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

Deliverable No: 6.3

Pre-evaluation and rank sampling

Due date of deliverable:	30-11-2011
Actual submission date:	5-12-2011
Version:	2nd version of D6.3
Main Authors:	Paola Mairota (P8), Luigi Boccaccio (P8), Rocco Labadessa (P8), Vincenzo Leronni (P8). Dr. Barbara Cafarelli from the University of Foggia (Italy) has contributed to D6.3 by collaborating for free with P8 for the landscape pattern indices statistical analysis. The LCCS map used in D6.3 was derived from a CORINE map by: Valeria Tommaselli (P1) and Cristina Tarantino (P1)

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

Deliverable title	Pre-evaluation and rank sampling
Deliverable number	D6.3
Deliverable version	Version 2
Previous version(s)	Version 1
Contractual date of delivery	30 November 2011
Actual date of delivery	05 December 2011
Deliverable filename	BIO_SOS_D6.3
Nature of deliverable	R
Dissemination level	PU = Public,
Number of pages	57
Workpackage	WP6 Task 6.2
Partner responsible	UNIBA (P8)
Author(s)	Paola Mairota, Luigi Boccaccio, Rocco Labadessa, Vincenzo Leronni Barbara Cafarelli (P8) Dr. Barbara Cafarelli from the University of Foggia (Italy) has contributed to D6.3 by collaborating for free with P8 for the landscape pattern indices statistical analysis. The LCCS map used in D6.3 was derived from a CORINE map by: Cristina Tarantino (P1) and Valeria Tommaselli (P1)
Editor	Paola Mairota (P8)
EC Project Officer	Florence Beroud

Abstract	Different kinds of approach to landscape configuration analysis were applied to a benchmark landuse/land cover map. A pre-evaluation landscape pattern analysis (LPA), a morphological spatial pattern analysis (MSPA) a landscape mosaic analysis and a landscape variation analysis, were carried out. These analyses provide a site and scale specific composite set of indices which can be used as a change biodiversity indicator set with reference to the CBD-SEBI focal areas: status and trends of the components of biological diversity, Ecosystem integrity, and ecosystem goods and services.
Keywords	Landscape pattern analysis, morphological spatial pattern analysis, landscape mosaic analysis, landscape variation analysis habitat fragmentation, biodiversity, indicators,

	sampling.

Signatures

Written by	**Responsibility- Company**	**Date**	**Signature**
Paola Mairota	Responsible for D6.3, UNIBA	1-DEC-2011	
Verified by			
Harini Nagendra	WP6 Leader, ATREE	30 Nov. 2011	
Approved by			
Maria Petrou	Quality Manager, CERTH	5 Dec. 2011	
Palma Blonda	Project Coordinator, CNR	5 Dec. 2011	

Table of Contents

1. Executive summary

D6.3 is a Deliverable of WP6 Task 6.2 (activity 1) aimed at reporting on the results of the pre-evaluation activities carried out by means of landscape pattern analysis (LPA) and on the ranked set sampling of 1km^2 grid cells. The purpose of the whole exercise, carried out in BIO_SOS site has been consistent with the main goals of the BIO_SOS project (i.e., production of validated land use/ land cover (LU/LC) maps from RS and extraction of indicators for monitoring biodiversity from spatial data).

1) Implementing the 1km^2 grid cells selection protocol in compliance with D4.3 in order to optimise (cost/effectiveness) of the sampling effort for both *in-situ* (in field) campaigns required to support WP5 in the validation of LU/LC maps produced by the EODHaM system, and for further activities to be carried out within WP6, namely those meant at the *in situ* General Habitat Categories (GHCs) identification and those relevant to WP6 Tasks 6.2 and 6.3. Further activities in Task 6.2 and Task 6.3 of WP6 related to those reported in D6.3 will mainly consist of an iteration of the procedure at a more detailed scale (both grain and extent) and on site surveys aimed at relating landscape configuration to selected animal taxa community structure (D4.3 and D6.6) and plant community structure, as well as in functional connectivity analysis at different scales.
2) Testing a landscape pattern analysis (LPA), a morphological spatial pattern analysis (MSPA) a landscape mosaic analysis (Riitters *et al.* 2000 and 2009; Estreguil and Caudullo 2010) and a landscape variation analysis procedure on categorical data in site IT3, aimed at the initial identification of a set of metrics capable of capturing spatially explicit attributes of natural and semi-natural landscape elements, associated with their extent and fragmentation, which can be used as indicators of biodiversity change relevant to the CBD-SEBI (Strand *et al.* 2009) focal areas: status and trends of the components of biological diversity, Ecosystem integrity, and ecosystem goods and services) (D2.1).

D6.3 expands the description of the sampling protocol provided in D4.3 and describes the methodological and operational details of both sampling and LPA procedure in order to provide inputs to WP6 Task 6.7 in which the development of an algorithm for indicator production and their trend evaluation will be carried out.

2. Introduction

The theoretical background assumed for the activities described in D6.3 is provided in D6.2 and partly in D4.3. Therefore, explicit reference to those deliverables is made here, particularly on issues such as those relevant to the definition of patches, to the *scale dependency of the spatial heterogeneity* (Wu 2004), and to the statistical behaviour of the indices (namely their distributions).

For the purposes of WP6 Task 6.2 (activity 1) a pre-evaluation landscape pattern analysis (LPA), a morphological spatial pattern analysis (MSPA) a landscape mosaic analysis (Riitters *et al.* 2000 and 2009; Estreguil and Caudullo 2010) and a landscape variation analysis, were carried out in order to retrieve information on focal LU/LC/GHC/habitat class relative amount, fragmentation *per se* (Fahrig 2003, i.e., independently than habitat loss), habitat vs. non-habitat contrast, and landscape heterogeneity.

These approaches, even though recognised as relevant to the assessment of structural aspects of fragmentation, rather than to functional ones, were considered appropriate (D6.2) to the fulfilment of the mentioned purposes given the nature of the products of the BIO_SOS project, namely EO derived LU/LC/GHCs and habitat maps.

MSPA and landscape mosaic analysis, initially beyond the scope of the BIO_SOS project, were carried out (to test at a regional scale the method proposed by Estreguil and Caudullo (2010)- This is based on the combination of morphologically classified maps with maps of the Landscape Mosaic Index (Wickham and Norton 1994; Riitters et al. 2000 and 2009), yielding a new index, called Similarity index, which is expected to quantify the proportion of edges in an anthropogenic (agriculture, urban) or natural- context (D.6.2).

Finally, the outcomes of both LPA and MSPA were used as inputs for a landscape variation analysis, meant to test the potential of those approaches to provide information on the occurrence of significant discontinuities in the landscape structure related to human pressures.

The composite set of these approaches appear to have the potential to assess changes in landscape pattern over time (as a response to pressures, e.g. anthropogenic driven change), such as those detectable by means of Earth Observation (EO) data. This is a precondition for further research on the ecological consequences of such changes, leading to habitat fragmentation/quality modification and (or, or both) to an increase matrix heterogeneity. Landscape functional connectivity is among such consequences.

3. Landscape pattern analysis (LPA) Morphological Spatial Pattern Analysis (MSPA), landscape mosaic analysis and landscape variation analysis on categorical data in IT3

In the IT3 BIO_SOS site ("Murgia Alta" IT9120007 SCI/SPA; Figure 3.1), LPA and MSPA were carried out with the aim of exploring the existence of a fragmentation gradient associated with a regime of decreasing protection that crossed areas subject to:

1. Both Natura 2000 (N2K) and the National Park (NP) official boundaries;
2. Only N2K official boundaries (areas of the NK2 site surrounding the NP);
3. Neither N2K nor NP official boundaries (areas outside both the N2K site and the NP).

The second and the third types of area type represent two different kinds of N2K boundaries where different kinds of impact are likely to occur, producing spatially-explicit (i.e., detectable by EO) effects on habitat types (as defined by Annex I of the 92/43/EEC Directive).

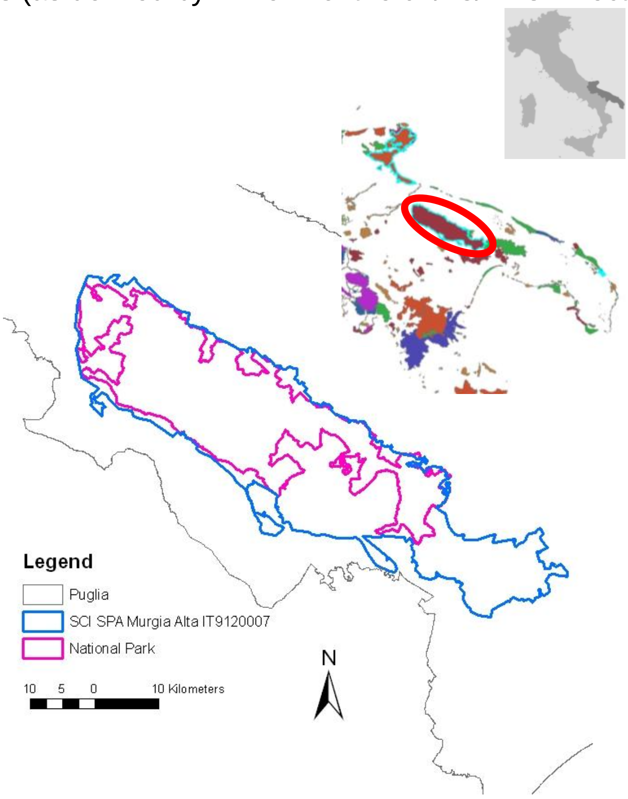


Figure 3.1 - IT3 BIO_SOS site ("Murgia Alta" IT9120007) location map.

3.1 Focal habitat types (Annex I 92/43/EEC Directive) for LPA in IT3

For the purposes of the LPA and MSPA in IT3, grassland ecosystems were considered as focal habitat types. This type of ecosystem is the most characteristic of the IT3 site and represents what remains of the ~80,000 existing at the beginning of the 20th century, due to transitions to other land uses (agriculture/urban).

By the early 1990s grassland extent had dropped to 40,000 ha. Substantial losses of this ecosystem have occurred between 1990 and 2000 (Figure 3.2), mainly due to EU incentives promoting durum wheat production, contemporaneous to the enforcement of the 92/43/EEC Directive. The present extent of natural grasslands is ~29,800 ha (% of the total area of the Natura 2000 site). This was mainly a response to both the enforcement of the 92/43/EEC Directive and the EU incentives to new cereal crop establishment (which were banned in 1994).

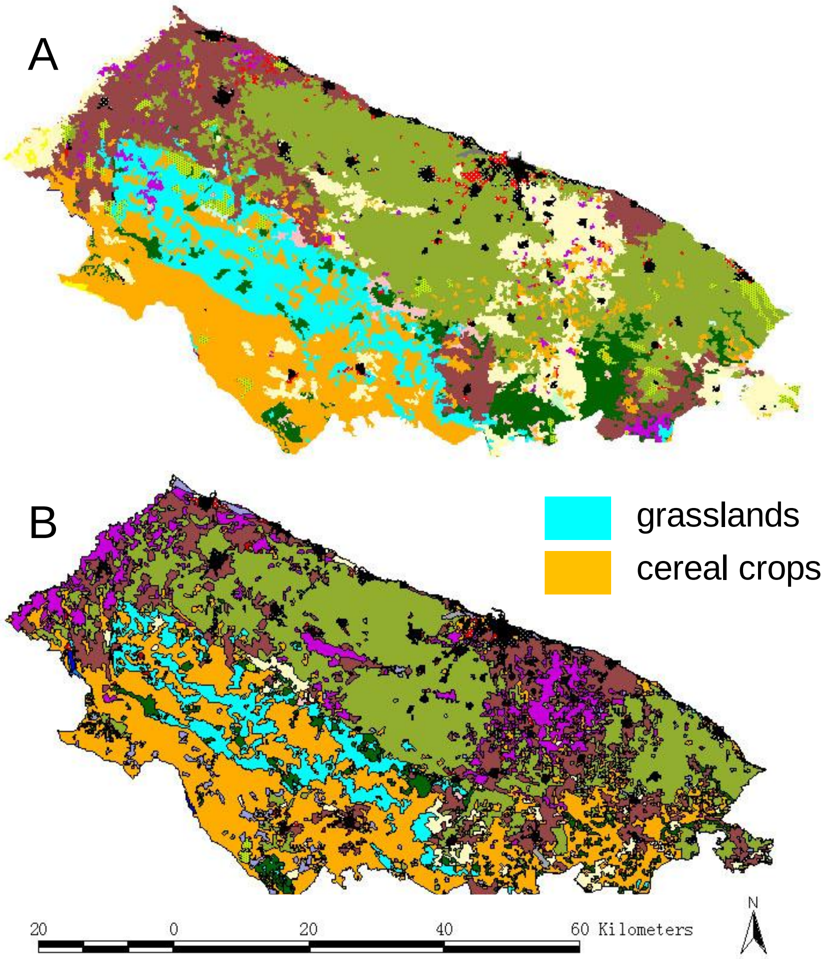


Figure 3.2 – Corine Land Cover changes (3rd level) from 1990 (A) to 2000 (B) in the former Bari province.

Agricultural intensification and land abandonment together provide two of the main pressures on biodiversity linked to these grassland ecosystems. The increasing extension of arable crops contributes directly to the reduction in the extent of semi-natural grassland. In addition, pastures become susceptible to scrub invasion after the decline of traditional management practices. Habitat fragmentation and conversion to bio-fuels or forestry are also increasingly threatening the landscape.

Two habitat types listed in Annex I of the 92/43/EEC Directive are associated with grasslands at the IT3 site (D2.2):

- 62A0 “Eastern sub-mediteranean dry grasslands (*Scorzoneratalia villosae*)”. Before the acceptance of the 62A0 code, these grasslands were considered as 6210 “Semi-natural dry grasslands and scrubland facies on calcareous substrates (*Festuco-Brometalia*)”. Due to their higher richness in endemic and orchid species these would be worth considering as priority habitats. Furthermore, IT3 62A0 grasslands belong to the endemic phytosociological alliance *Hippocrepido glaucae-Stipion austroitalicae*, which is mostly rich in Mediterranean elements and characterised by the priority species *Stipa austroitalica* Martinovsky in association with *Scorzonera villosa* subsp. *columnae*, *Hippocrepis glauca* and *Thymus spinulosus*;
- 6220* “Pseudo-steppe with grasses and annuals of the *Thero-Brachypodietea”*. These include very different (both annual or perennial) grassland communities, with these derived from an extremely intensive land use. However, only few facies among these are of real conservation interest.

As with most European grasslands (EEA 2010), IT3 grasslands can be defined as ‘semi-natural’ because they have developed through a mix of anthropogenic and natural processes including

long periods of grazing by domestic stock, cutting and even deliberate light burning regimes and are modified and maintained by human activities, mainly through grazing and/or cutting regimes (Turbé *et al.,* 2010).

These grasslands are among the most species-rich plant communities in Europe and they host a remarkable set of endemic and orchid species.

Two CLC categories are used for Natural grasslands (EEA 2010): Pastures (231) and Natural grasslands (321), however only the latter occurs within the IT3 site.

More than 100 animal species occurring in IT3 are listed in European Directives or other red lists:

- 33 vertebrate and invertebrate species are listed in Annex II and/or IV of Directive 92/43/EEC,

  Wolf (*Canis lupus*) and Jersey tiger moth (*Euplagia quadripunctaria*) are priority species;

  12 more insect species are listed in other national or international Red lists.
- 12 breeding and about 20 migrant/wintering birds are mentioned in Annex I of Directive 79/409/EEC;

  Lesser kestrel (Falco naumanni) and Lanner falcon (Falco biarmicus) are priority species and species of European conservation concern.

  Little bustard (*Tetrax tetrax*) and Egyptian vulture (*Neophron percnopterus*) are now considered extinct in IT3;
- Many listed bird species (e.g. *Burhinus oedicnemus*, *Coracias garrulus*, *Melanocorypha calandra*, *brachydactyla*, *Anthus campestris*, *Lanius minor*) and endemic insects (e.g. *Decticus loudoni*, *Rhacocleis japygia, Prionotropis appula, Melanargia arge*) are considered grassland specialists.

A check list of the IT3 animal species of conservation concern for IT3 is given, by Class, in tables 3.1-3.5, together with their international conservation status (abbreviations are explained at the bottom of the tables).

Table 3.1- INSECTS listed in Habitat Directive 92/43/EEC or other Red Lists

Species	Be II	Hab	RB It	RL IUCN	Endem	RB But
Coenagrion mercuriale castellani	+	II	VU	NT	+	
Decticus loudoni			VU		+	
Rhacocleis japygia			VU		+	
Saga pedo	+	IV	EN	VU		
Troglophilus andreinii			VU		+	
Onthophilus punctatus cicatricosus			NT			
Margarinotus ignobilis			NT			
Dinothenarus flavocephalus			NT			
Aphodius stoltzi			NT			
Euonthophagus amyntas			NT			
Carcharodus baeticus			NT			4
Muschampia proto			VU			
Gegenes nostrodamus			EN			
Maculinea arion	+	IV	LR			
Zerynthia polyxena	+	IV				
Melanargia arge	+	II, IV	NT	NE	+	4
Thymelicus acteon						2
*Euplagia quadripunctaria**		II		NE		

(*)Priority species, i.e., species subject to special conservation measures concerning their habitat in order to ensure their survival and reproduction in their area of distribution.

Table 3.2- AMPHIBIANS listed in annex II or IV of Habitat Directive 92/43/EEC.

Species	Be II	Hab	RB It	RL IUCN	Endem
Triturus carnifex	+	II, IV			
Triturus italicus	+	IV	LR		+
Bombina pachypus	+	II, IV	LR		+
Bufo balearicus	+	IV			
Hyla intermedia	+	IV			+

Table 3.3- REPTILES listed in annex II or IV of Habitat Directive 92/43/EEC.

Species	Be II	Hab	RB It	RL IUCN	Endem
Testudo hermanni		II, IV	EN	LR (EN)	
Lacerta bilineata		IV			+
Podarcis sicula		IV			
Mediodactylus kotschyi	+	IV	VU		
Coluber viridiflavus		IV			
Coronella austriaca	+	IV			
Elaphe lineatus	+	IV		DD	+
Elaphe quatuorlineata		II, IV	LR		
Elaphe situla		II, IV	LR	DD	
Natrix tessellata	+	IV			

Table 3.4- MAMMALS listed in annex II or IV of Habitat Directive 92/43/EEC.

Species	Be II	Hab	RB It	RL IUCN
Rhinolophus euryale	+	II, IV	VU	NT
Rhinolophus ferrumequinum	+	II, IV	EN	
Rhinolophus hipposideros	+	II, IV	VU	VU
Miniopterus schreibersii	+	II, IV	VU	NT
Myotis blythii	+	II, IV	VU	
Myotis myotis	+	II, IV	VU	
Pipistrellus pipistrellus		IV	VU	
Pipistrellus kuhli	+	IV		
Eptesicus serotinus	+	IV		
Plecotus austriacus	+	IV		
Muscardinus avellanarius		IV		
Canis lupus *	+	II, IV	VU	

(*)Priority species, i.e., species subject to special conservation measures concerning their habitat in order to ensure their survival and reproduction in their area of distribution.

Table 3.5- BIRDS listed in Annex I of Directive 79/409/EEC

Species	Phenology	Be II	SPEC	Eu Threat	RL IUCN	RB It
Ciconia ciconia	M	+	2	V		
Pernis apivorus	M	+	4	S		VU
Milvus migrans	M, B?	+	3	V		VU
Milvus milvus	M, B	+	4	S	NT	EN
Neophron percnopterus	Ex	+	3	E	EN	EN
Circaetus gallicus	M, B	+	3	R		EN

Table 3.5 (continued) - BIRDS listed in Annex I of Directive 79/409/EEC

Species	Phenology	Be II	SPEC	Eu Threat	RL IUCN	RB It
Circus aeruginosus	M, W	+		S		EN
Circus cyaneus	M, W	+	3	V		EB
Circus pygargus	M	+	4	S		VU
Buteo rufinus	M, W	+	3	(E)		
Hieraetus pennatus	M	+	3	R		
Falco naumanni *	M, B	+	1	(V)	VU	
Falco vespertinus	M	+	3	V		NE
Falco columbarius	M, W	+		S		
Falco subbuteo	M	+		S		VU
Falco biarmicus *	M	+	3	(E)		
Falco peregrinus	M	+	3	R		
Grus grus	M	+	3	V		EB
Crex crex	M	+	1	V		EN
Tetrax tetrax *	Ex	+	2	V	NT	
Burhinus oedicnemus	M, B, W?	+	3	V		EN
Eudromias morinellus	M	+		(S)		
Pluvialis apricaria	M, W		4	S		
Philomachus pugnax	M		4	(S)		
Gallinago media	M, W	+	2	(V)		
Caprimulgus europaeus	M	+	2	(D)		
Coracias garrulus	M, B	+	2	(D)	NT	EN
Melanocorypha calandra	B	+	3	(D)		
Calandrella brachydactyla	M, B	+	3	V		
Lullula arborea	M, B, (W)		2	V		
Anthus campestris	M, B	+	3	V		
Ficedula albicollis	M	+	4	S		
Lanius collurio	M, B	+	3	(D)		
Lanius minor	M, B	+	2	(D)		EN

(*)Priority species, i.e., species subject to special conservation measures concerning their habitat in order to ensure their survival and reproduction in their area of distribution.

Conservation and threat status categories and abbreviations in tables 3.1-3.5:

Be II = Species of Annex II of Convention of Berna (Convention on the Conservation of European Wildlife and Natural Habitats), Berna, 1979.

Hab = Annex II or IV of Habitat Directive 92/43/EEC (on the conservation of natural habitats and of wild fauna and flora), May 21 1992.
Annex II: animal and plant species of community interest whose conservation requires the designation of special areas of conservation
Annex IV: animal and plant species of community interest in need of strict protection
An asterisk (*) before the name of a species indicates that it is a priority species.

RL IUCN = IUCN Red list of threatened species, 1994-2009
EX = extinct;
CR = critically endangered;
EN = endangered;
VU = vulnerable;
NT = near threatened;
DD = data deficient;

NE = not evaluated.

RB It = Italian Red Book of Animals (Vertebrates, Invertebrates) using IUCN status categories, WWF Italy 1998-2002

Endem = endemic species or (subspecies)

Phenology (Table 3.5) = Abbreviations: B = breeding; M = migrant; W = wintering; Ex = Extinct

SPEC (Table 3.5) = Species of European Conservation Concern (Birds in Europe: their conservation status. BirdLife 2004).
Four levels of conservation status:
SPEC 1: Global conservation concern
SPEC 2: Unfavourable conservation status, concentrated in Europe
SPEC 3: Unfavourable conservation status, not concentrated in Europe
SPEC 4: Favourable conservation status, concentrated in Europe

RB But (Table 3.1)= Red Data Book of European Butterflies (Rhopalocera) (1999).
Using the same 4 categories of BirdLife (SPECs = Species of European Conservation concern)

Eu Threat (Table 3.5) = European Threat Status (Birds in Europe: their conservation status. BirdLife 2004)
E = endangered
V = vulnerable
R = rare
D = declining
L = localized
S = secure

3.2 Spatial extent and LU/LC map for LPA, MSPA, landscape mosaic analysis and landscape variation analysis in IT3

The spatial extent coincides with the core of the frame of the EO VHR image used (WP5) to produce the base LCCS map (100 km^2 approx.) in order to avoid incomplete 1 km^2 when selecting samples (Figure 3.3). The sampling extent covers parts of the N2K site and the NP as well as areas outside both. Thus, as specified above, three different areas were identified according to a decreasing protection regime: N2K-NP, NP and non- N2K-NP. Two different types of buffer zone (interfaces) were identified, one in which official bindings of the N2K apply but the actual legal provisions for the national park are not in force, the other with neither formal nor legal protection.

For MSPA, landscape mosaic analysis and landscape spatial variation analysis a 2x10km transect was extracted from the landscape extent used in LPA, including the two different types of buffer zones (Figure 3.3).

All the analysis were carried out on a pre-existing thematic map (Figure 3.4) as the EODHaM LCCS map was still in preparation (P1). Namely an LCCS map was used which was obtained by the reclassification of the existing ancillary LC/LU map (2006, 1:5000 nominal scale) by means of a site specific correspondence table (Table 3.6) assembled by P1 according to the rules set in D6.1 and in D6.10.

These types of map are regarded as non-alternative but complementary in the BIO_SOS project and are purposely used to initially stratify the landscape for subsequent sampling within the logical sequence steps to be undertaken for the validation of the LCCS/GHC maps (D4.3, section 3.2).

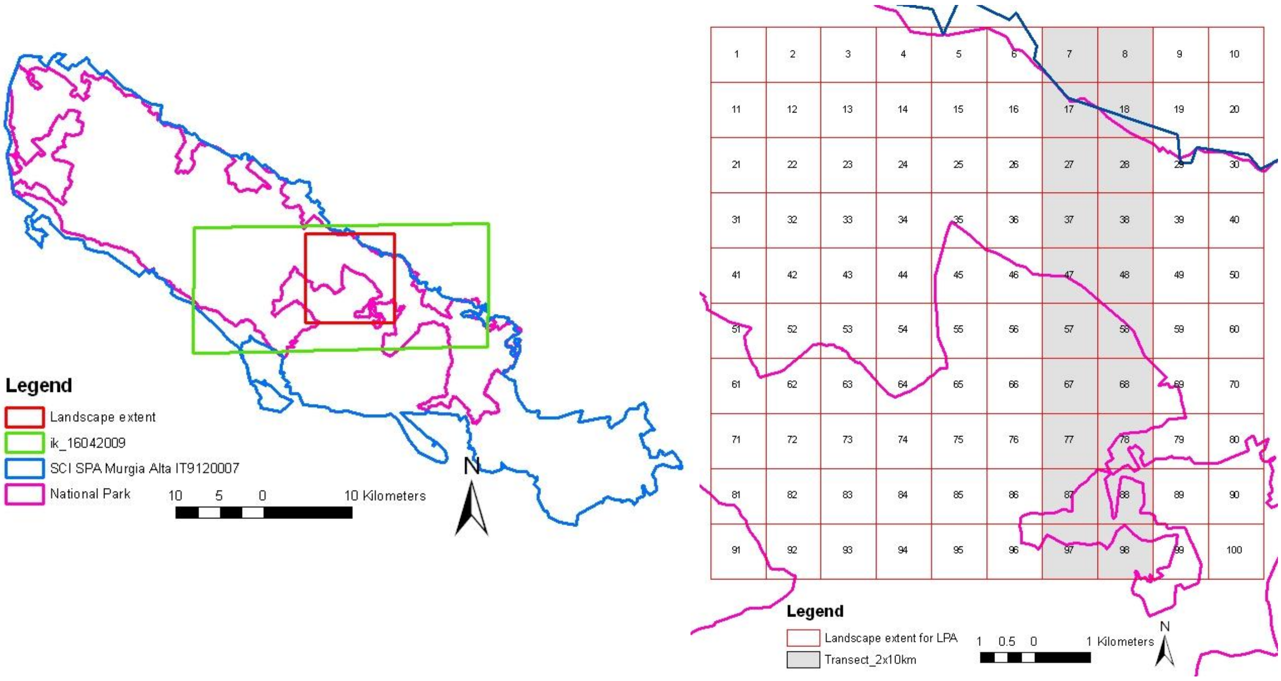


Figure 3.3 – Landscape extent for landscape pattern analysis in IT3 and 2x10km transect location.

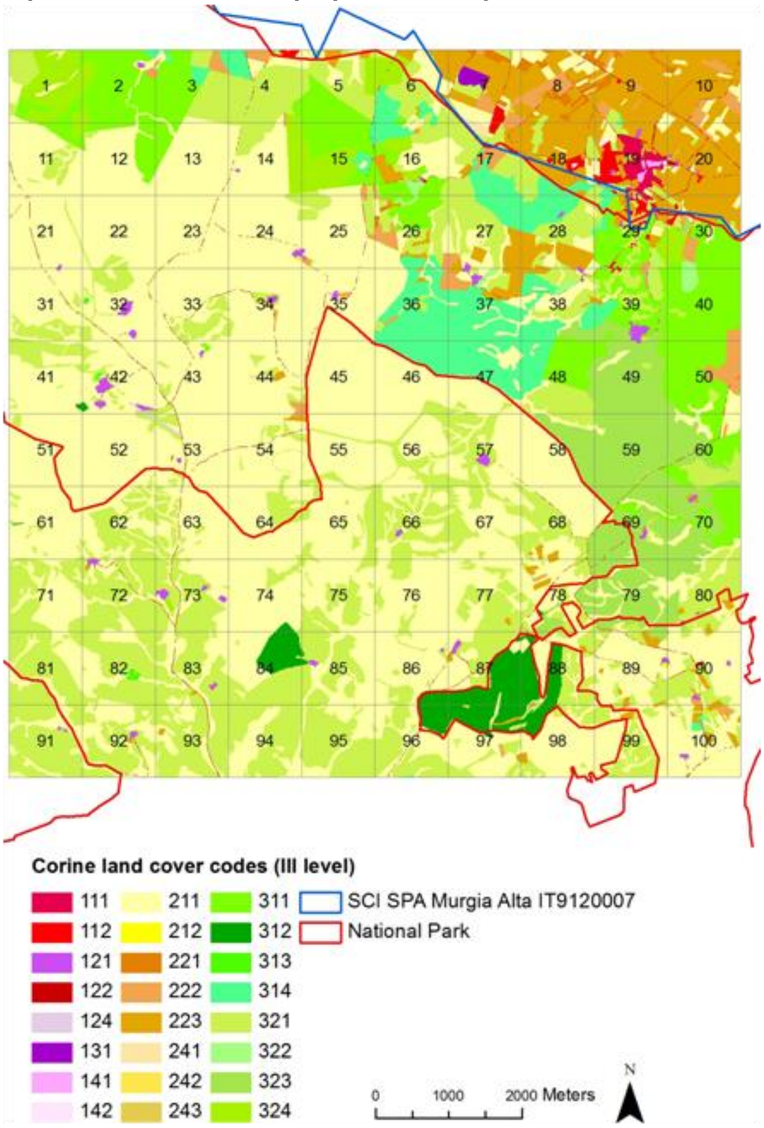


Figure 3.4 - Land cover / land use map of the selected study area.

Table 3.6 – Corine land cover and LCCS correspondence table for landscape area in IT3.

Original LU map coding (CLC_3rd 4th)	CLC code 3th level	CLC description	LCCS/DIC	LCCS/HIER
1112	111	Continuous urban fabric	B15	A1.A4.A13.A16
1121, 1122, 1123	112	Discontinuous urban fabric	B15	A1.A4.A13.A16
1211, 1212, 1216	121	Industrial or commercial units	B15	A1.A4.A12.A17
1221	122	Road and rail networks and associated	B15	A1.A3.A7.A8
124	124	Airports	B15	A1.A4.A12.A17
131	131	Mineral extraction sites	B15	A2.A6
1422	142	Sports and leisure facilities	B15	A1.A4.A13.A17
2111	211	Non irrigated arable land	A11	A3.A4.C1.D1
2123	212	Permanently irrigated land	A11	A3.C2.D3
221	221	Vineyards	A11	A2.C1.D1.A7.A10.W8
222	222	Fruit trees and berry plantations	A11	A1.C1.D3.A7.A10.W8
223	223	Olive grooves	A11	A1.B1.C1.D1.A7.A9.W8
241	241	Annual crops with permanent crops	A11	A3.C2.C3.C5.C17
242	242	Complex cultivation patterns	A11	UNKNOWN1
243	243	Land principally occupied by agriculture	A11	UNKNOWN2
311	311	Broadleaved forest	A12	A1.A3.A10.B2.D1.E2.B7
312	312	Coniferous forest	A11	A1.A8.B1.B3.B5.W7.A8.A9
313	313	Mixed forest	A11	A1.A8.A9.W7
314	314	Grasslands with trees	A12	A2.A6.A10.B4.E5.F2.F5.F10.G2.B12
321	321	Natural grasslands	A12	A2.A10.B4.E5.B12.E6
322	322	Moors and heathland	A12	A1.A4.A10.B3.B9
323	323	Sclerophyllous vegetation	A12	A1.A4.A10.B3.D1.E1.B9
3241, 3242	324	Transitional woodland/shrub	A12	A1.A4.A10.B3.D1.E2.B9

3.3 Sampling strategy for landscape pattern analysis

A stratified random sampling within a regular grid (SRSRG) was applied, as advocated in D4.3. The grid (Figure 3.5) was aligned with the standard one derived from the Infrastructure for Spatial Information in Europe (INSPIRE[1] RDM PP v4-3 2002) initiative of the European Commission, which is intended to create a European spatial information infrastructure that delivers to the users integrated spatial information services. The INSPIRE grid represents the spatial basis for the database holding information from all the 1 km squares in Europe produced within the EBONE project (EBONE D4.3). Such a database allowed for the identification of 13 environmental zones

[1] INSPIRE Directive: http://inspire.jrc.ec.europa.eu/documents/Data_Specifications/INSPIRE_Specification_CRS_v3.1.pdf; http://www.epsg-registry.org/)

of Europe (EnZ) and 84 environmental strata of Europe (EnS) (Metzger *et al.* 2005; Jongman *et al.* 2006). By means of such a 1km grid associated database, the spatial distribution of any parameter can be linked with variables available from each km square (e.g., altitude, estimates of habitats extent) or from the records made in the environmental strata and can be displayed at the continental level. Therefore the link to the INSPIRE grid and the EBONE database is regarded as an asset for further possible activities within the BIO_SOS project (e.g., up-scaling at the regional level -EnZ or EnS).

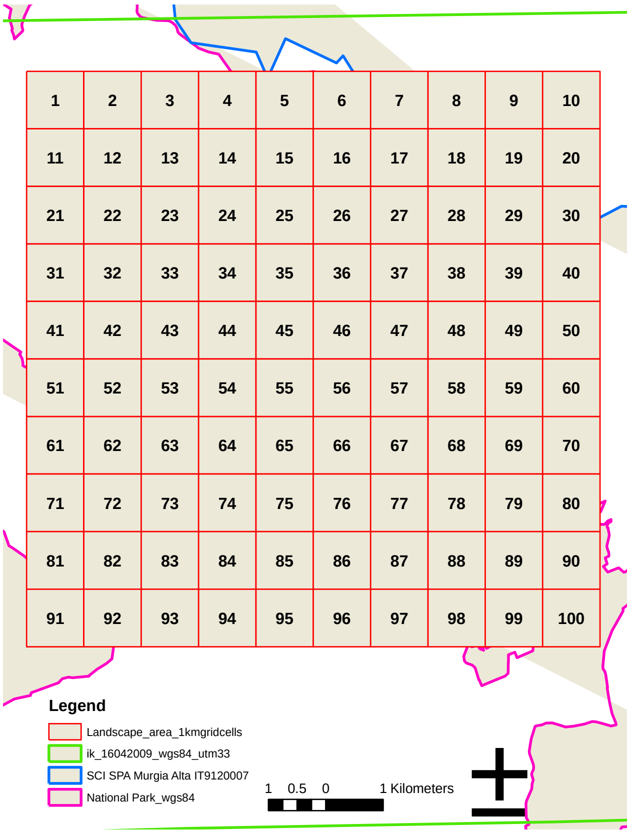


Figure 3.5 – 1x1 km grid over landscape extent for landscape pattern analysis in IT3.

A set of 30 1x1 km grid cells (at least one for each occurring class) was selected (Figure 3.6) within the spatial extent defined above (sub-section 3.2), which is comprised of 100 1x1 km grid cells. The selection procedure was based on the alternative option proposed in D4.3 (subsection 3.2). Namely an iterative procedure was implemented (Table 3.7):

1. a K-means classifier was applied to the proportions of each LCCS class within each of the 1 km grid cells (3 cluster), to group 1km^2 cell according to individual class relative upper-medium-lower occupancy within cell (boundary values differ from class to class);
2. Cells falling in upper-medium-low clusters with respect to the class relative share were identified;
3. LCCS classes were ranked according to decreasing relative importance based on % of landscape area;
4. Selection started with rare classes represented in few cells and iterated across all 22 classes. Where possible, random selection was carried out in medium occupancy cluster, yet upper/lower cluster were sampled if the class was not represented or unavailable in medium occupancy cluster;
5. Random selection of remaining cells (30-22= 8) within upper-medium-lower occupancy clusters of focal habitat, of which:
    a. 3 cells in upper cluster
    b. 3 cells in lower cluster
    c. 2 cells in medium cluster (1 cell having already been selected in step 4).

Table 3.7– *1x1 km grid cell selection procedure (class ranking and selection criterion).*

Rank	LCCS/DIC	LCCS/HIER code	LCCS/HIER Description	cell ID	selection criterion
1	A11	A3.C2.D3	Herbaceous.Multiplecrop.Irrigated	89	unique cell (upper cluster)
2	A11	UNKNOWN1	To be defined	34	unique cell (medium cluster)
3	A11	UNKNOWN2	To be defined	29	unique cell (upper cluster)
4	A11	A6	Cultivated and manged terrestrial areas	19	unique cell (upper cluster)
5	A11	A1.A8.A9.W7	Trees.Needleleaved.Evergreen.Plantations	42	randomly selected between 2 cells (medium cluster)
6	A11	A3.C2.C3.C5.C17	Herbaceous.Multiplecrop.Oneadditionalcrop. Trees.Simultaneous	17	single unselected cell (upper cluster)
7	B15	A2.A6	Nonbuiltup.Extractionsites	7	unique cell (upper cluster)
8	B15	A1.A4.A13.A17	Builtup.Nonlinear.Urbanareas. Scattered	18	unique cell (medium cluster)
9	A12	A1.A4.A10.B3.B9	Woody.Shrubs.Closed.5-0.3m.2-0.5m	37	randomly selected among 3 unselected cells (medium cluster)
10	A11	A2.C1.D1.A7.A10.W8	Shrubs.Singlecrop.Rainfed.Broadleaved. Deciduous.Orchards+ Technical attribute: Vineyards	9	single unselected cell (upper cluster)
11	B15	A1.A3.A7.A8	Builtup.Linear.Roads.Paved	73	randomly selected among unselected cells in the medium cluster
12	B15	A1.A4.A12.A17	Builtup.Nonlinear.Industrial.Scattered	57	randomly selected among unselected cells (medium cluster)
13	B15	A1.A4.A13.A16	Builtup.Nonlinear.Urbanareas.Lowdensity	4	single unselected cell (upper cluster)
14	A11	A1.C1.D3.A7.A10.W8	Trees.Singlecrop.Irrigated.Broadleaved.Deciduous.Orchards	26	randomly selected among unselected cells (medium cluster)
15	A11	A1.A8.B1.B3.B5.W7.A8.A9	Trees.Needleleaved.Largetomedium.Largesized. Continuous.Plantations.Evergreen	84	randomly selected among unselected cells (medium cluster)
16	A12	A1.A4.A10.B3.D1.E2.B9	Woody.Shrubs.Closed.5-0.3m.Broadleaved. Deciduous.2-0.5m	15	randomly selected between 2 unselected cells (medium cluster
17	A12	A2.A6.A10.B4.E5.F2.F5. F10.G2.B12	Herbaceous.Graminoids.Closed.3.03m.Mixed. Secondlayerpresent.Shrubs.Sparse.30-3m.0.8-0.3m	48	randomly selected among unselected cells (medium cluster)

18	A12 A1.A4.A10.B3.D1.E1.B9	Woody.Shrubs.Closed.5-0.3m.Broadleaved. Evergreen.2-0.5m	70	randomly selected among unselected cells (medium cluster)
19	A11 A1.B1.C1.D1.A7.A9.W8	Monoculture field of rainfed broadleaved evergreen tree crops, orchard+technical annex: olive groves	30	randomly selected among unselected cells (medium cluster)
20	A12 A1.A3.A10.B2.D1.E2.B7	Woody.Trees.Closed.30-3m.Broadleaved. Deciduous.7-3m	12	randomly selected among unselected cells (medium cluster)
21	A12 A2.A10.B4.E5.B12.E6	Herbaceous.Closed.3-0.03m.Mixed. 0.8-0.3m.Perennial	65	randomly selected among unselected cells (medium cluster)
22	A11 A3.A4.C1.D1	Herbaceous.Graminoids.Singlecrop.Rainfed	92	randomly selected among unselected cells (medium cluster)
	A12 A2.A10.B4.E5.B12.E6	Herbaceous.Closed.3-0.03m.Mixed. 0.8-0.3m.Perennial	72	randomly selected among unselected cells (upper cluster)
	A12 A2.A10.B4.E5.B12.E6	Herbaceous.Closed.3-0.03m.Mixed. 0.8-0.3m.Perennial	83	randomly selected among unselected cells (upper cluster)
	A12 A2.A10.B4.E5.B12.E6	Herbaceous.Closed.3-0.03m.Mixed. 0.8-0.3m.Perennial	95	randomly selected among unselected cells (upper ocluster)
	A12 A2.A10.B4.E5.B12.E6	Herbaceous.Closed.3-0.03m.Mixed. 0.8-0.3m.Perennial	39	randomly selected among unselected cells (medium cluster)
	A12 A2.A10.B4.E5.B12.E6	Herbaceous.Closed.3-0.03m.Mixed. 0.8-0.3m.Perennial	53	randomly selected among unselected cells (medium cluster)
	A12 A2.A10.B4.E5.B12.E6	Herbaceous.Closed.3-0.03m.Mixed. 0.8-0.3m.Perennial	22	randomly selected among unselected cells (lower cluster)
	A12 A2.A10.B4.E5.B12.E6	Herbaceous.Closed.3-0.03m.Mixed. 0.8-0.3m.Perennial	39	randomly selected among unselected cells (lower cluster)
	A12.A2.A10.B4.E5.B12.E6	Herbaceous.Closed.3-0.03m.Mixed. 0.8-0.3m.Perennial	53	randomly selected among unselected cells (lower cluster)

1	2	3	**4**	5	6	**7**	8	**9**	10
11	**12**	13	14	**15**	16	**17**	**18**	**19**	20
21	**22**	23	24	25	**26**	27	28	**29**	**30**
31	32	33	**34**	35	36	**37**	38	**39**	40
41	**42**	43	44	45	46	47	**48**	49	50
51	52	**53**	54	55	56	**57**	58	59	60
61	62	63	64	**65**	66	67	**68**	69	**70**
71	**72**	**73**	74	75	76	77	78	79	80
81	82	**83**	**84**	85	86	87	88	**89**	90
91	**92**	93	94	**95**	96	97	98	99	100

unselected	**random selection for the 22 classes**	**random selection of remaining cells**

Figure 3.6 – Selected 30 1x1 km grid cells for landscape pattern analysis and LCCS map validation in IT3.

This is a realistic sampling strategy allowing for:

1. a target of reference sample points per LCCS, proportional to the class occupancy in the selected 1x1 km grid cell, over all reference sample point numbers (SSSc), for the EO - derived LCCS map validation (which will be defined by P1 for each LCCSS class, D4.3, sub-section 3.1); the remainder reference sample points will be obtained through reference to high-resolution datasets (i.e., aerial photography/EO images interpretation);
2. the objective selection of 1x1 km landscapes for LPA, representing both the habitat fragmentation and landscape heterogeneity gradients (Figure 3.7).

However, it has to be noted that the application of this strategy in the IT3 site yields a non-uniform sample distribution. This is due to the characteristic spatial aggregation between classes within the site (e.g., urban land uses, including many rare classes, are clumped, whereas “natural” land uses appear as negatively segregated from urban and agricultural ones). Sampling in an area wider than the 100x100km landscape extent does not seem to solve the problem.

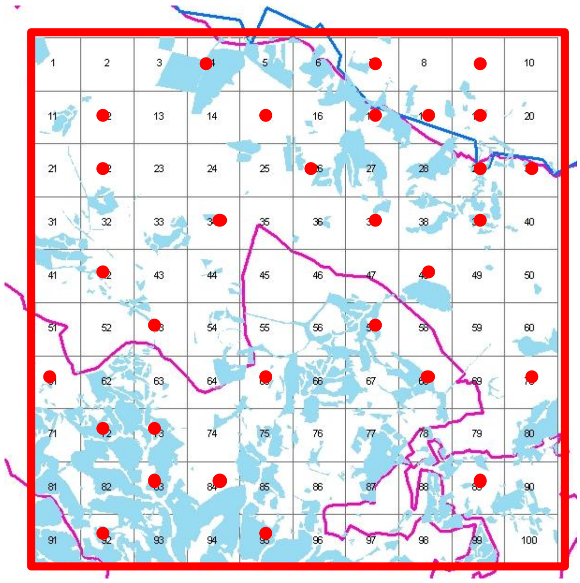


Figure 3.7 - Selected 30 1x1 km grid cells for LPA and analysis and LCCS map validation in IT3 overlain on the focal habitat type.

In addition to the 30 1x1km grid cells, a 2x10 km transect was selected encompassing the whole N/S dimension of landscape area and comprising 20 1x1 km cells (Figure 3.8). The transect was lain across areas outside both the N2K site and the NP, areas inside both N2K site and the NP, and areas inside N2K only, as defined above.
Such a transect was analysed to test the (sub-section 3.6) potential of LPA indices and MSPA feature classes (D6.2 and subsection 3.5 below) to be used in combination for the detection of landscape spatial variations.

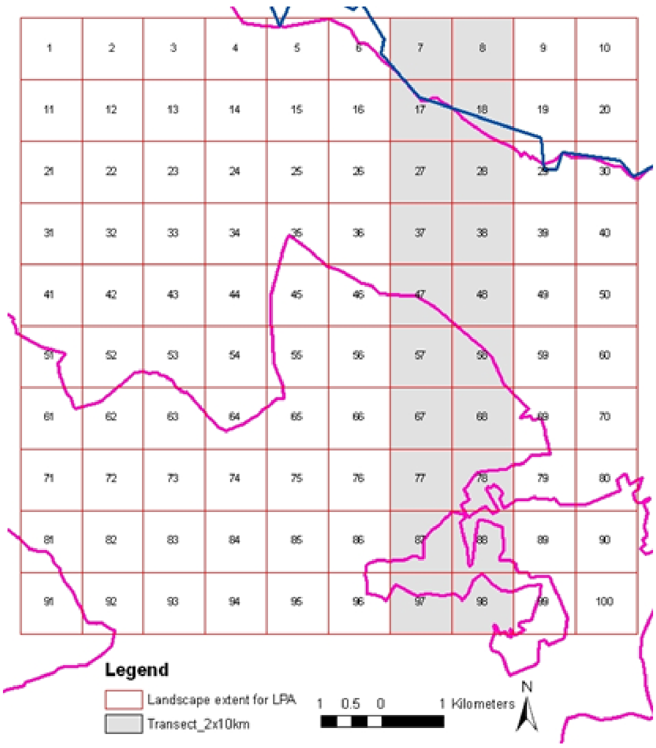


Figure 3.8 - Selected 2x10 km transect for landscape pattern analysis and LCCS map validation in IT3 overlain on the focal habitat type.

3.4 Landscape pattern analysis

3.4.1 Landscape pattern indices selection and definition of "patch"

With regard to the procedures for landscape pattern analysis (LPA), a set of landscape pattern indices (LPI) has been identified and computed, which describe spatial attributes of the focal LU/LC/GHC/habitat patches of the landscape mosaic.

Indices consist of landscape pattern metrics developed for categorical maps and are aimed at the characterization of the geometric and spatial (topological) properties of categorical map patterns represented at a single scale. In the definition of scale the notions of both extent and grain pertain (Kotliar and Wiens, 1996). The latter is in turn related both to the resolution allowed by the existing ancillary LU/LC maps and by RS sensors, and to the purpose of the analysis.

The identified set of indices (Table 3.8) result from a preliminary selection within the arsenal of available metrics focussing on those that are more relevant to the objectives of this study. The metric selection was guided by the available literature. The set of indices suggested is the same as those in McGarigal and McComb (1995). However the inclusion of indices related to the core area was not considered at this stage, because of the difficulty of objectively identifying edge width for each class. The "Effective Mesh Size" (Jaeger, 2000) index was also computed. This index has proven to a) monotonically decrease with increasing fragmentation and be consistent throughout the phases of the fragmentation process as defined by Jaeger (2000) based on Forman (1995); b) mathematically "intensive", meaning that it can be interpreted as quantifying an intrinsic landscape feature (Jaeger, 2000); c) mathematically "area proportionately additive", meaning that it is suitable for comparing fragmentation of regions of different extent and for assessing the influence of a part of a region to the fragmentation of the whole region (Jaeger, 2000).

This resulted in the selection of 28 metrics, quantifying different aspects of landscape pattern: area/density/edge, shape, isolation/proximity, contrast, contagion/interspersion, connectivity, composition (Table 3.8).

Patches are defined here as discrete, relatively homogeneous landscape elements relating to human perception limits, rather than other organism-centred definitions of patches. This approach is relevant here as it links with traditional vegetation associations (Rodwell *et al.* 2002) and existing European habitat classifications (e.g., the EUNIS system, Davies and Moss 2002) as well as the LU/LC/GHCs maps produced within the BIO_SOS project from RS data that are derived from human perception and interpretation of RS and field data. The derivation of the CBD/SEBI biodiversity indicators identified within the BIO_SOS project (D2.1) is therefore also related to these kinds of dataset.

Table 3.8 - Main characteristics of the selected landscape metrics. Source: FRAGSTATS documentation.

Class / Type / Level	**FRAGSTATS Index name (Acronym)**	*Units*	*Range*	*Equation*	*Meaning*
1 / a / C	Percent of landscape (PLAND)	%	0 < PLAND ≤ 100	$PLAND = P_i = \frac{\sum_{j=1}^{n} a_{ij}}{A}(100)$ P_i = proportion of the landscape occupied by class i a_{ij} = area (m^2) of patch ij A = total landscape area (m^2)	Percentage of the landscape composed of the corresponding patch type.
1 / a / C, L	Patch density (PD)	No. / 100 ha	PD > 0	$PD = \frac{n_i}{A}(10{,}000)(100)$ n_i = number of patches in the landscape of class i A = total landscape area (m^2)	Number of patches per a surface unit.
1 / a / C, L	Largest patch index (LPI)	%	0 < LPI ≤ 100	$LPI = \frac{\max_{j=1}^{n}(a_{ij})}{A}(100)$ a_{ij} = area (m^2) of patch ij A = total landscape area (m^2)	Percentage of the landscape composed of the largest patch of the corresponding patch type.
1 / a / C, L	Number of patches (NP)	No.	NP > 0	$NP = n_i$ n_i = number of class i patches in the landscape	Number of patches.
1 / a / C, L	Patch area distribution – mean (AREA_MN)	ha	AREA_MN > 0	$MN = \frac{\sum_{j=1}^{n} x_{ij}}{n_i}$ MN equals the sum, across all patches of the corresponding class, of the corresponding patch metric (in this case the patch area), divided by the number of patches of the same class	Average size of patch, calculated as mean.

Table 3.8 **- Main characteristics of the selected landscape metrics. Source: FRAGSTATS documentation.**

Class / Type / Level	**FRAGSTATS Index name (Acronym)**	***Units***	***Range***	***Equation***	***Meaning***
1 / a / C, L	Patch area distribution – area-weighted mean (AREA_AM)	ha	AREA_AM > 0	$AM = \sum_{j=1}^{n}\left[x_{ij}\left(\frac{a_{ij}}{\sum_{j=1}^{n} a_{ij}}\right)\right]$ AM equals the sum, across all patches of the corresponding class, of the corresponding patch metric (in this case the patch area) multiplied by the proportional abundance of the patch	Average size of patch, calculated as area-weighted mean.
1 / a / C, L	Patch area standard deviation (AREA_SD)	ha	AREA_SD > 0	$SD = \sqrt{\frac{\sum_{j=1}^{n}\left[x_{ij} - \left(\frac{\sum_{j=1}^{n} x_{ij}}{n_i}\right)\right]^2}{n_i}}$ SD equals the square root of the sum of the squared deviations of each patch metric (in this case the patch area) from the mean patch metric value (in this case the patch area) of the corresponding class, divided by the number of patches of the same class.	Absolute measure of patch size variability.
1 / a / C, L	Patch area coefficient of variation (AREA_CV)	%	0 < AREA_CV ≤ 100	$CV = \frac{SD}{MN}(100)$ CV equals the patch metric (in this case the patch area) standard deviation divided by the patch metric (in this case the patch area) mean, multiplied by 100 to convert to a percentage	Relative measure of patch size variability.

Table 3.8 **- Main characteristics of the selected landscape metrics. Source: FRAGSTATS documentation.**

Class / Type / Level	**FRAGSTATS Index name (Acronym)**	***Units***	***Range***	***Equation***	***Meaning***
2 / a / C, L	Total edge (TE)	m	TE ≥ 0	$TE = \sum_{k=1}^{m} e_{ik}$ e_{ik} = total length (m) of edge in landscape involving class i; includes landscape boundary and background segments involving class i.	Total length of edge involving the corresponding patch type.
2 / a / C, L	Edge density (ED)	m/ha	ED ≥ 0	$ED = \frac{\sum_{k=1}^{m} e_{ik}}{A}(10,000)$ e_{ik} = total length (m) of edge in landscape involving class i; includes landscape boundary and background segments involving class i. A = total landscape area (m^2).	Density of edge involving the corresponding patch type.
2-3 / a-d / C, L	Contrast-weighted edge density (CWED)	m/ha	CWED ≥ 0	$CWED = \frac{\sum_{k=1}^{m} (e_{ik} \cdot d_{ik})}{A}(10,000)$ e_{ik} = total length (m) of edge in landscape between classes i and k; includes landscape boundary segments involving class i. d_{ik} = dissimilarity (edge contrast weight) between classes i and k. A = total landscape area (m^2).	Density of edge involving the corresponding patch type weighted by the degree of structural and floristic contrast between adjacent patches; equals ED when all edge is maximum contrast and approaches 0 when all edge is minimum contrast.

Table 3.8 **- Main characteristics of the selected landscape metrics. Source: FRAGSTATS documentation.**

Class / Type / Level	**FRAGSTATS Index name (Acronym)**	***Units***	***Range***	***Equation***	***Meaning***
3 / d / C, L	Edge contrast index distribution – mean (ECON_MN)	%	0 < ECON_MN ≤ 100	$$ECON = \frac{\sum_{k=1}^{m} (p_{ijk} * d_{ik})}{p_{ij}} (100)$$ $$MN = \frac{\sum_{j=1}^{n} x_{ij}}{n_i}$$ p_{ijk} = length (m) of edge of patch ij adjacent to class k. d_{ik} = dissimilarity (edge contrast weight) between classes i and k. p_{ij} = length (m) of perimeter of patch ij. MN (Mean) equals the sum, across all patches of the corresponding patch type, of the corresponding patch metric values (in this case the edge contrast index), divided by the number of patches of the same type. MN is given in the same units as the corresponding patch metric (in this case the edge contrast index).	Mean patch edge contrast as a percent of maximum contrast; equals 100% when all edge is maximum contrast and approaches 0 when all edge is minimum contrast.
3 / d / C, L	Edge contrast index distribution – area weighted mean (ECON_AM)	%	0 < ECON_AM ≤ 100	$$ECON = \frac{\sum_{k=1}^{m} (p_{ijk} * d_{ik})}{p_{ij}} (100)$$ $$AM = \sum_{j=1}^{n} \left[x_{ij} \left(\frac{a_{ij}}{\sum_{j=1}^{n} a_{ij}} \right) \right]$$ p_{ijk} = length (m) of edge of patch ij adjacent to class k. d_{ik} = dissimilarity (edge contrast weight) between classes i and k. p_{ij} = length (m) of perimeter of patch ij. See above for a description of AM (area-weighted mean).	Similar to mean patch edge contrast, but patch edge contrast weighted by patch area

Table 3.8 **- Main characteristics of the selected landscape metrics. Source: FRAGSTATS documentation.**

Class / Type / Level	**FRAGSTATS Index name (Acronym)**	*Units*	*Range*	*Equation*	*Meaning*
3 / d / C, L	Total edge contrast index (TECI)	%	0 < TECI ≤ 100	$$TECI = \frac{\sum_{k=1}^{m} (e_{ik} * d_{ik})}{\sum_{k=1}^{m} e^{*}_{ik}} (100)$$ e_{ik} = total length (m) of edge in landscape between classes i and k; includes landscape boundary segments involving class i e^{*}_{ik} = total length (m) of edge in landscape between classes i and k - includes the entire landscape boundary and all background edge segments, regardless of whether they represent edge or not d_{ik} = dissimilarity (edge contrast weight) between classes i and k.	Total edge contrast as a percent of maximum contrast; equals 100% when all edge is maximum contrast and approaches 0 when all edge is minimum contrast
2 / b / C, L	Shape index distribution - mean (SHAPE_MN)	-	SHAPE_MN ≥ 1	$$SHAPE = \frac{p_{ij}}{\min p_{ij}}$$ $$MN = \frac{\sum_{j=1}^{n} x_{ij}}{n_i}$$ p_{ij} = perimeter of patch ij in terms of number of cell surfaces. min p_{ij} = minimum perimeter of patch ij in terms of number of cell surfaces See above for a description of MN (Mean).	Mean patch shape complexity. This is the simplest and most straightforward measure of shape complexity. It equals 1 when all patches are circular and increases as patches become non-circular. Option: area-weighted mean

Table 3.8 **- Main characteristics of the selected landscape metrics. Source: FRAGSTATS documentation.**

Class / Type / Level	**FRAGSTATS Index name (Acronym)**	***Units***	***Range***	***Equation***	***Meaning***
2 / b / P, C, L	Shape index distribution – area weighted mean (SHAPE_AM)	-	SHAPE_AM ≥ 0	$SHAPE = \frac{p_{ij}}{\min p_{ij}}$ $AM = \sum_{j=1}^{n}\left[x_{ij}\left(\frac{a_{ij}}{\sum_{j=1}^{n} a_{ij}}\right)\right]$ p_{ij} = perimeter of patch ij in terms of number of cell surfaces. min p_{ij} = minimum perimeter of patch ij in terms of number of cell surfaces. See above for a description of AM (area-weighted mean).	Similar to mean shape index, but patch shape index weighted by patch area
2 / b / C, L	Landscape shape index (LSI)	-	LSI ≥ 1	$LSI = \frac{E}{\min E}$ E = total length of edge in landscape in terms of number of cell surfaces; includes all landscape boundary and background edge segments. min E = minimum total length of edge in landscape in terms of number of cell surfaces.	Landscape shape complexity; equals 1 when the landscape consists of a single circular patch and increases as landscape shape becomes noncircular and the amount of internal edge increases. Landscape shape index provides a standardized measure of total edge or edge density that adjusts for the size of the landscape. Because it is standardized, it has a direct interpretation. LSI can also be interpreted as a measure of patch aggregation or disaggregation, similar to the class-level interpretation.

Table 3.8 - Main characteristics of the selected landscape metrics. Source: FRAGSTATS documentation.

Class / Type / Level	**FRAGSTATS Index name (Acronym)**	***Units***	***Range***	***Equation***	***Meaning***
2 / b / C, L	Fractal index distribution – mean (FRAC_MN)	-	1 ≤ FRAC_MN ≤ 2	$FRAC = \frac{2 \ln(.25\ p_{ij})}{\ln a_{ij}}$ $MN = \frac{\sum_{j=1}^{n} x_{ij}}{n_i}$ p_{ij} = perimeter (m) of patch ij. a_{ij} = area (m^2) of patch ij. See above for a description of MN (Mean).	Mean patch shape complexity; approaches 1 for simple geometric shapes (e.g. circle) and 2 for complex shapes
2 / b / C, L	Fractal index distribution – mean (FRAC_AM)	-	1 ≤ FRAC_AM ≤ 2	$FRAC = \frac{2 \ln(.25\ p_{ij})}{\ln a_{ij}}$ $AM = \sum_{j=1}^{n} \left[x_{ij} \left(\frac{a_{ij}}{\sum_{j=1}^{n} a_{ij}} \right) \right]$ p_{ij} = perimeter (m) of patch ij. a_{ij} = area (m^2) of patch ij. See above for a description of AM (Area-Weighted Mean).	Area-weighted mean patch shape complexity; approaches 1 for simple geometric shapes (e.g. circle) and 2 for complex shapes

***Table 3.8* - Main characteristics of the selected landscape metrics. Source: FRAGSTATS documentation.**

Class / Type / Level	**FRAGSTATS Index name (Acronym)**	***Units***	***Range***	***Equation***	***Meaning***
3 / e / L	Contagion index (CONTAG)	%	0 < CONTAG ≤ 100	$CONTAG = \left[1 + \frac{\sum_{i=1}^{m}\sum_{k=1}^{m}\left[(P_i)\left(\frac{g_{ik}}{\sum_{k=1}^{m} g_{ik}}\right)\right]\cdot\left[\ln(P_i)\left(\frac{g_{ik}}{\sum_{k=1}^{m} g_{ik}}\right)\right]}{2\ln(m)}\right](100)$ P_i =proportion of the landscape occupied by class i. g_{ik} =number of adjacencies (joins) between pixels of classes i and k based on the *double-count* method. m =number of classes present in the landscape, including the landscape border if present.	Tendency of patches towards aggregation. It considers all patch types present on an image, and considers like adjacencies (i.e., cells of a patch type adjacent to cells of the same type). The actual calculation is based on the adjacency matrix of cells of the same class.
3 / e / C, L	Interspersion and Juxtaposition Index (IJI)	%	0 < IJI ≤ 100	$IJI = \frac{-\sum_{k=1}^{m}\left[\left(\frac{e_{ik}}{\sum_{k=1}^{m} e_{ik}}\right)\ln\left(\frac{e_{ik}}{\sum_{k=1}^{m} e_{ik}}\right)\right]}{\ln(m-1)}(100)$ e_{ik} = total length (m) of edge in landscape between classes i and k. m = number of classes present in the landscape, including the landscape border, if present.	An indication of the tendency to intermix and intersperse of patches belonging to different classes. IJI measures the observed interspersion over the maximum possible interspersion for the given number of patch types, approaching 0 if very few classes are present, and increasing as the number of classes and interactions increases. IJI is calculated based on the patch adjacency matrix of each class.

***Table 3.8* - Main characteristics of the selected landscape metrics. Source: FRAGSTATS documentation.**

Class / Type / Level	**FRAGSTATS Index name (Acronym)**	***Units***	***Range***	***Equation***	***Meaning***
3 / e / C, L	Aggregation index (AI)	%	0 < AI ≤ 100	$$AI = \left[\sum_{i=1}^{m} \left(\frac{g_{ii}}{max \rightarrow g_{ii}} \right) P_i \right] (100)$$ g_{ii} = number of like adjacencies (joins) between pixels of class i based on the *single-count* method. max-g_{ii} = maximum number of like adjacencies (joins) between pixels of class i (see below) based on the *single-count* method. P_i = proportion of landscape comprised of class i.	Tendency of patches towards spatial aggregation. If patches are highly aggregated, AI approaches 100%. AI is calculated from an adjacency matrix, which shows the frequency with which different pairs of patch types (including like adjacencies between the same patch type) appear side-by-side on the map. Aggregation index takes into account only the like adjacencies involving the focal class, not adjacencies with other patch types. In addition, in contrast to all of the other metrics based on adjacencies, the aggregation index is based on like adjacencies tallied using the *single-count* method, in which each cell side is counted only once.
3 / f / C, L	Patch cohesion index (COHESION)	%	0 < COHESION ≤ 100	$$COHESION = \left[1 - \frac{\sum_{j=1}^{n} p_{ij}}{\sum_{j=1}^{n} p_{ij}\sqrt{a_{ij}}} \right] \left[1 - \frac{1}{\sqrt{A}} \right]^{-1} \cdot (100)$$ p_{ij} = perimeter of patch ij in terms of number of cell surfaces. a_{ij} = area of patch ij in terms of number of cells. A = total number of cells in the landscape.	Physical connectedness of the corresponding patch type. Below the percolation threshold, patch cohesion is sensitive to the aggregation of the focal class. Patch cohesion increases as the patch type becomes more clumped or aggregated in its distribution; hence, more physically connected.
1 / g / L	Shannon's diversity index (SHDI)	-	SHDI ≥ 0	$$SHDI = -\sum_{i=1}^{m} (P_i * \ln P_i)$$ P_i = proportion of the landscape occupied by class i.	A popular measure of diversity in community ecology, applied here to landscapes. Shannon's index is somewhat more sensitive to rare patch types than Simpson's diversity index.

Table 3.8 **- Main characteristics of the selected landscape metrics. Source: FRAGSTATS documentation.**

Class / Type / Level	**FRAGSTATS Index name (Acronym)**	***Units***	***Range***	***Equation***	***Meaning***
1 / g / L	Simpson's diversity index (SIDI)	-	0 ≤ SIDI ≤ 1	$$SIDI = 1 - \sum_{i=1}^{m} P_i^2$$ P_i = proportion of the landscape occupied by class i.	Another popular diversity measure borrowed from community ecology. It represents the probability that any 2 pixels selected at random would be different patch types.
1 / e / C, L	Effective mesh size (MESH)	ha	ratio of cell size to landscape area ≤ MESH ≤ total landscape area	$$MESH = \frac{\sum_{j=1}^{n} a_{ij}^2}{A} \left(\frac{1}{10{,}000} \right)$$ a_{ij} = area (m^2) of patch ij. A = total landscape area (m^2).	Based on the cumulative patch area distribution and interpreted as the size of the patches when the corresponding patch type is subdivided into S patches, where S is the value of the splitting index. MESH is redundant with DIVISION, as they are perfectly, but inversely, correlated. MESH and AREA_AM are conceptually closely related, but computationally they are quite different at the class level. While AREA_AM provides an absolute measure of patch structure, MESH provides a measure of patch structure relative to PLAND.
1 / e / C, L	Splitting index (SPLIT)	-	1 ≤ SPLIT ≤ number of cells in the landscape area squared	$$SPLIT = \frac{A^2}{\sum_{j=1}^{n} a_{ij}^2}$$ a_{ij} = area (m^2) of patch ij. A = total landscape area (m^2).	Based on the cumulative patch area distribution and is interpreted as the effective mesh number, or number of patches with a constant patch size when the corresponding patch type is subdivided into S patches, where S is the value of the splitting index.

Table 3.8 **- Main characteristics of the selected landscape metrics. Source: FRAGSTATS documentation.**

Class / Type / Level	**FRAGSTATS Index name (Acronym)**	***Units***	***Range***	***Equation***	***Meaning***
1 / e / C, L	Landscape division index (DIVISION)	Proportion	0 ≤ DIVISION < 1	$$\text{DIVISION} = \left[1 - \sum_{j=1}^{n}\left(\frac{a_{ij}}{A}\right)^2\right]$$ a_{ij} = area (m^2) of patch ij. A = total landscape area (m^2).	Based on the cumulative patch area distribution and is interpreted as the probability that two randomly chosen pixels in the landscape are not situated in the same patch of the corresponding patch type. Note the similarity with SIDI, only here the sum is across the proportional area of each patch in the focal class, rather than the proportional area of each class in the landscape. Although DIVISION is redundant with MESH, DIVISION is interpreted as a probability, whereas MESH is given as an area.

Class: 1 Areal metrics, 2 linear metrics, 3 topological metrics (Baskent and Jordan 1995).
Type: *a* area/density/edge, *b* shape, *c* isolation/proximity, *d* contrast, *e* contagion/interspersion, *f* connectivity, *g* composition Haines-Young and Chopping (1996, McGarigal et al. 2002)
Level: P patch, C class, L landscape.

3.4.2 Landscape pattern indices computation

Computation of landscape metrics was carried out by means of FRAGSTATS free software (McGarigal and Marks 1995; McGarigal *et al.* 2002). Polygon files were converted into raster files, according to the authors' recommendation, using a raster resolution no larger than ½ of the side of the smallest patch. In this case a 1m cell size seemed to accommodate both the fulfilment of this requirement and acceptable computing costs (time).

Cell aggregation to form patches was based on the 8-neighbour rule (i.e., cells were considered as members of the same patch if adjoining orthogonally and diagonally), which is assumed to reflect ecological requirements of many potential target taxa in a further connectivity study.

The status (enabled-true *vs.* disabled-false) has to be set for each class considered in the analysis. Though not affecting the computation, the status defines whether the corresponding class should be included in the results file. Conversely, the "background" field affects the calculation of many metrics.

A .*.csv class properties file was compiled setting a "false" status for all classes except for the focal class (i.e. natural grasslands), and a "false" background for all classes (Table 3.9).

Patch types other than the focal class (LCCS: A2_A10_B4_E5_B12_E6) are not treated as "background" (*sensu* McGarigal *et al.* 2002) as they affect the spatial configuration of the focal class by affecting the contrast (sub-section 3.4.2.1) between focal class and its neighbourhood.

Table 3.9 - Class properties table for existing LU/LC classes in IT3 landscape area.

ID	*LCCS code*	*Status*	*Background*
1	A1_A4_A13_A16	false	false
2	A1_A4_A12_A17	false	false
3	A1_A3_A7_A8	false	false
4	A2_A6	false	false
5	A6	false	false
6	A1_A4_A13_A17	false	false
7	A3_A4_C1_D1	false	false
8	A3_C2_D3	false	false
9	A2_C1_D1_A7_A10_W8	false	false
10	A1_C1_D3_A7_A10_W8	false	false
11	A1_B1_C1_D1_A7_A9_W8	false	false
12	A3_C2_C3_C5_C17	false	false
13	UNKNOWN1	false	false
14	UNKNOWN2	false	false
15	A1_A3_A10_B2_D1_E2_B7	false	false
16	A1_A8_B1_B3_B5_W7_A8_A9	false	false
17	A1_A8_A9_W7	false	false
18	A2_A6_A10_B4_E5_F2_F5_F10_G2_B12	false	false
19	A2_A10_B4_E5_B12_E6	**true**	false
20	A1_A4_A10_B3_B9	false	false
21	A1_A4_A10_B3_D1_E1_B9	false	false
22	A1_A4_A10_B3_D1_E2_B9	false	false

3.4.2.1 Site specific edge contrast weights definition

In order to compute contrast metrics (Table 3.8), edge contrast weights must be defined as objectively as possible to approximate functional differences between LU classes. These are anyway landscape and analysis specific.

For the definition of edge contrast weights, a set of descriptors reputed appropriate (by means of expert knowledge) to represent each class and underline structural and functional differences between class pairs were identified (Table 3.10). These were:

A. “naturalness”, qualifying the management (from urban to natural);
B. “soil cover”, qualifying the degree of intactness of the herbaceous cover;
C. “plant community type”, qualifying the stage of a plant community succession;
D. “vegetation structure”, qualifying canopy cover.

Each descriptor was broken down into levels pertaining to an artificial vs. natural condition gradient for that descriptor itself. At each level, quantification scores were associated, ranging from 0 to 0.5. The score range for each descriptor is different as descriptors do not affect contrast in the same way.

Table 3.10 – Class descriptors and related levels and scores for edge contrast weights definition.

Descriptor	range	level 1	score		level 2	score		level 3	score		level 4	score		level 5	score
A Naturalness	0-0.4	urban	0.1	<	intensively managed	0.2	<	extensively managed	0.3	<	semi-natural	0.4			
B Soil cover	0-0.15	bare/artificial	0.05	<	seasonal	0.1	<	permanent	0.15						
C Plant community type(*)	0-0.5	crops	0.1	<	pioneer herbaceous communities	0.2	<	grasslands	0.3	<	scrubs	0.4	<	woods	0.5
D Vegetation structure	0-0.15	open	0.05	<	semi-open	0.1	<	closed	0.15						

(*) 0.05 to be added for transitional or mixed situations.

Considering a class pair, the absolute value difference between each class descriptor weight was computed. (ΔA, ΔB,□ΔC, ΔD). The sum of the differences for all descriptors indicates the contrast for a particular edge between the given class pairs. Edge contrast weight range between 0 and 0.9 (increasing weights represent greater edge contrast). An example of the rationale adopted is given in Table 3.11 for a given pair of classes and the procedure involves:

1. Selection of appropriate discriminating descriptors, according to class arrangement in the study area
2. Assigning a score to each level of the discriminating descriptor
3. Grading each class using descriptor scores
4. Calculating the difference |Δ| between each descriptor scores, for each descriptor between classes
5. Computing the edge contrast weight as the sum of the differences for each class pair.

Table 3.11 – Example of edge contrast weights definition for one class pair.

LC Classes	A Naturalness	B Soil cover	C Plant community type	D Vegetation structure	Sum
Continuous urban fabric	0.1	0.05	0.2	0.05	0.4
Broad-leaved forest	0.4	0.15	0.5	0.15	1.2
	ΔC	**ΔB**	**ΔD**	**ΔA**	**ΔSum**
	0.3	0.1	0.3	0.1	**0.8**

3.4.3 Landscape pattern indices statistical analysis

To assess the contribution of landscape configuration to fragmentation independently from the contribution of habitat relative amount (fragmentation *per se*, Fahrig 2003), and to rank samples according to a fragmentation gradient, the computed LPA metrics for the sample set were statistically treated similar to McGarigal and McComb (1995). All statistical data analysis were performed in R-2.14.0 for Windows.

Regression analysis of original indices (response variables) against habitat area (PLAND, independent variable) was used to obtain "residual configuration indices" from "original indices". For the selection of the most appropriate regression model (e.g., linear, parametric), as well as of the most appropriate (if needed) response variable transformation (e.g., log_{10}, square root), the statistical behaviour of each response variable, namely their distribution, was considered.

A further selection of a smaller set of residual configuration indices was carried out based on multiple correlations, in order to reduce the noise deriving from the between indices correlation still persisting after treatment.

Principal component analysis (PCA) was then applied to summarise the non-redundant residual configuration indices into a selected set of few components representing a fragmentation gradient for the focal class (LCCS: A2_A10_B4_E5_B12_E6).

3.5 Morphological Spatial Pattern Analysis (MSPA)

The method developed by Soille and Vogt (2009), based on mathematical morphology was applied to obtain a pixel-level spatial pattern classification for the focal class (LCCS: A2_A10_B4_E5_B12_E6).

The method was applied by means of the freeware "GUIDOS" (Graphical User Interface for the Description of image Objects and their Shapes http://forest.jrc.ec.europa.eu/download/software/guidos). This enables the automatic implementation of spatial pattern mapping based on mathematical morphology analysis into seven mutually exclusive spatial pattern classes or "feature classes", or (Riitters *et al.* 2007) "structural classes" (Table 3.12). These can be grouped into four main structural classes (core, islet, boundary and connector). The proportion in boundary and connector structural classes quantifies the proportion of all edge pixels in an analysis unit (landscape).

The software also allows for the computation of a number of measures useful for the quantification of, for example, feature class frequency, relative share in pattern class, proportion of edges (fragmentation) and connectors (structural connectivity) and islets (isolated small patches more prone to disappear).

In order to apply this method a binary map (focal class = foreground *vs.* featureless context of the focal class = background) was produced that considered the 2x10km transect (Figure 3.9) at the same resolution (cell size 1m) used for the LPA.

The settings used for the MSPA in Guidos are summarised in Table (3.13). Given the difficulty of objectively identifying the most appropriate edge width for the focal class, the MSPA analysis over the transect was repeated using different edge widths, ranging from 5m to 100m. This has meant varying part of the definition of the observation scale (i.e., the MSPA parameter edge width) keeping constant the extent and the grain.

Table 3.12 – MSPA output classes.

Main MSPA Feature classes	MSPA Feature sub classes	Main MSPA Feature classes types	Main MSPA Feature classes description
1) Core		core	foreground pixels beyond a distance of a given size parameter s to the background and obtained by erosion of the input map with a Euclidian disk of radius equal to s
2) Islet		islet	foreground pixels that do not contain any core
3) Perforation		boundary	background pixels inside core units
4) Edge		boundary	boundary pixels of a cluster of core pixels
5a) Loop		connector	foreground pixels with no core that connects the same core unit
	5b) Loop in Edge	connector	
	5c) Loop in Perforation	connector	
6a) Bridge		connector	foreground pixels with no core that connects at least two different core units
	6b) Bridge in Edge	connector	
	6c) Bridge in Perforation	connector	
7) Branch		connector	foreground pixels with no core that is connected at one end only to a connector (an edge of core or an edge of perforation)

Table 3.13 - Settings of the four MSPA-parameters.

MSPA-Parameter	Option	Description
Foreground Connectivity	8	8-neighbour rule (i.e., cells are considered as “connected” if adjoining orthogonally and diagonally)
EdgeWidth	5-10-15-20-25-30-40-50-100	define the width or thickness of the non-core classes (in pixels)
Transition	1	illustrate all detected connections. The pixel values of the MSPA segmentation are independent of the selected setting
Intext	1	distinguish internal from external features, where internal features are defined as being enclosed by a perforation

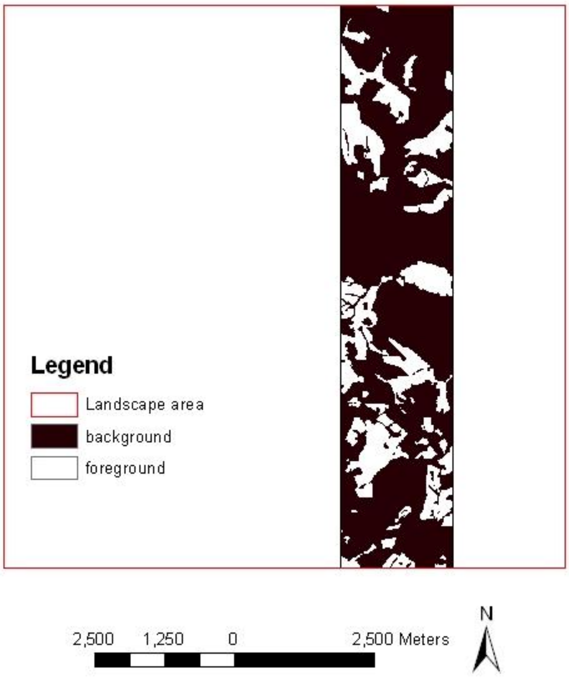


Figure 3.9 – Input binary raster map for MSPA.

3.6 Landscape mosaic analysis

The objective of this research activity was to apply to the IT3 BIO:SOS site the landscape composition characterization known as “landscape mosaic analysis” (Estreguil and Caudullo, 2010; Riitters *et al*., 2009). This methodology is based on the calculation of a pixel-level landscape mosaic indicator, which classifies each land-cover pixel according to the land-cover composition in a fixed-area neighbourhood surrounding the individual pixel.
For this purpose, the LCCS classification of the landscape extent (10x10 km, see Figure 3.3) was reclassified into 3 main classes, i.e., natural, agricultural and urban (Table 3.14). The term “natural” here indicates any unpaved land that is not used for agriculture, including also natural woodlands and forestry plantations as well as grazed grasslands (Table 3.14).

Table 3.14 Correspondence between land use / land cover classification in Corine Land Cover (CLC), Land Cover Classification System (LCCS) and landscape mosaic types.

CLC code 3rd level	CLC description	LCCS/HIER	Landscape mosaic analysis class description	Landscape mosaic analysis class code
111	Continuous urban fabric	A1.A4.A13.A16	Urban	1 - U
112	Discontinuous urban fabric	A1.A4.A13.A16	Urban	1 - U
121	Industrial or commercial units	A1.A4.A12.A17	Urban	1 - U
122	Road and rail networks and associated	A1.A3.A7.A8	Urban	1 - U
124	Airports	A1.A4.A12.A17	Urban	1 - U

CLC code 3rd level	CLC description	LCCS/HIER	Landscape mosaic analysis class description	Landscape mosaic analysis class code
131	Mineral extraction sites	A2.A6	Urban	1 - U
142	Sports and leisure facilities	A1.A4.A13.A17	Urban	1 - U
211	Non irrigated arable land	A3.A4.C1.D1	Agricultural	2 - A
212	Permanently irrigated land	A3.C2.D3	Agricultural	2 - A
221	Vineyards	A2.C1.D1.A7.A10.W8	Agricultural	2 - A
222	Fruit trees and berry plantations	A1.C1.D3.A7.A10.W8	Agricultural	2 - A
223	Olive grooves	A1.B1.C1.D1.A7.A9.W8	Agricultural	2 - A
241	Annual crops with permanent crops	A3.C2.C3.C5.C17	Agricultural	2 - A
242	Complex cultivation patterns	UNKNOWN1	Agricultural	2 - A
243	Land principally occupied by agriculture	UNKNOWN2	Agricultural	2 - A
311	Broadleaved forest	A1.A3.A10.B2.D1.E2.B7	Natural	3 - N
312	Coniferous forest	A1.A8.B1.B3.B5.W7.A8.A9	Natural	3 - N
313	Mixed forest	A1.A8.A9.W7	Natural	3 - N
314	Grasslands with trees	A2.A6.A10.B4.E5.F2.F5.F10.G2.B12	Natural	3 - N
321	Natural grasslands	A2.A10.B4.E5.B12.E6	Natural	3 - N
322	Moors and heathland	A1.A4.A10.B3.B9	Natural	3 - N
323	Sclerophyllous vegetation	A1.A4.A10.B3.D1.E1.B9	Natural	3 - N
324	Transitional woodland/shrub	A1.A4.A10.B3.D1.E2.B9	Natural	3 - N

A raster (cell size 1m) of the 2x10km transect was extracted from the whole landscape and a moving window analysis was performed using FRAGSTATS. The percent of landscape (PLAND) for each of the three land mosaic classes using a square kernel (window) was computed. The window size (50 m) was selected based on expert knowledge to reflect the scale at which edge effects in terms of plant community composition and structure can potentially occur in the focal LCCS class corresponding to natural grasslands (A2.A10.B4.E5.B12.E6). Three raster files (i.e., one for each class) with values ranging from > 0 to 100 were thus obtained. These were then combined applying the three thresholds (10%, 60% and 100%) indicated by Riitters *et al.,* 2009. Based on the suggested combinations arising from simultaneously applying these thresholds to each land mosaic class, the landscape mosaic index resulted in 19 integer values ranging from 1 to 19, each one identifying a different landscape mosaic type (Table 3.15).

Table 3.15 - Landscape mosaic classes definition with proportions of each class. In the labels field, upper-case letters indicate a percentage of landscape of at least 60% for the corresponding land mosaic class, lower-case letters indicate a percentage of landscape of less than 60% but more than 10%, while the letter is absent for a percentage lower than 10%.

Urban (U)	Agricultural (A)	Natural (N)	Landscape mosaic labels	Landscape mosaic index	Landscape mosaic description
100	0	0	UU	1	Predominantly urban
80 - 100	0 - 10	0 - 10	U	2	
60 - 90	10 - 40	0 - 10	Ua	3	
60 - 90	0 - 10	10 - 40	Un	4	
60 - 80	10 - 30	10 - 30	Uan	5	
0	100	0	AA	6	Predominantly agricultural
0 - 10	80 - 100	0 - 10	A	7	
10 - 40	60 - 90	0 -10	Au	8	
0 - 10	60 - 90	10 - 40	An	9	
10 - 30	60 - 80	10 - 30	Aun	10	
0	0	100	NN	11	Predominantly natural
0 - 10	0 - 10	80 - 100	N	12	
10 - 40	0 - 10	60 - 90	Nu	13	
0 - 10	10 - 40	60 - 90	Na	14	
10 - 30	10 - 30	60 - 80	Nua	15	
30 - 60	30 - 60	0 - 10	ua	16	Mixed
30 - 60	0 - 10	30 - 60	un	17	
0 - 10	30 - 60	30 - 60	an	18	
10 - 60	10 - 60	10 - 60	uan	19	

3.7 Landscape spatial variation in IT3

The 2x10 km transect was considered to test the (Sub-section 3.6) potential for LPA indices and MSPA feature classes (D6.2 and Subsection 3.5 below) to be used for the detection of landscape spatial variations.
The analysis was carried out in two steps, based on selected landscape pattern indices and on MSPA feature classes:

1. a “moving window” analysis;
2. a “moving split window analysis”.

3.7.1 Moving window analysis on selected landscape pattern indices

Moving window (MW) analysis was performed using FRAGSTATS with the aim of obtaining information on the local-based (i.e., pixel level) landscape structure as opposed to focal class or global landscape structure.

This leads to a quantification of the local pattern gradient across the landscape space. Thus it is possible to apply a gradient perspective (D6.2) to landscape structure even using categorical data (McGarigal and Cushman 2005).

A square kernel (window) was specified and applied to 2x10km transect. The window size (50 m) was selected based on expert knowledge to reflect the scale at which edge effects in terms of plant community composition and structure can potentially occur in the focal LCCS class.

The moving window analysis was performed at the class level for two selected LPA indices (contrast weighted edge density CWED and effective mesh size MESH, see section 3.8.1).

The resulting continuous surfaces were used as inputs for the moving split windows analysis (Subsection 3.6.2)

3.7.2 Moving split window analysis on selected landscape pattern indices and on MSPA feature classes

The moving split-window (MSW) technique is a method used in landscape ecological studies (Johnston *et al.* 1992, Mairota and Papadimitriou 1995, Choesin 2001, Camarero *et al.* 2006) to detect ecotone or landscape boundary location.

The window used for the moving split-window technique consisted of 4 “plots”, where a plot is represented by one 1x1km grid cell of the 2x10 km transect (Figure 3.9 and 3.10).

A zonal statistical procedure was performed using a 250x250m grid on each continuous surface obtained from the MW analysis (section 3.6.1) and on the output raster files relative to the non-core MSPA structural types (i.e., islet, boundary, connector) (Figure 3.9). The variables considered form an array of uncorrelated variables. This is a precondition to the applicability of Euclidean metrics. Thus each plot was divided into 16 cells in order to obtain, for each plot, a mean value for the variable considered.

Dissimilarities between adjacent window halves were calculated using the squared Euclidean distance (SED) metric. This is computed as the square of the difference between the means of each variable in adjacent windows, summed across all variables measured:

$$SED_{nw} = \Sigma_{i=1\ to\ a} (X_{iAw} - X_{iCw})^2 \text{ (Eq. 1)}$$

where: *A* and *B* denote window halves, *n* is a station or midpoint between window halves, *w* is window width, and *a* is the number of variables sampled at each station.

As the window is moving along the transect, a series of values that represent successive differences between window halves is produced.

Discontinuities or boundary locations occur at maximum SED values, indicating that the rate of attribute change is at a maximum.

For the purposes of the MSW the 2x10km transect was in addition split into two 1x10km (Figure 3.10).

The SED was computed for each individual variable separately and then for the whole array.

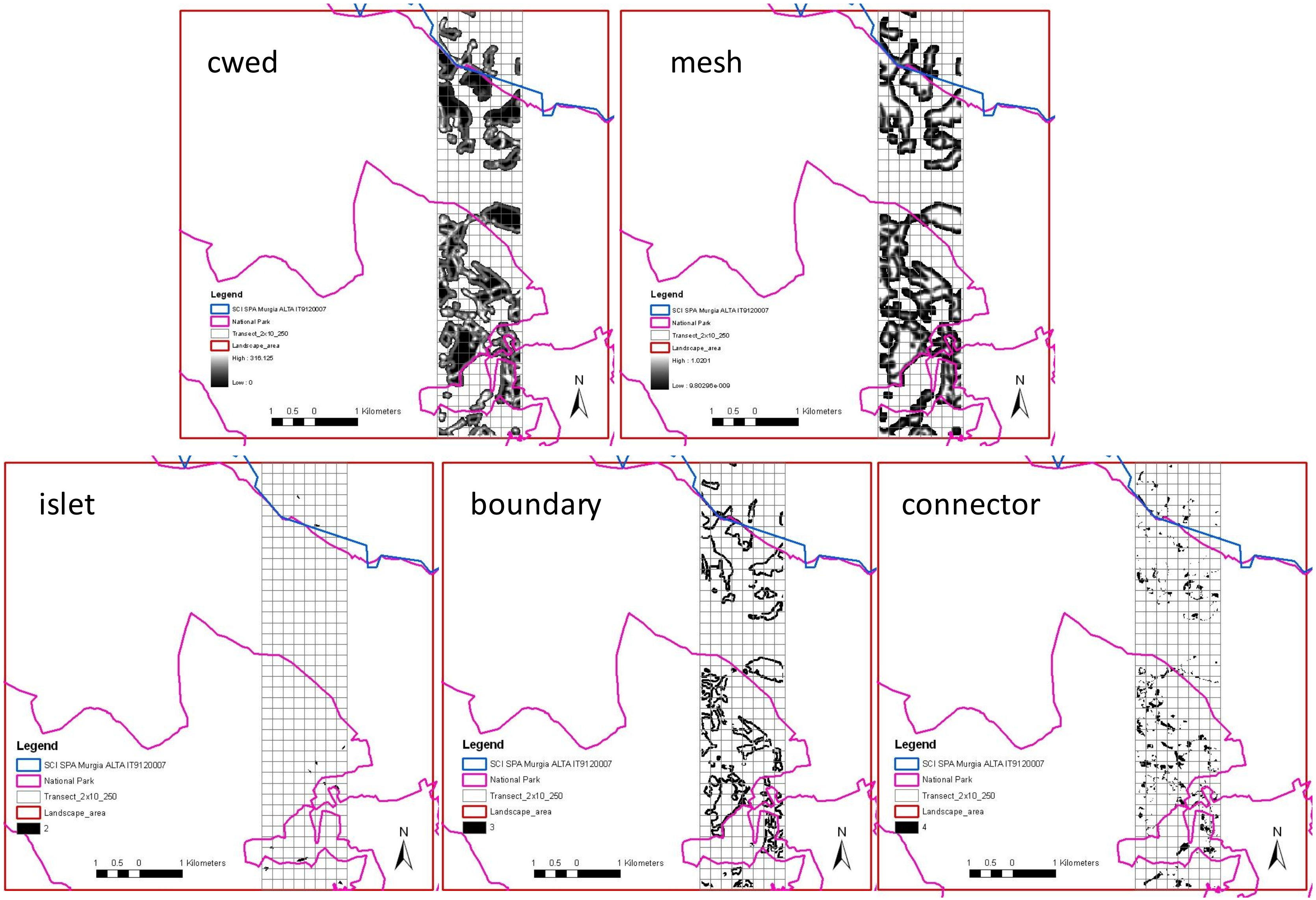


Figure 3.9 - Array of variables used in the moving split window analysis. Two variables (CWED and MESH) result from the landscape pattern analysis, via a moving windows procedure. The other three variables (islet, boundary and connector) were obtained from the morphological spatial pattern analysis.

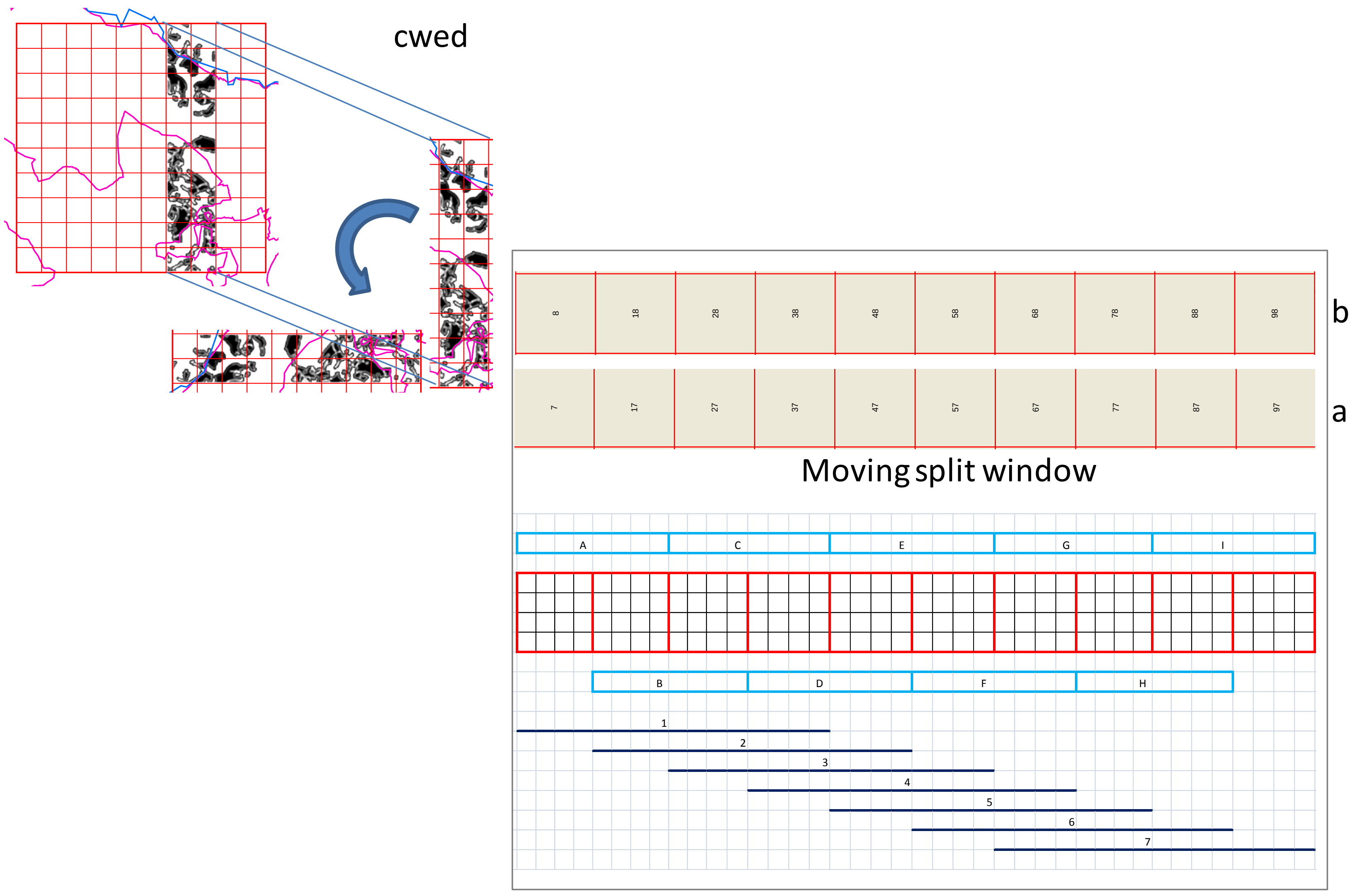


Figure 3.10 – Example scheme for the mowing split window (MSW) analysis. Numbers (1-7) indicate the steps of the MSW; capital letters (A-I) indicate window halves; lowercase letters (a, b) indicate the two parts of the 2x10 transect.

3.8 Benchmark results for IT3

The early results provided in D6.3, based on the existing ancillary LC/LU map, have to be considered as a benchmark test of the procedures proposed as it is assumed that the maps derived from EO data will be used to update the existing ancillary LC/LU map to generate a reference product for the site (e.g., for 2009), and these will retain the same nominal scale (cartographic ratio).

3.8.1 Landscape pattern analysis

As expected, strong correlations were found between pairs of indices. Therefore, an initial selection was done based on clear redundancy of some indices (i.e., number of patches, NP, vs. patch density, PD; contagion, CONTAG, vs. interspersion and juxtaposition, IJI, total edge, TE, vs. total edge contrast index, TECI; edge density, ED, vs. contrast weighted edge density CWED; AREA_AM, vs. patch area mean, AREA MN; shape index weighted mean, SHAPE_AM, vs. shape index mean, SHAPE_MN; fractal index weighted mean, FRAC.AM, vs. fractal index mean, FRAC.MN; edge contrast index area weighted mean, ECON_AM, vs. edge contrast index mean, ECON_MN; effective mesh size, MESH, vs. landscape division index, DIVISION).

The regression analysis was used to evaluate the independent relationship between focal class area (PLAND) and the 16 selected indices. In this way, generalized linear models or semi-parametric models, depending on the relationship between each of indices and PLAND, were fitted in order to obtain “residual indices” from “original indices”. Also a log-transformation was used when it was considered necessary.   Some indices appeared independent from PLAND (Table 3.16). In these cases, the original variable was used in the subsequent analysis.

Table 3.16 – Summary of the regression models used.

Response variable	Model
PD	original variable
LPI	LM
LSI	original variable
AREA.AM	LOG LM
SHAPE.AM	original variable
FRAC.AM	original variable
CWED	LOG LM
TECI	original variable
ECON.AM	original variable
COHESION	LM
MESH	SPM
SPLIT	GLM
AI	original variable
CONTAG	original variable
SHDI	original variable
SIDI	original variable

LM = linear model, LM_LOG = log linearmodel , SPM = semi-parametric model, GLM = generalised linear model.

In order to remove further redundant indices or residual indices the correlation matrix between each pairs of indices and residual indices was evaluated. Then, a cluster analysis based on the correlation matrix was performed, yielding three groups (Figure 3.11).

1. First group: largest patch index (LPI), patch area-weighted mean (AREA_AM), patch cohesion index (COHESION), effective mesh size (MESH).

2. Second group: landscape shape index (LSI), patch density (PD), shape index weighted mean (SHAPE_AM), fractal index weighted mean (FRAC.AM), contrast weighted edge density (CWED), total edge contrast index (TECI), edge contrast index area weighted mean (ECON_AM), splitting index (SPLIT), aggregation index (AI).
3. Third group: contagion index (CONTAG), Shannon's diversity index (SHDI), Simpson's diversity index (SIDI).

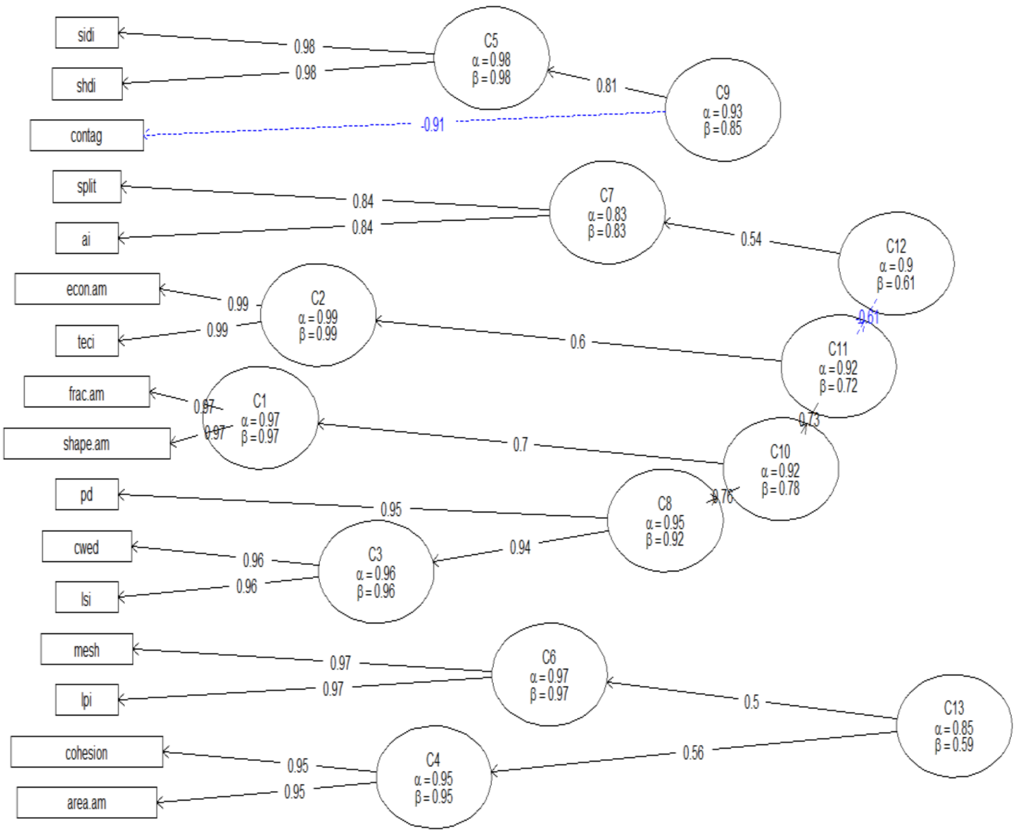


Figure 3.11 – Cluster analysis for indices and residual indices.

The choice of an index within a group of redundant ones was based on personal knowledge of the study area with reference to interpretability.

Nine non-redundant configuration indices were thus selected: patch cohesion index (COHESION), effective mesh size (MESH), patch density (PD), fractal index weighted mean (FRAC_AM), contrast weighted edge density (CWED), total edge contrast index (TECI), splitting index (SPLIT), contagion index (CONTAG), Shannon's diversity index (SHDI).

Finally, a principal component analysis (PCA) was applied to summarize these nine remaining non-redundant configuration indices into fewer principal components potentially indicating independent gradients in configuration for the focal class.

The first three components were considered which explained 71% of the variance, even though component loadings, however significant, turned out to be rather low (Table 3.17, Figures 3.12 and 3.13).

Table 3.17- Loadings of the first three principal components.

	Components								
	1	2	3	4	5	6	7	8	9
Standard deviation	1.7973	1.341538	1.15016	0.979883	0.917185	0.62877	0.498384	0.365509	0.26151
Proportion of Variance	0.358921	0.199969	0.146985	0.106686	0.09347	0.043928	0.027598	0.014844	0.007599
Cumulative Proportion	0.358921	0.55889	0.705875	0.812561	0.906031	0.949959	0.977557	0.992401	1
Loadings:									
pd	**0.418**	-0.263	0.286	0.306	-0.243	0.207	-0.119	-0.403	0.55
frac.am	**0.436**		**-0.456**			0.197	0.266	0.636	0.277
cwed	**0.474**	-0.318	-0.121			0.249		-0.197	-0.742
teci	**0.413**		-0.355	-0.159	0.113	-0.733	-0.244	-0.228	0.103
cohesion	-0.278	-0.198	**-0.581**	-0.246	0.316	0.4	-0.114	-0.403	0.226
mesh	-0.203		-0.389		-0.879			-0.135	
split	-0.196		-0.266	0.861	0.224	-0.181	0.23	-0.108	
contag	0.256	**0.595**		-0.15		0.153	0.625	-0.373	
shdi	-0.128	**-0.643**		-0.224		-0.319	0.628	-0.105	

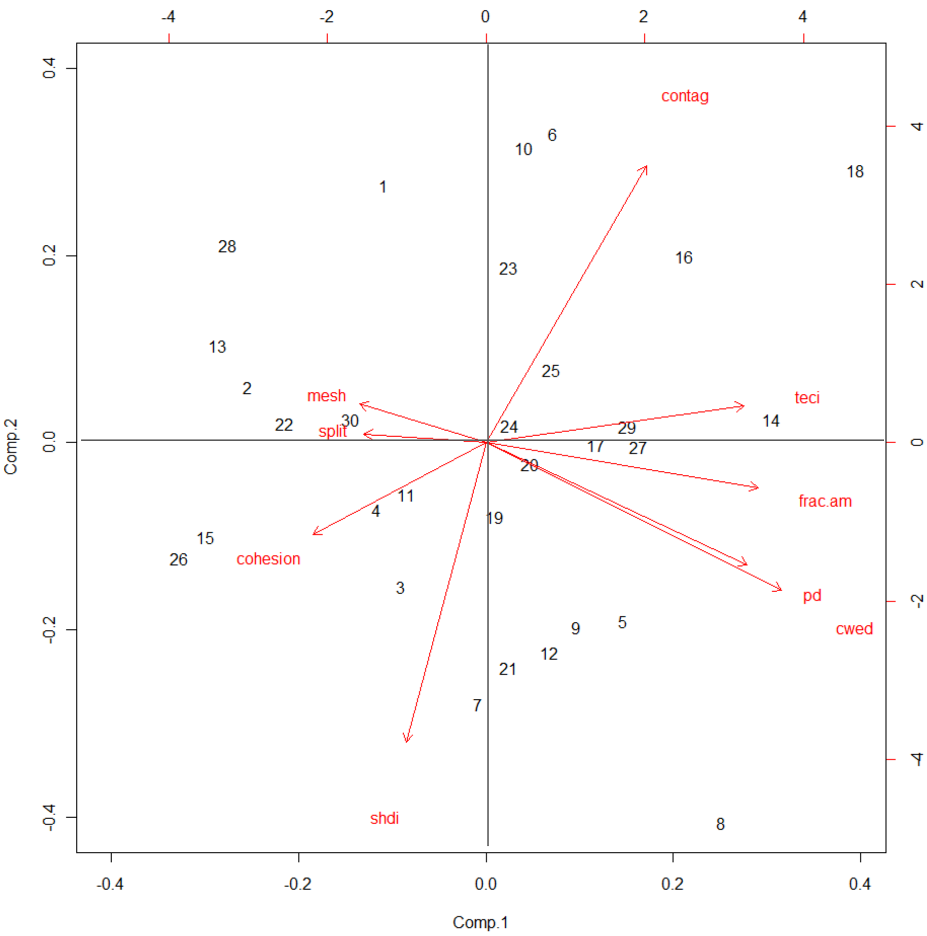


Figure 3.12 - Biplot for PC1 and PC2.

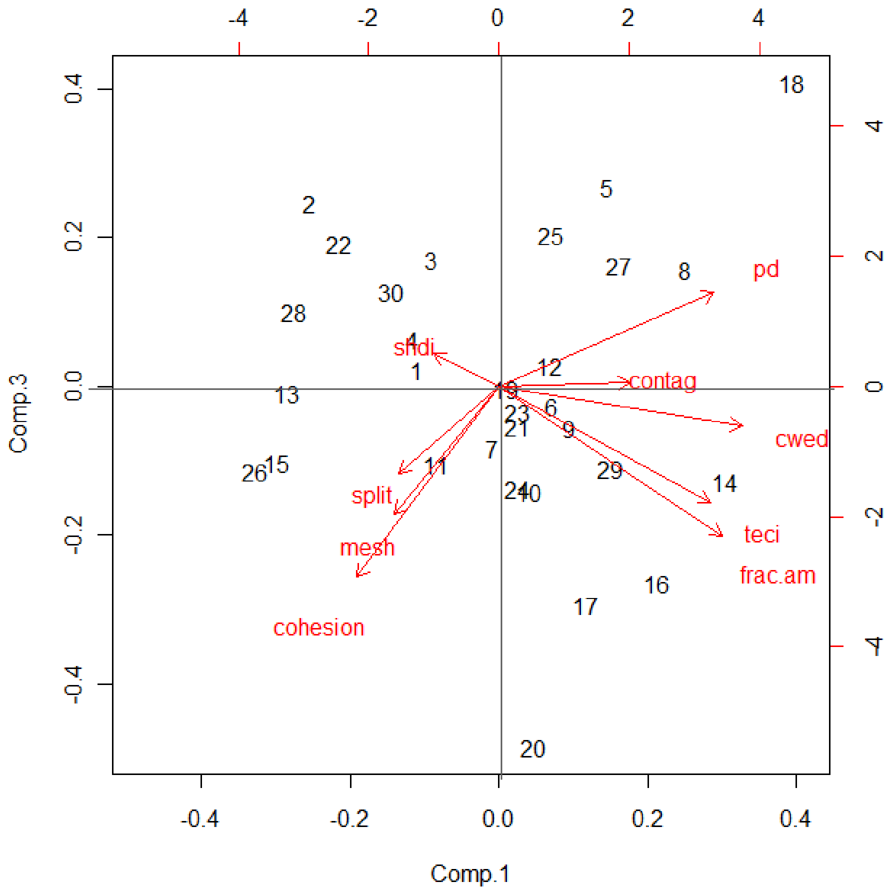


Figure 3.13 Biplot for PC1 and PC3.

The first and the third components are characterised by indices computed at the class level, whilst the second component is characterised by indices computed at the landscape level.

On the basis of the PCA results and observing the biplots (Figures 3.12 and 3,13), the observations (1x1 km grid cells, i.e., landscapes) most associated with each component were identified. It was found, observing the landscapes associated with each component, that these could be divided into two distinct groups (Figure 3.14). Therefore, an ANOVA was performed to assess the significance of the difference between the values of the indices of the paired groups.

Significant differences (*p-value*<0.05) resulted between the paired groups of 1x1km grid cells associated with PC1, PC2 and partly for those associated with PC3. In addition in the case of PC1 and PC2, the two groups appear as spatially segregated with respect to the boundary of the N2K/NP.

The first component (PC1) represents a gradient in patch contrast, shape and density. A group of landscapes (grid cell n.19, 29, 42, 53, 57, 61, 89, 92) associated with this component shows relatively high values of the contrast weighted edge density (CWED), indicating a relatively high density of edges involving the focal class which in addition is in a relatively high contrast condition. In the same cells the focal class shows a relatively high patch density index. The other group of landscapes associated with this component (grid cells n.4, 12, 15, 18, 48, 70, 84, 95), instead shows relatively lower CWED and PD.

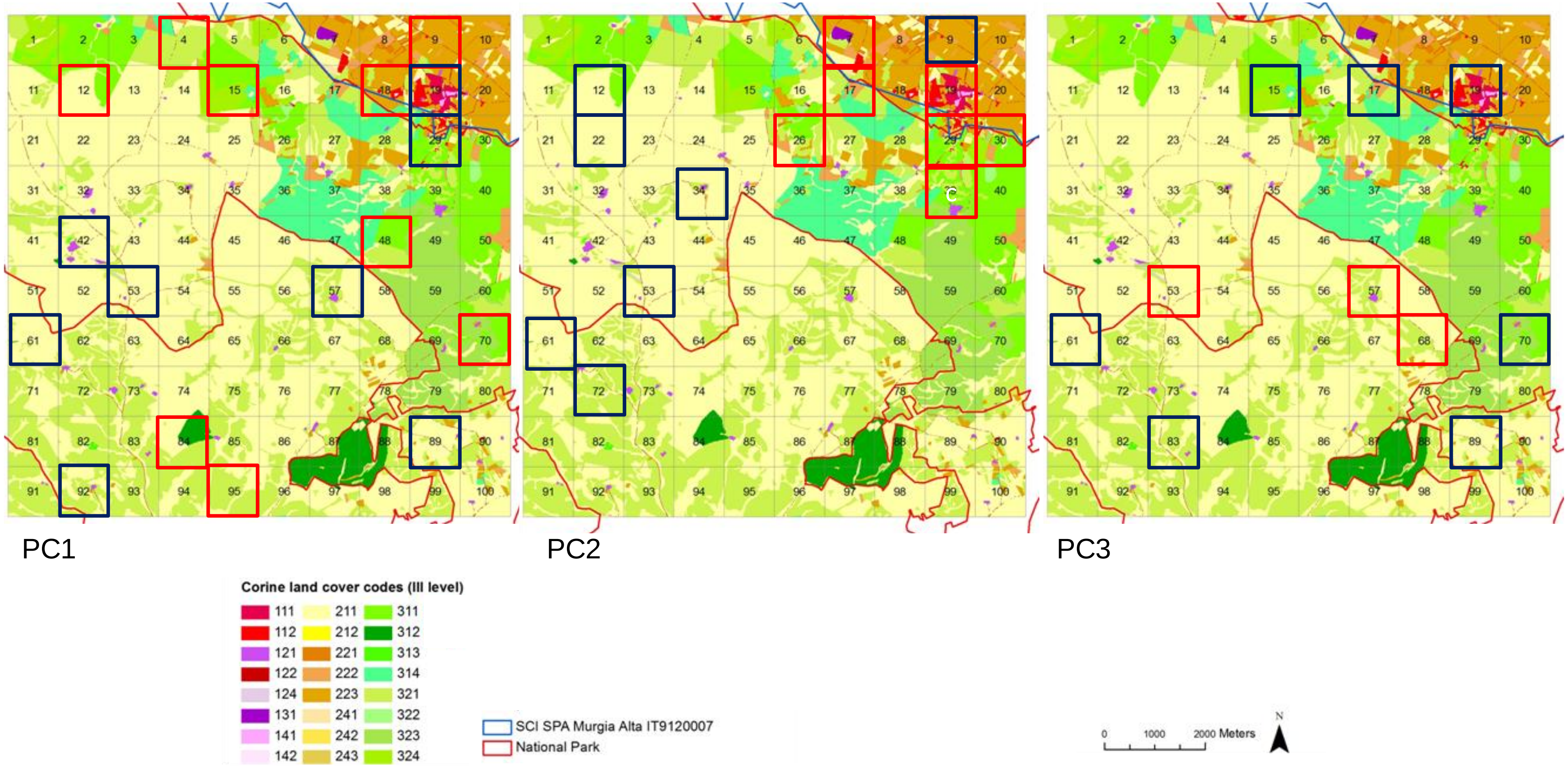


Figure 3.14 – Landscapes associated to each component among the 30 landscapes analysed. Two groups of landscapes for each component are indicated by red and blue solid contour.

The second component (PC2) represents an independent gradient in landscape contagion (CONTAG) and heterogeneity (SHDI). A group of landscapes (grid cell n.9, 12, 22, 34, 53, 61, 72) associated with this component show relatively high values of the contagion index and relatively low values of the diversity index. In these landscapes, either the focal class is the dominant one (grid cells n. 72) or it is highly fragmented in a homogenous (agricultural) matrix (grid cells 9, 12, 22, 34, 53, 61). The other group of landscapes associated with this component (grid cells n. 7, 17, 19, 26, 29, 30, 39), instead show relatively low values of the contagion index and relatively high values of the diversity index. In these cells, the focal class is fragmented in a heterogeneous landscape.

The third component (PC3) represents a gradient in patch cohesion index (COHESION) and in the fractal index weighted mean (FRAC_AM). The ANOVA between the two groups of landscapes associated with this component indicates a significant (*p-value*<0.05) difference only between the means of the FRAC_AM index. However, all landscapes associated with PC3 (grid cells. 15, 17, 19, 61, 53, 57, 68, 70, 83, 89) seem to be characterised by a high degree of fragmentation of the focal class.

The landscape configuration cannot be exhaustively described by a single PC (and the associated set of indices with no relation to focal class amount). However, the component associated with indices computed at the landscape level (PC2, CONTAG and SHDI) assists in exploring the relation between fragmentation and landscape heterogeneity. It indicates that in the examined situation and at the present observation scale, fragmentation occurs both in homogenous landscapes (mainly dominated by crop monocultures) and in more heterogeneous ones, where either mixed agriculture or urban land uses, or both, are present or, as in the case of grid cell 37, another “natural” LC/LU occurs. Both components associated with indices computed at the class level (PC1, mainly CWED and PD, PC3, COHESION, FRAC_AM) enable us to assess the fragmentation process in any of its phases (Jaeger, 2002, Forman, 1995) for the focal class. Among other principal components PC5, with which the MESH index is associated, represents a gradient in fragmentation of the focal class.

3.8.2 Morphological pattern analysis

The MSPA structural classes obtained for the complete range of edge widths (5m-100m) are shown in Figure 3.15. As expected (see Vogt *et al*. 2007), the share of the main MSPA structural classes (core, islet boundary and connector) either decreased (core) or increased with increasing edge width (Figure 3.16).

For the given working scale and the given proportion of focal class in the landscape (24% approx.), an edge width of 40 m appears as the most informative one. At this edge width, all main structural class types (core, islet boundary, connector) are present and they share of boundary peaks. This means that a further increase in the edge width determines an increase in the proportion of all edge pixels (boundary and connector structural classes) due to the sole increase in the connector structural class.

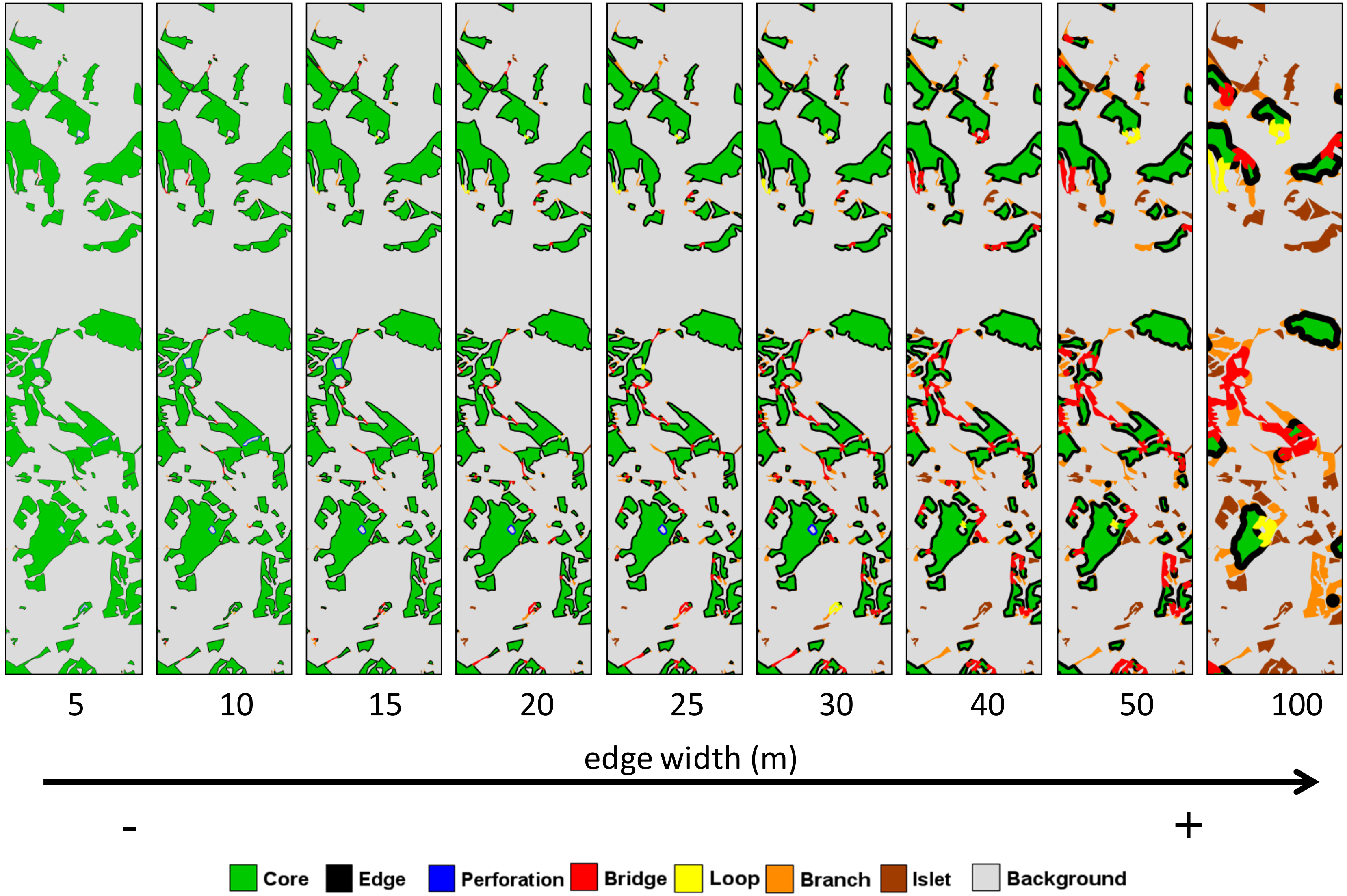


Figure 3.15 - Morphological spatial pattern analysis for the 2x10 km transect.

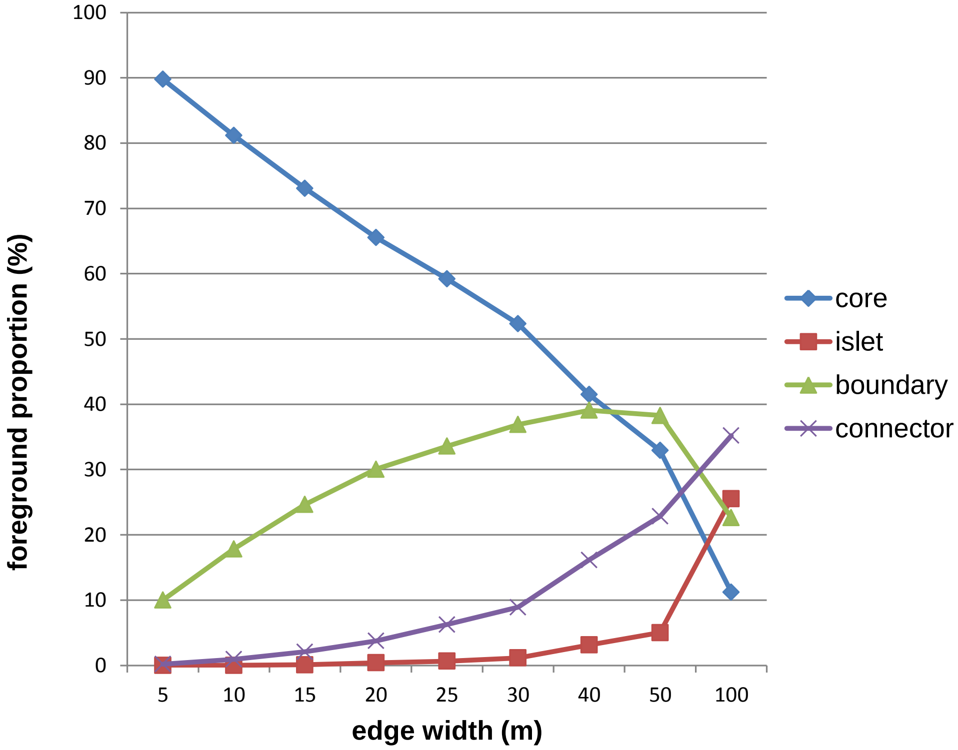


Figure 3.16 – MSPA main structural classes as a function of edge width.

3.8.3 Landscape mosaic analysis

The resulting landscape mosaic map and a graphical representation of the structure of the landscape mosaic within the 2x10km transect are shown in Figure 3.17.

The structure of the landscape mosaic can be used to describe a particular landscape mosaic and, more importantly, to make comparisons across space and/or time. Therefore, using the values provided by the map, a diversity profile (Table 3.18) could be constructed for the examined landscape using Hill's numbers (Hills 1993, 1997). This is a parametric family given by:

$$N(\alpha) = (\Sigma\ p_i^{\alpha})^{1/\ (1-\alpha)} \quad (1)$$

where $\alpha \geq 0$. For given values of α, this family links the most commonly used measures of diversity (richness, eveness, Shannon's entropy and Simpson's index). For completeness, also Hurlbert's eveness index (Hulbert 1971) was computed, according to Beisel and Moreteau (1997), which can sharpen the interpretation of the structure of the studied landscape when compared with the Pielou's eveness index (Pielou 1966).

Diversity and evenness profiling are gaining momentum in ecology. Evenness profiling in particular, seems very promising to provide deeper insights into community structure, revealing the contributions of both rare and common species to biodiversity trends (Studeny *et al.* 2011). This can be adapted for analyses of landscape mosaic structure and class composition within the context of change detection and characterization.

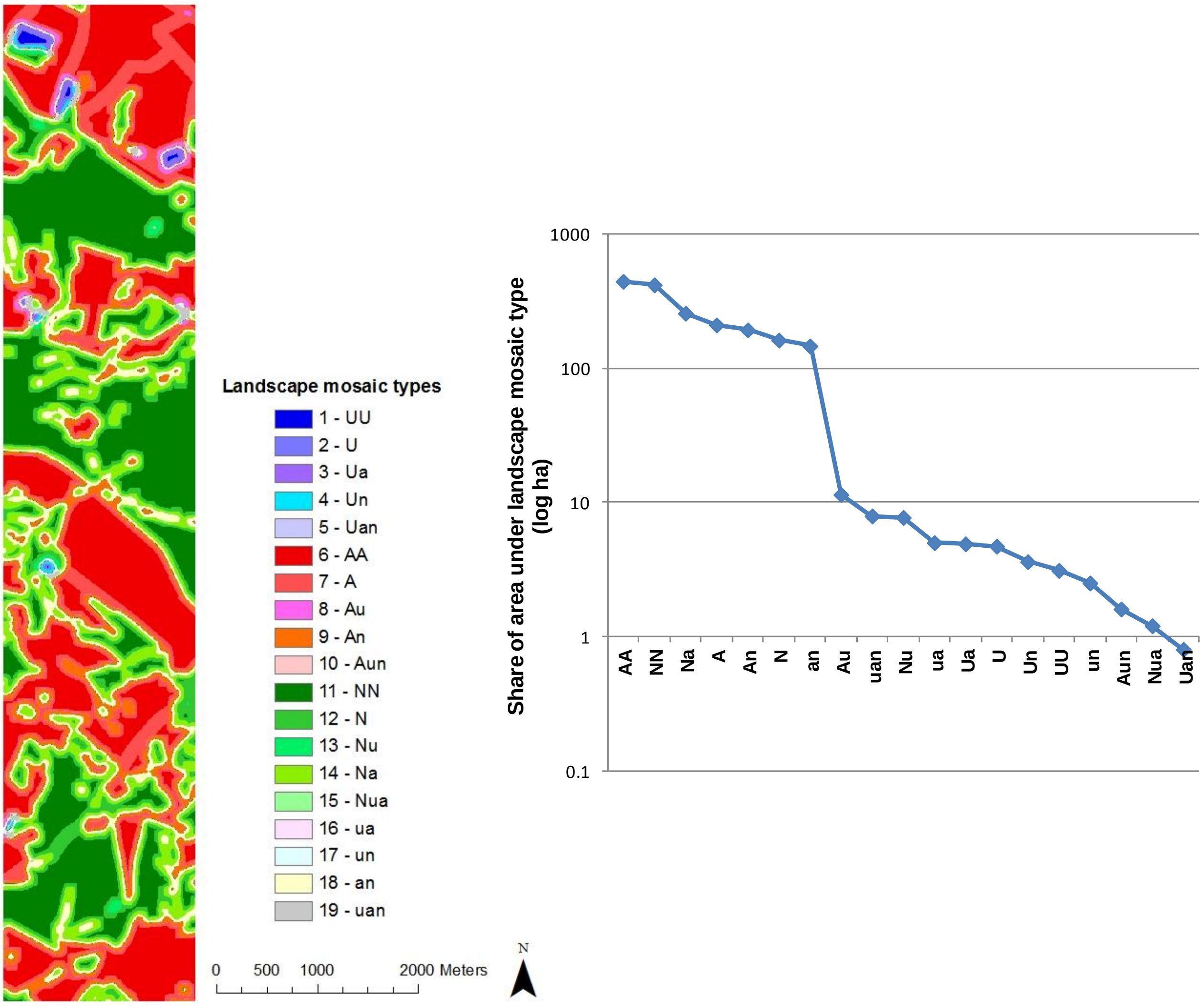


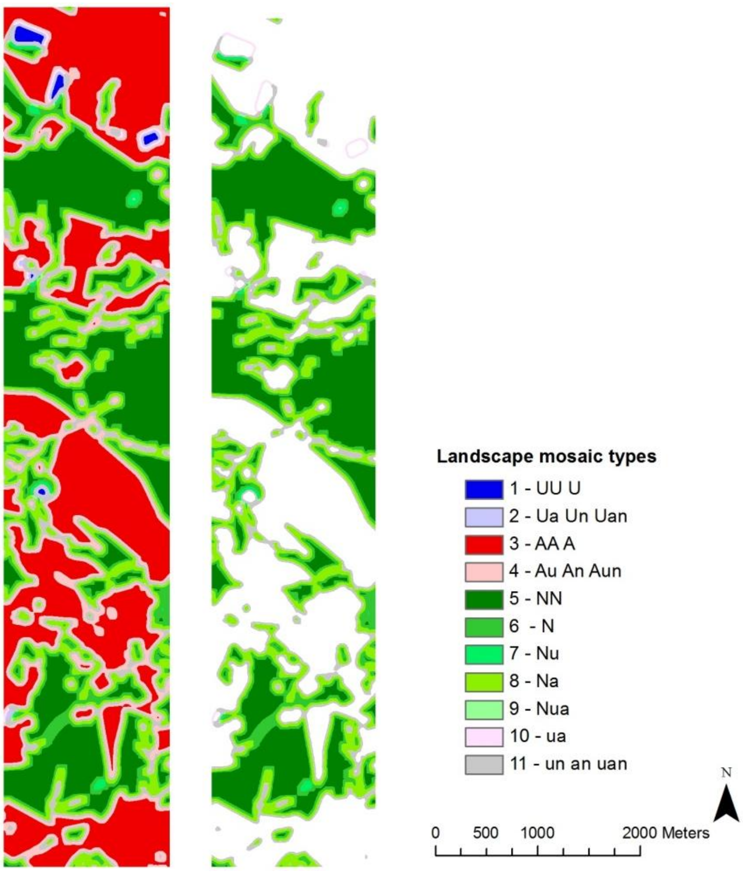
Figure 3.17 Landscape mosaic map and importance/diversity curve.

Table 3.18 - Diversity profile for the landscape mosaic of the 2x10km transect.

Hill number's	definitions	values
N0	S (class types number)	19
N1	e^H	7.342
N2	$1/\lambda$	6.281
E1 (Pielou's eveness index)	H/Hmax	0.677
E2	N1/N0	0.386
E3	N1-1/N0-1	0.352
E4	N2/N1	0.856
E5	N2-1/N1-1	0.833
Hulberts' eveness index	(H-Hmin)(Hmax-Hmin)	0.668
λ (Simpson's index)		0.159
H (Shannon's index)		1.994
Hmax	[ln(S)]	2.944
Hmin	according to Beisel and Moreteau 1997	0.082

Depending on the purpose of the study, landscape mosaic types can be aggregated into groups in order to visualize specific landscape aspects (Estreguil and Caudullo, 2010). For example, mosaic types dominated by agricultural or urban land uses can be grouped into higher level categories, while a more accurate level of detail can be used for the “natural” types. In addition, specific mosaic types can be extracted from the landscape mosaic map (Figure 3.18).
The landscape mosaic types extracted for the interest class (i.e., natural) can be aggregated into four main categories (Estreguil and Caudullo, 2010):

- natural landscape mosaic (NN): 100% of the landscape corresponding to the analysis window is covered by habitats classified as “natural”;
- mainly natural landscape mosaic (N): at least 80%, but less than 100%, of the landscape corresponding to the analysis window is covered by habitats classified as “natural”;
- mixed natural landscape mosaic (Nu, Nau, Na): the percentage of landscape corresponding to natural habitats ranges from 60% to 80%; habitats and species in this mixed pattern are potentially suffering edge effects from other land uses;
- some natural landscape mosaic (Aun, Uan, un, an, uan): the percentage of landscape corresponding to natural habitats ranges from 10% to 60%; most probably, natural habitats are present in poorly connected patches suffering edge effects from agricultural and/or urban land.



a b

Figure 3.18 - Landscape mosaic map based on an aggregation of landscape mosaic types (a), and landscape mosaic types extracted for the “natural” types (b).

Finally, the landscape mosaic map was used in combination with the MSPA output maps, as proposed by Estreguil and Caudullo (2010), in order to assign each pixel of the non core MSPA main structural classes to a landscape mosaic type. Then, the similarity index was computed. This is defined by Estreguil and Caudullo (2010) as the ratio between the share of a given MSPA class under a certain landscape mosaic type and the total amount of MSPA class. This index appears very useful in characterising the context of each non-core MSPA main structural class, and thus can be used to monitor change (Figure 3.19).

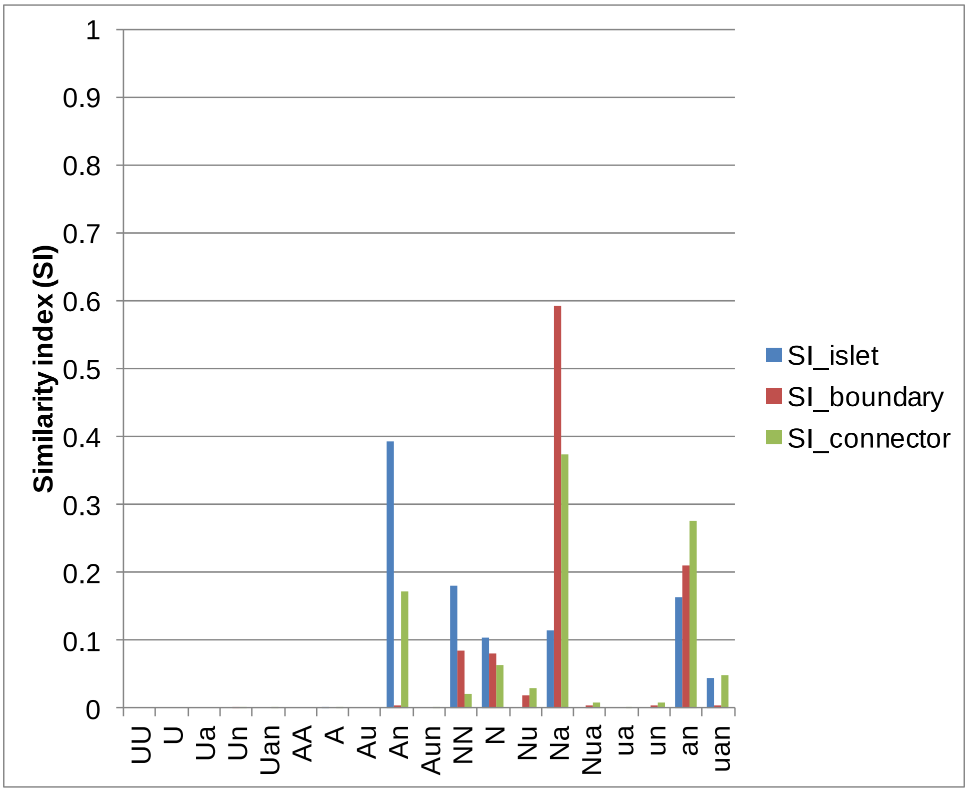


Figure 3.19 – Similarity index for the non-core MSPA main structural types.

3.8.4 Landscape spatial variation

The moving window analysis indicates the occurrence of sharp discontinuities coinciding with the midpoints of the windows 4 and 5, respectively for the two parts (a, b) (Figure 3.20).

At these locations the boundary of the National Park internal to the N2K site crosses the transect.

This circumstance therefore suggests the results obtained are very promising. The selected metrics deriving both from landscape pattern analysis (CWED and MESH) and from morphological spatial pattern analysis (islet, boundary connector, i.e., non-core main structural types), seem to be capable of indicating “critical points” where threats to biodiversity and ecosystem integrity are more likely to occur.

These metrics, for the specific landscape and for the observation scale of this study, appear adequate to form a set of metrics capable of capturing spatially explicit attributes of a landscape focal class, associated with its fragmentation.

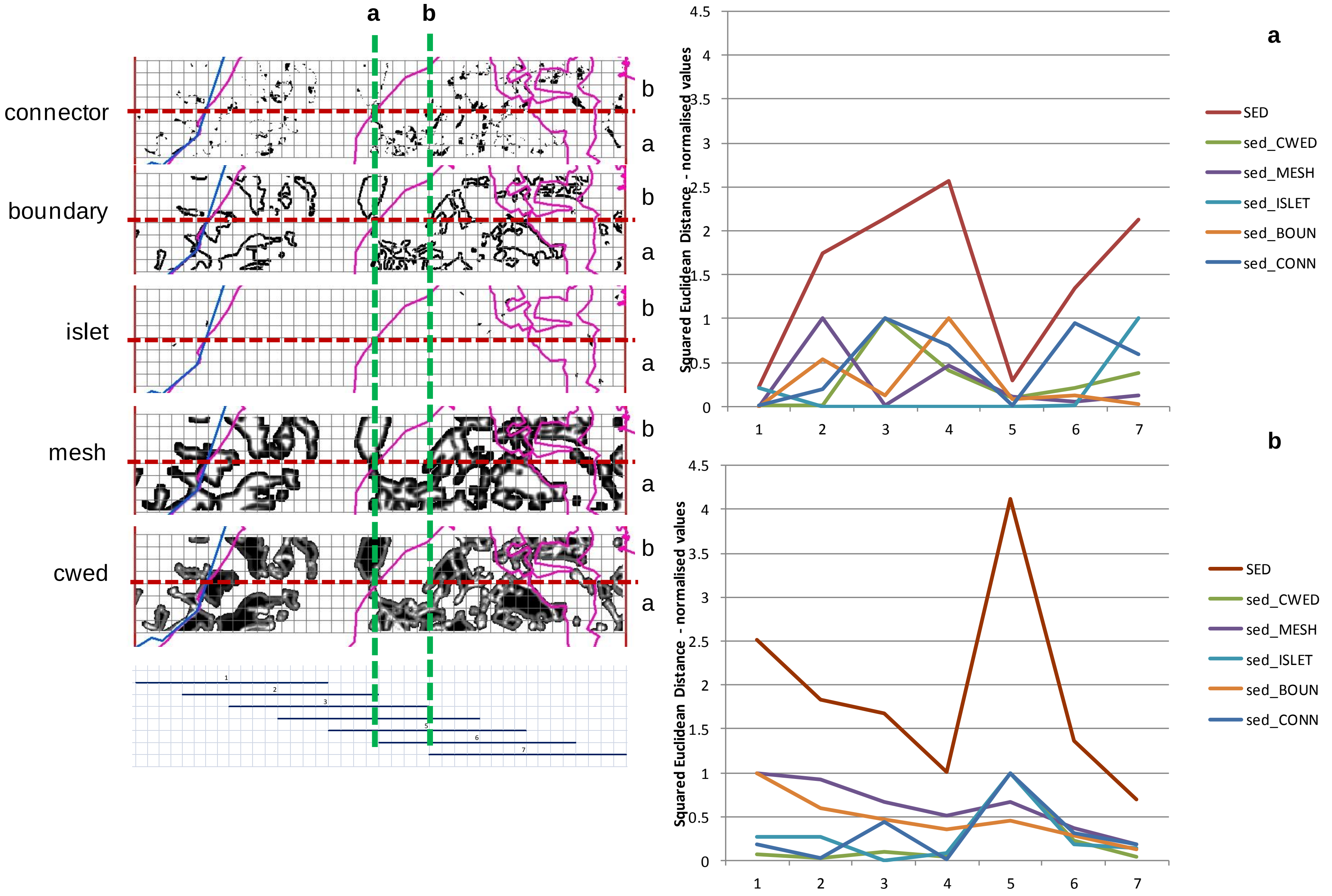


Figure 3.20- Results of the moving split window analysis on a 2x10 km transect . On the left: 2x10km transects for the whole array of variables. For each transect the two parts of the transect (a, b) are separated by a red dashed line. The green dashed lines indicate (a, b), for the corresponding part of the transect, the station of the SED where the discontinuity occurr. On the right: Graphical representation of the SED and of its relations with the values obtained for each individual variable (sed). Peaks indicate the occurrence of discontinuities.

4. Concluding remarks

The pre-evaluation landscape pattern analysis (LPA) carried out confirms that the landscape configuration cannot be exhaustively described by a unique set of indices. A landscape- and observation-scale specific set was identified for IT3 BIO_SOS site considering natural grasslands as the focal class. Such indices are capable of providing information about landscape configuration (fragmentation) independently from the contribution of focal class amount (fragmentation *per se*, Fahrig 2003).

For the examined landscapes, LPA has also allowed us to gain insights on the relations between landscape heterogeneity and fragmentation.

This analysis has also provided the expert judgement capability necessary to perform ranked set sampling. Among the 30 landscapes, 9 will be selected for the purpose of LCSS validation, of GHCs field identification and task 6.3. The 30 landscapes can in fact be divided into three groups: group 1, where the focal class is fragmented in a homogeneous matrix; group 2, where the focal class is fragmented in an heterogeneous matrix; and group 3, where the focal class is not fragmented or poorly fragmented. The rank sampling will consist of a random sampling of 3 landscapes within each of the three groups.

The morphological spatial pattern analysis (MSPA) has provided a structural characterisation of the landscape and indicated, for the specific landscape and observation scale, the most appropriate value for the most critical parameters which need to be set (i.e., edge width). Thus, for the examined landscape a quick procedure based on this methodology can be implemented for change assessment.

The landscape mosaic analysis too has proven useful to this end, by allowing an effective characterisation of the structure of the landscape by means of landscape diversity profiling. In addition, when used in combination with MSPA, the landscape mosaic analysis allows the context of each non-core MSPA main structural class to be characterised which appears a very useful tool for change monitoring. In addition, this kind of local (i.e., pixel based) pattern analysis could be used as a refinement of the existing ancillary data-set within the framework of the EO GHC map production.

The combined use of LPA, namely the quantification of the local pattern gradient across the landscape space, MSPA within the moving split window analysis, has also proved appropriate when defining a set of indices capable of identifying landscape discontinuities and indicating “critical points” where threats to biodiversity and ecosystems integrity are more likely to occur.

On the whole, the activities carried out provide a site and scale specific composite set of indices derived by different kinds of approaches to landscape configuration analysis and by their combination. This set can be used as a change biodiversity indicators set with reference to the CBD-SEBI (Strand *et al.* 2009) focal areas: status and trends of the components of biological diversity, Ecosystem integrity, and ecosystem goods and services (D2.1).

All the approaches to landscape configuration can be applied to any site and any observation scale. Therefore, these initial conclusions will be evaluated further during WP6_Task 6.2 activities in connection with the other scheduled activities to be carried out at finer scales (e.g. within patch scale), which will be done also in combination with the LPA analysis on continuous data.

5. References

Baskent E.Z., Jordan G.A., 1995 Characterising spatial structure of forest landscapes. Canadian Journal of Forest Research, 25:1830-1849

Beisel J-N., Moreteau J-C.(1997) A simple formula for calculating the lower limit of Shannon's diversity index, Ecological Modelling,99(2):3 289-292

Camarero J.J, Gutiérrez E., Fortin M.J (2006) Spatial patterns of plant richness across treeline ecotones in the Pyrenees reveal different locations for richness and tree cover boundaries *Global Ecology and Biogeography,* 15*:*182–191

Choesin D.N. (2001) Use of landscape ecological analysis to determine ecotone locations: an evaluation based on field data JMS 6 (2)91 – 99

EEA 2010 EU (2010) Biodiversity Baseline. Luxembourg ISBN 978-92-9213-164-7 ISSN 1725-2237 doi:10.2800/6160

Estreguil C and Caudullo G (2010) ID 5.3 (Intermediate Deliverable, July 2010): Pattern Related Measures and Indicators for Selected Sites at Varying Spatial Scales in Selected Environmental Strata EBONE http://www.ebone.wur.nl/NR/rdonlyres/298E8A25-FEB4-4E0C-B7E3-1C725D3F7006/143155/EBONED53_EstreguilandCaudullo2010_final.pdf

Fahrig L. (2003). Effects of habitat fragmentation on biodiversity. Annual Review of Ecology, Evolution and Systematics 34:487-515

Forman, R.T.T. (1995). Land mosaics: the ecology of landscape and regions. Cambridge University Press, CambridgeHaines-Young R. and Chopping M. (1996), Quantifying landscape structure: a review of landscape indices and their application to forested landscapes, Prog Phys Geog, vol. 4, pp. 418–445, 1996.

Hill, M. O. (1973) Diversity and evenness: A unifying notation and its consequences. Ecology 54:427–432.

Hurlbert S.H. (1971) The nonconcept of species diversity: a critique and alternative parameters. Ecology, 52: 577-586.

Jaeger, J.A.G. (2000). Landscape division, splitting index, and effective mesh size: New measures of landscape fragmentation. Landscape ecology 15: 115-130.

Johnston C.A., Pastor J. and Pinay G. (2002) Quantitative methods for studying landscape boundaries, In: Hansen A.J. and di Castri F. (eds) *Landscape boundaries: consequences for biotic diversity and ecological flows* Springer-Verlag Inc., New York), 107-125

Kotliar, N.B. and Wiens, J.D. (1990). Multiple scales of patchiness and patch structure: A hierarchical framework for the study of heterogeneity. Oikos 59: 253-260

Mairota P., Papadimitriou F. (1995) Spatial discontinuities in a southern Italian cultural landscape: Testing a methodology. In: Griffiths G.H., 1995 [Ed.] *Landscape Ecology: Theory and Application*. Proceedings of the IALE(UK) Fourth Annual Conference, 19-20 September 1995 Reading, UK. Colin Gross Printers Ltd., Garstang UK. ISBN 0-9524263-1-5 pp.102- 109

McGarigal K, Cushman SA (2005) The gradient concept of landscape structure. In: Wiens J, Moss M (eds) Issues and perspectives in landscape ecology. Cambridge University Press, Cambridge, pp 112–119

McGarigal K, Cushman SA, Neel MC, Ene E. 2002. *FRAGSTATS: Spatial pattern analysis program for categorical maps.* Comp. software prog. Univ. Mass., Amherst. Documentation. Available online at: http://www.umass.edu/landeco/research/fragstats/documents/fragstats_documents.html (Accessed on 07/11/2011)

McGarigal K. and McComb W.C. (1995). Relationships between landscape structure and breeding birds in the Oregon Coast Range. Ecological Monographs 65: 235-260

McGarigal, K. and Marks, B.J. (1995). *FRAGSTATS*: spatial pattern analysis program for quantifying landscape structure. General Technical Report PNW-GTR-351, USDA Forest Service, Pacific Northwest Research Station, Portland.

Moss D., Davies C.E. (2002). Cross-references between the EUNIS habitat classification and the nomenclature of CORINE Land Cover. NERC/Centre for Ecology & Hydrology, 49pp. (CEH Project Number: C00389)

Pielou E.C. (1966) Species-diversity and pattern-diversity in the study of ecological succession. J. Theor. Biol., 10: 370-383.

Riitters K.H., Wickham J.D., Vogelmann J.E., Jones K.B. (2000). National land-cover pattern data. Ecology 81:604.

Riitters K.H., Wickham J.D., Wade T.G. (2009) An indicator of forest dynamics using a shifting landscape mosaic. Ecological Indicators 9: 107-117

Riitters KH, Vogt P, Soille P, Kozak J, Estreguil C (2007) Neutral model analysis of landscape patterns from mathematical morphology. Landsc Ecol 22(7):1033–1044. doi:10.1007/s10980-007-9089-3

Rodwell J.S., Schaminée J.H.J., Mucina L., Pignatti S., Dring J., Moss, D. (2002). The diversity of European vegetation. An overview of phytosociological alliances and their relationship to EUNIS habitats. EC-LNV report 2002/054, Wageningen, NL

Soille P. and Vogt P., 2009. Morphological segmentation of binary patterns. Patterns Recognition Letters. doi:10.1016/j.patrec.2008.10.015

Studeny A.C., Buckland S.T., Illian J.B., Johnston A. (2011) Goodness-of-fit measures of evenness: a new tool for exploring changes in community structure. Ecosphere 2(2):2-19

Turbé A., De Toni, A., Benito, P., Lavelle, P,; Lavelle, P., Ruiz, N., Van der Putten, W. H., Labouze, E., and Mudgal, S., (2010), *Soil biodiversity: functions, threats and tools for policymakers*, Bio- Intelligence Service, IRD, and NIOO, Report for European Commission (Directorate-General for the Environment) http://ec.europa.eu/environment/soil/pdf/biodiversity_report.pdf

Wickham, J.D. and Norton D.J. (1994). Mapping and analysing landscape pattern. Landscape Ecology 9: 7-23

Wu, J. (2004). Effects of changing scale on landscape pattern analysis: Scaling relations. Landscape Ecology 19: 125-138

Abbreviations and Acronims

BIO_SOS = Biodiversity Multisource Monitoring System: from Space TO Species
BIOHAB = A Concerted Action of the Fifth Framework – A framework for the coordination of Biodiversity and Habitats
CBD-SEBI = Convention on Biological Diversity - Streamlining European Biodiversity Indicators
CLC= CORINE Land Cover
CORINE = Coordinate Information on the Environment
D=Deliverable
DoW= Description of Work
EBONE = European Biodiversity Observation Network
EnS = Environmental strata of Europe
EnZ = Environmental zones of Europe
EO = Earth Observation
EODHaM = Earth Observation Data for Habitat Monitoring
EPA= Environmental Protection Agency
GHC = General Habitat Category
INSPIRE = Infrastructure for Spatial Information in Europe
LANDSAT = Land Satellite
LC/LU = Land Cover / Land Use
LCCS = Land Cover Classification System
LPA = Landscape pattern analysis
LPI= Landscape pattern indices
MSPA= Morphological spatial pattern analysis
N2K = Natura 2000
NP = National Park
PCA = Principal Component Analysis
RDM PP (INSPIRE) = Reference Data and Metadata Position Paper
RS = Remote Sensing
SCI=Site of Community Interest
SPA= Special Protected Area
SRSRG = Stratified Random Sampling within a Regular Grid
SSS = reference Sample Set Size
VHR= Very High Resolution
WP = Work Package
WT = Workplan Table