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Translating land cover/land use classifications to habitat taxonomies for landscape monitoring: a Mediterranean assessment

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Abstract Periodic monitoring of biodiversity changes at a landscape scale constitutes a key issue for conservation managers. Earth observation (EO) data offer a potential solution, through direct or indirect mapping of species or habitats. Most national and international programs rely on the use of land cover (LC) and/or land use (LU) classification systems. Yet, these are not as clearly relatable to biodiversity in comparison to habitat classifications, and provide less scope for monitoring. While a conversion from LC/LU classification to habitat classification can be of great utility, differences in definitions and criteria have so far limited the establishment of a unified approach for such translation between these two classification systems.

Focusing on five Mediterranean NATURA 2000 sites, this paper considers the scope for three of the most commonly used global LC/LU taxonomies—CORINE Land Cover, the Food and Agricultural Organisation (FAO) land cover classification system (LCCS) and the International Geosphere-Biosphere Programme to be translated to habitat taxonomies. Through both quantitative and expert knowledge based qualitative analysis of selected taxonomies, FAO-LCCS turns out to be the best candidate to cope with the complexity of habitat description and provides a framework for EO and in situ data integration for habitat mapping, reducing uncertainties and class overlaps and bridging the gap between LC/LU and habitats domains for

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landscape monitoring—a major issue for conservation. This study also highlights the need to modify the FAO-LCCS hierarchical class description process to permit the addition of attributes based on class-specific expert knowledge to select multi-temporal (seasonal) EO data and improve classification. An application of LC/LU to habitat mapping is provided for a coastal Natura 2000 site with high classification accuracy as a result.

**Keywords** Mapping · Land cover · Land use · Habitat · Earth observation · Taxonomies · Natura 2000 · Classification schemes

**Introduction**

Effective and timely multi-annual biodiversity monitoring of protected sites and other endangered and biologically important landscapes is critical for detecting changes which might impact on a site’s conservation status, quality and resources (Townsend et al. 2009). Such monitoring is essential to evaluate the effectiveness of conservation policies in protecting biodiversity and ecosystems from human activities (Vacˇka´rˇ et al. 2012). Earth observation (EO) data offer significant opportunities for assessing and monitoring habitats and their contained biodiversity, not least because of the availability of data from past and current spaceborne missions with continuity provided by planned future missions (Vanden Borre et al. 2011). Over the past two to three decades, data from High Resolution (HR) sensors (i.e., spatial resolution: 3–30 m) on board platforms such as the Landsat TM/ETM + and SPOT have routinely provided synoptic spatial views of expansive landscapes and regions, allowing maps of land covers (LC) and land use (LU) to be generated and intra-annual and inter-annual changes quantified. In recent years, the advent of very high resolution (VHR) satellites (i.e., spatial resolution: <3 m) has also provided opportunities for more detailed mapping and studies of changes in habitat coverage, landscape fragmentation, and human pressure, albeit over smaller areas through comparison with pre-existing validated fine-grain (1:5,000 or better) maps obtained by ortho-photo visual interpretation and in-field campaigns.

However, the focus on LC/LU mapping in many countries and regions has distracted from the need to provide detailed information on habitats. Habitats offer greater scope for linking EO data to biodiversity (Nagendra 2001). Hence, there is often a need to translate LC/LU maps to those representing habitats with this undertaken through re-labelling and, where appropriate, merging of similar land cover classes (Lengyel et al. 2008) and, where needed, through integrating in situ data for habitat discrimination. Difficulties nevertheless arise because of different levels of definition and criteria used by specific classification systems. Morphological-structural and physio-ecological criteria are considered both in LC/LU and habitat classifications, while phyto-sociological criteria tend to be emphasized in some habitat taxonomies. Commonly used classification systems dealing with LC/LU or habitats also tend to be limited in their ability to map all aspects of the landscape and often do not contain the full diversity of LC/LU or habitat types. Furthermore, most were not designed to be compatible and hence lack interoperability between different LC/LU systems (Neumann et al. 2007; Herold et al. 2008) as well as between LC/LU and habitat taxonomies. A good LC/LU system should be able to describe with the same level of detail all relevant aspects of the earth surface and should well discriminate the concept of LC (biophysical attributes of the earth surface) from LU (the human intent applied to those attributes) (Turner et al. 2001).

As habitat mapping is increasingly required, partly in response to legal obligations, the majority of nations and regions have generated, as a minimum, maps of LC/LU using a range of classification schemes. The challenge, therefore, is to select the most useful LC/LU taxonomy for habitat mapping. Such taxonomy should also provide the best translation to a habitat taxonomy that is directly relevant to national and international reporting obligations. Thus, protocols are required to harmonize the different systems and standardize new and pre-existing products for long-term monitoring purposes (Boteva et al. 2004; Dimopoulos et al. 2005; Mücher et al. 2009; Bunce et al. 2010). Among the LC/LU taxonomies, the FAO land cover classification system (LCCS) (Di Gregorio and Jansen 1998, 2005) taxonomy was identified (Herold et al. 2008) as the most appropriate for providing a common language for translating and harmonizing different LC/LU legends, as recognized by the panel of the Global Observation of Forest and Land Cover Dynamics (GOFC-GOLD) (GOFC-GOLD report n.20 2004). The main objective of this work is to investigate the potential of the FAO-LCCS...
for LC/LU translation and mapping to a habitat classification system, in comparison to other commonly used LC/LU taxonomies, with the aim of facilitating biodiversity monitoring.

Based on five Natura 2000 sites in the Mediterranean countries of Italy and Greece, a qualitative analysis is carried out to identify the taxonomy able to provide the most effective framework to embed expert knowledge for LC/LU to habitat translation and provide useful insights for EO data selection. In addition, a quantitative analysis, based on similarity and congruency measures, is carried out to complement (support) the qualitative findings. Finally, an application of the LC/LU to habitat mapping is provided for a Natura 2000 coastal site.

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Selection of LC/LU and habitat classification systems

An overview of the most commonly used taxonomies for LC/LU and habitat mapping in European Countries is provided in this section (Table 1). The classification schemes for both habitats and land covers vary in the number and types of classes defined, in their implementation (hierarchical or otherwise), and in the features used for class definition. For mapping purposes, those taxonomies that can best describe the vegetation composition/structure should be preferred. These would also enable the monitoring of habitat qualitative features from the perspective of vegetation dynamics induced by global warming coupled with anthropogenic disturbances, which respectively determine species distribution shifts (Williams and Jackson 2007) and, either indirectly or directly the onset of successional processes, whose effects on physiognomy can be represented by this type of classification taxonomies. These effects might affect vegetation/animal community relations at the local scale and influence food webs and connectivity at the landscape level. A series of maps based on this kind of taxonomies might provide signals to managers to select among the range of possible options which are being proposed to adapt conservation to global changes (Heller and Zavaleta 2009).

Following the approach developed by Salafsky et al. (2003) for classifying threats, we assessed if classification systems were: (a) Hierarchical—Creates a logical way of grouping classes; (b) Comprehensive—Covers all possible objects on the scene by a class label; (c) Consistent—All entries at a given level of the taxonomy are of the same type; (d) Expandable—New classes can be added without changing the full hierarchy; (e) Exclusive—Any given “object” can only be placed in one position within the hierarchy; (f) Geographically invariant—The labeling of a same object is invariant across different locations (see Table 1). For mapping purpose, systems meeting all these criteria are relevant to ensure a full coverage of the landscape and avoid uncertainty in describing objects. Criteria (b) and (d) are particularly useful in ecological studies for site management purposes. As an example, some habitat taxonomies do not include anthropic habitats or threatened vegetation types of ecological importance for species conservation in some geographical areas (e.g. Mediterranean).

The FAO-LCCS satisfies all criteria listed above. In LCCS, a land cover class is defined by the combination of a set of independent diagnostic criteria, termed “classifiers”, hierarchically arranged. Since the set of criteria can be indefinitely enlarged, LCCS is an open (expandable) classification system with a virtually infinite amount of mutually exclusive classes. The classification in LCCS has two main phases: (1) the Dichotomous phase, where a dichotomous key, based on three classifiers (i.e., presence of vegetation, edaphic conditions and artificiality of cover), is used to define eight major land cover types; (2) the Modular-Hierarchical phase, where a combination of a predefined set of classifiers allows the definition of more detailed land cover classes. In each set, the classifiers are divided into three groups: (a) “pure land cover” classifiers; (b) “environmental” attributes; (c) “specific technical” attributes (Di Gregorio and Jansen 1998, 2005).

A software program (http://www.africover.org/software_down.htm) has been developed to provide a step-by-step guide to defining classes within LCCS. Each land cover class is described by three elements: (a) a Boolean formula, consisting of a string of classifiers used for class definition (e.g. A12/A2.A5.A11.B4-A12.B1, that is “natural terrestrial vegetated/open((70–60)–40 %) tall herbaceous forbs”); (b) the name of the land cover class (e.g. “Open annual short
| A) Habitat classification scheme | Brief description | Fulfilled criteria (Salafsky et al. 2003) | Reference |
|---------------------------------|------------------|------------------------------------------|-----------|
| CORINE Biotopes                 | First uniform classification system for European Union (EU) habitats, based on the phytosociological approach. Provides the basis for the description of the Annex I habitat types and for the development of Palaearctic and EUNIS habitat classifications | Hierarchical, comprehensive, consistent, exclusive, geographically invariant | Moss and Wyatt (1994) |
| Natura 2000 Annex I of the 92/43/EEC Directive | Defines a hierarchical classification scheme for the natural habitat types of EU to be preserved in the Natura 2000 Network. This system is the main European Union legal instrument concerning biodiversity and conservation of natural habitats. Many habitats of ecological importance are not mentioned. Habitat types and their definitions may be subject to different interpretations at a national level | Hierarchical, consistent, exclusive | Council of the European Union (2007), Petermann and Ssymank (2007), Feola et al. (2011), Vanden Borre et al. (2011) |
| European Nature Information System (EUNIS) | Pan-European habitat classification system (natural to artificial habitats), directly linked to the Natura 2000 classification scheme. It provides a more detailed and complete coverage of habitat types and seems particularly well suited for habitat monitoring programs | Hierarchical, comprehensive, consistent, exclusive, geographically invariant | Davies and Moss (2002), Lengyel et al. (2008) |
| General Habitat Categories (GHCs) | Habitat classification system developed for consistent habitat surveillance and monitoring and for detection of habitat changes. Based on 16 plant life forms (Raunkiaer 1934) and 18 non-plant life forms | Hierarchical, comprehensive, consistent, expandable, exclusive, geographically invariant | Bunce et al. (2008, 2011) |

| B) LC classification scheme | Brief description | Reference |
|---------------------------|------------------|-----------|
| CORINE Land Cover (CLC)   | Classification system largely used in EU. Not consistent (some classes are a mix between land cover and land use categories). It is only virtually expandable | Hierarchical, comprehensive | Bossard et al. (2000) |
| International Geosphere-Biosphere Programme (IGBP) DISCover Land Cover classification system | Classification system developed to cover the entire Earth’s surface. It is not comprehensive since the marine environments are not considered and the scheme is neither hierarchical, nor expandable | Consistent, exclusive | Belward (1996) |
| The Food and Agricultural Organisation (FAO) Land Cover Classification System (LCCS) | Classification system based on a set of independent diagnostic criteria and a tool for harmonizing different LC/LU legends | Hierarchical, comprehensive, consistent, expandable, exclusive, geographically invariant | Di Gregorio and Jansen (1998, 2005) |
herbaceous vegetation on temporarily flooded land”); and (c) a numerical (GIS-friendly) code (http://www.africover.org/LCCS_hierarchical.htm).

Materials and methods for qualitative and quantitative analysis

Five sites belonging to the Natura 2000 Network were used in this study, with two being in Italy and three in Greece (see Fig. 1). Pre-existing LC/LU, habitat and vegetation maps realized at a scale of 1:5,000 through visual interpretation of digital panchromatic orthophotos and validated by field surveys were used. During in-field campaigns, ancillary data on vegetation composition and structure, crop cover and type, stratification, land use and management, soil and site (e.g. aspect and slope) and water salinity, were collected, geocoded by a GPS and integrated into a GIS geodatabase using ArcGIS 9.2.

Fig. 1 Study sites location map within the context of EU 27 Natura 2000 Network and Biogeographical regions. For each site BIO_SOS code, Natura 2000 codes and SCI area are reported

| Site name         | BIO_SOS code | SCI code   | SPA code   | SCI (ha) | Brief description               |
|-------------------|--------------|------------|------------|----------|---------------------------------|
| Murgia Alta       | IT3          | IT9120007  | IT9120007  | 125880   | Calcareous plateau with Mediterranean steppe grasslands |
| Le Cesine         | IT4          | IT9150032  | IT9150014  | 2148     | Coastal wetlands               |
| Ekvoles           | GR1          | GR2120001  | GR2120005  | 8481     | Coastal wetlands               |
| Kalama            |              |            |            |          |                                 |
| Elos Kalodiki     | GR2          | GR2120002  | GR2120006  | 845      | Inland, freshwater wetland      |
| Stena Kalama      | GR3          | GR2120004  |            | 1867     | River gorges                   |
Based on expert knowledge from practitioner botanists, ecologists and EO data processing experts, the relationships between LC/LU (LCCS; CLC; IGBP) and habitat domains (Annex I, EUNIS, CORINE Biotopes) were determined. Expert knowledge was used to identify and fill the gaps (Perera et al. 2012) between the two domains and to integrate, where needed, in-field data for converting LC/LU into habitat classes.

In each site, a pre-existing vegetation map was used as reference map to define the labels of natural and semi-natural class types and find appropriate relationships between different taxonomies, whilst the LC/LU map, derived from photo interpretation, was used as reference map for labelling of artificial/agricultural types. Ancillary data were integrated where needed. To each patch of the appropriate reference map was assigned a set of labels, each corresponding to a specific category within a taxonomy. The rules defined in the user’s manual of the taxonomies listed in Table 1 were strictly applied. LC/LU classes were assigned considering CLC at Level III and LCCS at Level II and Level III of the Modular-Hierarchical phase for terrestrial and aquatic/flooded classes, respectively. Habitat types were assigned according to EUNIS, Annex I, CORINE Biotopes at Level III, and GHC at Level III (no qualifiers). GHC categories were identified by using the key to Annex I (Bunce et al. 2010) and the EBONE handbook (Bunce et al. 2011). This information was arranged in a look up table, to enable a qualitative review and quantitative analyses aiming at analysing the relationships between LC/LU to identify the LC/LU taxonomy most suitable for habitat mapping.

Regarding the quantitative comparison of taxonomies, several studies have recently contributed to define a frame where the interoperability between taxonomies is assessed by introducing some semantic similarity measures of the different classification schemes (Ahlqvist 2004, 2005, 2008; Feng and Flewelling 2004; Fritz and See 2008). In those studies, the comparison was performed class by class by building a suitable semantic representation out of the definition of each class, in each of the taxonomies to be compared. In contrast to these approaches, the quantitative analysis proposed in this paper does not focus on class definitions but aims at somehow measuring the congruency of the results of different taxonomies being applied at the given selection of sample sites. The approach is conceptual and is not related to either spatial or semantic properties.

To start with, the Jaccard’s Similarity Index for each pair of sites was calculated (for the five sites studied, there are ten possible pairwise comparisons). The index reflects the overlap in the landscape composition between the two sites. More specifically, when comparing two sites, the number of LC/LU classes they have in common was recorded in both sites. This number was then divided by the total number of classes observed. Jaccards value ranges from 0 when the two sites have no common LC/LU classes to 1 when both sites have exactly the same landscape composition. This index evidences only the presence of classes and not their coverage. For any given pair of sites, this was repeated for each taxonomy.

Once all the pairwise comparisons were performed, for each taxonomy the resulting ten values of similarity, one for each pair of sites, allowed the ranking of all site pairs according to their similarity, from more similar to less similar. If the taxonomies produced congruent comparisons then these rankings should coincide. In order to test for this congruence among taxonomies a numerical estimator of the “distance” among taxonomies was introduced. The “distance” metric adopted compares two taxonomies by contrasting the two rankings produced. Specifically, the index is calculated as the number of pair exchanges needed to make the two rankings identical. Given the length $N$ of the rankings ($N = 10$ in our case) the distance ranges from 0, when the rankings are identical, to the maximum value $N!/(2^*(N−2)!)$, which corresponds to the distance between a sequence of 10 numbers ordered increasingly, and the same sequence in the reversal order. As the number of exchanges increases this means that the taxonomies are less similar. By simulations it was verified that this “distance” index satisfies the properties of a metric.

Finally, a LC/LU to habitat mapping application to a Natura 2000 coastal study site, Le Cesine, in Italy (IT4) was carried out based on the findings of the qualitative analysis and the pre-existing thematic layers (Tomaselli et al. 2012) available for the site (i.e., LC/LU and in situ data on lithology, soil surface and subsurface, water quality), as described further in the next section. The algorithm for LC/LU to habitat mapping was realized within eCognition 8.7 (www.ecognition.com) environment and Decision Tables (DTs) were used to describe the complex relationships.
involved in the mapping. DTs correspond to a formalism widely used in software engineering to describe complex relations among predicates and actions (Fisher 1966). DTs have proven to be easier to understand and review than code, and have been successfully used to produce specifications of complex systems and their decision trees (Pooch 1974). It is important to note that auxiliary software tools can also be used to create, validate and process DTs (e.g. LogicGem by Catalyst Corp.). A decision table summarizes the action to be taken depending on the values of conditions that exist at the time the decision table is consulted. DTs override system flow charts in more complex circumstances, particularly where several criteria determine an action demanding more specialized models. A typical decision table is divided into 4 parts: (1) a condition stub—which shows the conditions that determine which actions will result; (2) condition entries are the combination of conditions expressed as rules; (3) an action stub which contains the possible actions which can occur as a result of the different condition combinations; (4) action entries containing the action to be taken.

In DTs, conditions are expressed as questions that may be answered by Yes/No responses. The condition entries are then specified as combinations of these responses. The relevant action for each combination of conditions is recorded by an X in the action stub (see next section).

Results and discussion

Table 2 links the different LC and habitat taxonomies at the maximum level of detail, allowing both qualitative comparison and quantitative analysis between the schemes.

A qualitative review of habitat and LC/LU taxonomies

Habitat taxonomies: Annex I and EUNIS

The comparison of the different habitat legends highlighted several omissions in the Annex I scheme with respect to EUNIS, for the sites considered (Table 2), namely: (a) different shrub vegetation types of high conservation value; (b) nitrophilous and sub-nitrophilous (subject to grazing) grasslands that are often functionally linked to Annex I habitat types (e.g., habitat type 6220*); (c) reeds and sedges communities, as already highlighted by Petermann and Ssymank (2007). In other cases, Annex I habitat types are not well defined, such as habitat 6220*—“Pseudosteppe with grasses and annuals of the Thero-Brachypodietea”, which contains either annual or perennial communities.

Habitat taxonomies: Annex I and GHCs

The correspondence between Annex I habitat types and GHCs was not always unique, with the same habitat assigned, in some cases, to several GHCs depending upon local conditions and conservation status. As an example, habitat 6220* in GHC can refer either to Caespitose hemicyryptophytes (CHE) or to Leafy hemicyryptophytes/Caespitose hemicyryptophytes (LHE/CHE) if located in natural environments, or to the category Urban (herbaceous) (URB(GRA)) if falling within managed areas. However, to identify a specific habitat type, GHC methodology provides additional environmental, site, management and other qualifiers (Bunce et al. 2011) to be selected on the basis of expert knowledge.

LCCS and CLC taxonomies with respect to Annex I

A certain level of disagreement between the LCCS and CLC is well documented in the literature (Jansen and Di Gregorio 2002; Neumann et al. 2007; Herold et al. 2008), especially when considering those CLC classes that represent land cover complexes, or that are defined by using a mix of LC and LU criteria, and particularly for those that are regarded as artificial or managed (e.g., agriculture) categories or where there is uncertainty as to whether these are “natural” or “managed”, as evidenced in Table 3 (Bossard et al. 2000; Di Gregorio and Jansen 2005). A further limitation of CLC in describing natural and semi-natural vegetated environments is that class descriptions have a very broad meaning. Within each coarse vegetated class, a number of habitats occur. As an example from Table 2, CLC class 4.2.1 “salt marshes” (second column) can be associated to six habitats including 1310, 1410, 1420, 7210 (Annex I, third column) and A2.53C and A2.53D (Eunis, fifth column). This means that one-to-many LC/LU to habitats relations occur and hence the CLC system.

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Table 2 Habitats characterizing the five Mediterranean study sites according to different LC and Habitat classification schemes

| Presence/Absence | CLC3 AX 1 Lev.3 | CORINE Biotopes Levs. 3–4–5 | EUNIS Levs. 3–4–5 | IGBP | LCCS DPH Lev. I/II | LCCS DPH and MHPH | GHCs Lev. II/III |
|------------------|------------------|-----------------------------|-------------------|------|-------------------|-------------------|------------------|
| 10111 1.1.1 Continuous urban fabric / | 86.1 Towns | J1.1 Residential buildings of city and town centres | 13 Urban and built-up | B15 | A1A4A13A14 High Density Urban Areas | | |
| 10111 | / | 86.1 Towns | J1.2 Residential buildings of villages and urban peripheries | | | A1A4A13A16 Low Density Urban Areas | URB-ART |
| 11111 1.1.2 Discontinuous urban fabric / | 86.2 Villages | J2.1 Scattered residential buildings | | | | | |
| 10000 1.2.1 Industrial or commercial units / | 86.3 Active industrial sites | J2.3 Rural industrial and commercial sites still in active use | | | A1A4A12A16 Low density industrial and/or other areas | | URB-ART |
| 10000 | / | J2.4 Agricultural constructions | | | A1A4A12A17 Scattered industrial and/or other areas | | |
| 11000 1.2.2 Road and rail networks / / | / | J4.2 Road networks | | | A1A3A7A8 Paved roads | | URB-ART/ROA |
| 10000 1.3.1 Mineral extraction sites / | 86.41 Quarries | J3 Extractive industrial sites | | | A2A6 Extraction sites | | URB-NON |
| 00111 2.1.1 Non-irrigated arable land / | 82.11 Field crops | I1.1 Intensive unmixed crops | 12 Croplands | A11 | A3A4B1X2C3D4C7C19D5 Sprinkler Irrigated Graminoid Crop(s) (One Additional Crop) (Herbaceous Terrestrial Crop Sequentially) | | CUL-CRO |
| 11000 | / | 82.11 Field crops | I1.3 Arable land with unmixed crops grown by low-intensity agricultural methods | | A3A4B2XXC1D1 Monoculture of small size field of rainfed graminoid crops (single crop) | | CUL-CRO |
| 00111 2.1.2 Permanently irrigated land / | 82.12 Market gardens and horticulture | I1.1 Intensive unmixed crops | | | A3A4B1X2C3D4C7C19D6 Drip Sprinkler Irrigated Graminoid Crop(s) (One Additional Crop) (Herbaceous Terrestrial Crop Sequentially) | | CUL-CRO |
| 01000 | / | I1.3 Arable land with unmixed crops grown by low-intensity agricultural methods | | | A3A4B2XXC2D3 Small size field of irrigated no-graminoid crops | | CUL-CRO |
| 10000 2.2.1 Vineyards / | 83.21 Vineyards | FB.4 Vineyards | | | A2B2XXC1D1W8-A7A10 Monoculture of small size fields of Rainfed broadleaved deciduous shrub crops-Orchards | | CUL-WOC |
| 10000 2.2.2 Fruit trees and berry plantations / | 83.15 Fruit orchards | G1D4 Fruit orchards | | | A1B2XXC2D2W8-A7A10 Small size fields of irrigated broadleaved deciduous tree crops-Orchards | | CUL-WOC |
| 11000 2.2.3 Olive groves / | 83.11 Olive groves | G2.91 Olea europaea groves | 2 Evergreen Forests | | A1B1X2C1D1W8-A7A9B4 Monoculture of medium size field of broadleaved evergreen of rainfed tree crops-Orchards | | CUL-WOC |
Table 2 continued

| Presence/Absence | CLC3 AX 1 Lev 3 | CORINE Biotopes Levs. 3–4–5 | EUNIS Levs. 3–4–5 | IGBP | LCSC DPH Levs. I/II | LCSC DPH and MHPH | GHCs Levs. I/II |
|---|---|---|---|---|---|---|---|
| 11000 2.3.1 Pastures | / | 34.81 | E1.6 Subnitrophilous annual grassland | 10 Grasslands | A12 | A2A5A16B4XXE5-B12E7 Closed annual medium/tall forbs | HER-THE |
| 10000 / | 87.1 Fallow fields | E1.61 Subnitrophilous annual grassland | A2A5A16B4XXE5-B12E7 Closed annual medium/tall forbs | HER-THE |
| 10000 2.4.1 Annual crops associated with permanent crops | / | 8 Agricultural land and artificial landscapes | I Regularly or recently cultivated agricultural, horticultural and domestic habitats | 12 Croplands | A11 | A3A5B2XXC2D3-C35C17 Small size fields of irrigated non-graminoid crops (one additional crop-tree crop with simultaneous period)-Orchards | CUL-CRO/WOC |
| 00001 2.4.3 Land principally occupied by agriculture | / | 82.3 Extensive cultivation | A11 A1B1XXC1D1-B4W8 Rainfed Tree Crop(s) Crop Cover: Orchard(s) | CUL-WOC |
| 10000 3.1.1 Broad-leaved forest | 91AA 41.73 Eastern white oak woods | G1.73 Eastern Quercus pubescens woods | A12 | A1A3A10B2XXD1E2-B6 Broadleaved deciduous closed medium high trees | TRS-FPH/DEC |
| 10001 9250 41.78 Quercus troiana woods | G1.78 Trojan oak woods | A1A3A10B2XXD1E2-B6| Semi-deciduous closed medium high trees | TRS-FPH/DEC |
| 00100 9350 41.79 Mediterranean valonia oak woodland | G1.7/P-41.79 Mediterranean [Quercus macrolepis] woodland | A1A3A10B2XXD1E2-F1-B7 Broadleaved Deciduous Low Trees, Single Layer | TRS-FPH/DEC |
| 00111 92A0 44.1 Riparian willow formations | G1.1 Riparian [Salix], [Alnus] and [Betula] woodland | A1A3A10B2XXD1E1-F1-B7 Broadleaved Evergreen Low Trees, Single Layer | TRS-FPH/DEC |
| 00001 92C0 44.71 Oriental plane woods | G1.3P-44.71 [Platanus orientalis] woods | A1A3A10B2XXD1E2-F1-B5 Broadleaved Deciduous High Trees, Single Layer | TRS-FPH/DEC |
| 00110 92D0 44.81 Oleander, chaste tree and tamarisk galleries | F9.3/P-44.81 [Nerium oleander], [Vitex agnus-castus] and [Tamarix] gales | 7 Open Shrublands | A1A4A11B3-A12B4 Open ((70–60)–40 %) Medium To High Shrubs (Shrubland) | TRS-TPH/EVR + TRS-FPP+EVR |
| 10000 3.1.2 Coniferous forest | / | 83.31 Conifer plantations | G3.F Highly artificial coniferous plantations | 2 Evergreen Forests | A11 | A1B1XXC1D1W7-A8A9B3 Monoculture of large size fields of needleleaved evergreen rainfed tree crops-Plantations | CUL-WOC |
| 01000 / | 83.31 Conifer plantations | G3.F1 Native conifer plantations | A1B1XXC1D1W7-A8A9B3 Monoculture of large size fields of needleleaved evergreen rainfed tree crops-Plantations | CUL-WOC |
| Presence/Absence | CLC3 AX 1 Lev.3 | CORINE Biotopes Levs. 3–4–5 | EUNIS Levs. 3–4–5 | IGBP | LCCS DPH | LCCS DPH and MHPH | GHCs Lev. II/III |
|------------------|-----------------|-----------------------------|-----------------|------|---------|----------------|----------------|
| 10000 3.1.3 Mixed forest / | 43 Mixed woodland | Gl.732 Italo-Sicilian Quercus pubescens woods | 5 Mixed Forests | A12 | A1A3A10B2XXD1E2-B6 Broadleaved Deciduous medium–high trees | TRS-FPH/DEC |
| 10000 3.1.4 Grasslands with trees / | / | E7 Sparsely wooded grasslands | 10 Grasslands | A2A6A10B4XXE5F2F5F10G2-B12E6G7 Medium-tall grasslands with low trees | HER + TRS-MPH |
| 10000 3.2.1 Natural grasslands 6210 | 34.3 Dense perennial grasslands and middle European steppes (Festuco-Brometea) | El.2 Perennial calcareous grassland and basic steppes | A2A6A10B4XXE5-B12E6 Closed perennial medium-tall grasslands | HER-LHE/CHE |
| 11000 3.2.1 Natural grasslands 6220* | 34.5 Mediterranean xeric grasslands | El.313 Medit. xeric grassland Medit. annual communities of shallow soils | A2A5A11B4XXE5-A13B13E7 Open (40–20–10) % annual short herbaceous veg. | HER-CHE/THE |
| 10000 6220* | 34.5 Mediterranean xeric grasslands | El.4 Mediterranean tall-grass and Artemisia steppes | A2A6A10B4XXE5-B12E6 Closed perennial medium-tall grasslands | HER-CHE/THE |
| 10000 6220* | 34.5 Mediterranean xeric grasslands | El.C1 Dry mediterranean lands with unpalatable non-vernial herbaceous veg. Asphodelus fields | A2A6A10B4XXE5-B12E6 Closed perennial medium-tall grasslands | HER-CHE/THE |
| 10000 / | 34.5 Mediterranean xeric grasslands | El.C2 Dry medit. lands with unpalatable non-vernial herbaceous veg. Thistle fields | A2A6A10B4XXE5-B12E6 Closed perennial medium-tall grasslands | HER-CHE/THE |
| 10000 62A0 | 34.53 East Mediterranean xeric grasslands | El.55 Eastern sub Mediterranean dry grassland | A2A6A10B4XXE5-B12E6 Closed perennial medium-tall grasslands | HER-LHE/CHE |
| 0010 6420 | 37.4 Mediterranean tall humid grasslands | E3.1 Mediterranean tall humid grassland | A2A6A11B4C2E5-A12B11E6 Interrupted open (70–60–40 %) perennial tall grassland | HER-LHE/CHE |
| 0001 3.2.2 Moors and heathland / | 31.86 Bracken fields | E5.3 [Pteridium aquilinum] fields | A2A5A11B4-A12B11 Open (70–60–40 %) Tall Forbs | HER-HCH/EVR |
| 01000 3.2.3 Sclerophyllous veg. 2250* | 16271 Juniperus oxycedrus ssp. macrocarpa thickets | B1.631 Dune Juniperus thickets (Dune prickly juniper thickets) | 6 Closed shrublands | A1A4A10B3XXD2E1-B9 Needleaved evergreen medium/high closed shrubland (thickets) | TRS-MPH/CON EVR |
| 00011 / | 45.41 Greek kermes oak forests | G2.1P-45.41 Greek [Quercus cocciifera] forests | A1A4A10B3XXD1E1F1-B8 Broadleaved Evergreen High Thicket, Single Layer | TRS-MPH/EVR |
| 01000 / | 32214 Lentisc brush | F5.514 Thermo-Medit. brushes, thickets and heath-garrigues (Lentisc brush) | A1A4A10B3XXD1E1-B9 Broadleaved evergreen medium/ high thicket | TRS-MPH/EVR |
| 00001 / | 32.5 Eastern garrigues | F6.2 Eastern garrigues | 4 Deciduous Broadleaf Forests | A1A4A11B3XXD1E2F1-A12B9 Broadleaved Deciduous (70–60–40 %) Medium High Shrubland, Single Layer | TRS-SCH/DEC |
| Presence/Absence | CLC3 AX 1 Levs. 3–4–5 | CORINE Biotopes Levs. 3–4–5 | EUNIS Levs. 3–4–5 | IGBP | LCSC DPH | LCSC DPH and MHPH | GHCs | GHSs |
|-----------------|------------------------|-----------------------------|-------------------|------|----------|-------------------|------|------|
| 01000           | / 32.5 Eastern garrigues | P6.2C Eastern Erica garrigues | 7 Open Shrublands | A1A4A1B3XSD1E1-B10 | TRS-DCH/EVR | Broadleaved evergreen open dwarf shrubland |
| 00100           | 5330 32.22–32.26 Tree-spurge formations-Thermo-medit. broom fields (retamares) | P5.55/P-32.22-P-32.26 [Euphorbia dendroides] formations-Thermo-Mediterranean broom fields (retamares) | 6 Closed shrublands | A1A4A1B3XSD1E1-F1-B9 | TRS-LPHEVR | Broadleaved Evergreen Medium High Thicket, Single Layer |
| 00110           | 5420 33.3 Aegean phrygana | P7.3/P-33.3 Aegean phrygana | 7 Open Shrublands | A1A4A1B3XSD1E1-B12B9 | TRS-SCH/EVR | (70–60–40 %) Medium High Shrubland, Single Layer |
| 11000           | 3.2.4 Transitional woodland shrub | / 31.8A2 Italo-Sicilian sub-Mediterranean decid. thickets | F5.51 Thermo-Mediterranean brushes, thickets and heath-garrigues | 6 Closed shrublands | A1A4A1B3XSD1E1-B9 | Broadleaved deciduous closed medium/high shrubland |
| 10000           | / 31.8A2 Italo-Sicilian sub-Mediterranean decid. thickets | F5.32 Italo-French pseudo-maquis | | | TRS-MPH/DEC | |
| 01100           | 3.3.1 Beaches, dunes, and sand plains | 1210 16.12 Sand beach annual communities (Cakiletea maritimi) | B1.1 Sand beach driftlines | 10 Grasslands | A2A5A1B3XSD1E1-B13E7 | | annual short forbs |
| 01100           | 2110 16.211 Embryonic dunes (Agropyron juncei) | B1.31 Embryonic shifting dunes | | | A2A6A1B3XSD1E1-B12E6 | | perennial medium-tall grasslands |
| 00100           | 2120 16.212 White dunes (Ammophilion arenariae) | B1.32 White dunes | | | A2A6A1B3XSD1E1-B12E6 | | perennial tall grasslands |
| 00100           | 2230 16.228 Mediterranean-Atlantic dune Malcolmia communities | B1.48 Tethyan dune deep sand therophyte communities | | | A2A5A1B3XSD1E1-B13E7 | | annual short herbaceous veg. |
| 10001           | 3.3.3 Sparsely vegetated areas | 8210 62.1 Calcareous cliffs with chasmophytic veg. | H3.2 Basic and ultra basic inland cliffs | 16 Barren or Sparsely Vег. | A2A5A1B3XSD1E1-B13E6 | | perennial short forbs |
| 01000           | 4.1.1 Inland marshes | 3170* 22341 Short Mediterranean amphibious swards (Isoleion) | C3.421 Mediterranean-Atlantic amphibious communities (Short Medit.amphibious communities) | 11 Permanent Wetlands | A2A5A1B3C2E5-B13E7 | | annual short herbaceous veg. on temporarily flooded land |
| 00101           | 3280 24.53 Mediterranean river mud communities | C2.5 Temporary running waters (wet phase) | | | A2A5A1B3C2E5F10G2F1-A8A1B11E6G7 | | Tall Rooted Forbs With Low Emergents On Waterlogged Soil Single Layer |
| Presence/Absence | CLC3 AX 1 | CORINE Biotopes Levs. 3–4–5 | EUNIS Levs. 3–4–5 | IGBP | LCCS DPH | LCCS DPH and MHPH | GHCs Levs. II/III |
|-----------------|-----------|-----------------------------|-------------------|------|---------|---------------------|------------------|
| 01100 4.2.1 Salt marshes | 1310 | 15.1 Salt pioneer swards (Thero-Salicornietea, Frankeniion pulverulentae, Saginion marit.) | A2.55 Pioneer saltmarshes | A2A5A1B4C2E5-B13E7 Open annual short herbaceous veg. on temporarily flooded land | THE + SPV/TER |
| 01100 1410 | | 15.5 Mediterranean salt meadow (Juncetalia maritimi) | A2.522 Upper saltmarshes (Mediterranean Juncus maritimus and Juncus acutus saltm.) | A2A6A1B4C2E5-B1IE6 Perennial closed tall grasslands on temporarily flooded land | SHY/HEY + EHY/HEL |
| 01100 | 1420 | 15.6 Saltmarsh scrubs (Arthrocnemetea fruticosi) | A2.526 Upper saltmarshes (Mediterranean saltmarsh scrubs) | A1A4A1B3C2D3-B10 Aphyllous Closed Dwarf Shrubs On Temporarily Flooded Land | TRS-SCH/EVR |
| 01010 | 7210 | 53.31 Fen Cladium beds | D5.24 Fen Cladium mariscus beds | A2A6A1B4C2E5-B1IE6 Perennial closed tall grasslands on temporarily flooded land | SHY/HEY + EHY/HEL |
| 01000 | / | 53.11 Common reed beds (Phragmitetum) | A2.53C Mid-upper saltmarshes and saline and brackish reed, rush and sedge beds Saline beds of Phragmites australis | A2A6A1B4C2E5-B1IE6 Perennial closed tall grasslands on temporarily flooded land | SHY/HEY + EHY/HEL |
| 01000 | / | 53.17 Halophyte clubrush beds (Scirpion maritimi) | A2.53D Mid-upper saltmarshes and saline and brackish reed, rush and sedge beds Geolittoral wetlands and meadows: saline and brackish reed, rush and sedge stands | A2A6A1B4C2E5-B1IE6 Perennial closed tall grasslands on temporarily flooded land | SHY/HEY + EHY/HEL |
| 00110 4.2.3 Intertidal flats | / | 53.1/53.11 common reed beds (Phragmitetum) | A2.53C Mid-upper saltmarshes and saline and brackish reed, rush and sedge beds/Saline beds of Phragmites australis | 10 Grasslands A2A6A1B4C3-B11 Closed Tall Grassland On Waterlogged Soil | SHY/HEY + EHY/HEL |
| 01000 5.1.1 Water courses | / | 53.4 Small reed beds of fast flooding waters (Glycerio-Sparganion) | C2 Surface running waters | 17 Water bodies A2A6A1B4C2E5-B12E6 Perennial closed medium-tall grasslands on temporarily flooded land | SHY/HEY + EHY/HEL |
| 00100 5.1.2 Water bodies | 3150 | 22.13 X (22.41 & 22.421), 22.431 Natural eutrophic lakes with Magnopotamion or Hydrocharition-type veg. | C1.3 Eutrophic waterbodies | 11 Permanent Wetlands A2A5A1B4C-A8A17B13 Sparse ((20–10–4) %) Short Rooted Forbs On Waterlogged Soil | HER-SHY |
| 01100 5.2.1 Coastal lagoons | 1150 | 23.2 Vegetated brackish and salt waters | X03 Brackish coastal lagoons | 17 Natural Waterbodies A2A5A1B4C4E5-A15B12E6 Perennial open (40–20–10 %) medium-tall herbaceous veg. on permanently flooded land | AQU + TER + SHY + EHY + CHE + LHE/ CHE |
| 00100 5.2.2 Estuaries | 1130 | 13.2 Estuaries | A4.3/B-IMU.EstMu Variable or reduced salinity sublittoral muds | A1B1C2D2-A4 Turbid Shallow Perennial Natural Waterbodies (Flowing) | SEA + TER + SHY + EHY + CHE + LHE/ CHE |

Codes for BIO_SOS sites as in Fig. 1. A binary code 1/0 is used to indicate presence/absence of a specific class in the set of study sites ordered as follows: IT3, IT4, GR1, GR2, GR3 (e.g., 10111 means presence in all sites except at IT4)

AXI Annex 1 taxonomy, DPH dichotomous phase, MHPH modular hierarchical phase, Lev. level

* is used for priority habitas
### Table 3: Ambiguities between different LC and habitat taxonomies

| Taxonomy 1 | Closest class in other taxonomy | Challenges in translation |
|------------|---------------------------------|---------------------------|
| **LCCS**   | **CLC**                          |                           |
| Within A11 “cultivated and managed terrestrial areas”, as “Needleleaved evergreen tree crops” with the indication of “Plantation” | 3.1.2 “Coniferous forests”, which includes both natural forests and plantations | Difficulty in separating natural forest from plantation in CLC |
| Within A12 “natural and semi-natural terrestrial vegetation” | 2.3.1 “pastures”, implying the presence of some level of (managed) human activity in this area | Although grasslands refer to sub-nitrophilous vegetation, they cannot be included in LCCS class A11 “cultivated and managed terrestrial areas”, because this implies the presence of one or more crops |
| Defined as “broadleaved evergreen tree crops” in LCCS third level, with the use of LCCS technical attributes providing the possibility of adding additional specific labels (e.g. olive grove) | 2.2.3 “olive groves”, which involves land use information | LCCS does not enable the provision of land use information, although secular olive groves have been recently included in Annex I of the European Directive. Perhaps additional attributes such as some agricultural practices (e.g. tree-distance, shape of the crown) might be included in the LCCS scheme to discriminate this class from other crop types |

| **IGBP** | **CLC** | |
|-----------|---------|---------------------------|
| Class 10—“Grasslands” | 2.3.1—“Pastures”, 3.2.1—“Natural grasslands”; 3.3.1—“Beaches, dunes, and sand plains”, part of 4.2.1—“Salt marshes”, 4.2.3—“Intertidal flats” and part of 3.2.2—“Moors and heathlands” | Definition of IGBP classes is much too broad, encompassing multiple CLC categories |

| **LCCS** | **GHC** | |
|-----------|---------|---------------------------|
| “needleleaved evergreen—medium high thicket”; height between 0.5 and 3.0 m. | MPH/CON (mid phanerophytes/conifers); height between 0.6 and 2.0 m | The GHC category falls within the corresponding LCCS |
| “needleleaved evergreen - medium high thicket”; height between 3.0 and 5.0 m | TPH/CON (tall phanerophytes/conifers); height between 2.0 and 5.0 m | Imperfect correspondence due to the shifting in height ranges |
| “Artificial”—referring to a primarily non-vegetated class | “Artificial” nested within the super category “Urban”, also including vegetated areas functionally related to buildings | In GHCs, a vegetated area can correspond to Vegetated herbaceous (HER) or URB, according to the land use; pointing out the difference between LCCS approaches which focus primarily on land cover, and GHCs, which focus on land cover as well as land use |
does not provide a useful framework for fine-grain habitat mapping. Consequently, any monitoring activity based on such a taxonomic scheme is unlikely to differentiate changes in habitat composition, connectivity and disturbances over short periods of time. Compared to the CLC, LCCS provides a higher level of detail as many different “pure” land cover classifiers can be used for class discrimination (Tomaselli et al. 2011). In Table 2 (eighth column), two different LCCS class codes are associated to two different habitats (i.e., 1310, 1420) in one-to-one relations. The remaining four (i.e., 1420, 7210, A2.53C and A2.53D) of six habitats associated to CLC 4.2.1 are still linked to the same LCCS class code (i.e., A24/A2.A6.A12.B4.C2.E5-B11.E6 “aquatic perennial closed tall grassland on temporarily flooded land”). Nevertheless such ambiguity can be solved by combining environmental attributes, such as lithology, soils, landform and water quality, with the “pure” classifiers of the modular hierarchical phase, as evidenced in Table 4, where habitats 1410 and A2.53D have been distinguished from the pair 7210 and A2.53C, with these still not separable. For Le Cesine (IT4) site, Table 4 evidences how the use of LCCS environmental attributes can solve the ambiguity of most LC/LU classes to habitat transitions up to the level of habitats and one-to-one class relationships can be found. Figure 2 offers a visual description of LCCS potentialities in terms of both its finer habitat discrimination with respect to CLC (Fig. 2a) and detection of “within” class changes related to a specific class modification (Fig. 2b). Within LCCS, specific floristic attributes can also be added to complete habitat class description. However this attribute cannot be considered for habitat mapping since it cannot be easily detected from EO data, mainly when EO hyper-spectral data are not available (Nagendra 2001).

Concerning LC/LU and subsequent habitat mapping from VHR EO data, multi-temporal (seasonal) and/or context-sensitive information is generally required for improving classification (Bruzzone et al. 2004; Amoruso et al. 2009). If only one date is analysed, due to the limited number of available spectral bands (e.g., 4 in IKONOS and QuickBird) different objects of the scene can have similar spectral signatures in the image even if fine spatial details of the landscape can be detected in a VHR image. Consequently, an appropriate selection of multi-seasonal images should be carried out before any classification. To do this, expert knowledge elicitation of the most useful features for class discrimination (e.g. the different periods of maximum biomass and plant development for terrestrial vegetated classes (A12); the different months of flooding period for the aquatic or regularly flooded vegetated classes (A24) or specific agricultural practices to differentiate crops within cultivated classes (A11)) is recommended. Such information should be embedded within the LCCS framework for the improvement of LC/LU classification and subsequent habitat mapping. In this paper, Table 4, in the column labelled “additional expert prior information”, reports the information useful for the selection of an appropriate minimum (for cost optimization) set of a multi-temporal EO image set for class discrimination in the IT4 site.

**IGBP and CLC with respect to Annex I habitats**

With regards to IGBP and CLC, as already evidenced in Herold et al. (2008), general weaknesses and inconsistencies of the IGBP class set are provided mainly by thresholds in height and cover, when considering forest definition, and the poor and coarse definition of class 11 (wetlands). In this specific case, 17 LC classes are too few and coarse to achieve the discrimination of detailed and fine classes such as habitat types (see Table 4 for further details). This is a logical consequence of the fact that IGBP has been designed for the detection of LC types at a global level and large scale (Herold et al. 2008; Tchuente et al. 2011) and is not best suited for habitat classification and monitoring at the scale of individual protected areas.

**LCCS and GHG habitats**

Habitats, as defined in (Bunce et al. 2011), can be considered “as an ecological refinement of the land cover categorisation as developed by FAO in the LCCS”. GHCs contain information about life form, height, leaf type and cycle. Therefore, LCCS classes as defined by means of pure classifiers (including life form, height, leaf type and cycle) can provide a good match with GHCs. However, some discrepancies between the two systems can be highlighted. This is the case of ranges and thresholds in height defined by GHC for chamaephytes and phanerophytes which do not correspond exactly to those defined by LCCS for trees and shrubs. In addition, LCCS defines different
| EUNIS  | Annex I | LCCS dichotomous (iii level) and modular hierarchical classifiers with code | Life form | Cover | Height (m) | Water seasonality (only for A24) | Leaf type | Leaf phenology | Cycle annual/Perennial |
|--------|---------|--------------------------------------------------------------------------|----------|-------|-----------|----------------------------------|-----------|----------------|-----------------------|
| C3.421 | 3170    | Herbaceous A24/A2.A5                                                     | 40–15 %  | A13   | 0.3–0.03  | Temporary flooded                | /         | /              | Annual                |
| A2.526 | 1420    | Woody shrubs                                                            | >65 %    | A12   | <0.5      | Temporary flooded                | A24/A2.A5 | C2              | (E7)                  |
| A2.522 | 1410    | Herbaceous graminoids                                                    | >65 %    | A12   | 0.8–0.3   | Temporary flooded                | A24/A2.A5 | C2              | Perennial             |
| A2.53D | X       | Herbaceous graminoids                                                    |          |       |           |                                  | A2.A6     |                 | (E6)                  |
| D5.24  | 7210    | Herbaceous graminoids                                                    |          |       |           |                                  |           |                 |                       |
| A2.53C | X       | Herbaceous graminoids                                                    |          |       |           |                                  |           |                 |                       |
| C2     | X       | Herbaceous graminoids                                                    |          |       |           |                                  |           |                 |                       |
| X03    | 1150    | Herbaceous                                                              | 40–15 %  | A13   | /         | Permanent flooded                | /         | /              | Perennial             |
| E1.6   | X       | Herbaceous forbs                                                        | >65 %    | A10   | 0.8–3     |                                  | /         | /              | Annual                |
| B1.1   | 1210    | Herbaceous                                                              | 40–15 %  | A11   | 0.3–0.03  |                                  | /         | /              | (E7)                  |
| E1.313 | 6220    | Herbaceous                                                              |          |       |           |                                  |           |                 |                       |
| F5.51  | X       | Woody shrubs                                                            | >65 %    | A10   | 0.5–3     |                                  | /         | Broad-leaved    | Deciduous (E2)        |
| B1.631 | 2250    | Woody shrubs                                                            | >65 %    | A10   | 0.5–3     |                                  | /         | Needle-leaved   | Evergreen (E1)        |
| F5.55  | X       | Woody shrubs                                                            | >65 %    | A10   | 0.5–3     |                                  | /         | Broad-leaved    | Evergreen (E1)        |
| F5.514 | X       | Woody shrubs                                                            | >65 %    | A10   | 0.5–3     |                                  | /         | Evergreen       | Perennial             |
| F6.2C  | X       | Woody shrubs                                                            | 65–40 %  | A11   | <0.5      |                                  | /         | Evergreen       | Perennial             |
| B1.31  | 2110    | Herbaceous graminoids                                                    | 65–40 %  | A11   | 0.8–0.3   |                                  | /         | /              | Perennial             |
| Selected LCCS code | Input | Additional expert prior information | LCCS environmental attributes | Full code for habitat discrimination |
|-------------------|-------|-------------------------------------|------------------------------|-------------------------------------|
| A24/A2.A5         | March–May (June) | Nov–Feb |Calcareaeous rock—Calcarenite (M233) |Leptosols (N12-LP) |Fresh water (R1) |A24/A2.A5.E7 +R1,M233,N2,N12-LP |
|                   | June–October | (Nov) dec–apr (May) |Unconsolid-Clastic sedimentary rock—Sand (M213) |Solonchaks (N12-SC) |Saline water (R3) |A24/A2.A5.E7 +R3,M233,N2,N12-SC |
| A24/A1.A4.D3      | June–September (Oct) | (depending on veg.type) |Unconsolid-Clastic sedimentary rock—Sand (M213) |Solonchaks (N12-SC) |Saline water (R3) |A24/A1.A4.D3 +R3,M213,N12-SC |
| A24/A2.A6.E6      | June–September | (Nov) dec–mar (Apr) |Unconsolid-Clastic sedimentary rock—Sand (M213) |Solonchaks (N12-SC) |Brakish/Saline water (R2/R3) |A24/A2.A6.E6 +R2/R3,M213,N12-SC |
|                   |           |       |Calcareaeous rock—Calcarenite (M233) |Histosols (N12-HS) |Fresh/Brakish water (R1/R2) |A24/A2.A6.E6 +R1/R2,M233,N12-HS |
| A24/A2.A5.E6      | June–September | Full year |/ |/ |/ |Brakish water (R2) |A24/A2.A5.E6 +R2 |
| A12/A2.A5.E7      | March–June | / |Calcareaeous rock—Calcarenite (M233) |Acrisoi (N12-AC) |/ |A12/A2.A5.E7 +M233,N12-AC |
|                   | April–September | / |Loose and shifting sands (N3) |Arenosols (N12-AR) |/ |A12/A2.A5.E7 +M233,N12-AR |
|                   | March–May (June) | / |Soil surface, very stony (40–80 %) (N6) |Leptosols (N12-LP) |/ |A12/A2.A5.E7 +M233,N6,N12-LP |
| A12/A1.A4.D1.E2   | March–October | / |Calcareaeous rock—Calcarenite (M233) |Leptosols (N12-LP) |/ |A12/A1.A4.E2 +M233,N12-LP |
| Input | Additional expert prior information | LCCS environmental attributes | Full code for habitat discrimination |
|-------|-------------------------------------|-----------------------------|--------------------------------------|
|       | Selected LCCS code                  | Period of maximum biomass for perennial or of development for annual classes | Flooding period (months) | Lithology-parent material | Soil-surface aspect | Soil-subsurface aspect | Water quality |
|       | A12/A1.A4.D2.E1                    | Full year                    | / | Unconsolid-Clastic sedimen. rock—Sand (M213) | / | Arenosols (N12-AR) | / | A12/A1.A4.E1 +M213.N12-AR |
|       | A12/A1.A4.D1.E1                    | Full year                    | / | Unconsolid-sedimentary rock—Sand (M213) | / | Leptosols (N12-LP) | / | A12/A1.A4.D1.E1 +M213.N12-LP |
|       |                                     |                             | | Calcareous rock—Calcarenite (M233) | / | | | |
|       | A12/A2.A6.E6                       | April–August                 | / | Unconsolid-sedimentary rock—Sand (M213) | Loose and shifting sands, with dunes (N7) | Arenosols (N12-AR) | / | A12/A2.A6.E6 +M213.N7.N12-AR |

Two habitats (i.e., D5.24 and A2.53C) remain undistinguishable. Additional expert prior information useful for discriminating classes from EO data are reported in columns 11 and 12.
ranges of height for herbaceous types, whereas these ranges are not provided in GHC (Kosmidou et al. 2012). Table 3 provides further details. A critical difference between LCCS and GHCs lies in the definition of the “Artificial” categories. In LCCS “Artificial” is a primarily non vegetated class. In GHC, “Artificial” falls within the super category “Urban”, applying to buildings or land functionally related to buildings, which includes vegetated areas. Hence a vegetated area can fall in vegetated Herba-
ceous (HER) or in Urban (URB), according to the land use, and have a different ecological value.

Quantitative analysis: similarity measure and distance matrix

With respect to the sites, the overall greatest similarity measured by the Jaccard’s index is observed between sites GR1 and GR2 (Table 5) (i.e., two similar environments belonging to the same country, Greece). The same result holds in all the classification systems, except in Annex I; that is probably due to the exclusion of all the artificial and certain semi-natural habitat types in the Annex I classification. Similarity in artificial and semi-natural class types implies similarity in human practices, usually more homogeneous in the same country than in different ones. Contrarily, the most similar sites, according to Annex I, are GR1 and IT4, which contain the higher percentage of natural (Annex I) classes, 70 and 48 %, respectively. Focusing on the classification systems, the highest values, ranging from 0.454 to 0.875 are the ones obtained by IGBP, due to the few and coarse classes that result in an artificial high number of overlaps. EUNIS, CORINE Biotopes and LCCS show low values on average, and also quite similar ranges (EUNIS from 0.057 to 0.409; CORINE Biotopes from 0.081 to 0.409; LCCS from 0.031 to 0.500). EUNIS and CORINE Biotopes are closely related classification systems and that justifies the results. As stated, LCCS provides a very flexible tool, permitting class definitions to be enriched by adding further attributes. The detailed level of class description yields a better discrimination and a reduced number of co-occurrences in the site composition. Annex I also arises from CORINE Biotopes, but the results are quite different due to the emphasis of Annex I on natural habitat types, leading to results that emphasize the similarity in composition of natural habitats of high biological value. Thus, the Jaccard’s index values applied to Annex I are in strongest disagreement with those for other systems. Moreover, when considering the Annex I data set, the best score is obtained by IT4 with GR1, both coastal wetlands, and by GR3 with IT3 (probably due to the presence and dominance of woody habitat types in both these sites). On the other hand, the high similarity values of the pairs GR1–GR2 and GR2–GR3, within the majority of the taxonomies may be due to common practices of management of semi-natural and artificial areas.

The results of the similarity measure on the given dataset are then used to build up a distance matrix for a selection of taxonomies, the ones allowing for a satisfactorily detailed description of classes (thus excluding IGBP), as shown in Table 5b. The selected taxonomies are hierarchical in structure: for three of them (LCCS, EUNIS, GHCs) the classes are defined through a pre-selected set of classifiers/criteria/attributes; moreover all but Annex I include “human” classes. The comparison of habitat taxonomies always generates small distance values and suggests a similar behaviour. Annex I turns out to be the “least similar” taxonomy with respect to all the remaining habitat taxonomies, possibly due to the lack of “artificial” classes in this classification scheme. On the other hand, the comparison of LCCS and CLC3 exhibit the highest distance, confirming that a conversion from one LC taxonomy to the other should be handled with care due to the many-to-many relationships between the two classification schemes. A reason for such differences in behaviour might rely on the discrimination of primarily vegetated from non-vegetated areas, which is done at the top of the hierarchy in LCCS, thus determining a mismatch from the very beginning of the descent along the branches of the taxonomic trees. However, the congruency of the two systems is improved if environmental attributes are added to the LCCS classification. This trend is reproduced for the comparison of LCCS with all other taxonomies. About the comparison of Land Cover and Habitat taxonomies, a good match would be expected for taxonomies used in related projects such as CLC and Corine Biotopes and the measured distance confirms it. However the best results in the comparison are the ones obtained by LCCS with the addition of the environmental attributes, which turns out to have the overall lowest distances to almost all habitat taxonomies but Annex I. The highest similarity is obtained
The translation of LC class *salt marshes* from CLC taxonomy into LCCS taxonomy can identify 5 different habitats on the basis of land cover classifiers and additional environmental attributes, b LCCS legend can describe within class changes due to specific class modification as in the example reported in this figure.
for the coupling EUNIS—LCCS when the environmental attributes are taken into account. Regarding GHCs, the rule based system in (Bunce et al. 2010) has been used to assign Level II/III classes, starting from the Annex I classification, which actually represents the best match. However, since the classification has been stopped at the first level, it can be expected that a further refinement of the classification would give more detailed results, and thus greater similarity especially when compared to LCCS, which shares with GHCs similar building rules. As a conclusion, this numerical test based on a small data set confirms what was expected from the qualitative reasoning about the main characteristics of the systems.

LC to habitat mapping in Le Cesine Natura 2000 site (IT4)

The effort to translate between LC/LU and habitat mapping was based on (a) the pre-existing LC/LU map (Fig. 3a) and the additional thematic maps (i.e., lithology, soil surface aspect and soil subsurface aspect, water quality obtained by in-field campaigns) which, layered into a GIS (Fig. 3b), were used as inputs of the mapping process and (b) the expert-knowledge elicited in Table 4 and coded as decision rules in the Decision Table shown in Table 6.

The input LC/LU classes are: nine (semi) natural LCCS classes represented by the subset LCCS code elements reported in Table 4, column labeled as “input”; three additional cultivated (A11) classes (i.e., no-graminoid crops, coniferous plantation and olive groves) and two artificial (B15) categories (i.e., paved roads and scattered urban areas). The full LCCS class dichotomous and hierarchical codes are provided in Fig. 3a in the LC/LU map legend. The code components corresponding to cover density and height classifiers were not considered in the mapping process, as already discussed in the previous section and evidenced in Table 4. Eighteen output habitats are expected for this site (see columns “Annex I” and/or “Eunis” in Table 4). The habitats were reported in the “action entries” section of Table 6, which includes also the corresponding plant species explicated in the LCCS technical attribute. Nevertheless, this attribute was not used in the mapping process which is mainly

| Pair of sites | IGBP | CLC3 | LCCS-MHP | LCCS + environmental attributes | CORINE biotopes | ANNEX I | EUNIS | GHCs | LCCS | LCCS + ENV. ATTR |
|--------------|------|------|----------|---------------------------------|-----------------|---------|-------|------|------|-----------------|
| IT3-IT4      | 0.4545 | 0.3200 | 0.1351  | 0.1795                          | 0.2105          | 0.1111  | 0.1556 | 0.3077 |      |                 |
| IT3-GR1      | 0.4545 | 0.1923 | 0.0286  | 0.0750                          | 0.0811          | 0.0476  | 0.0682 | 0.2083 |      |                 |
| IT3-GR2      | 0.5000 | 0.2174 | 0.0270  | 0.0909                          | 0.1000          | 0.0769  | 0.0811 | 0.2500 |      |                 |
| IT3-GR3      | 0.6667 | 0.2174 | 0.1556  | 0.1563                          | 0.1724          | 0.3000  | 0.1714 | 0.3333 |      |                 |
| IT4-GR1      | 0.7778 | 0.4737 | 0.1389  | 0.1944                          | 0.2571          | 0.3333  | 0.2286 | 0.3462 |      |                 |
| IT4-GR2      | 0.6667 | 0.3158 | 0.0233  | 0.0588                          | 0.1212          | 0.1111  | 0.0909 | 0.2917 |      |                 |
| ITA-GR3      | 0.5000 | 0.2500 | 0.0263  | 0.0278                          | 0.1176          | 0.0556  | 0.0571 | 0.1538 |      |                 |
| GR1-GR2      | 0.8750 | 0.6429 | 0.4000  | 0.4348                          | 0.4091          | 0.2941  | 0.4091 | 0.4444 |      |                 |
| GR1-GR3      | 0.6667 | 0.4375 | 0.1923  | 0.2593                          | 0.2308          | 0.1667  | 0.2308 | 0.2500 |      |                 |
| GR2-GR3      | 0.7500 | 0.4286 | 0.2500  | 0.3500                          | 0.3158          | 0.1818  | 0.3158 | 0.3125 |      |                 |

Abbreviations of BIO-SOS codes as in Fig. 1, b distances of taxonomies measured as pair wise exchanges separating the corresponding Jaccard’s index rankings on the given sites dataset.
based on the contribution of the additional environmental attributes from in-field campaigns.

The LC/LU to habitat mapping was carried out based on the decision rules of Table 6. Within each patch of the input LC/LU map, the labels of all GIS layers were combined as in the last column of Table 4. Then the combination of True/False conditions in Decision Table 6 was checked. As a result, for each input LCCS class (entry), a habitat label was identified (action) and assigned to the corresponding patch of the output map. Figure 4 illustrates two examples related to the discrimination of some habitats already discussed in previous sections. Figure 5 shows the final output habitat map. As evidenced in Fig. 4b and in Fig. 5, an ambiguity still remains between 7210 and EUNIS A2.53C habitats because they have the same environmental attributes.

The pre-existing habitat map from in-field campaign available for this site was used as reference map for validating the final habitat output map. The label of each patch in the output map was compared to the label of the corresponding patch in the reference map. A confusion matrix was generated to evaluate the mapping performance in terms of overall accuracy (OA) and error tolerance (Congalton and Green 2009) of the output map. The OA was obtained as the ratio of the number of patches in the output maps correctly assigned by the total number of patches considered. The resulting accuracy was 97% with an error tolerance of 0.02%.

Fig. 3 a Pre-existing LC/LU map in LCCS taxonomy for Le Cesine site (IT4). The alphanumeric code components used for translating between LC/LU to habitat mapping are evidenced in bold and corresponds to the ones representing the dichotomous category (i.e., A12 natural and semi-natural terrestrial vegetated or A24 Natural and semi-natural aquatic vegetated), leaf type (D1 broadleaved, D2 needleaved, D3 aphyllous) and leaf phenology (E6 perennial or E7 annual). The rectangular boxes include LC/LU classes which are considered as a single input to the mapping algorithm because they have the same bold codes but correspond to different habitats. The discrimination of such habitats requires the integration of the additional environmental attributes reported in Table 4, per each input. The remaining code components correspond to information such as specific plant height that do not influence the mapping algorithm nor cannot be easily measured from remote sensed data without LIDAR data. b GIS input layers including, per each LCCS class, the environmental attributes used for habitat disambiguation in LCCS to Annex I/Eunis mapping (i.e., water quality; soil-surface aspect; soil subsurface aspect; lithology)
Table 6 Decision rules for LCCS to ANNEX1/EUNIS mapping

| Conditions STUB (inputs) | CONDITION ENTRIES (Y is used for TRUE Entries) |
|-------------------------|-----------------------------------------------|
| **LCCS code for inland water habitats** |
| A24/A2.5.E7              | Y Y                                             |
| A24/A1.A4.D3             | Y                                               |
| A24/A2.A6.E6             | Y Y Y Y                                         |
| A24/A2.A5.E6             | Y                                               |
| A2/A2/A5.E7              | Y Y                                             |
| A12/A1.A4.D2.E2          | Y                                               |
| A12/A1.A4.D2.E1          | Y                                               |
| A12/A1.A4.D1.E1          | Y Y Y Y                                         |
| A12/A2.A6.E6             | Y                                               |
| **LCCS code for other waters** |
| Not_Defined (ND)         | Y Y 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 Y Y Y Y Y |
| Flat to almost flat              | Y Y Y Y Y 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 - Calcareous | Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y |
| Unconsolidated sedimentary rock - Sand | Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y |
| Soil checks                      | Y Y                                             |
| Histosols                        | Y                                               |
| Lephtosols                       | Y Y                                             |
| Acreosols                        | Y                                               |
| Astosols                         | Y                                               |
| Soil - Surface Aspect Soil surface, stony (5-40%) | Y                                               |
| Loose and shifting sands         | Y                                               |
| Soil surface, very stony (40-80%) | Y                                               |
| Loose and shifting sands, with dunes | Y                                               |
| Elevation                        | Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y |
| Water quality                    | Y                                               |
| Fresh water                      | Y                                               |
| Saline water                     | Y                                               |
| Brackish/Saline water            | Y                                               |
| Fresh/Brackish water             | Y                                               |
| Brackish water                   | Y                                               |
| Climate                          | Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y Y |

**POSSIBLE ACTIONS (Outputs)**

| ANNEX 1 / (EUNIS) codes class | ACTION TO BE TAKEN (X is TRUE for action to be taken) |
|---------------------------------|----------------------------------------------------|
| Outputs                         | Technical attributes (species) not used in mapping |
| 3170 (A7.421)                  | Annals of Isoto-Naunicolories                      |
| 1310 (A2.51/A2.55)             | Salicornia spp., Suaeda spp., Parapholis spp., or annals of Thalassaliotina and/or Sagina maritima |
| 1420 (A2.526)                  | Sarcocornia spp., Suaeda vers.: Arthrocnemum spp. or perennial species of Sarcocornia               |
| 1410 (A2.522)                  | Junior spp., Carex spp., Plantago arenaria: or perennial species of Holofernea mollis               |
| 7210 (A9.24)                   | Cladium maritimum                                  |
| ND (A2.53C)                    | Phragmites australis                               |
| ND (A2.53D)                    | Scirpus spp., Bolboschoenus maritimus              |
| ND (C2)                        | Sparganium erectum                                 |
| 1150 (C035)                    | Ruppia spp., Potamogeton spp.                     |
| ND (E1.6)                      | Annals of Saltaliotic media                        |
| ND (F5.51)                     | Ruphus spp.                                       |
| 2550 (B1.531)                  | Juniperus communis                                 |
| 5330 (F5.55)                   | Myrtus Communis                                    |
| ND (F5.514)                    | Potamogeton natans                                 |
| ND (F6.2C)                     | Equisetum fluviatile                               |
| 1210/B1.1                      | Calcis maritima                                    |
| 2110/B1.31                     | Amphibranche juncea                                |
| 0220/B1.313                    | Annals of Typha latifolia                         |

Not_Defined (ND) is used when no AnnexI code is available.
**Fig. 4** Graphical representation of the decision actions and condition combination for discriminating: **a** The habitats associated to LCCS class A12/A1.A4.D1.E1 (i.e. terrestrial vegetated natural and semi-natural woody shrubs broadleaved deciduous). **b** The habitats associated to LCCS class A24/A2.A6.E6 (i.e., natural and semi-natural aquatic vegetated herbaceous graminoids perennial).

**Fig. 5** Output habitat map including both Annex I and EUNIS habitats with the latter used only when no Annex I codes exist to label the remaining habitat types of the study site.
Conclusions

Land cover maps are at the basis of habitat maps and biodiversity indicator extraction. The selection of an appropriate LC/LU classification system for habitat mapping applications is a crucial issue for long term monitoring. It is particularly important when working with remote sensing imagery at very high spatial resolution due to the complexity of class description and the limited spectral resolution (few spectral bands) that requires multi-temporal imagery and the integration of ancillary data in order to minimize uncertainty in mapping (Lechner et al. 2012).

The qualitative review of CLC, IGBP and LCCS for habitat mapping oriented applications in Mediterranean sites indicates that LCCS allows the finest discrimination of natural and semi-natural types with respect to CLC and IGBP by using the simple pure land cover classifiers of the Modular-Hierarchical phase. This facilitates the subsequent translation of LC/LU into habitat maps based on the additional use of LCCS environmental and technical attributes. The selection of these attributes depends on expert knowledge which, in this study, appeared mandatory for achieving an appropriate class description very close to specific habitat types. As a result, the FAO-LCCS scheme can be considered as an appropriate and user-friendly framework for long-term monitoring of the conservation status of habitats as expert knowledge can be easily embedded in such a framework.

The introduction of new fields for a more detailed description of specific LCCS classifiers and to capture important expert knowledge information is recommended for facilitating the exploitation of the opportunity offered by VHR EO satellite imagery to regularly update LC/LU and habitat maps for fine-grain change detection. More specifically, a new field should be added to the LCCS classifier “Life Cycle” (Leaf type/phenology) to indicate the maximum biomass and flowering periods of perennial and annual vegetated classes, respectively. A new field should also be added to the LCCS classifier “Water Seasonality”, to indicate the start–end months of the flooding period. The proposed additional information can be used for appropriate multi-temporal EO image selection and classification improvement. Such information can be very useful for the automatic discrimination of LC/LU classes which might have similar spectral signatures when only a single date EO image is used in the classification process.

Food and Agricultural Organisation has recently developed a so called LCML (Land Cover Meta Language) aiming at classifying LC features with simple groups of elements arranged in different ways in order to describe the more complex semantic in any separate application ontology. Classes derived by LCML can be customized to user requirements, even though maintaining common identities between users. LCML is at the basis of a new version of LCCS (v.3, not yet published) that will be much more flexible and efficient than the previous version.

This research demonstrates that LCCS shows the overall lowest distances (greatest similarity) to almost all habitat taxonomies but Annex I as the latter does not include artificial and agricultural classes. EUNIS and GHCs show the greatest similarity to LCCS, with the last two sharing similar building rules and categories.

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