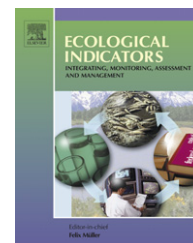


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Indicating disturbance content and context for preserved areas

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ABSTRACT

An accepted goal of conservation is to build a conservation network that is resilient to environmental change. The conceptual patch-corridor-matrix model views individual conservation areas as connected components of a regional network capable of sustaining metapopulations and biodiversity, and assessment of contextual conditions in the matrix surrounding conservation areas is necessary for planning. Context is often assessed in terms of fixed-width buffers surrounding conservation areas, but in practice, different locations within the same conservation area experience different contexts. We present an alternate approach for describing the landscape context of conservation areas, and we illustrate the approach by assessing vegetation disturbance measured by Landsat NDVI changes over a 4-year period for 51 conservation areas in the Apulia region of south Italy. Insights gained from a multi-scale assessment of disturbance, coupled with information about land use and habitat mosaics are necessary to understand the distinctive features of different preserved areas and thus, to formulate appropriate plans for a regional conservation network to maintain or enhance biodiversity in the region.

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1. Introduction

The establishment of protected areas is widely recognized as being critical to nature and landscape conservation (WRI/IUCN/UNEP, 1992; Andelman and Willig, 2003; Waldhardt, 2003). Building a conservation network that is resilient to environmental change (e.g., land cover conversion, land use intensification or habitat fragmentation) is a primary goal of conservation (Noss and Cooperrider, 1994). One approach to planning is based on a patch-corridor-matrix model (Forman, 1995) that views individual areas as “islands” of habitat that are connected by habitat corridors such that all areas together constitute a regional habitat network capable of sustaining metapopulations or affecting regional biodiversity (e.g.,

Hanski, 1999; Opdam, 2002). With that model, the ‘contents’ of the network are described by landscape descriptions of patches and corridors, for example indices of existing biodiversity, land use and cover, and anthropogenic or natural stresses and constraints within the boundaries of conservation areas, and each area is deemed as spatially homogeneous with respect to those descriptors (Fig. 1).

In contrast, the “context” of conservation areas refers to the nature of the surrounding landscapes which may have important effects on what goes on within a park or a reserve (Janzen, 1983; Wiens, 2002). Context is important to biodiversity because at the patch level a community may depend on the patch quality which may be affected by patch boundary permeability and the neighbouring patch types (e.g., Andrén,

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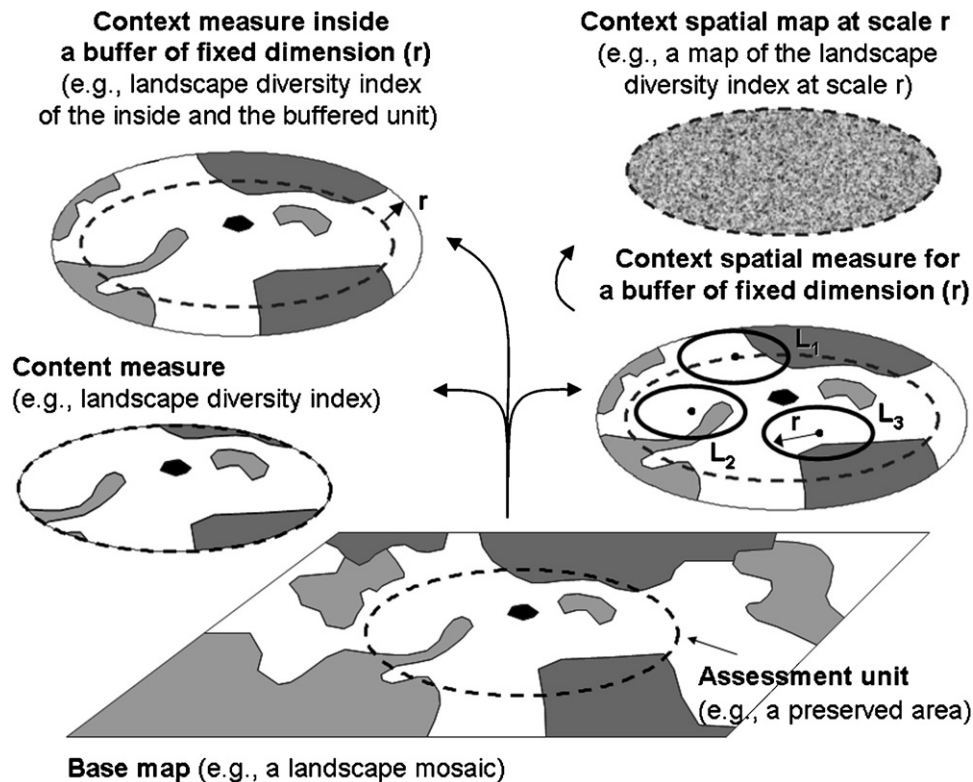


Fig. 1 – The classical approach that describes the contents of a conservation area (i.e., the assessment unit; lower left) and its context (i.e., a fixed buffer assessment unit; upper left) in comparison to an approach that describes the context of each location within a conservation area (right). The methods employed in this paper uses the latter approach and accommodate multi-scale assessments by varying r , the size of the area over which context is assessed. In the figure the base map is a habitat mosaic and the assessment unit is described by a diversity index. Maps quantifying abiotic constraints, biodiversity descriptors, or agents of pressure could also be used. See text for additional discussion.

1994). At the landscape level, the context, that could be envisioned as a 'buffer' around a site, may or may not help to maintain ecosystem functioning within a protected area, allowing animal and plant dispersal and gene flow (Hansen and Rotella, 2002) essential for population maintenance (Woodroffe and Ginsberg, 1998; Thies et al., 2003). Incompatible land uses (e.g., development), the spill-over of exogenous stresses (e.g., agricultural practices) (Rand et al., 2006), and edge effects such as impoverishment of vegetation and changes in biotic composition (Harper et al., 2005) are important even in the most remote regions of the globe (Laurance et al., 2002). DeFries et al. (2005) evaluated 198 tropical forest protected areas over a 20-year period and found that 25% of the areas experienced a decline in forest habitat area within the administrative boundary whereas 70% experienced a decline in the surrounding landscape extending 50 km from protected area boundaries. Assessment of environmental conditions in nearby unprotected areas helps to inform the creation and management of protected areas (Shafer, 1999; Margules and Pressey, 2000).

'Scale' is an issue when considering the context of preserved areas because context depends on how much of the surrounding landscape is included. When context is envisioned as a fixed-width buffer area surrounding conservation areas (e.g., DeFries et al., 2005), scale issues can be

examined by changing buffer width to incorporate more or less of the surrounding area (Fig. 1). This approach describes differences between the regions inside and outside the conservation area, but it does not take into account potential differences within the same conservation area. For example, a location at the center of a conservation area experiences a different context in comparison to a location at the edge of the conservation area (Fig. 1).

A logical extension of a buffer analysis applied to an entire protected area is to identify a separate buffer or context for each location within a protected area (Fig. 1). Because this approach still imposes an arbitrary measurement scale (i.e., the choice of the buffer width), it would be even more informative to perform the buffering of all locations using a range of buffer widths (i.e., a neighborhood analysis with different window sizes). Depending on the buffer sizes considered, the size of the conservation area, and the proximity of a given location to the boundary of the conservation area, the context for that location may then include area inside and/or outside of the conservation area.

Landscape context and spatial scales are particularly relevant in highly developed regions where protected areas are geographically scattered and relatively small and where ongoing human activities and new land-cover types can be juxtaposed within increasingly fragmented native land-covers

and habitats. Apulia is a region of south Italy that has been dominated by widespread and intensive human activities for more than two millennia, and practically no location in the region is completely free of human influence (Zurlini et al., 2006a). A preserved area contained in a regional context of relatively low disturbances (e.g., land cover conversion, fires or pollution) is likely to be at risk less than a similar area contained in a highly dynamic landscape (August et al., 2002). Human activities inside and outside preserved areas take place at multiple spatial scales ranging from the regional differentiation of tourist and agricultural areas (Petrosillo et al., 2006; Zurlini et al., 2006a), to the land care decisions made by individual farmers within small agricultural fields.

In this paper, we are interested in quantifying the spatial pattern of disturbance at multiple scales and in investigating how the environmental conditions of differently scaled contexts of preserved area may affect planning and managing conservation networks in the face of human disturbance. We evaluate human activities in terms of disturbances as they relate to candidate conservation areas in the Apulia region belonging to the Natura 2000 network (Council Directive, 1992). We adopt the Pickett and White (1985) definition of disturbance as “any relatively discrete event in space and time that disrupts ecosystem, community, or population structure and changes resources, substrates, or the physical environment”. Large disturbances are generally distinct from small disturbances, and small disturbances are usually more frequent than large disturbances (Turner and Dale, 1998). Since habitat is defined partly by vegetation cover, we measure disturbance by any detectable alteration of land cover reflecting small and relatively frequent vegetation changes which we attribute to human-driven processes (Zurlini et al., 2006a). Disturbances are measured over a 4-year period by using synoptic maps of vegetation greenness prepared from satellite imagery.

The disturbance content and context of all locations within and near the conservation areas are gauged by using a moving-window algorithm to define a unique set of fixed-area landscapes for each location within preserved areas. We derive disturbance profiles at multiple scales for preserved areas and compare the results of the multi-scale analyses with results obtained by performing a traditional content operation. We show that insights gained from the multi-scale assessment, when integrated with information about land use and habitat mosaics in the landscape, help to understand the distinctive features of different preserved areas and to formulate appropriate regional network plans to maintain or enhance biodiversity in the region.

2. Materials and methods

2.1. Study area

Apulia is an administrative region in southern Italy that has been inhabited for thousands of years, so that man and nature have a long historical interrelationship. Owing to the intensity of human land uses in the Mediterranean region, particularly in the last several centuries, plant communities have been shaped into a mosaic-like pattern composed of different

degradation and regeneration stages (Naveh and Lieberman, 1994). As a result, the fine-scale heterogeneity of the landscape has increased in this region. Regional landscapes are the fingerprints of the local culture and the history of interaction between man and nature.

The climate in the region is mainly Mediterranean semi-arid, characterized by hot and dry summers and a moderately cold and rainy winter season. The regional land cover composition as described by the CORINE land cover map (Heymann et al., 1994) at a scale of 1:100,000 updated in 1999 (Fig. 2A), is mainly composed of agro-ecosystems. The central and northern part of the region is characterized by arable lands (CORINE code 2.1, 39.8%) devoted to the production of cereals and vegetables, while extensive centuries-old olive groves (code 2.2.3, 22.6%), fruit orchards and vineyards (codes 2.2.1 and 2.2.2, 6.4%), and heterogeneous agricultural areas (code 2.4, 13.3%) dominate the central and southern parts of Apulia. Major towns and small urban settlements (codes 1.1, 1.2, 1.3, 1.4) account for only 3.8% of the entire area. Natural habitats are unevenly distributed with major forested areas (code 3.1, 7.3%) concentrated in the Gargano peninsula. Small remnants of xeric oak forests are interspersed with olive groves, shrub and herbaceous vegetation associations (code 3.2, 1.4%) and permanent pastures (code 2.3.1, 5.2%) in Dauno and Murge Apennines.

2.2. Preserved areas

The Natura 2000 network was established under the European Union's Habitats Directive (Council Directive, 1992) to safeguard Europe's most important wildlife areas and species. Being a part of Natura 2000 means that a selected area benefits from increased protection as set out in the Directive. Member states must take all necessary measures to guarantee the conservation of selected areas and avoid their degradation. Not all economic activities are excluded from the selected areas, but Member states must ensure that such activities are carried out in a way that is compatible with the conservation of the habitats and species hosted. From the Apulia Natura 2000 database, we selected the 51 out of 77 “Special Areas for Conservation” (SAC, Council Directive, 1992) that were larger than 100 ha as assessment units in this study (see Fig. 2B). Those 51 assessment units account for 21.6% of the Apulia region area and they have been identified to protect regional habitats of high conservation value based on the Habitat Directive (Council Directive, 1992) like oak forests (mostly with *Quercus pubescens* and *Quercus ilex*), marshes, lagoons, sub-Mediterranean arid grasslands (e.g., *Thero-Brachypodietea* or *Festuco-Brometalia* associations), and coastal habitats of dunes, garigues, steppes and sub-Mediterranean maquis. Animal species richness of relevant conservation value (i.e., no generalist or cosmopolitan species) is high with 13 mammals, 5 reptiles, 1 amphibian and 52 birds out of 20, 9, 10 and 81 species present in the Natura 2000 national network, respectively (Ufficio Parchi Regione Puglia, 2006). Mammals, with the exception of the wolf (*Canis lupus*), reptiles and amphibian have small home ranges and are sensitive to local changes and disturbances during all phases of their lifecycle, while most of the birds, particularly hawks (e.g., the lesser kestrel, *Falco naumanni*) and owls (e.g., the eurasian eagle-owl,

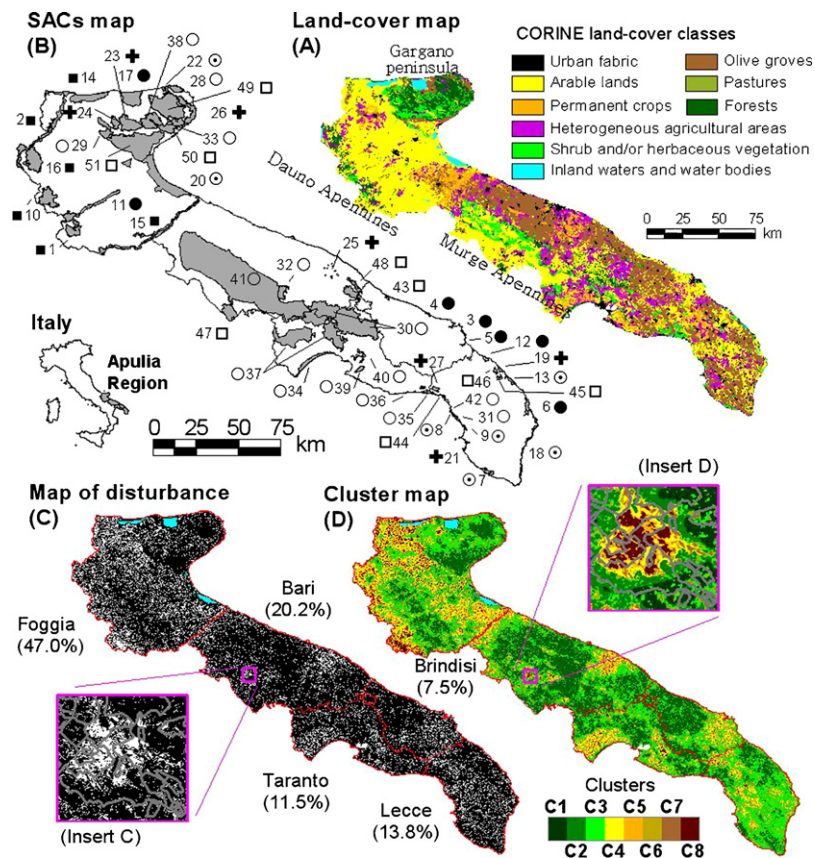


Fig. 2 – (A) Simplified CORINE 1999 land cover map of the Apulia region. (B) Localization of the special areas for conservations (SACs) used in the analysis and group membership. See Fig. 5 for SAC's name and group identification. SAC number 48 “Murgia dei Trulli” and SAC number 16 “Monte Sambuco” are the two examples presented in Fig. 7. (C) The map of disturbance (white color) for the Apulia region between August 1997 and August 2001. Province administrative boundaries are shown in red, and the percentage of disturbance within each province is shown in brackets beside the province name. The inset shows an example overlay with the land cover map of a fire affecting arable lands, dry grasslands and fragments of coniferous forests. (D) Spatial distribution of the eight clusters of disturbance profiles calculated as a multiscale spatially explicit context measure. The inset shows an example overlay with the land cover map.

Bubo bubo), have bigger home ranges and multi habitat needs but a high sensitivity during the nesting period (Ufficio Parchi Regione Puglia, 2006).

2.3. Map of disturbance

The first step in describing land cover and land use dynamics for the Apulia region was to derive a binary map of disturbed and undisturbed areas. This was accomplished by applying a standardized bi-temporal change detection procedure (Zurlini et al., 2006b) to the values of the Normalized Difference Vegetation Index (NDVI, Goward et al., 1991) derived by a cloud-free set of six Landsat images with a pixel size of 0.09 ha. In order to capture mainly man-induced changes and disturbances, a 4-year temporal window from June 1997 to June 2001 was used. This interval was considered to be a representative example of the disturbance regime of the study area.

A pixel was labeled as disturbed if its value was within the larger positive (i.e., right tail) or larger negative (i.e., left tail) values of the standardized NDVI difference map distribution

based on a threshold value. A disturbance map was produced using as a threshold the values for the percentiles of the 20% of the pixels of the study area on both distribution tails. A second map of disturbance was calculated for the percentile of the 10% for comparison purposes for some of the calculated indicators. Urban areas, water bodies and brackish environments were excluded from the analysis and no distinction was made between NDVI gain and loss. Zurlini et al. (2006a) provide additional details on the image processing techniques and preparation of the disturbance map.

In this paper, NDVI is used as an integrative ecological measurement that can detect both natural variation in ecosystem structures and functions (Kerr and Ostrovsky, 2003) and changes arising from human activities, such as habitat or land-cover conversion as well as land-use changes and farming practices (Pettorelli et al., 2005). Extreme NDVI changes represent a disturbance following the definition of Pickett and White (1985).

In Apulia, typical disturbances are related to land-use or land-cover and reflect changes associated with urban sprawl, conversion of perennial habitat (e.g., grassland) to cultivated

fields, new olive grove plantations, and farming practices such as fire, grazing, and crop rotation. Such farming practices are disturbances because they affect species persistence and populations (Benton et al., 2002), diversity of both weeds and animal communities (McLaughlin and Mineau, 1995), ecosystem services quality (Tscharntke et al., 2005), and pollutant diffusion in commodity production landscapes (e.g., consider the emerging field of landscape ecotoxicology; Johnson, 2002). Agricultural fields could be more dynamic than other types of land-cover systems, and farming practices could spread disturbance agents in the landscape to other neighbouring land-use types like natural areas or permanent cultivations (Rand et al., 2006). Thus, land-use and land-cover classes within a landscape not only might be disturbed by various agents, but also might act as a “source” or a “sink” as to the potential spread of disturbance agents to neighbor areas, as it may occur because of, for instance, fire, pests, disease, alien species, and urbanization.

2.4. Disturbance pattern analysis at multiple scales

We applied a moving window algorithm to quantify and describe disturbance patterns at multiple scales (Zurlini et al., 2006a, 2007). In this application, spatial patterns are characterized by the proportion of disturbance (i.e., the proportion of pixels labeled as disturbed; P_d). For each subject pixel (i.e., for each location) we measured P_d within a fixed area window that represents the context of that location at that scale, and assigned the value to the location of the subject pixel. The measurements were made for each location at multiple scales by using 10 square arbitrarily chosen window sizes in pixel units of 3, 5, 9, 15, 25, 45, 75, 115, 165, and 225; thus, the window area ranges from 0.81 to 5852.25 ha. Depending on the size of a SAC and the location of a subject pixel in a SAC, this range of window sizes sometimes resulted in multi-scale context being evaluated entirely within a SAC, and sometimes only partly with a SAC. In this way, each location in each preserved area was characterized according to the amount and of disturbance within its surrounding landscape, for several landscape sizes.

Consider now a specific location within a SAC. The multi-scale profile of P_d is defined by the set of P_d values measured at different window sizes. This profile can be interpreted with respect to the disturbance experienced by that location at different spatial scales which potentially correspond to changes in context. For example, a small window with low P_d , combined with a large window with high P_d implies a relatively undisturbed area embedded in a larger region with more disturbance. If the profile for a location has constant P_d over all window sizes, it experienced equal proportion of disturbance at all spatial scales. If profiles are similar for two different locations, then both locations have experienced in their surrounding landscapes the same proportion of disturbance at different spatial scales. Conversely, dissimilar profiles imply differences in multi-scale spatial patterns of disturbance.

2.5. Data analysis

The most common or typical disturbance profiles were identified by using the k-means unsupervised algorithm

(Legendre and Legendre, 2000) to group pixels together according to similarity of P_d values over window size. Recognizing that any clustering solution is at least partly arbitrary, we specified that eight clusters be identified after experimenting with other alternatives. Geographic mapping of clusters was performed by labeling each pixel on the map according to the cluster it was contained in.

Three different kinds of indicators were then obtained for each SAC (Fig. 1B): (1) the proportion of disturbed area inside the assessment unit (P_d) as ‘content’ measure of disturbance; (2) the proportion of disturbance inside two buffers surrounding the SAC with fixed radii of 3.3 km (“ P_d -big buffer”) and 1.7 km (“ P_d -small buffer”) as a single scale context measure in an enlarged assessment unit; (3) the proportion of pixels in the SAC that belonged to each of the eight clusters (P_c) as a measure of multi-scale spatial context properties for the assessment unit. The largest window used in the multi-scale analysis was similar in size to the larger of the two fixed-buffer radii. Comparisons between the two different disturbance maps were made for the first and second type of indicators, as well as for the general behavior of the disturbance clusters. The similarity between the two content measures was evaluated by calculating the Pearson linear correlation coefficient and by testing for its significance (Sokal and Rohlf, 1995).

In a second cluster analysis, SACs were then grouped together based on their composition in terms of P_c , derived by the disturbance clusters of the 20% percentile map, using a minimum variance cluster algorithm (Ward’s method; Legendre and Legendre, 2000) to identify groups of SACs that contained similar proportions of disturbance profiles.

3. Results

3.1. Map of disturbance

Disturbance exhibited an uneven distribution reflecting both regional land-cover class differences as well as finer-scale (local) geographic heterogeneity. For the 20% percentile threshold case, approximately 47% of all disturbance was concentrated in the large plain of the Foggia province which is devoted to intense agricultural practices (Fig. 2C). The disturbance in this area is mainly an expression of human dominated land-cover classes, characterized by periodic turnover, with arable lands and heterogeneous agricultural areas comprising the 61.4% of changes (Fig. 2C and Table 1). Permanent crops and olive groves account for another 24.2%, and natural land-cover classes account for 11.6% reflecting successional processes for shrub lands and human caused disturbances such as arson in forests and pastures. Approximately the same figures hold when the 10% percentile disturbance map was considered.

With the exception of arable lands where disturbed areas generally mimic field boundaries, the spatial patterns of disturbance, though exhibiting a clearly patchy structure, do not match the landscape mosaic on the CORINE map. This suggests that causes of many disturbances were not simply related to gross changes of land-cover class or land-use type as for crop rotation practices, but other less specific agents of

Table 1 – Cluster percentage regional incidence, percentage of land cover class disturbed, and land-cover percentage composition for disturbance profile for the 20% percentile disturbance map case based on an aggregation of the original CORINE land cover classes into eight classes (CORINE codes shown in parentheses)

Land cover class (CORINE code)	Percentage of disturbance (%)	Percentage of cluster (%)							
		C1	C2	C3	C4	C5	C6	C7	C8
Arable lands (2.1)	46.3	32.2	46.0	28.3	46.9	47.8	37.5	53.2	73.2
Forests (3.1)	6.5	7.4	7.6	9.5	6.2	6.1	7.5	5.0	4.5
Heterogeneous agricultural areas (2.4)	15.1	9.2	11.9	16.0	18.5	17.6	18.3	14.7	7.5
Olive groves (2.2.3)	12.7	38.3	19.5	27.6	7.54	2.78	16.2	7.1	0.8
Pastures (2.3.1)	4.0	7.0	5.1	5.9	2.8	2.5	4.56	3.7	2.8
Permanent crops (2.2.1, 2.2.2)	11.5	0.6	3.4	3.7	15.2	22.2	10.5	14.4	10.6
Scrub and/or herbaceous vegetation associations (3.2)	1.1	1.7	1.1	2.3	0.8	0.6	1.6	0.9	0.4
Urban fabric (1.1, 1.2, 1.3, 1.4)	2.8	3.6	5.4	7.2	2.1	0.5	3.9	1.0	0.2
Cluster regional incidence (%)		31.75	18.61	14.03	11.16	6.34	9.33	5.17	3.61

disturbance (e.g., fires like in the inset in Fig. 2C) may take place and spread in different ways in the mosaic. From a management perspective the deployment of strategy for disturbance control is then complicated because it cannot just rely on measures targeted at agricultural practices.

3.2. Content and context analysis at a single scale

One way to compare disturbance content and context is to evaluate P_d values versus the proportion of disturbance

measured inside two different buffers. Results showed scale dependence and a threshold dependence (Fig. 3) because spatial patterns of disturbance in the Apulia region were far from a purely random distribution.

For the 10% percentile disturbance map the amount of disturbance inside a preserved area (P_d) was statistically linearly correlated to both the smaller ($r = 0.881$, p -value < 0.01) and the bigger ($r = 0.772$, p -value < 0.01) buffer content measures. For the 20% percentile disturbance map there was no statistically significant correlation ($r = 0.037$, p -value $= 0.797$) between

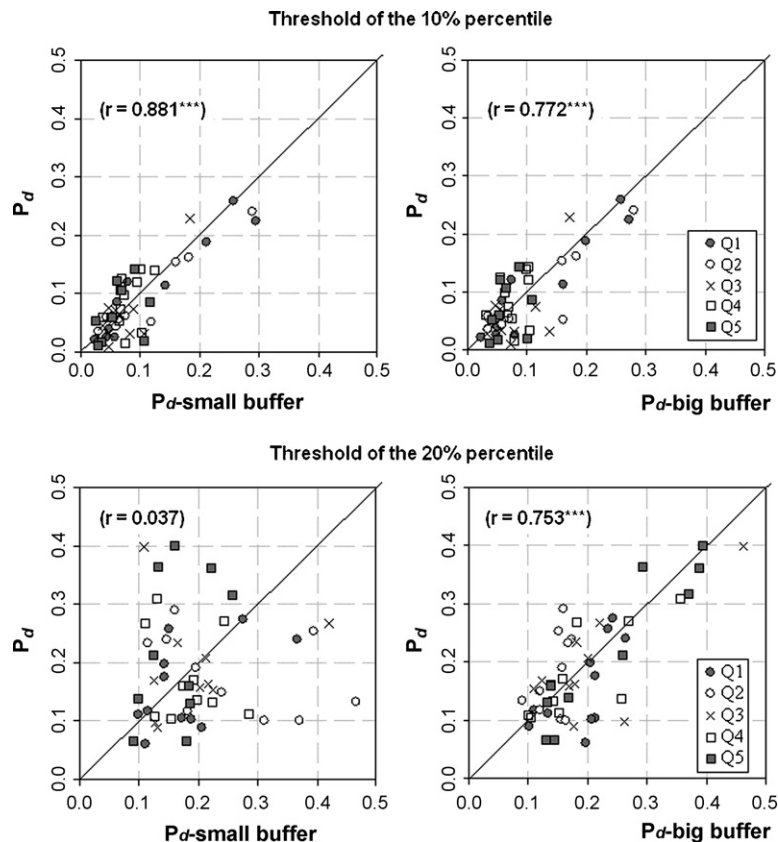


Fig. 3 – Comparison of the amount of disturbance (P_d) within a SAC and the amount of change within a SAC with a small (P_d —small buffer; left) and a big (P_d —big buffer; right) buffer of 1.7 and 3.3 km, respectively. Preserved areas are represented with different symbols based on quantile ranking in five size classes (Q1 = smallest, Q5 = largest). The one to one relation is indicated by the continuous line.

disturbance within a SAC (P_d) and within 1.7 km of the boundary (P_d -small buffer). In this case, increasing the buffer size dramatically modified the relation between the content and the context, and a significant correlation was found ($r = 0.753$, p -value < 0.01).

Although some of those correlations are statistically significant, it is still hard to predict disturbance in an enlarged area (i.e., a certain scale) from the amount of disturbance within the conservation area, or vice versa. The scatter around the one to one line (Fig. 3) was still quite large even for the smaller buffers. While the expected scenario of a lower proportion of disturbance inside the areas compared to the surrounding landscape is partially realized (i.e., all the points on the left of the one to one relation in Fig. 3), for some SACs P_d is larger than the single scale context measure which implies that these SACs are actually a “source” of disturbance for the landscape matrix in which they are embedded.

These results were not affected very much by the size of the preserved areas. SAC area was not significantly correlated with any of the content indicators of disturbance (no p -values less than 0.60). Smaller SACs do not show lower values of P_d than bigger SACs, and a buffered preserved area does not relate to particular levels of disturbance for any buffer radius (Fig. 3).

The results from the classical buffering procedure illustrate the importance of choice of scale (i.e., the buffer width) when the disturbance is spatially or hierarchically organized, and how any one choice can be different from another choice. If there is no ecological rationale to decide the buffer width, the results are arbitrary and limited to the specific scale(s) used in the analysis. This is also an example of the modifiable areal unit problem (Jelinski and Wu, 1996).

3.3. Multi-scale map of clusters

Mean values of the amount of disturbance measured inside a particular window (mean P_d) for each group obtained after the clustering of the disturbance maps of the study area are shown in Fig. 4 in a way that makes it easier to compare the effect of threshold and window size across clusters. Clusters can hardly be related to real-world terms (e.g., edges, gaps in canopy or reduced vegetation) with the exception of areas actually disturbed or changed (e.g., field with crop rotation or fires) as they describe pattern properties rather than structural causes.

For the 20% percentile map (Fig. 4, right) at one extreme cluster 1 (C1) comprises 31.75% of all area (Table 1), and it corresponds to locations where disturbance is very low for all window sizes. This profile was common for forests, for example for SACs in the Gargano peninsula (Fig. 2A), as well as in all places where the landscape matrix is made up of olive groves. Cluster 2 (C2) is similar but it includes locations where disturbance is higher only for bigger window sizes. At the other extreme, cluster 8 (C8) comprises 3.61% of the region (Table 1) and corresponds to locations of actual disturbance, usually associated with arable lands. For C8, the cluster mean P_d value approaches 1.0 in the smallest windows and decreases monotonically to 0.39 for larger windows, indicating that disturbance is concentrated and occurs in compact patches (see inset C and D in Fig. 2). Similarly, clusters 6 and 7 include locations of actual disturbance because their profiles have mean P_d values greater or equal than 0.5 for small windows. For these two clusters, the decrease in mean P_d for the first four window sizes is more rapid compared to C8, implying that the disturbances are more widespread and fragmented in comparison. The profile for cluster 5 (C5) describes locations where mean P_d is similar for all window sizes, indicating a region of scale-invariant disturbance (i.e., locations in the geographical world experiencing the same amount of disturbance at each investigated scale). The other clusters comprise pixels that are not themselves disturbed, but occur more or less near disturbed pixels. Cluster 3 (C3), for example, represents areas with a pattern of localized, low level disturbance (but higher than the mean regional level of 0.20) that occur in a context of even lower disturbance amount. Locations of cluster 4 (C4) are the opposite of locations of C3, as they are undisturbed locations that are very near or embedded in disturbed areas.

For the 10% percentile map (Fig. 4, left) similar patterns are shown by the cluster mean profiles, and differences are due mainly to the intensity of the distribution sampled. As in the previous case, C1 represents areas with very low multiscale disturbance levels while C8 corresponds to locations of actual disturbance. These clusters can be envisioned as a gradient of different types of multi-scale profiles of disturbance that characterize the spatial organization of disturbance in the Apulia region.

For both maps, cluster profiles converge to a common value indicated by the dotted line in Fig. 4. If an imaginary window that is big enough to encompass the entire region was used to

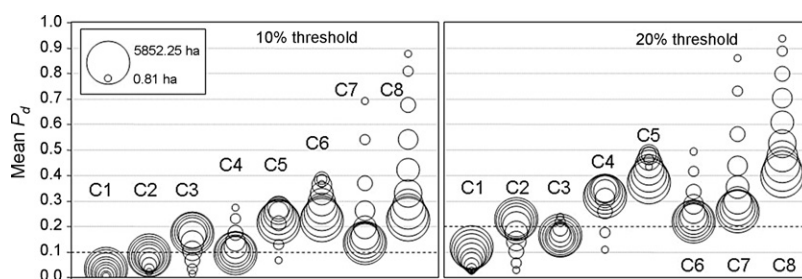


Fig. 4 – Amount of disturbance mean value for the 10 window sizes and the eight clusters, C1–C8, identified through the multivariate analysis of the real map of disturbance of the Apulia region based on the 10% percentile (left) and the 20% percentile threshold (right). The size of the circle indicates the size of the analysis window as illustrated in the inset.

sample the disturbance map, then all of the locations in the region must experience the same overall value (i.e., the global disturbance proportion). This fact forces cluster profiles to asymptotically approach that value with increasing window size. The 'convergence point' for all profiles is necessarily at $P_d = 0.2$ or 0.1 because the overall proportion of disturbance was set at that level by definition. For the Apulia map, in C1, C2, C3, C6, and C7 the largest window was large enough that the profile approached the asymptotic value, and thus was large enough that the profile reliably described both large and small scale disturbances. For the other clusters, larger windows would be needed to reach the convergence point and to fully capture the pattern, and this in turn suggests that there was a larger scale pattern or structure of disturbance in the region that was not detected by our choice of window sizes.

Moving from the scale domain to geographic space, the map of clusters in the Apulia region has a spatial structure which appears to be related to land-cover types (Fig. 2A). The G-test (Sokal and Rohlf, 1995) for independence of clusters and

land-use classes (based on the data from which Table 1 was derived) was significant ($p < 0.001$) and indicates that disturbance profiles are not distributed randomly among land-use classes. For example, olive groves are a relatively stable land-cover type and it is logical that they contribute most to cluster 1 because the profile for that cluster indicates very low disturbance overall. At the other extreme, arable land which exhibits a large amount of disturbance from farming practice forms most of cluster 8. The remaining profiles are difficult to relate to CORINE land-cover classes because the CORINE map is a single scale product while the cluster map is derived by summarizing information sampled at multiple scales.

3.4. Single versus multiple scale content analysis

Each SAC is fully identified by considering the proportion of its area belonging to each of the eight disturbance profiles (P_c), thus summarizing the new context-oriented information along a multiple scale gradient of pattern (Fig. 5). SACs showed a great variability in terms of cluster composition due

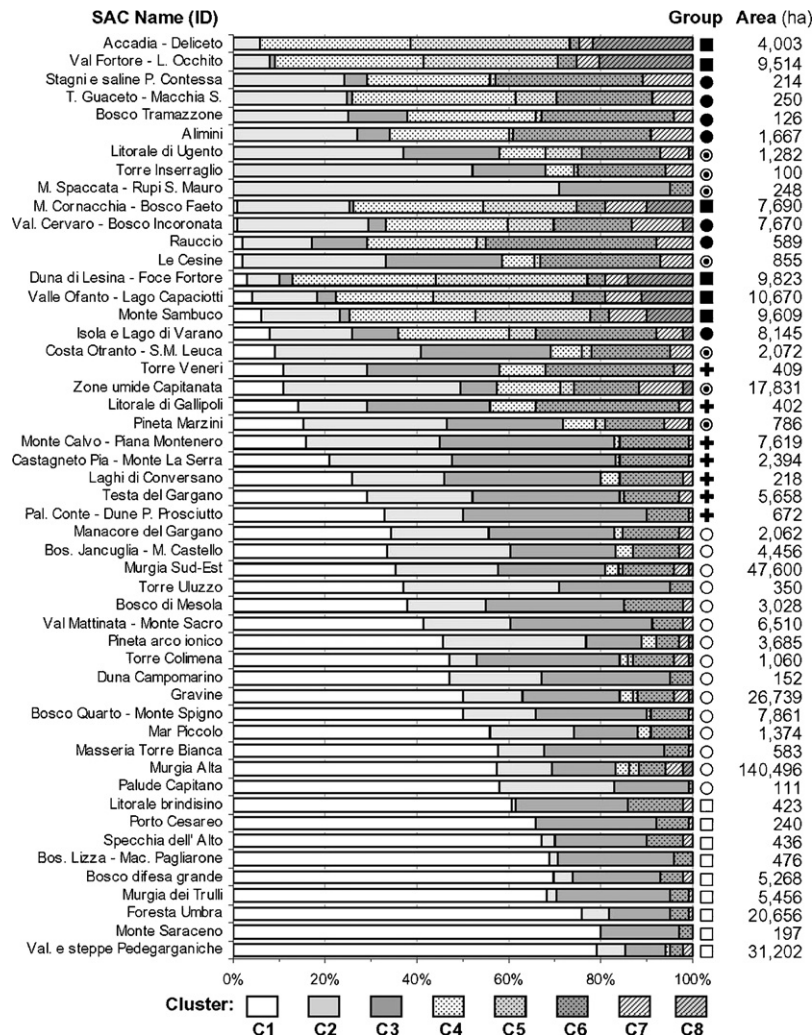


Fig. 5 – Comparison of the area extent, the group membership and the proportion of pixels inside a special area for conservation (SAC) belonging to each of the eight clusters (P_c from cluster C1–C8) identified by the multiple scale context analysis. Six groups of SACs can be recognized after a minimum variance clustering analysis on the 51 SAC's profiles. Symbols indicate group one (□), group two (○), group three (+), group four (⊙), group five (●) and group six (■).

to both cluster presence and P_c range values for each cluster. As an example the SAC “Valli e steppe Pedegarganiche” was made up by 80% of cluster C1, 10% of cluster C3 and 5% of cluster C2 (Fig. 5, bottom). This suggests that disturbance amount is low and dispersed, and only at bigger scales does the pattern of disturbance become comparable to the mean regional level (i.e., the convergence point). For SAC “Accadia-Deliceto”, cluster C1 and C3 were absent while clusters C8 (22%), C4 (33%) and C5 (35%) characterize the area (Fig. 5, top). This suggests a disturbance pattern of high local disturbance with an aggregated or patchy distribution rather than a dispersed one.

From the manager's perspective, the amount of disturbance inside the preserved area (P_d) may be of central importance because disturbance has a direct effect on the habitats (hence on local biodiversity) that are of interest and the manager can only direct actions within the boundary of the preserved area. But as in the single scale context measure, when related to the multiple scale content indicators P_d does not relate in a clear way to the P_c composition profiles. With the exception of the cluster C2, a significant correlation (p -value < 0.01) was found between P_d and P_c for the seven remaining clusters but the strength of the linear relation as well as the sign change from negative for cluster C1 ($r = -0.822$) and C3 ($r = -0.566$) to positive for the others (C4, $r = 0.892$; C5, $r = 0.798$; C6, $r = 0.380$; C7, $r = 0.738$; and C8, $r = 0.732$). A content indicator like P_d is not able to fully describe scaling properties of the disturbance pattern.

3.5. Interpreting multi-scale disturbances

The grouping of SACs using cluster composition identified six groups. We can suggest that each group represents a different ‘risk group’, and that the SACs in each group have similar management needs and priorities linked to habitat disturbance. Furthermore, the scale of management needed is indicated by our analysis. At one extreme, SACs belonging to group number one, where dominant patterns are related to cluster C1 and C3, are at low risk of habitat loss or transformation due to disturbance both local and regional (Fig. 6). For this group, management actions could focus on

controlling the low level of disturbance at a very local scale. At the opposite extreme, group six collects areas at risk of high disturbed context and content as dominant patterns are related to clusters C8, C5 and C4. In these SACs, management actions could be targeted to reduce the disturbance within SACs, but that management would have to be integrated by broader regional scale measures aimed at disturbance reduction in the surrounding matrix as well. Group three and four collect SACs where local intense disturbance is less important and aggregated (low values for clusters C7 and C6) while diffuse disturbance patterns prevail at higher scales (high values for clusters C6 and C4). Once again local actions, though effective, need to be coupled to management measures that act at intermediate scales.

4. Discussion

Efficient protected area networks must be based not only on current species and habitat distributions but also on the landscape's long-term capacity to support populations and conserve biological diversity (Cabeza and Moilanen, 2001). We have to build a conservation network that is resilient in time to environmental change (Noss and Cooperrider, 1994). Using vegetation disturbance as a proxy to represent important habitat change in a dynamic network, this paper demonstrates the importance of considering the disturbance context of locations across scales in order to evaluate risks to a network of SACs. The disturbance contained within the boundaries of a protected area, or within a fixed-width buffer surrounding it, are not fully informed guides to the changes imposed on that area. But even recognizing that the multi-scale spatial context is still arbitrary whenever window sizes were not chosen on a particular ecological base, it still has the advantage of addressing and taking scale effects into account in pattern analysis as well as applying a “landscape perspective” (Fahrig, 2005) leading to spatially explicit management measures.

The patch-matrix model (Forman, 1995) is based on a substantially schematic and rather static view of the landscape. This model has been proved to contribute in addressing specific problems in biodiversity conservation and landscape planning (cf. national programs for biodiversity conservation like the “GAP analysis program” in the USA (Scott et al., 1996) or the “Map of Italian Nature” in Italy (Zurlini et al., 1999)). But it has relevant limitations when complex systems, including also anthropogenic disturbance, are considered (McIntyre and Hobbs, 1999). Assuming, for instance, that each preserved area is an island is unrealistic, since local processes and species richness are inter-related and supported or affected by the context (Ricketts et al., 2001; DeFries et al., 2005), in addition surrounding land-use practices could modify the conservation capacity of each areas despite the loss of some habitats (Hughes et al., 2002). The same notion of “ecological corridor” supported by the patch-matrix model itself can be misleading if not associated with particular species requirements and not envisioned in a multiscale perspective taking into account how species might differently experience habitats and landscape mosaics (Riitters et al., 1997; Kerkhoff et al., 2000). Only recently managers and management agencies have begun to

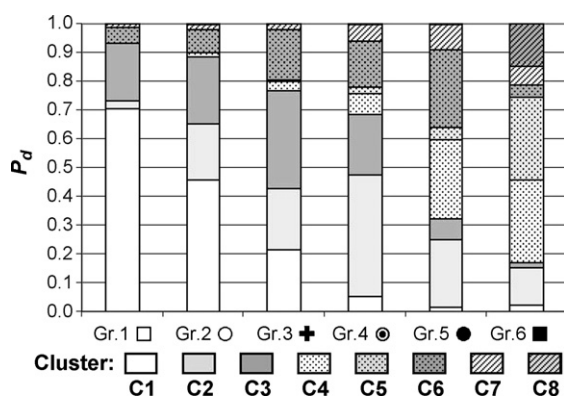


Fig. 6 – Centroids of the six groups of SACs after the Ward's analysis of SACs' clusters profiles. Groups are ordered from lower group one (□) to higher group six (■) intensity of disturbance at multiple scales.

shift toward “mosaic management” in which spatial heterogeneity and the effects of external factors are explicitly considered (Crow, 2002).

Other measures of disturbance or habitat modification could be employed instead of NDVI like the comparison of land-cover thematic maps for different dates. But our choice of the NDVI as an ecologically relevant measure of disturbance was motivated by two main reasons. First, it is now possible to obtain time series of remote sensed images that allow one to identify causes of change as well as to quantify patterns and rates of the dynamics of a landscape (Kerr and Ostrovsky, 2003). Though not addressed in our work, the use of a context oriented approach would integrate a system dynamic analysis with a multiple scale spatial description. Second, NDVI as an integrative index can reflect both cropping changes such as fallow land to crop or its reverse and the effects of drought, disease, fire, succession, urbanization, and other changes (Pettorelli et al., 2005). Even though not a specific indicator, NDVI allows to describe a wider variety of disturbances affecting ecological systems. These disturbances are not all equally likely to affect habitat and biodiversity in the same way, or at the same spatial-temporal scales. The effect of resource and habitat fragmentation, for example, may be to enhance habitat for some species, and spatial variation in habitat can promote the coexistence of different species in the same geographic region (Whittaker et al., 2001; Olff and Ritchie, 2002). More detailed interpretations of disturbance from NDVI are needed to understand positive and negative effects on local species populations. At the same time, we can speculate that the relatively high frequency dynamics of land-cover classes, as we measured by changes in NDVI, are inherently important because in this region the change is almost surely a sign of anthropogenic activity (i.e., disturbance) that affects habitat in one way or another. It can be helpful to know where, to what degree, and at what spatial scales anthropogenic disturbances are operating, even though we have to consider that disturbances can produce negative but also positive effects on biodiversity (Connell, 1978; Tscharnkte et al., 2005).

Not all the “pieces” of biodiversity (i.e., species, populations or habitats) have the same conservation significance and carry the same risk of extinction (cf., Zurlini et al., 2002). One of

the fundamental aims of conservation management and reserve design is the safeguarding of the diversity of species “typical” or rare of the habitat or habitats within a reserve (Usher, 1991). The same applies to ecosystems or habitat mosaics which sustain species populations in landscapes like those in Apulia. Pressey et al. (1994) introduced the concept of “irreplaceability value” to underline that if an area has species found nowhere else it will have a very high conservation value. If an area contains only common and widespread species, then it has a low irreplaceability value or it could be modified and the community changed without losing and/or risking conservation targets. Thus, native threatened and endemic taxa, or relevant irreplaceable areas which most can suffer reduction and extinction risks (Pimm et al., 1995) like, for instance, CORINE land covers or CORINE habitats which result of EU importance and lead to a SAC identification (Council Directive, 1992), could be defined as the exclusive biodiversity of a region (Cowling et al., 1995; Kerr, 1997). This exclusive diversity is the primary historical memory of ecosystems which must be preserved if we want ecosystems to maintain their identities, to persist in time, and repeat over and over again (Holling et al., 1995). Then, disturbance inside or in the neighbourhood of exclusive diversity areas represents a serious threat to biodiversity.

That information when coupled with the knowledge of the spatial distribution of relevant habitats of conservation priority and endangered animal populations, is fundamental for proper conservation management. When all SACs are considered (Fig. 2B) regional managers can prioritize interventions and optimize investments evaluating the risk estimates at multiple scales and the role of different SACs in the network. Among SACs of group 6, the preserved areas of “Val Fortore—Lago d’Occhito” (SAC 2) and “Valle Ofanto—Lago Capasciotti” (SAC 15) may be a priority as element of connection between the Gargano peninsula and the Dauno Appennines mountain chain (Fig. 2A).

From a single SAC perspective, Fig. 7 shows an example of two preserved areas with the spatial arrangement of different locations, belonging to the eight clusters of multiple scale disturbance patterns (Fig. 7). That reveals how portions of preserved area and CORINE land-cover classes with different conservation significance can be affected by different multi-

Table 2 – Examples of general guidelines for the management of preserved areas based on the group membership

Groups	Multiple scales disturbance profile type	Guidelines
1 ○ 2 □	Low disturbance for multiple scale contexts	Management at local scale like single farm, crop field or patch aimed: • To control of patch edge erosion • To regulate of land-cover conversion • To rule crops practices
3 + 4 ⊙	Intermediate disturbance at middle scale contexts	Management at the scale of a Municipality aimed; • To maintain large and structurally complex patches of native vegetations • To build buffers around sensitive conservation targets • To integrate urban planning regulations with conservation targets
5 ● 6 ■	Intense disturbance for multiple scale contexts	Management at the scale of a Province or entire Region aimed: • To maintain structural complexity throughout the landscape • To sustain historical disturbance regimes • To promote regulations to minimize threatening of ecosystem-specific processes

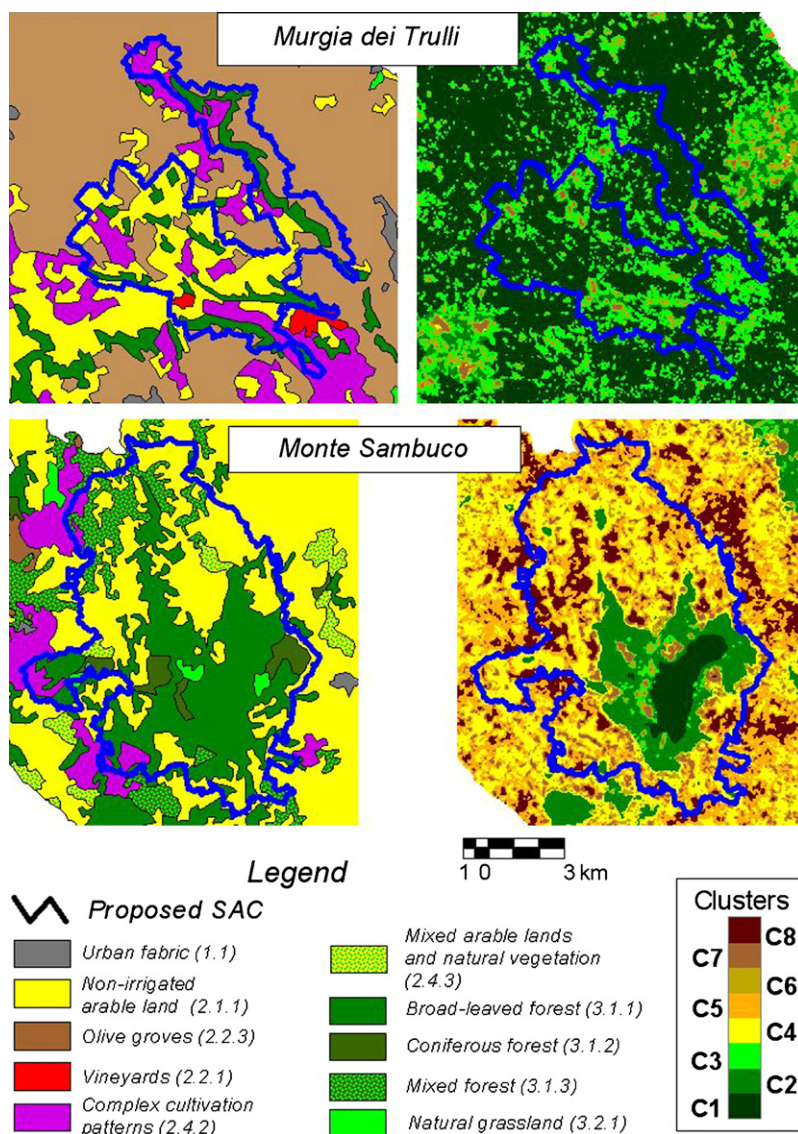


Fig. 7 – CORINE land-cover maps (left) and clusters maps (right) for the “Murgia dei Trulli” (Bari province) and the “Monte Sambuco” (Foggia province) SACs as an example of application of the multiple scale context analysis to support the identification and management of more fragile and disturbed locations inside the preserved areas. CORINE codes shown in parentheses.

scale disturbance contexts. It is evident that in Fig. 7 there are locations of some habitats at risk of being eroded as such because of particular multiscale disturbance source contexts. On one extreme, SAC “Monte Sambuco” belongs to group six and shows how disturbance taking place in arable lands could affect forests habitats, where the majority of protected birds are, or change the calcareous natural grasslands rich in orchids. Managers could try to maintain large and structurally complex patches of native vegetations by locally controlling forest edge erosion, conversion of grasslands to fields or imposing rules on crop practices (e.g., regulating stubble fires), but without a large scale management plan taking care of the arable land matrix surrounding the SAC conservation efforts could be thwarted. On the other extreme for group one, managers of the SAC “Murgia dei Trulli” may focus actions to safeguard local quality and structural integrity of patches of

oak forests (*Quercus trojana*) and populations of the four-lined snake (*Elaphe quatuorlineata*), the leopard snake (*Elaphe situla*) or the Hermann’s tortoise (*Testudo hermanni*). Measures could take place at the field scale by, for example, avoiding forest edge erosion, protecting fence drywalls or controlling the use of chemicals in olive groves. Table 2 presents some general guidance that could be suggested for the different SACs groups though specific measures depend on local type of conservation targets, managers autonomy and different municipal or regional planning constraints.

5. Conclusions

Relating change at multiple scales to land use and habitats can reveal useful information about driving forces and multi-scale

properties of ecological changes and landscape dynamics. Most current conservation plans implicitly assume that biodiversity and human systems are static and do not consider the dynamics of anthropogenic activities. But the actual process of identifying and implementing reserve networks violates that assumption. Conservation investments are constrained by budgets, and opportunities to implement conservation actions tend to be unpredictable, both in space and through time. Thus, implementing reserve networks is a sequential process, requiring decades to achieve conservation objectives (e.g., Pimm et al., 2001; Balmford et al., 2002). In the interim, some biodiversity is lost and the geography of both human dominated and natural landscapes change. Conservation strategies that consider landscape context as well as content are needed to effectively design reserve networks.

A context oriented analysis is an example of a multi-scale and spatially explicit approach capable to simultaneously detect spatial and scaling behavior of ecological processes and structures, thus overcoming some major limitations of more scale dependent analysis based on the patch-matrix model. Our results suggest that the management of special areas for conservation could depend less on detailed knowledge of local spatial patterns of disturbance and more on broader-scale patterns of the drivers of disturbance, at least for traditional rural and commodity production landscapes like in the Apulia region. Consequently, management actions should try to combine the knowledge of both historical disturbance regimes (Fischer et al., 2006) and their spatial pattern at multiple scales to sustain and strength conservation policies across scales and to build up a preservation network resilient in time to environmental change and able to maintain vital ecosystem services, and to protect irreplaceable habitats and global biodiversity.

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