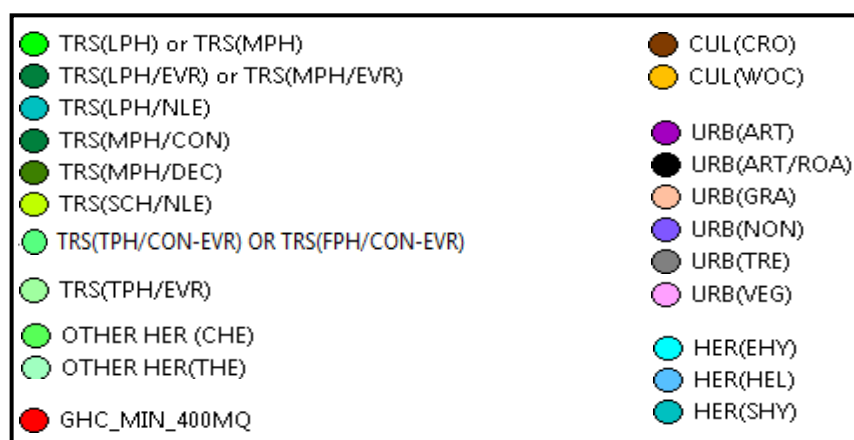
Figure 6.9.a Final output GHC map obtained from the pre-existing LC/LU map in LCCS taxonomy. The GHC map covering the IT4 Natura 2000.
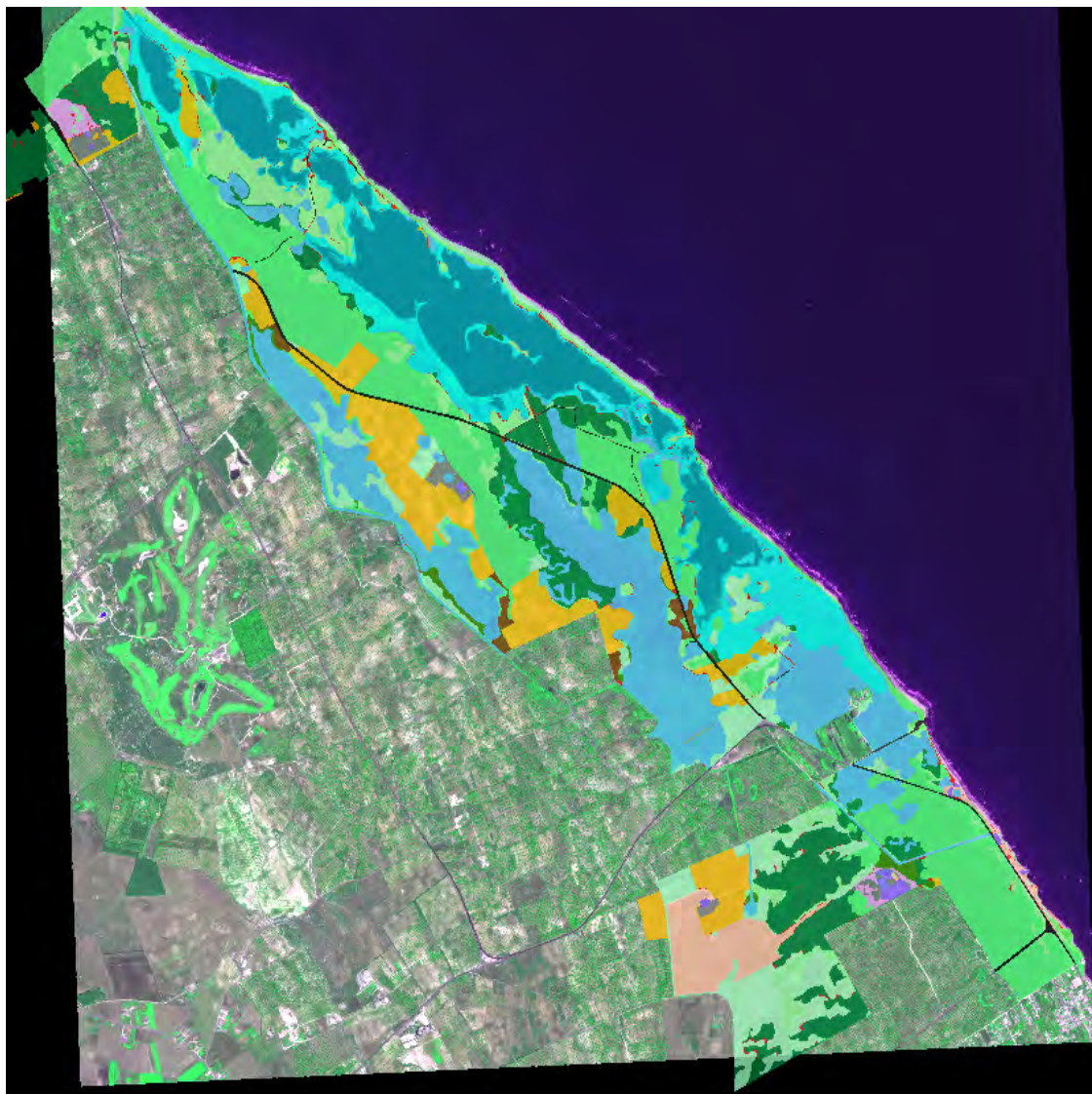
(b)
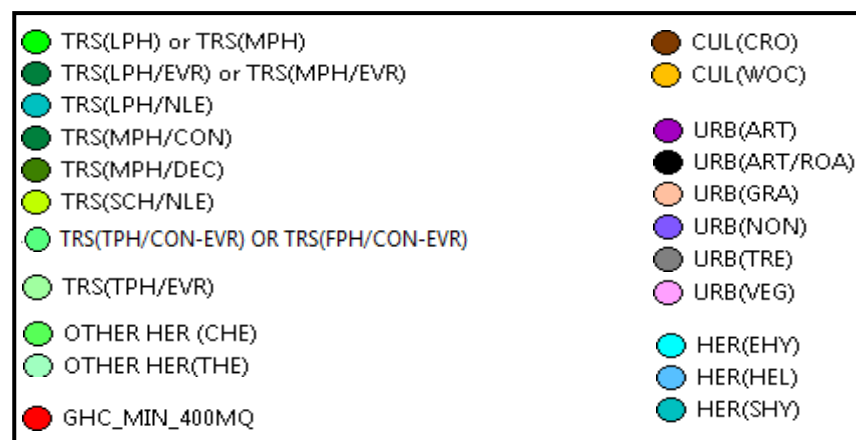
Figure 6.9.b. Final output GHC map obtained from the pre-existing LC/LU map in LCCS taxonomy. The GHC map is overlaid to the EO July QuickBird calibrated MS image, which was used to extract both texture information and *fRatioWaterIndex,* the latter as SIAM^TM output.

6.2   LCCS / GHC to Annex I mapping in IT4

Table 6.3 reports a decision table to translate GHC categories into Annex I habitats, according to the EBONE Key [Bunce et al. 2011b]. Both Annex I and EUNIS codes are reported in the table (see OUTPUTS column/lines).

At the present stage of the project, the values of some GHC environment qualifiers are not yet available (e.g., the Ellenberg values) for the IT4 site. For this reason, to provide Annex I/EUNIS maps:

- mapping rules were defined and adopted by using the LCCS map as input. The mapping rules were defined on the basis of the environmental LCCS attributes characterizing class description in LCCS taxonomy. The decision table is reported in Table 6.4a. The technical LCCS attributes, including species information, are reported in Table 6.4b, but were not used in the LCCS to Annex I/EUNIS mapping.

- For   Annex I/EUNIS habitat mapping, the rules of Table 6.4a were used only for LCCS classes in the LC/LU map which did not correspond to URB, CUL, SPV GHC super-categories in the output GHC map (Figure 6.9.a). In other words, the GHC map was used to mask the LC/LU when producing the Annex I/EUNIS habitat map.

The overall accuracy of the Annex I/ EUNIS habitat map in Figure 6.7 is 94 % with an error tolerance of 0.06. Quality measurements were based on a pre-existing Annex I/EUNIS map produced, by means of in-field campaigns, within the previously cited Interreg project. Figure 6.10 shows both Annex I and EUNIS habitats, whereas, Figure 6.11 shows only Annex I habitats.

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Table 6.3 Decision table for GHC to ANNEX I / EUNIS mapping. A: *Annex I* taxonomy; E: *EUNIS* taxonomy.

E	C3.421	A2.51/A2.55	A2.526	A2.522	D5.24	D5.1	D5.2	C2	X03	E1.6	F5.51	B1.63(1)	(F5.55)	F5.514	F6.2C	B1.1	B1.31	(B1.32)	(B1.48)	E1.313
A	3170	1310	1420	1410	7210	X	X	X	1150	X	X	2250	5330	X	X	1210	2110	2120	2230	6220

Decision table — **Y is TRUE for INPUTS and X is TRUE for OUTPUTS**

Category	INPUTS	C3.421	A2.51/A2.55	A2.526	A2.522	D5.24	D5.1	D5.2	C2	X03	E1.6	F5.51	B1.63(1)	(F5.55)	F5.514	F6.2C	B1.1	B1.31	(B1.32)	(B1.48)	E1.313
GHC	THE or LHE/THE or CHE/THE or URB (GRA)										Y										
	MPH/DEC or URB (TRE)											Y									
	MPH/CON												Y								
	MPH/EVR or TPH/EVR or URB (TRE)													Y	Y						
	LPH/EVR or SCH/EVR or URB (TRE)															Y					
	THE or LHE/THE																Y				
	CHE or CHE/THE or LHE/CHE																	Y	Y		
	THE or THE/GEO or LHE/THE																			Y	
	THE or THE/GEO or LHE/THE or URB (GRA)																				Y
	THE or THE/GEO	Y																			
	THE		Y																		
	SCH/NLE or LPH/ NLE			Y																	
	EHY or HEL or EHY/HEL					Y	Y	Y	Y	Y											
	SHY or SHY/EHY +EHY										Y										
Life Form Qualifiers	EVR-LAR																Y	Y			
	EVR-SMA; CUS																	Y			
	CHE-TUS																		Y	Y	
	SHY-LEA										Y										

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Category	Item																		
Env Qualifiers (Moisture regime)	Dry or Very dry								Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Seasonally wet	Y				Y													
	Wet		Y	Y	Y	Y	Y	Y	Y										
	Aquatic									Y									
Env Qualifiers (Eutrophy)																			
Env Qualifiers (Acidity)																			
Env Qualifiers (Salinity)	Fresh water					Y													
	Saline water		Y	Y	Y					Y					Y				
	Brakish water									Y									
Soil	Sand												Y		Y	Y	Y	Y	
	Calcareous																		Y
Site Qualifiers (Geomorphological element)	1.25 Dune											Y	Y			Y	Y	Y	
	1.14 Rock pavement																		Y
Site Qualifiers (Inland water)	2.21 Pond - temporary	Y																	
	2.24 Salt marsh pools									Y									
Site Qualifiers (Coastal element)	5.2 Grey dunes; 5.6 Maritime exposure											Y	Y						
	5.1 Yellow dune/white dunes															Y	Y		
	5.2 Grey dunes																	Y	
	5.5 Strand line															Y			
	5.4 Salt marsh		Y	Y	Y	Y	Y	Y											
Site Qualifiers (Bogs/Mires/Wetlands)	6.9 Reed Beds					Y													
Manag. Qualifiers	1.4 Fallow										Y								
	6.3 Canal								Y										
Linear element	LSC											Y							
	ANN															Y			
	GST																Y	Y	
	WAT								Y										

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ANNEX I / (EUNIS) classes	OUTPUTS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	3170 / (C3.421)	X																			
	1310 / (A2.51/A2.55)		X																		
	1420 / (A2.526)			X																	
	1410 / (A2.522)				X																
	7210 / (D5.24)					X															
	X / (D5.1)						X														
	X / (D5.2)							X													
	X / (C2)								X												
	1150 / (X03)									X											
	X / (E1.6)										X										
	X / (F5.51)											X									
	2250 / (B1.631)												X								
	5330 / (F5.55)													X							
	X / (F5.514)														X						
	X / (F6.2C)															X					
	1210 / (B1.1)																X				
	2110 / (B1.31)																	X			
	2120 / (B1.32)																		X		
	2230 / (B1.48)																			X	
	6220 / (E1.313)																				X

Table 6.4a. Decision Table for LCCS to ANNEX I/EUNIS mapping. A: *Annex I* taxonomy; E: *EUNIS* taxonomy.

E	C3.421	A2.51/A2.55	A2.526	A2.522	D5.24	D5.1	D5.2	C2	X03	E1.6	F5.51	B1.63(1)	(F5.55)	F5.514	F6.2C	B1.1	B1.31	(B1.32)	(B1.48)	E1.313
A	3170	1310	1420	1410	7210	N	N	N	1150	N	N	2250	5330	N	N	1210	2110	2120	2230	6220

INPUTS — Y is TRUE for INPUTS and X is TRUE for OUTPUTS

Category	INPUTS	C3.421	A2.51/A2.55	A2.526	A2.522	D5.24	D5.1	D5.2	C2	X03	E1.6	F5.51	B1.63(1)	(F5.55)	F5.514	F6.2C	B1.1	B1.31	(B1.32)	(B1.48)	E1.313
LCCS FOR INLAND	A2.A5.A13.B4.C2.E5.B13.E7	Y	Y																		
	A1.A4.A12.B3.C2.D3.B10				Y																
	A2.A6.A12.B4.C2.E5.B11.E6					Y	Y	Y	Y												
	A2.A6.A12.B4.C2.E5.B12.E6										Y										
	A2.A5.A16.B4.C1.E5.A15.B12.E6											Y									
LCCS FOR OTHER HABITATS	A2.A5.A10.B4.E5.B12.E7												Y								
	A1.A4.A10.B3.D1.E2.B9													Y							
	A1.A4.A10.B3.D2.E1.B9														Y						
	A1.A4.A10.B3.D1.E1.B9															Y	Y				
	A1.A4.A11.B3.D1.E1.B10																	Y			
	A2.A5.A11.B4.E5.B13.E7																		Y		
	A2.A6.A11.B4.E5.B12.E6																			Y	
	A2.A6.A10.B4.E5.B11.E6																			Y	
	A2.A5.A11.B4.E5.A13.B13.E7																			Y	Y
LCCS environmental attributes																					
Major landforms	Level land, Plain	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Slope classes	Flat to almost flat	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Lithology-Parent material	Calcareous rock - Calcarenite	Y				Y	Y	Y	Y				Y	Y			Y	Y			Y
	Unconsolid- Clastic sedimentary rock - Sand		Y	Y	Y									Y	Y		Y	Y	Y	Y	
Soil aspect	Solon chacks		Y	Y	Y				Y												
	Soil surface, stony (5-40%)																	Y			

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		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Loose and shifting sands																	Y		Y	
	Soil surface, very stony (40-80%)																				Y
	Loose and shifting sands, with dunes																		Y	Y	
	Histosols					Y	Y														
	Leptosols												Y		Y	Y	Y				Y
	Arenosols											Y						Y	Y	Y	Y
Elevation	Altitude < 50m	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Water quality	Fresh water	Y							Y												
	Saline water		Y	Y																	
	Brakish/Saline water				Y			Y													
	Fresh/Brakish water					Y	Y														
	Brakish water								Y												
Climate	Subtropics – Winter rainfall	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	OUTPUTS																				
ANNEX I / (EUNIS) classes	3170 / (C3.421)	X																			
	1310 / (A2.51/A2.55)		X																		
	1420 / (A2.526)			X																	
	1410 / (A2.522)				X																
	7210 / (D5.24)					X															
	X / (D5.1)						X														
	X / (D5.2)							X													
	X / (C2)								X												
	1150 / (X03)									X											
	X / (E1.6)										X										
	X / (F5.51)											X									
	2250 / (B1.631)												X								
	5330 / (F5.55)													X							
	X / (F5.514)														X						
	X / (F6.2C)															X					

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	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1210 / (B1.1)																X				
2110 / (B1.31)																	X			
2120 / (B1.32)																		X		
2230 / (B1.48)																			X	
6220 / (E1.313)																				X

Table 6.4b. The technical attributes related to LC class description in LCCS taxonomy. Such attributes were not used for LCCS to Annex I/Eunix mapping.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Technical attributes (species)	Annuals of Isoeto-Nanojuncetea	Y																			
	Salicornia spp.; Suaeda spp.; Parapholis spp. or annuals of Thero-Salicornietea and/or Saginetea maritimae		Y																		
	Sarcocornia spp.; Suaeda vera; Arthrochnemum spp. or perennial species of Sarcocornietea			Y																	
	Juncus spp.; Carex spp.; Plantago crassifolia; or perennial species of Juncetea maritimi				Y																
	Cladium mariscus					Y															
	Phragmites australis						Y														
	Scirpus spp.; Bolboschoenus maritimus							Y													
	Sparganium erectum								Y												
	Ruppia spp.; Potamogeton spp.; …									Y											
	Annuals of Stellarietea mediae										Y										
	Rubus spp.											Y									
	Juniperus macrocarpa												Y								
	Pistacia lentiscus													Y							
	Erica forskalii														Y						
	Cakile maritima															Y					
	Agropyron junceum																Y				
	Ammophila arenaria																	Y			
	Annuals of Malcolmietalia																		Y		
	Annuals of Tuberarietea																			Y	

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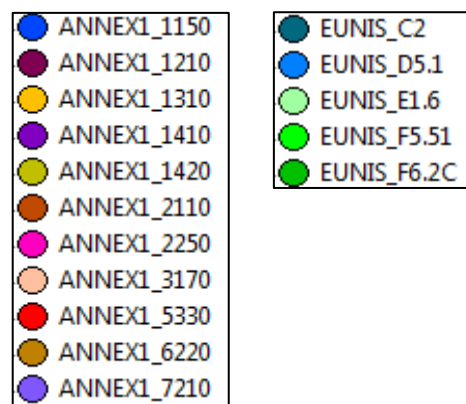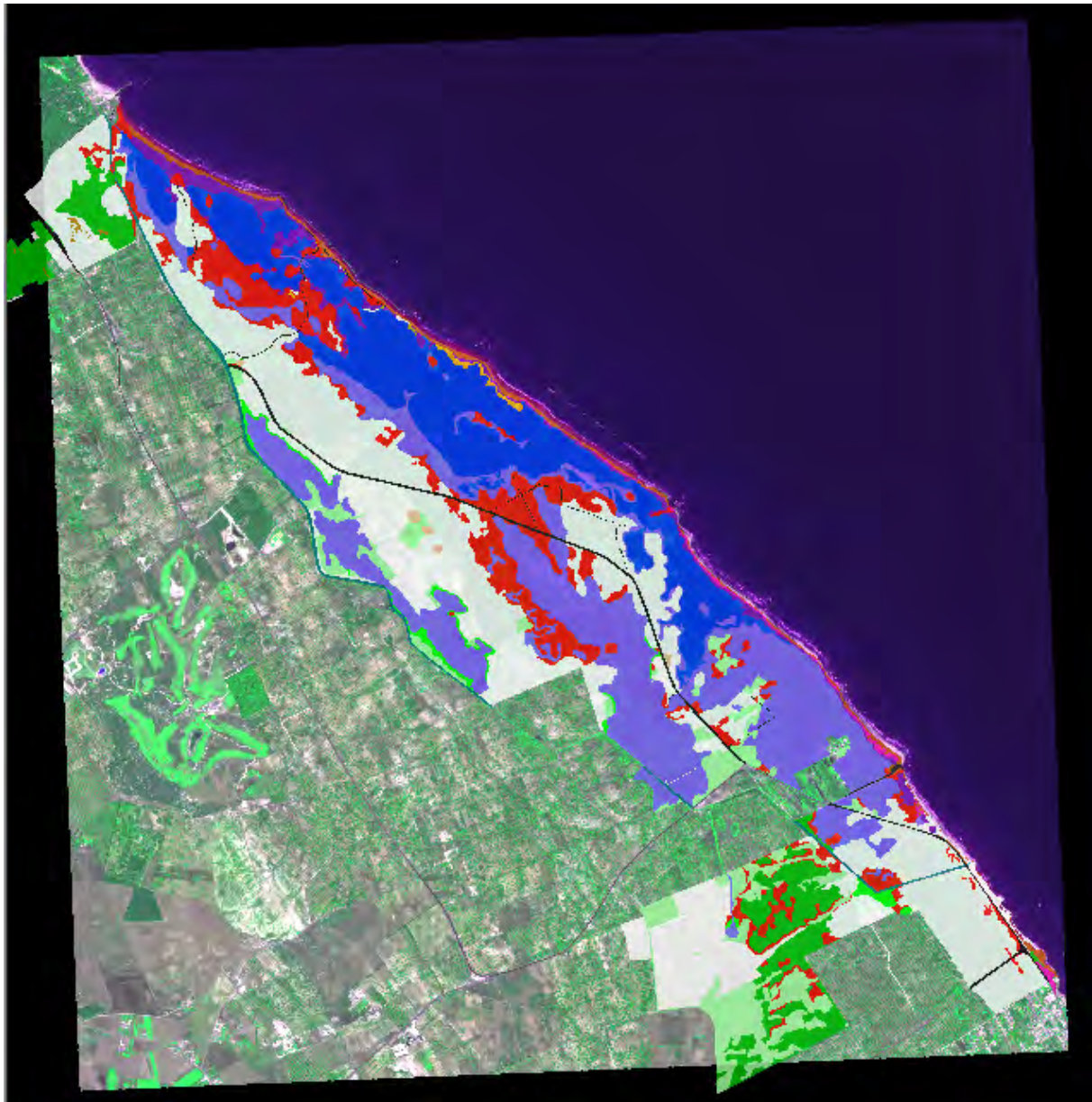| Legend	
🔵 ANNEX1_1150	🔵 EUNIS_C2
🟣 ANNEX1_1210	🔵 EUNIS_D5.1
🟡 ANNEX1_1310	🟢 EUNIS_E1.6
🟣 ANNEX1_1410	🟢 EUNIS_F5.51
🟡 ANNEX1_1420	🟢 EUNIS_F6.2C
🟤 ANNEX1_2110	
🟣 ANNEX1_2250	
🩷 ANNEX1_3170	
🔴 ANNEX1_5330	
🟤 ANNEX1_6220	
🟣 ANNEX1_7210	

Figure 6.10 Habitat map including both Annex I and EUNIS habitats. The LCCS to Annex I/EUNIS rules reported in the decision Table 6.4 were used. GHC super categories were used to mask for URB, SPV, CUL areas (in white).
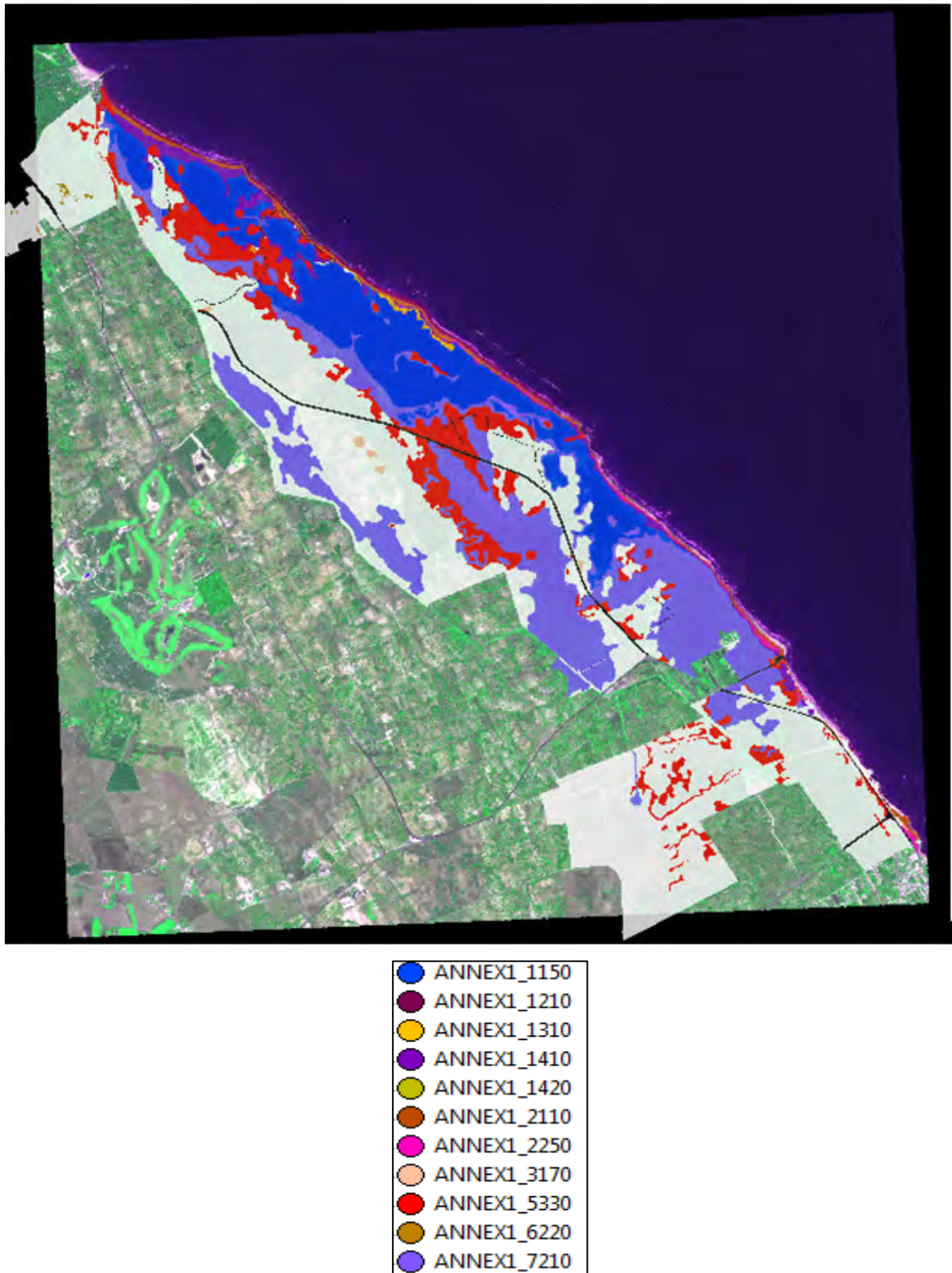
Figure 6.11 Habitat map including only Annex I Habitats for IT4 site. The LCCS to Annex I/EUNIS rules reported in the decision Table 6.4 were used. GHC super categories were used to mask for URB, SPV, CUL areas (in white). EUNIS habitats were masked in white.

7. Results discussion and conclusions

The data reported appear to confirm the feasibility of the modular approach proposed in the BIO_SOS project for the production of LC/LU maps, GHC and Annex I habitat maps. The explicit description of both LC/LU classes in the 3-D world domain and GHC classes and their translation into the 2-D domain is at the basis of the automatic mapping of LC/LU into GHC habitats. However, at the present stage of the project such a description has not yet been fully accomplished. For the training cases considered in the present deliverable, the description of both LC/LU classes and GHCs classes of interest is implicit in the implementation undertaken within eCognition software. Future work will focus on the development of these descriptions within the framework of *semantic networks* in Task 5.2 of WP5.

Draft maps of LCCS classes were generated from SIAM™ 1st stage classifications of Landsat and SPOT sensor data (AND ALSO QUICKBIRD DATA), in the UK site. The mapping was undertaken within eCognition environment but the rules used will be implemented by means of tools dealing with classification through semantic nets. From the work undertaken, the following can be concluded:

Feasibility of classification of LCCS and GHCs

a) For the Dyfi catchment, all LCCS classes existing, including within the Natura 2000 site, can be classified using a combination of SIAM™ spectral categories, a DEM and ancillary data layers. In the work carried out in Italy, a pre-existing LC/LU map (scale 1:5000) was used along with the water index output provided by the SIAM™™ software applied to pre-classify a summer QuickBird image.

b) In Wales, the requirement for ancillary data layers is anticipated but they will be reduced as optical data of finer spatial resolution from spaceborne sensor data will become available. However, a DEM is considered essential.

c) The classification of VHR resolution data can support the classification of high and medium high resolution data (i.e., those associated with Landsat and SPOT sensors). Indeed, most of the ancillary data layers used in Wales were themselves derived from high or very high resolution remote sensing data.

d) The use of spectral categories provides a more repeatable classification between sensors and dates, although for the same vegetation type, some category assignments can vary because of seasonal phenology.

Image requirements.

a) Single date imagery acquired during the summer months in Wales allows classification of most LCCS through the use of spectral categories and DEM information alone.

b) Some habitats (e.g., coniferous forests, medium tall grasslands) are better classified using imagery acquired pre-flush or post-senescence.

c) Imagery acquired during the winter months in Wales (i.e., mid-November to mid-March) are considered unsuitable for mapping because of the low sun angle (at higher latitudes). Correction of illumination differences using a DEM is unlikely to compensate for these shadowing effects.

d) The use of multi-temporal imagery (at least dual season) allows better discrimination of some categories, either because they are more distinct in one season or because the phenological changes are large (e.g., in the case of broadleaved woodlands and bracken or seasonally inundated areas).

Use of semantic information for LCCS and GHC mapping
- LC/LU classification
  a) In the classification, semantic rules are used to map some LCCS classes with these based largely on growing, adjacency rules and topographic information.

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b) In Wales, the landscape is either relatively simple (e.g., as in the case of sand flats and saltmarshes) or complex (e.g., within the active bog). The use of semantic rules will be relatively low in such environments, except within areas associated with artificial surfaces and linear features (e.g., drainage ditches, tracks).

c) In Italy a 1:5000 pre-existing LC/LU map was used.

- Translation to GHCs
  a) In Wales, the majority of LCCS classes can be translated into GHCs at relatively coarse spatial resolution. However, as the resolution increases, the number of classes in both taxonomies will increase and the one to one correspondence may reduce. As a consequence additional semantic rules may be required.
  b) In Italy, mainly adjacency topological information and external source of information were used to disambiguate GHCs on the basis of both their semantic description reported in the EBONE handbook [Bunce et al. 2011] and phenological information, respectively.

Assessment of LCCS and GHC classification accuracy
  a) Several techniques are available to support the assessment of classification accuracy, including the use of standard confusion matrices.
  b) The assessment of GHC map accuracy requires an appropriately collected dataset with a sufficient number of samples. For this purpose, an extensive field campaign is being conducted during the period mid-July to mid-September, in Wales, and in September, in Italy.
  c) Whilst the number of samples which can be collected through field survey is low, a far greater number can be acquired using combinations of LiDAR and hyperspectral data if available.

In Wales, focus is on the use of VHR, airborne multispectral and hyperspectral data for classifying LCCS but also GHCs directly. The methods will be applied also to Cors Caron (Tregaron Bog) site to provide an independent assessment of the ability to differentiate LCCS and ultimately detect change based on spectral categories.

Translation from GHC to Annex I / EUNIS habitats

In Italy, the environmental attributes associated to each LCCS class description were used, in combination with the information provided by GHC map, to provide Annex I / EUNIS habitat maps. The data obtained seem to confirm that LCCS taxonomy for land cover mapping can be the most fruitful for both GHC and Annex I/ EUNIS habitat mapping.
Direct translation of GHC maps into maps by means of the EBONE key is not yet possible at this stage of the project due to the scarcity of data (e.g. Ellenberg values) for the IT4 site.

7.1 Conclusions

The main objective of D5.1 was to provide a significant proof of the feasibility of the EODHaM proposed modular system at both HR and VHR spatial resolution for the automatic mapping of LC/LU classes into GHC and Annex I habitats. The emphasis is on the feasibility to bridge LCCS and GHC taxonomies by integrating EO products with "on site" data through ecological modelling. "On site" data include ancillary data/information which, by definition, is any data/information which cannot be inferred from appearance (visual, pictorial) properties of 3-D objects in a (3-D) scene depicted in a (2-D) EO image domain. The "on site" campaigns will also include "in field" campaigns.

LCCS and GHC class description in the framework of semantic networks, which are described in Section 3, will be undertaken in WP5 and WP6 as future work.

A secondary objective was to solve the ambiguities among the different GHCs which can correspond to the same LCCS LC/LU class as an advancement of D6.10.

The results provided in the present deliverable are considered encouraging also for a deeper integration of the different background expertise of the BIO_SOS consortium towards the automation of the proposed system.

8.   Appendix 1. Further details on spatial relations.

Spatial relations between objects represent an important part of the future semantic nets. Since semantic nets will describe a simplified 3D real world seen from above, it is relevant to analyze only spatial relations in a 2D space.

First, objects need to be defined (Egenhofer and Herring, 1991) (fig. 3.7):

- A region is a 2-complex in R^2 with a non-empty, connected interior.
    - A region without holes is a region with a connected exterior and a connected boundary
    - A region with holes is a region with a disconnected exterior and a disconnected boundary
- A line is a sequence of connected 1-complexes in R^2 such that they neither cross each other nor form closed loops.
    - A simple line is a line with two disconnected boundaries.
    - A complex line is a line with more than two disconnected boundaries.
- A point is a single 0-cell in R^2.

A region with connected and disconnect boundary; and a simple and complex line (Egenhofer and Herring, 1991).

Spatial relations can be categorized as follows (Egenhofer and Herring, 1991; Shariff et al., 1998):

iv) **Topological relationships** require the concept of neighborhood and are invariant under topological transformations, such as translation, scaling and rotation. Examples are concepts like neighbour and disjoint.

v) **Non topological relationships:**

a. **Spatial order relationships (or cardinal direction relations)** rely upon the definition of order or strict order. In general, each order relation has a converse relationship. For example, behind is a spatial order based upon the order of preference (Freeman, 1975) with the converse relationship in-front. These relations are based on the existence of a vector space and are subject to change under rotation, while they are invariant under translation and scaling of the reference frame

b. **Metric relationships** (or distance relations) exploit the existence of measurements, such as distances and directions. For instance, "within 5 miles from the interstate highway" describes a corridor based upon a specific distance. These relations express spatial properties that reflect the concept of a metric and, therefore, change under scaling, but are invariant under translation and rotation.
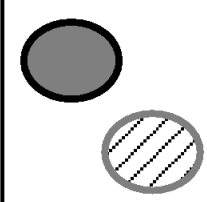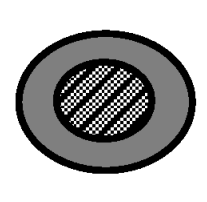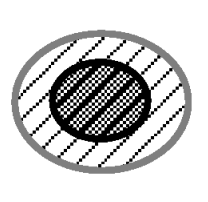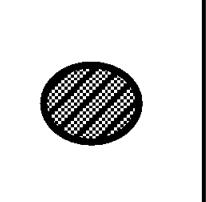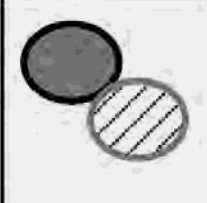
One issue is to characterize such relations on semantic nets, i.e. with semantically understandable labels, i.e. we must study the correspondences between formal representation of spatial representations and natural-language. While formal spatial relations –topologic, distance, and direction relations- have well defined semantics, natural-language spatial relations have more complex semantics and often imply more than one type of formal spatial relation (Schwering and Raubal, 2005). This aspect has been well studied by Shariff et al. (1998) regarding line-region relations. They showed that one natural-language spatial relation such as "goes to" may actually correspond to various formal spatial relations according to the individual expertise or the context. Shariff et al. (1998) concluded from their study that topology is more critical for the semantics of spatial relations than metric. Metric can be used to specify the spatial relations when one term may be associated with various topological relations. It means that spatial relations should be first defined in terms of topological relations and if possible completed by non-topological relations.

8.1   Topological relations

This issue on the gap between semantic and formal spatial relations is summarized by Li et al. (2009) as follows: "Considering of finding a user-friendly representation method about topological relations, we should make the grand total of adopted topological relationships as small as possible. As we know, if too many topological relationships are used, it may be hard to remember all these names and the users might become confused."

Most studies then aimed at identifying the formal topological relations and then assign it a semantic meaning. This approach was chosen by Egenhofer and Herring (1991) who proposed the 9-intersection model to define all possible spatial relations between 2 regions. They identified 8 possible relations and then assign it a semantic label (fig. 3.8):

- DISJOINT: If all four intersections among all object parts are empty, the two objects are disjoint. Disjoint is linear, such that two objects are either disjoint or they are not.

- MEET: If the intersection between the boundaries is not empty, whereas al other intersections are empty, the two objects meet. The nature of meet is such as it only matters that the two objects share at least a common part of the boundary.

- OVERLAP: Two objects overlap if they have common boundaries and interiors and the boundaries have common parts with the opposite interiors.

- COVERS: An object A covers another object B if both objects share common boundaries and interiors: B's interior intersects with the boundary of A; and none of A's interior is part of B's boundary. COVERS has a converse relationship COVERED-BY which has the reverse definition of the boundary-interior intersections.

- INSIDE: An object A is inside of another object B if (1) A and B share common interiors, but not boundaries, (2) A's boundary intersects with the interior of B, and '3) none of B's boundary coincides with A's interior. Like COVERS, INSIDE has a converse relationship, called CONTAINS with corresponding specifications which are the same except for the reverse opposite intersections.

- EQUAL: Two objects are equal if both intersections of boundary and interior are not empty while the two boundary-interior intersections are empty.

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disjoint
$$\begin{pmatrix} \emptyset & \emptyset & \neg\emptyset \\ \emptyset & \emptyset & \neg\emptyset \\ \neg\emptyset & \neg\emptyset & \neg\emptyset \end{pmatrix}$$

contains
$$\begin{pmatrix} \neg\emptyset & \neg\emptyset & \neg\emptyset \\ \emptyset & \emptyset & \neg\emptyset \\ \emptyset & \emptyset & \neg\emptyset \end{pmatrix}$$

inside
$$\begin{pmatrix} \neg\emptyset & \emptyset & \emptyset \\ \neg\emptyset & \emptyset & \emptyset \\ \neg\emptyset & \neg\emptyset & \neg\emptyset \end{pmatrix}$$

equal
$$\begin{pmatrix} \neg\emptyset & \emptyset & \emptyset \\ \emptyset & \neg\emptyset & \emptyset \\ \emptyset & \emptyset & \neg\emptyset \end{pmatrix}$$

meet
$$\begin{pmatrix} \emptyset & \emptyset & \neg\emptyset \\ \emptyset & \neg\emptyset & \neg\emptyset \\ \neg\emptyset & \neg\emptyset & \neg\emptyset \end{pmatrix}$$

covers
$$\begin{pmatrix} \neg\emptyset & \neg\emptyset & \neg\emptyset \\ \emptyset & \neg\emptyset & \neg\emptyset \\ \emptyset & \emptyset & \neg\emptyset \end{pmatrix}$$

coveredBy
$$\begin{pmatrix} \neg\emptyset & \emptyset & \emptyset \\ \neg\emptyset & \neg\emptyset & \emptyset \\ \neg\emptyset & \neg\emptyset & \neg\emptyset \end{pmatrix}$$

overlap
$$\begin{pmatrix} \neg\emptyset & \neg\emptyset & \neg\emptyset \\ \neg\emptyset & \neg\emptyset & \neg\emptyset \\ \neg\emptyset & \neg\emptyset & \neg\emptyset \end{pmatrix}$$

Spatial relations between 2 regions according Egenhofer and Herring (1991).

Other formal spatial relations were also defined in RCC8 and correspondences between 9-intersection and RCC8 models were built.

Table I. ID MODEL MATRIX WITH RCC-8

ID model	RCC-8 expression	ID
$ID(A,B) = \begin{bmatrix} \emptyset & \neg\emptyset \\ \neg\emptyset & \emptyset \end{bmatrix}$	Disconnected (DC)	Disjoint
$ID(A,B) = \begin{bmatrix} \emptyset & \neg\emptyset \\ \neg\emptyset & \neg\emptyset \end{bmatrix}$	Externally Connected (EC)	Meet
$ID(A,B) = \begin{bmatrix} \neg\emptyset & \emptyset \\ \emptyset & \neg\emptyset \end{bmatrix}$	Equal (EQ)	Equal
$ID(A,B) = \begin{bmatrix} \neg\emptyset & \neg\emptyset \\ \neg\emptyset & \neg\emptyset \end{bmatrix}$	Partially Overlapping (PO)	Overlap
$ID(A,B) = \begin{bmatrix} \neg\emptyset & \emptyset \\ \neg\emptyset & \neg\emptyset \end{bmatrix}$	Tangential Proper Part (TPP)	Covered By
$ID(A,B) = \begin{bmatrix} \neg\emptyset & \neg\emptyset \\ \emptyset & \neg\emptyset \end{bmatrix}$	Tangential Proper Part Inverse (TPPi)	Cover
$ID(A,B) = \begin{bmatrix} \neg\emptyset & \emptyset \\ \neg\emptyset & \emptyset \end{bmatrix}$	Non-Tangential Proper Part (NTPP)	Contain By or Inside
$ID(A,B) = \begin{bmatrix} \neg\emptyset & \neg\emptyset \\ \emptyset & \emptyset \end{bmatrix}$	Non-Tangential Proper Part Inverse (NTPPi)	Contain

Correspondences between RCC8 and 9-intersection model (left column)

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Complementarily, Egenhofer and Herring (1991) also defined formal spatial relations between one region and one line, 2 simple lines and 2 complex lines. However, we will here consider lines as objects so that same 8 relations can be used.

Once topological relations have been defined, they have to be detailed/described by attributes based on direction and metric relations.

8.2   Cardinal direction relations

Li et al. (2009) defined direction relations as follows: "Directional relationship between objects specifies the plausible range of positions where an object in a description must appear with respect to the position of another object. Here the directional relationships involve global directional relationships and local directional relationships."

- Global directional relations:

Global directional relationships specify positions based on cardinal and intercardinal compass directions. Generally, the set of global directional relationships in 3D space is the same as the one in 2D space, totally including eight relations
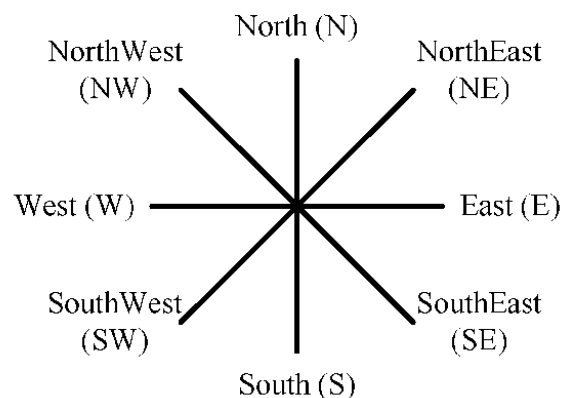
Eight global directional relationships (Li et al., 2009)

- Local directional relations:

Local directional relationships specify positions based on the sides and corners of objects. These relations are similar to but more complex than global directional relationships because sides and corners differ contextually depending on the particular objects. Examples of local directional relations are Front, Back, Left, Right.

8.3   Metric relations

In the case where an ordinal attribute is required to describe details about topological relations , Shariff et al. (1998) consider three metric concepts:

- **splitting**, which determines how the region's and line's interiors, boundaries, and exteriors are cut;

- **closeness**, which determines how far apart the region's boundary is from the parts of the line,

- **approximate alongness**, which combines the closeness measures and the splitting ratios.

Four each of this category, a list of indexes has been defined.

Alboody et al. (2009) improved the way of defining topological relations by including metric measures to answer questions as "how many times do two regions touch?" and "are the two regions points touch or lines touch or together?". For this purpose they introduced two concepts: the Concept of Separation number and the Concept of neighbourhoods of a spatial element.

8.4   Complementary issues on spatial relations

Dealing with spatial relations requires considering a few additional issues such as:

- Uncertain spatial regions: Alboody et al. (2010) adapted the 9-intersection model to uncertain spatial regions, considered as regions with broad boundaries. They identified 152 topological relations between 2 uncertain regions.

- Scale issue: when talking about urban structure, Lüscher et al. (2007) claim that characteristics of urban structures may depend largely on the scale for which they are defined.

- Temporal evolution of relations and objects' attributes: objects attributes such as colour, shape, size may evolve in time. For instance, the leafs of a tree will have different colours according to the season. This is an important aspects to be considered when building semantic nets. Spatial relations also evolve in time. In Egenhofer and Al-Taha (1992), authors analyze the temporal evolution of topological relationships according to changes applied on objects (scaling changes, translation changes, rotation changes) (Appendix 3). They computed topological distances between topological relationships in order to estimate the next most likely state given an initial state and a process applied on it (fig. 3.13).
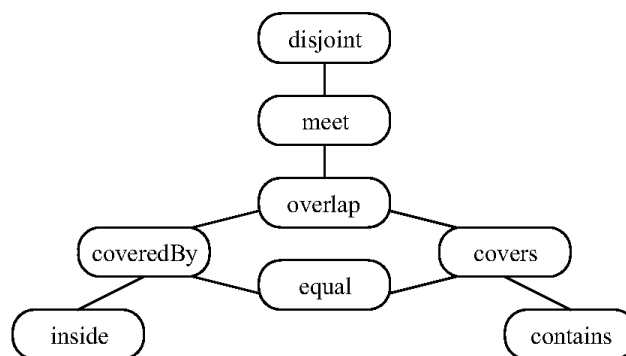
The Closest-Topological-Relationship-Graph (Egenhofer and Al-Taha, 1992)

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9.   Appendix 2. Acronym list

BIO_SOS	**Biodiversity Multisource Monitoring System: from Space TO Species**
CORINE	**COoRdination of INformation on the Environment**
DTM	**Digital Terrain Model**
EBONE	**European Biodiversity Observation Network**
EO	**Earth Observation**
EODHaM	**EO Data for Habitat Monitoring**
ESA	**European Space Agency**
EUNIS	**European Nature Information System**
FAO	**Food and Agriculture Organization**
FAO-LCCS	**FAO - Land Cover Classification System**
GHC	**General Habitat Category**
LC/LU	**Land Cover/Land Use**
LCC	**Land Cover Change**
LCCS	**Land Cover Classification System**
MS	** Multi Spectral**
RGB	**Red Green Blue**
SIAM™	**Satellite Image Automatic Mapper™**
VHR	**Very High Resolution**
HR	**High Resolution**

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