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Definition and application of expert knowledge on vegetation pattern, phenology, and seasonality for habitat mapping, as exemplified in a Mediterranean coastal site

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Abstract

Habitats are effective indicators of biodiversity. Remote sensing data and techniques are of great utility for their long-term monitoring. Habitat maps can be derived from land cover (LC) maps through rules obtained from expert knowledge and integrated with *in situ* data. Spatial (vegetation pattern) and temporal (phenology and water seasonality) relationships were explored and documented to infer reliable rules for LC (according to the Food and Agricultural Organization Land Cover Classification System (FAO-LCCS) taxonomy) to habitat (Annex I to the 92/43 EEC Directive and EUNIS) class translation. A coastal site in southern Italy was considered as study site for the definition and validation of such rules. Phenological data of the plant communities were collected on the basis of vegetation plots randomly distributed within the study site. Water seasonality was extracted from periodical observation of the water surface. Vegetation pattern was analyzed by means of vegetation survey along transects. The potentiality of rules, based on this specific expert knowledge, was tested in an experimental setting for habitat mapping. The overall accuracy of the habitat map was 75.1%. Such a result supports the usefulness of prior expert knowledge for habitat mapping from LCCS classes and disambiguation on one-to-many relations between LC/LU and habitat types.

Keywords: *Habitat mapping, phenology, seasonality, standard zonation, vegetation pattern*

Introduction

Habitats are effective indicators of biodiversity and their periodic and consistent monitoring across EU, in terms of extent, status, and changes, may provide an effective tool for policy-makers (Bunce et al. 2013). Remote sensing (RS) data and techniques are of great utility for long-term habitat monitoring (Nagendra 2001; Lengyel et al. 2008), not only because of the availability of a large amount of multi-temporal data, but also in consideration of the obligation of EU member states to monitor and report periodically on the conservation status of all Annex I habitat types of the 92/43/EEC Directive (Habitat Directive). The use of RS data is a well consolidated approach for the production of land cover (LC) maps. Nevertheless, LC maps are not easily relatable to habitat maps (Adamo et al. 2014, 2016).

The selection of an appropriate LC classification system for habitat mapping applications is a crucial issue. The Food and Agricultural Organization (FAO)–Land Cover Classification System (LCCS) (Di Gregorio & Jansen 2005) has been considered as an appropriate and user-friendly framework for long-term monitoring of the conservation status of habitats. LCCS allows the finest discrimination of natural and semi-natural types with respect to other widely used LC taxonomies. Nevertheless, in most cases, the translation from LCCS classes to Annex I habitats may result in a one-to-many correspondence and, for further discrimination, additional information is needed (Tomaselli et al. 2013; Kosmidou et al. 2014).

Tomaselli et al. (2013) demonstrated that some ambiguous classes can be well discriminated in habitat types, when using information defined by

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"environmental attributes" such as lithology, soil aspect, water quality (as provided by LCCS). Nevertheless, when ambiguities remain unresolved, or when data related to the environmental attributed are not available, or not sufficient, or lack in consistency, alternative information can be used. Such information can be obtained from the observation of some periodic events, such as the vegetative growth stages of dominant species or entire plant communities or, in the case of aquatic habitats, seasonal variations of the water regime.

Phenology and seasonality have been defined as the study of the timing of periodic biological and non-biological events (Lieth 1974; Schwartz 2003). Frequent coverage of remotely sensed data allows the observation of extensive vegetated areas at a landscape or at global scale, but multi-seasonal observations are required for discriminating specific vegetated classes (Nagendra 2001; Nagendra et al. 2013). Matching the satellite-based phenology with the in-field observed phenology of specific plant phenophases is a procedure revealing several problems related to incompatibility of spatial/temporal scales and to lack of ground-based observations. Consistent in-field observations and the definition of an adequate scale are then required (Liang & Schwartz 2009).

Ecological gradients characterizing specific landscapes may be used to infer information useful to improve habitat discrimination. In fact, vegetation pattern directly refers to the relationship between environmental gradients and plant communities' distribution. The deductive approach for vegetation, habitat and ecosystem mapping has been broadly applied (Franklin 1995; Blasi et al. 2000). One of the most frequently used methods for producing vegetation maps, through RS imagery, the "predictive vegetation modeling", has been defined as the prediction of plant communities distribution across a landscape, according to the spatial distribution of relevant environmental variables (Whittaker 1973; Austin 1980; Franklin 1995). The relative importance of the considered variables changes with different spatial scales (Blasi et al. 2000). On a very broad (global) scale, climate is the major determinant of vegetation patterns and habitats distribution. On a national and regional scale, besides climate, other physical variables, such as lithology and topography have to be considered. On a local scale, micro-ecological factors, such as soil types, exposure, solar radiation, relative humidity, etc. may also be taken into account (Blasi et al. 2000; Guisan & Zimmermann 2000; Miller et al. 2007; Wu et al. 2012). In the case of coastal environments, the vegetation pattern is associated with some major ecological gradients driving the establishment of well-defined vegetation types (Chapman 1992). This type of vegetation pattern is called "zonation". In coastal sites, the wetland plant communities are arranged in concentric belts, according to various interrelated factors, such as water regime, flooding period, soil moisture, and salinity (Pennings & Callaway 1992; Alvarez-Rogel et al. 2000). In many cases, spatial zonation is clearly dependent on micro-elevation, that can be used as a proxy for determinants, such as salinity and moisture gradients (Ivajnšič & Kaligarič 2014; Ivajnšič et al. 2016). In the case of coastal dunes, the vegetation pattern depends on gradients related to coherence, salinity, organic matter content in soil substrata, wind, salt spray, wave inundation, and also to sand movement and dune morphology, according to an ideal linear distribution pattern of plant communities along sea–inland environmental gradients, the so called "standard zonation" (Ranwell 1972; Doing 1985; Acosta et al. 2007).

In this paper, the potentiality of the information on certain intrinsic characteristics (i.e. phenology, seasonality, vegetation pattern, topology) of coastal and other terrestrial habitats surrounding the coastal areas is investigated and exploited in an experimental mapping setting to translate LCCS classes into habitat classes, according to the Annex I of the Habitats Directive (92/43/EEC). A Mediterranean coastal area, Le Cesine, located on the Adriatic coast of Puglia Region, was selected as study site and some intrinsic features of the habitat types were explored in order to define appropriate rules for mapping and translation purposes.

Materials and methods

Study site, LC and habitat taxonomies

"Le Cesine" (SCI IT9150032; SPA IT9150014) is one of the oldest protected areas in Puglia, Important Bird Area (IBA) as well as Ramsar site, and covers an area of about 2148 ha (Figure 1). Despite its limited extent, the site hosts a high diversity in terms of habitat and vegetation types (Medagli et al. 2015). The wetland part of the study site is characterized by a system of ponds, marshes, and wet meadows with several types of helophytic vegetation (reeds, sedges, and rushes communities). Inward, the woody vegetation is composed of a mosaic of *Pinus halepensis* stands and different types of Mediterranean maquis and garrigues, while the agricultural areas are mainly composed of olive groves.

As for LC class schemes, we referred to the FAO–LCCS (Di Gregorio & Jansen 2005). As for habitat taxonomies, we used the Annex I of the Dir. 92/43 EEC (Council of the European Union, 2007) and the EUNIS classification (Davies & Moss 2002). EUNIS has recently been recommended as a common reference for habitats in the framework of the EU INSPIRE Directive (Ichter et al. 2014) and as

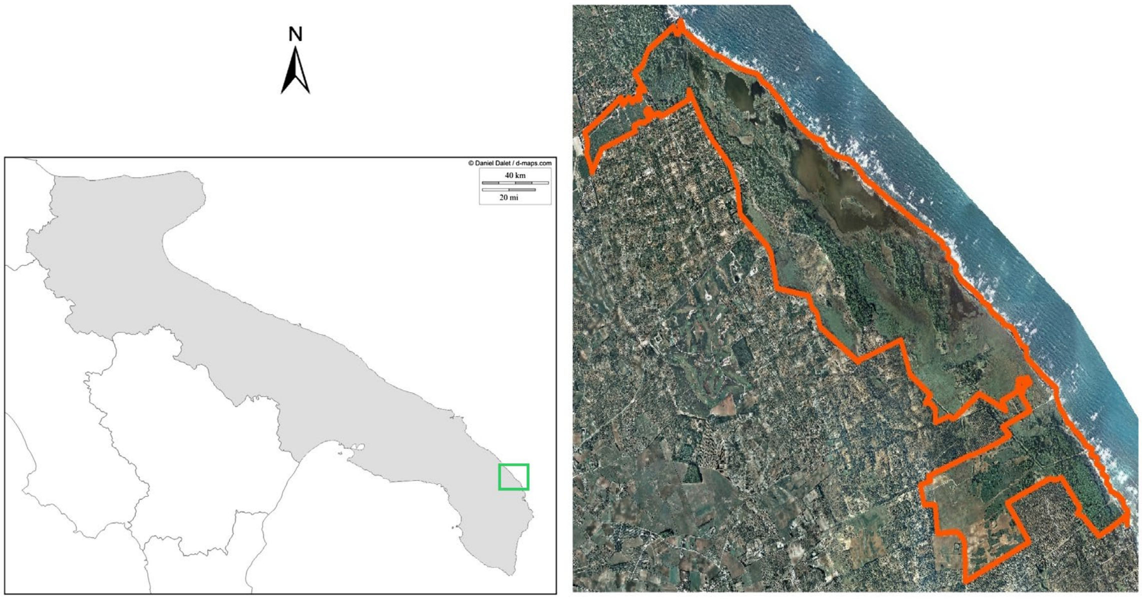

Figure 1. Study site.
Note: In orange, the boundaries of the SCI.

reference taxonomy for the establishment of the red list of European habitats (Rodwell et al. 2013).

LC map

A pre-existing validated LC map (scale 1:5000) in CORINE land cover (CLC) was available from a previous Interreg IIIA Greece–Italy project (InfoNat: Integrated Development of Information System for monitoring and management of Natura 2000 protected areas in Greece and Italy – pilot application in common ecosystems of Greece–Italy. INTERREG IIIA, 2006–2008). CLC classes were converted to LCCS using the LCCS2 software (Di Gregorio & Jansen 2005). Field surveys were carried out in 2011–2013 to validate such classes. A random sampling design within a 250-m cell regular grid, in turn nested within a 1-km cell standard regular grid (INSPIRE), was used (Figure 2); within this grid, 50 circular 50-m radius vegetation plots, randomly distributed throughout the site and covering all the habitat types, were recorded and mapped. For each of these points, information was collected on vegetation composition and structure, crop cover and type. Such information, geocoded by GPS, was integrated into a GIS geodatabase using ArcGIS 10.2 (ESRI Inc.).

Data collection for habitat discrimination (phenology, seasonality, vegetation structure and pattern)

In order to explore and validate the potentiality of information deriving from phenology and water

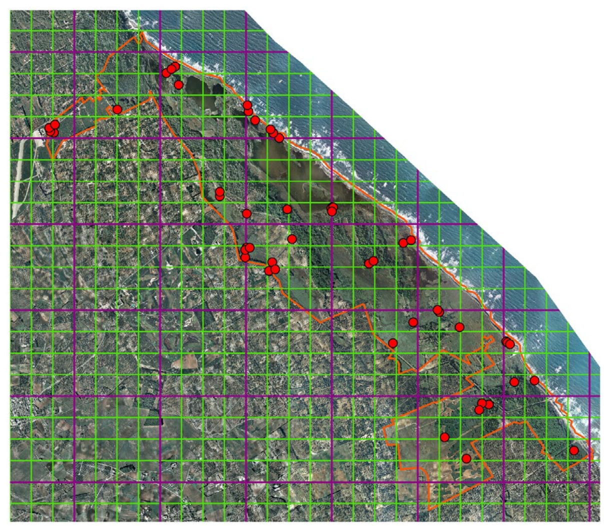

Figure 2. The sampling design.
Notes: In purple, the 1-km cell grid; in green, the 250-m cell grid and, in red, the 50-m radius vegetation plots.

seasonality for habitat discrimination, the seasonal variations of the sampled vegetation–habitat types were surveyed. Phenological data were collected for the plant communities falling within the selected 50 plots for the validation of the LCCS maps. For each plant community, one or more focal species (in the sense of the dominant species giving the vegetation physiognomy) were selected. In general, one species for the almost monospecific communities (e.g. *Phragmites australis* for reed beds) and two or three species for the more complex vegetation types were considered. For

Table I. Phenological scale according to Dierschke (1994).

Woody		Herbaceous (forbs)		Herbaceous (graminoids)	
Stage	Description	Stage	Description	Stage	Description
0	Dormant buds	0	No visible shoots	0	No visible shoots
1	Green buds	1	Shoots without unfolded leaves	1	Shoots without unfolded leaves
2	First leaves	2	First unfolded leaf (development at 25%)	2	First unfolded leaf
3	Leaves production at 25%	3	2–3 unfolded leaves (development at50%)	3	2–3 unfolded leaves
4	Leaves production at 50%	4	Several unfolded leaves (develop. at 75%)	4	First development of the stem
5	Leaves production at 75%	5	Almost all leaves unfold.	5	Stem partially developed
6	Leaves production completed	6	Full development	6	Plant fully developed
7	First leaves turning yellow	7	Starting of withering	7	Starting of withering
8	Leaves turning yellow at 50%	8	Withering at 50%	8	Withering at 50%
9	Leaves turning yellow at 75%	9	Withering more than 50%	9	Withering more than 50%
10	Leaves turning yellow more than 75%	10	Epigeal part fully withered	10	Epigeal part fully withered
11	Leaves fallen	11	Epigeal part disappeared	11	Epigeal part disappeared

each community, the phenological stages of a group of individuals representing the entire population (15–20, depending on the vegetation type) were recorded and then the average of the recorded values was calculated to obtain the population phenology. When more than one dominant species were present in a plant community, a weighted average of the population phenology was used. The phenological stages were observed for two years (2012–2013), at monthly intervals. Both vegetative and generative stages of each selected species were recorded applying the Dierschke's scale (Dierschke 1994) (Table I).

To collect information on water seasonality, the presence and depth of surface water were recorded at monthly intervals. Water depth was measured by means of a cm-marked sampling rod at regularly spaced points along sampling transects arranged perpendicularly to the edge of the water bodies. Thereby, the "seasonality" or the trend of the flooding and dry period for each aquatic habitat type or plant community (shrub and herbaceous, annual and perennial plant communities subject to flooding) was delineated throughout the year.

In order to investigate the application of topological rules for LC to habitat translation based on vegetation pattern, available literature on ecological gradients and vegetation pattern relationships in Mediterranean coastal wetlands was examined (Doing 1985; Alvarez-Rogel et al. 2000; Acosta et al. 2007; Cutini et al. 2010; Feola et al. 2011). For the identification of the habitat types and the description of the vegetation zonation, the obtained information was integrated to field research carried out in the framework of previous works on the study site (Tomaselli et al. 2011; Medagli et al. 2015).

For the correlation between vegetation types and habitat types, we referred to the Italian Interpretation Manual for the Habitats of Directive 92/43 EEC (Biondi et al. 2009), to the Interpretation Manual of EU Habitats (European Commission 2013) and to Schaminée et al. (2012).

Application of rules for habitat mapping

An experimental setting for the exploitation of expert knowledge in LCCS to Annex I/EUNIS habitats translation and the production of a habitat map was carried out.

The input LC map was expressed in LCCS. The rules used for the translation of LCCS to habitat classes include both spatial and temporal relations. Spatial relations include the adjacency (spatial topological) relations among objects in the LCCS map. Temporal relations refer to phenology and water seasonality. On the basis of the phenological properties of vegetated classes (temporal relations), two WorldView2 images, 2 m spatial resolution, obtained in the data warehouse of the FP7 BIO_SOS project (www.biosos.eu) were acquired in June and November 2013, the crucial periods (maximum and minimum of the biomass) for habitat discrimination in the study site. The Green/Red Ratio index (Ritchie et al. 2010), defined as the ratio of green (546 nm) to red (659 nm) reflectance, was used as a proxy to define the photosynthetic status of vegetation. The linearity (geometric) attribute was also considered as a discriminant feature for some coastal habitat types (Tomaselli et al. 2012; Adamo et al. 2016). The requirement of linearity in the shape of a patch (object) was extracted within the eCognition software based on the length/width ratio (Trimble 2011). The rule set, based on the use of both temporal and spatial relations (including topological), was developed with eCognition software by Definiens.

Results

LCCS classes

The complete list of LC classes and associated natural and semi-natural habitat types is provided in Supplementary material.

As evidenced in Tomaselli et al. (2013), having Le Cesine site as a case study, on the basis of LCCS classifiers and environmental attributes, some ambiguous classes can be well discriminated in habitat types. In other cases, ambiguities remain unsolved. In this case, and also when data related to environmental attributes are not available, or not sufficient, alternative information can be used, as illustrated in the following sections.

Phenology and seasonality

For each habitat type, both vegetative (veg) and generative (gen) phenological stages were recorded, though only the vegetative ones are useful for our purposes. Some woody habitat types are characterized by an evergreen canopy layer (foreground) and an herbaceous layer (background), having different phenological signatures (e.g. G2.91 – Olive groves; G3.F1 – Pine plantations; F6.2C – Garrigues). In these cases, the phenological data were recorded separately for each of the layers. A synthesis of the collected phenological data is given in Table II, while a schematic presentation of the recorded vegetative data is given in Figure 3. Different colors correspond to different phenological stages and each row shows the phenological signature of each habitat type. Some habitat types belonging to the same LC class may be separated on the basis of their phenological signature. This is the case of the class LCCS A12/A2.A5.E7 (natural terrestrial vegetation/herbaceous, forbs, annual), including habitats 1210 (Annual vegetation of drift lines) and 6220 (Pseudo-steppe with grasses and annuals of the *Thero-Brachypodietea*). These are both annual vegetation types of sandy soils with similar morpho-structural features, but show a clear shift between corresponding vegetative cycles and phenological stages. Nevertheless, phenology rules are not always effective, as in the case of class A24/A2.A6.E6 (natural aquatic vegetation/herbaceous, graminoids, perennial), including five habitat types of aquatic herbaceous vegetation, all sharing the same phenological signature.

In Figure 4, the schematic representation of water seasonality recorded on a monthly basis is given for the aquatic habitat types.

Some aquatic habitat types are well characterized by both phenology and water seasonality. This is the case of the habitats 1310 (*Salicornia* and other annuals colonizing mud and sand) and 3170 (Mediterranean temporary ponds), belonging to the same LCCS class A24/A2.A5.E7 (natural aquatic vegetation/herbaceous, forbs, annual), and well separated on the basis of both their phenological signature and water seasonality (Figures 3 and 4). Figure 5 shows the annual herbaceous halophilous vegetation of salt marshes assigned to the habitat type 1310 (*Salicornia* and other annuals colonizing mud and sand) in different seasons. Different stages related to phenology and water seasonality are clearly detectable in specific periods of the year.

Vegetation pattern: adjacency rules and topological relations

The analyzed plant communities are distributed in three main spatially differentiated zones, as schematically reported in Tables IIIa and IIIb.

Nevertheless, the described sequences are ideal generalizations and the complete expected zonation is present only where disturbance is not significant. As an example, the erosion of the dune belt, along with several types and degrees of human pressures, has caused strong reduction to the extent of the dune habitat types 2120 (shifting dunes along the shoreline with *Ammophila arenaria* (“white dunes”)) and 2250 (coastal dunes with *Juniperus* spp.), with important changes in the dune habitat sequence.

Application of rules for habitat mapping: LCCS to habitat synchronization based on temporal and spatial relations

In Table IV, the set of the rules used for the mapping is summarized; only the LCCS classes characterized by a one-to-many type of correspondence with habitats are reported.

For objects labeled as LCCS class A12/A2.A5.E7 (natural terrestrial vegetation/herbaceous, forbs, annual) the discrimination to the three output habitats (i.e. X/E1.6, 6220/E1.313 and 1210/B1.1), the geometric rule (i.e. habitat shape linearity) was first adopted to identify objects belonging to habitat 1210/B1.1 (annual vegetation of drift lines/sand beach drift lines), due to the intrinsic “elongatedness” of this habitat. To discriminate the remaining objects as habitat X/E1.6 (X/Subnitrophilous annual grasslands), which is generally green in November, or habitat 6220/E1.313 (Pseudo-steppe with grasses and annuals of the *Thero-Brachypodietea*/Mediterranean annual communities of shallow soils), which is not, a phenology rule could be used. However, since 6220/E1.313 is very sensitive and grows rapidly with episodic rain events and temperatures still high in November (for southern Italy), the phenology rule might be affected by the rainfall regime. In such cases, the phenology rule should be substituted by a topological rule concerning the adjacency of 6220/E1.313 to habitat X/F6.2C (X/Eastern *Erica* garrigues). This last rule is strictly site-specific. In fact, the adoption of such a kind of rule is justified for habitats 6220/E1.313 and X/F6.2C as they both correspond to different growth stages of the same vegetation dynamic series and thus can be assumed to

Table II. Synthesis of the phenological (vegetative) data recorded in 2012–2013 for all natural, semi-natural, and agricultural habitats.

LCCS	For/back	EUNIS	Annex I	7 November 2012		6 December 2012		15 January 2013		11 February 2013		27 March 2013		20 April 2013		17 May 2013		12 June 2013		11 July 2013		8 August 2013		8 September 2013		15 October 2013	
				Veg	Gen	Veg	Gen	Veg	Gen	Veg	Gen	Veg	Gen	Veg	Gen	Veg	Gen	Veg	Gen	Veg	Gen	Veg	Gen	Veg	Gen	Veg	Gen
A11/A1.A7.A9.W8	For	G2.91	\	6	10\11	6	10	6	0	6	0	6	0	6	0	6	0	6	0	6	0	6	0	6	0	6	0
A11/A1.A7.A9.W8	Back	G2.91	\	3\5	0	4\6	0	6	6\7	6	7\10	6	7\10	6\7	7\11	10\11	11	11	0	11	0	11	0	11	0	2\3	0
A11/A1.A8.A9.W7	For	G3.F1	\	6	–	6	–	6	–	6	–	6	–	6	–	6	–	6	–	6	–	6	–	6	–	6	–
A11/A1.A8.A9.W7	Back	G3.F1	\	6	7\10	6	11	6	11	6	2	6	2\4	6	6\7	6	7\11	6\7	7\11	6\9	11	10	0	10	0	2\4	0
A12/A1.A4.D1.E1	\	F5.514	\	6	10\11	6	10\11	6	0	6	0	6	0	6	0\2	6	2\4	6	4\5	6	6\7	6	7\10	6	7\10	6	10
A12/A1.A4.D1.E1	For	F6.2C	\	6	5\7	6	8\10	6	9\11	6	9\11	6	9\11	6	0	6	0	6	0	6	1\2	6	2\4	6	4\6	6	6\10
A12/A1.A4.D1.E1	Back	F6.2C		11	0	3\4	0	4\5	0	4\6	2\6	6	7	6\7	7\10	8\10	11	10	11	10\11	11	11	0	11	0	11	0
A12/A1.A4.D2.E1	\	B1.63	2250	6	10\0	6	10\0	6	10\0	6	10\2	6	10\6	6	10	6	10	6	10	6	10	6	10	6	10\11	6	10\11
A12/A1.A4.D1.E2	\	F5.51	\	6	10\11	6	10\11	6	0	6	0	6	0	6	0	6	3\4	6	6\7	6	10	6	10	6	10	6	10\11
A12/A2.A5.E7	\	E1.6	\	4\6	0	6	0	6	5\6	6	6\7	6	7\10	6	7\10	7\10	10\11	10\11	11	11	0	11	0	11	0	4\5	0
A12/A2.A5.E7	\	E1.313	6220	11	0	3\4	0	4\5	0	4\6	2\6	6	7	6\7	7\10	8\10	11	10	11	10\11	11	11	0	11	0	11	0
A12/A2.A5.E7	\	B1.1	1210	7	7\10	9	0	10	0	4\5	0	6	4\6	6	6\7	6	7\10	6	10	6	11	6	11	6\7	7\11	7\8	7\11
A12/A2.A6.E6	\	B1.31	2110	8\10	11	9\10	11	9\10	11	9\10	11	4\5	0	5\6	1\3	6	4\6	6	7\10	6	10\11	6\7	11	7\8	11	8\10	11\0
A24/A2.A5.E7	\	C3.421	3170	7\10	11	9\10	11	–	–	–	–	1\3	0	3	0	5\6	0	6	0	6	2\6	6	6\10	6	7\10	6\10	7\11
A24/A2.A5.E7	\	A2.55	1310	6\7	10	–	–	–	–	–	–	–	–	–	–	–	–	0\2	0	3\4	0	4	0	5\6	1\2	6	5\7
A24/A2.A6.E6	\	A2.522	1410	6\8	10\11	9	11	9	10\11	6\9	10\11	6\9	0	6	0\2	6	0\6	6	0\7	6	0\10	6	0\10	6	3\10	6\7	6\11

A24/A2.A6.E6	\	D5.24	7210	6\7	11	7\8	11	7\9	11	7\9	11	5\6	0	6	3\4	6	6\7	6	7\10	6	10	6	10	6	10\11	6\7	11
A24/A2.A6.E6	\	A2.53C	\	8\9	11	9	11	10	11	10	11	4\5	0	5\6	0	6	0	6	0	6	2\3	6	3\4	6	7\10	6\7	10
A24/A2.A6.E6	\	C3.31	\	7\8	11	9\10	11	10	11	10	11	10	11	4\5	0	5\6	0	6	0	6	0	6	3\6	6	7\10	6\7	11
A24/A2.A5.E6	\	X03	1150	–	–	–	–	–	–	–	–	–	–	6	0	6	6\7	6	7\10	6	10	6	10\11	6	–	6	–

be adjacent. Even though the elicitation of such rules appears complex, once defined, their implementation allows automatic regular (how frequently is needed) updating of the site habitat maps to monitor changes, with consistent reduction of in-field campaigns' cost. Such campaigns can be limited to only places where changes are detected.

The adjacency topological rule alone was used for translating objects labeled as LCCS class A12/A1.D2.E1 (natural terrestrial vegetation/woody, needle-leaved, evergreen) into habitat 2250/B1.63 (Coastal dunes with *Juniperus* spp./Dune *Juniperus* thickets) and/or X/G3.F1 (X/Native conifer plantations), as the former is adjacent to habitat 2110/B1.31 and the latter is not. The same type of rule was also applied for discriminating objects labeled as LCCS class A24/A2.A5.E7 (natural aquatic vegetation/herbaceous, forbs, annual) in the input LC map to output habitat 3170/C3.421 (Mediterranean temporary ponds/short Mediterranean amphibious communities) and/or 1310/A2.55 (*Salicornia* and other annuals colonizing mud and sand/pioneer saltmarshes), with this adjacent to the lagoon 1150/X03. Such adjacency rules, which are based on widely generalizable and easily recognizable patterns, also in other Mediteranean areas, could probably be successfully applied also in other similar sites.

The discrimination of objects labeled as LCCS A24/A2.A6.E6 (natural aquatic vegetation/herbaceous, graminoids, perennial) into output habitats 1410/A2.522 (Mediterranean salt meadows (*Juncetalia maritimi*)/Mediterranean *Juncus maritimus* and *Juncus acutus* saltmarshes), 7210/D5.24 (Calcareous fens with *Cladium mariscus* and species of the *Caricion davallianae*/Fen *Cladium mariscus* beds), X/A2.53C (X/Saline beds of *Phragmites australis*) and X/C2 (X/Surface running waters), was more complex and involved geometric (linearity) and topological (adjacency) rules.

In Figures 6 and 7 two subsets of the output habitat map, along with the input LC map, relevant to two different subsets of the analyzed area are shown. In Figure 6, the case of two objects labeled as A24/A2.A5.E7 (natural aquatic vegetation/herbaceous, forbs, annual) in the LC map (Figure 6(a)) corresponding to the habitat types 1310/A2.55 (*Salicornia* and other annuals colonizing mud and sand/Pioneer saltmarshes) and 3170/C3.421 (Mediterranean temporary ponds/Short Mediterranean amphibious communities), respectively, on the habitat map (Figure 6(b)), is reported. In this case, the adjacency to the habitat 1150/X03 (coastal lagoons) is the expert rule used. In Figure 7(a), in yellow color, the LC class A24/A2.A6.E6 (natural aquatic vegetation/herbaceous, graminoids, perennial) is labeled as habitat class 1410/A2.522 (Mediterranean salt meadows (*Juncetalia maritimi*)/Mediterranean *Juncus*

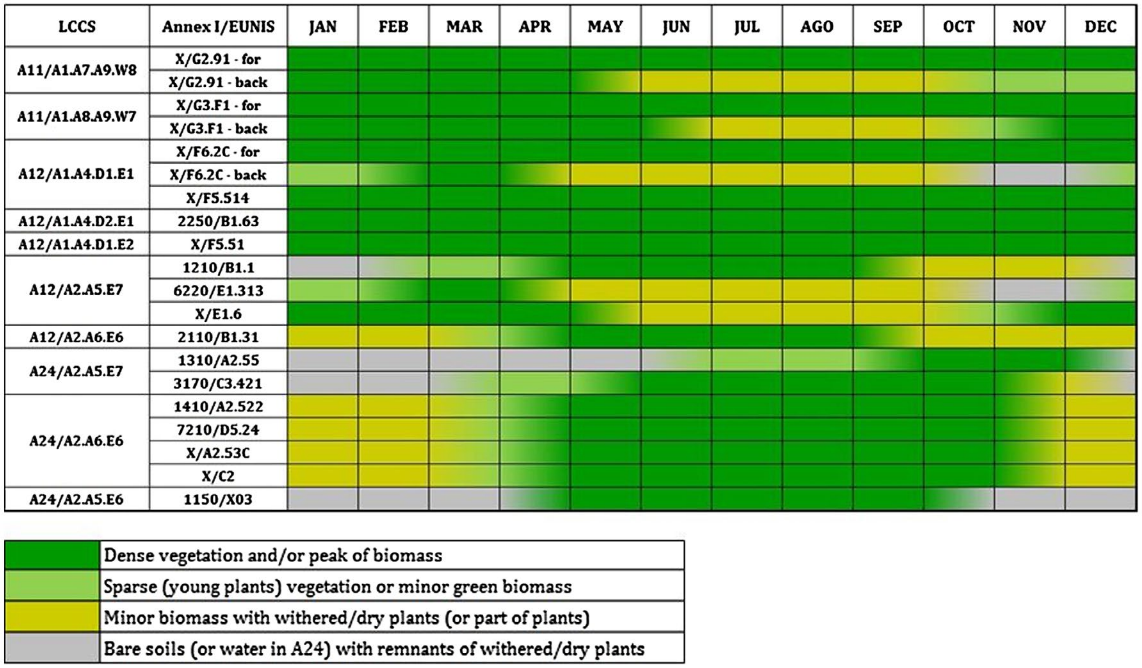

Figure 3. Visual representation of the vegetative data recorded in 2012–2013 for all natural, semi-natural, and agricultural habitats.
Notes: For those habitat types characterized by an evergreen canopy layer (foreground, "for") and an herbaceous layer (background, "back"), the corresponding phenological signatures are represented separately.

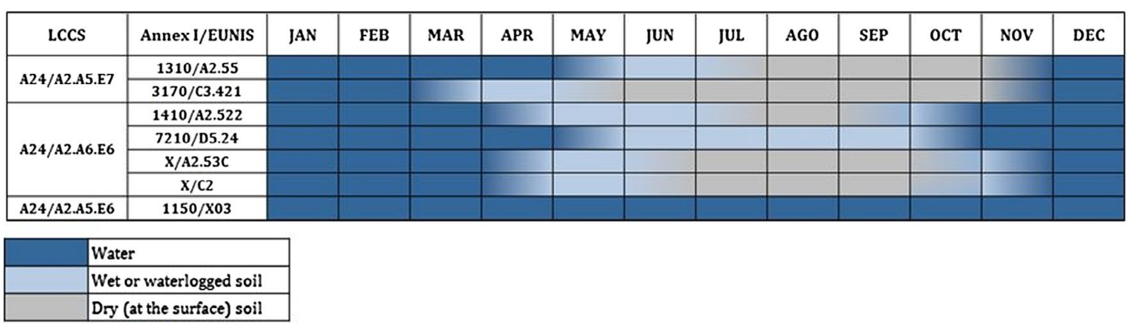

Figure 4. Visual representation of the water seasonality recorded, on a monthly basis, for the aquatic habitat.

Table IIIa. Spatial pattern of the brackish wetland plant communities.

Zone	Pattern of flooding	Characterized by (vegetation)	Annex I taxonomy	EUNIS taxonomy	Habitat description
Inner/central zone	Permanently flooded	*Potamion pectinati*	1150	X03	Brackish coastal lagoons
Middle zone	Irregularly flooded	*Soncho-Cladietum marisci; Phragmitetum communis*	7210; X	D5.24; A2.53C	Fens with *Cladium mariscus*; *Phragmites australis* beds
Upper/external zone	Rarely flooded	*Phragmitetum communis*	X	A2.53C	Saline beds of *Phragmites australis*

maritimus and *Juncus acutus* saltmarshes) (Figure 7(b)), verifying the adjacency rule to 1150/X03 and the elongated shape. The output habitat map was validated using reference randomly selected samples on the image and validated by *in situ* campaigns. The final OA (75.1% with error tolerance 5.0%) was lower than the one (97.0% with error tolerance 2.1%) obtained with environmental attributes alone in Tomaselli et al. (2013), but still significant as the proposed knowledge-based approach was utilized without incorporating any ground truth data for habitat mapping.

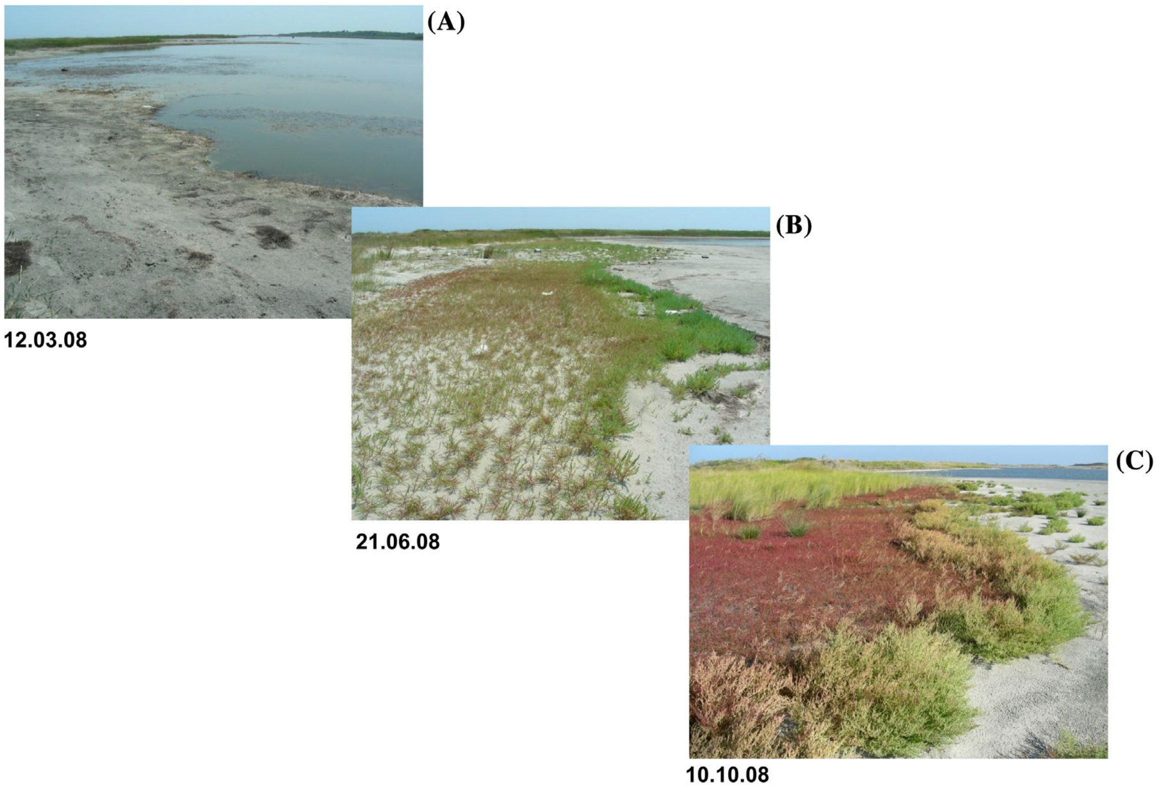

Figure 5. Pictures taken in correspondence of the coastal site of Le Cesine, respectively, in winter (a) – flooding period, spring (b) – peak of productivity and autumn (c) – when the land dries up and representing habitat 1310 (Salicornia and other annuals colonizing mud and sand, subtype 15.11 – Glasswort swards (Thero-Salicornietalia)) in different phenological and seasonal stages.

Table IIIb. Spatial pattern along the dune beds.

Zone	Characterized by (vegetation)	Annex I taxonomy	EUNIS taxonomy	Habitat description
First belt	*Cakiletea maritimae*	1210	B1.1	Annual vegetation of drift lines
Second belt	*Ammophiletea* (*Elymus farctus*)	2110	B1.31	Embryonic shifting dunes
Third belt	*Ammophiletea*(*Ammophila arenaria*)	2120	B1.32	White dunes
Fourth belt	*Juniperion turbinatae*	2250	B1.63	Coastal dunes with *Juniperus* thickets

Table IV. Summary of the rule types used for LC to habitat translation in Le Cesine.

		Rule type		
LCCS	Habitat	Adjacency	Linearity	Phenology
A12/A1.D2.E1	X/G3.F1	X		
	2250/B1.63	X		
A12/A2.A5.E7	X/E1.6	X	X	X
	6220/E1.31	X	X	X
	1210/B1.1		X	
A24/A2.A5.A7	3170/C3.421	X		
	1310/A2.41	X		
A24/A2.A6.E6	1410/A2.522	X	X	
	7210/D5.24	X	X	
	X/A2.53C	X	X	
	X/C2	X	X	

Discussion and conclusions

When attempting to define rules for the translation from LCCS classes to Annex I or EUNIS habitat types, additional information is required (Adamo et al. 2016). Part of this information is already defined by the criteria forming the basis of LCCS environmental attributes. Nevertheless, the above-mentioned information may not be sufficient or, even when this information is available, it often lacks

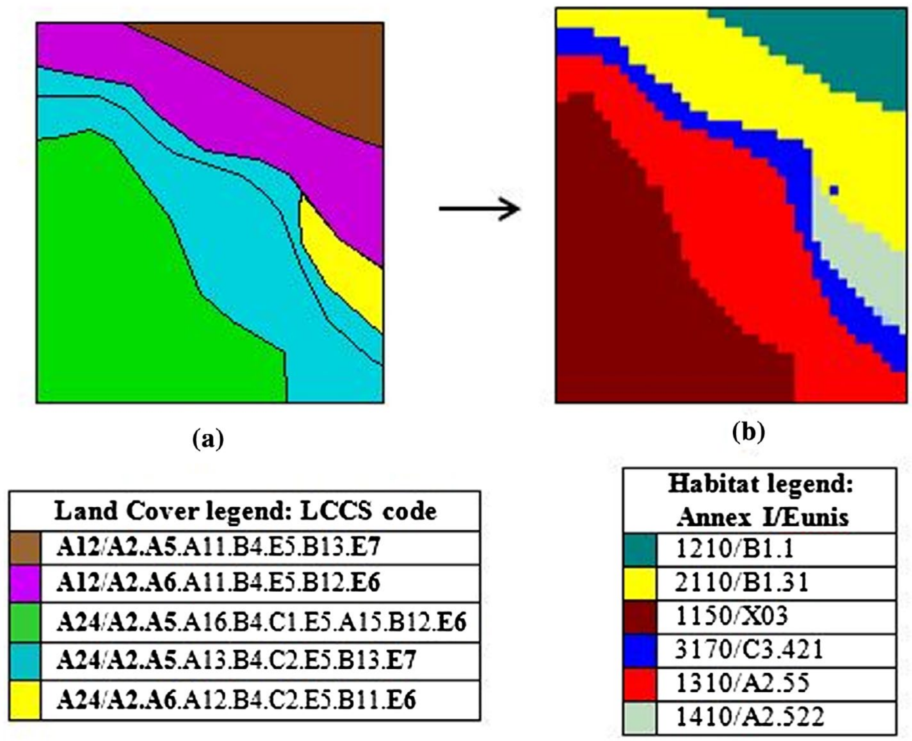

Figure 6. (a) In cyan color, land cover class **A24/A2.A5**.A13.B4.C2.E5.B13.**E7** split in two different patches which are labeled as habitat class 1310/A2.55, verifying the adjacency rule to 1150/X03 or as habitat class 3170/C3.421 verifying the not adjacency rule, respectively, in red and in pink in (b).

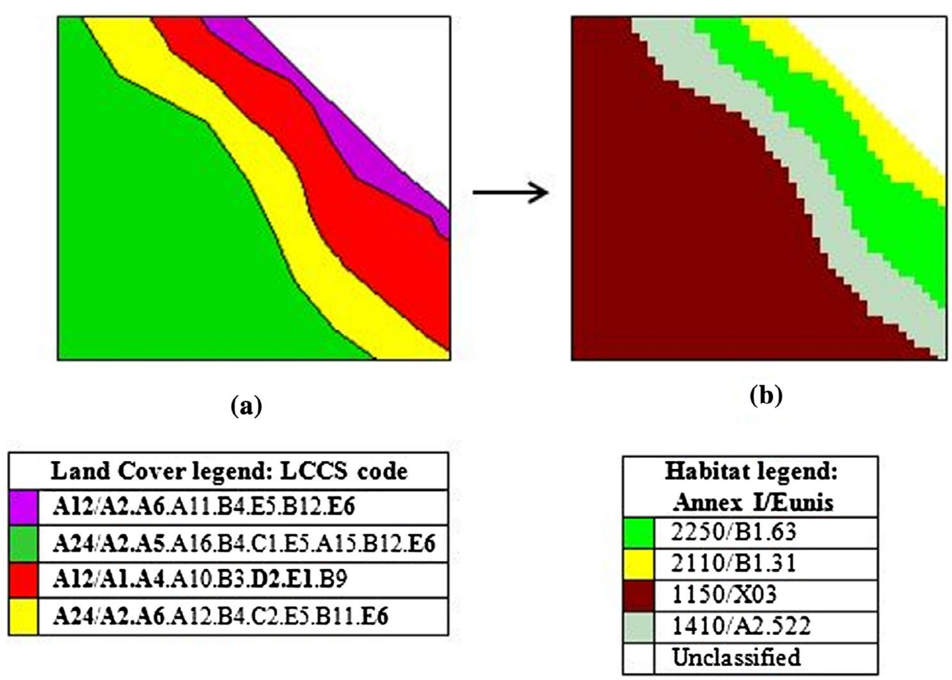

Figure 7. (a) In yellow color, land cover class **A24/A2.A6**.A12.B4.C2.E5.B11.**E6** labeled as habitat class 1410/A2.522 (b), verifying the adjacency rule to 1150/X03 and the elongated shape.

consistency. In fact, partial data-sets can be supplied by Public Services or Research Institutions but, when attempting to harmonize such information, major inconsistencies arise, often due to different data collecting protocols depending on their specific purposes.

Plant communities sharing the same LCCS class may be discriminated by different phenological signatures. The experimental mapping demonstrated that expert knowledge related to temporal relations, in terms of class phenology and water seasonality, spatial relationships (adjacency), and shape features can be integrated and exploited for habitat discrimination. The resulting OA (75.1%) is significant as provided without any ground truth.

For an effective spatial and temporal match of in-field data and RS data, a careful selection of multi-seasonal images should be carried out before any classification. The experimental setting demonstrated that expert knowledge related to temporal relations, in terms of class phenology and water seasonality, is an essential prerequisite for an appropriate selection of multi-temporal RS image for LC/LU and habitat monitoring over time. At the same time, phenology and seasonality rules as described above require specific expert knowledge and consistency of the field data collection. Phenology and water seasonality are criteria included in the LCCS (version 2), but with different meanings. In fact, phenology refers only to leaf phenology. Regarding water seasonality, it refers to the length of flooding period but without giving more specific information (i.e. the specific season). In such form, this information has a limited potential for class discrimination at habitat level. In the new version (version 3) of LCCS, based on a land cover metalanguage, the opportunity to exploit temporal relationships is provided. Temporal relationships relate two or more "objects" through temporal correlation, thus providing the possibility to define some seasonal conditions.

Adjacency rules are based on vegetation pattern and appear particularly effective in the case of coastal environments, due to the close correlation between ecological gradients and vegetation pattern. In the case of the study site Le Cesine, the observed spatial patterns are in accordance with the existing literature for central-southern Italian peninsula and Puglia region (Frondoni & Iberite 2002; Biondi & Casavecchia 2010; Cutini et al. 2010; Sciandrello & Tomaselli 2014). Nevertheless, the complete expected zonation pattern is observed only where disturbance is not significant.

In any case, the entire vegetation pattern could not be adequately explained only on the basis of the underlying environmental factors, especially at coarse spatial scales. Their complex interactions and combinations have also to be taken into account and related with the spatial heterogeneity of soil properties and other micro-ecological factors, such as soil texture, micro-topography, and organic matter (Adam 1990; Silvestri et al. 2005). Moreover, coastal ecosystems are affected by many disturbance factors (Van der Maarel 2003). Human activities cause habitat loss, alteration, fragmentation, and isolation, resulting in significant changes at the general spatial pattern (Malavasi et al. 2016). For example, a complete sequence of sand dune communities can be observed when disturbances have not significantly affected the dunes. In most cases, the "ideal" sequence is rarely complete and, in case of strong disturbances, regression effects may also occur. In particular, when erosion takes place, the different zones become mixed or inverted (Doing 1985; Acosta et al. 2007). Moreover, fragmentation affects certain shape properties of some specific vegetation classes, such as the elongatedness of some coastal habitat types. As for coastal sites that include wetland habitats, the peripheral belts and the surrounding areas are particularly subjected to extent reduction, loss or various types of changes, mainly due to the influence of human activities (farming, grazing, and tourism), which mostly induce extensive landscape and vegetation pattern modifications.

In some cases, habitat modifications in wetland areas, especially at the early stages, are not well detectable by means of RS data. In the case of the study site, halophytic scrub communities have replaced sedge and reed communities over time, due to the water salinization during the last decades. This phenomenon does not occur in the whole wetland, but it is limited to the back-dune zone. This modification is, at present, detectable only by field surveys and not by RS imagery, due to its discontinuous distribution and micro-pattern vegetation mosaic (scrubs and reeds or sedges intermixed in a fine vegetation mosaic).

The extraction of a general scheme relevant to most of the sites is not so straightforward, especially due to human influence and disturbances. The suggested approach should be applied to other sites distributed along Mediterranean coastal areas, in order to verify its reliability and the extent to which it could be generalized. The methodology could also be extended to other habitats and in environments different from the coastal site locations; in this case, other variables such as elevation, exposure, micro-climatic conditions should be taken into account. The effectiveness of the LC-to-habitat translation process depends on the extent of knowledge about habitat ecological features, as well as the availability of context information and ancillary data. In any case, when defining and applying general adjacency or topological rules based on spatial vegetation pattern, a precise knowledge of micro-ecological variables such as soil moisture, soil type, water table level, micro-topography, as well as local expert information is required.

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Supplemental data

Supplemental data for this article can be accessed [http://dx.doi.org/10.1080/11263504.2016.1231143].

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