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A novel Multilevel Biodiversity Index (MBI) for combined field and satellite imagery surveys

Roberto Cazzolla Gatti [a,*], Claudia Notarnicola [b]

[a] *Bio-Clim-Land Centre, Biological Institute, Tomsk State University, Tomsk, Russia*
[b] *Eurac Research, Institute for Earth Observation, Bolzano, Italy*

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A B S T R A C T

In an epoch of fast and dramatic changes in ecosystems, a complete survey of biodiversity and an analysis of its spatial patterns from the field shall be associated with satellite imagery, which can provide a synoptic observation in space and time of the territory. This work presents the preliminary results of a new approach to monitor the biodiversity of a well-defined area, which takes into account species diversity and the landscape characteristics in terms of ecosystems diversity (land cover classes). We developed a Multilevel Biodiversity Index (MBI) and we tested it in a study site of 400 km^2, belonging to the Central Mediterranean Ecoregion and consisting of forested areas, scrublands and steppes (Murge). With the aim to reach a global land cover classification system and a standardisation of the biodiversity surveys, the MBI can be easily adapted to study areas of different ecoregions on Earth. This index could certainly be useful for future studies and to address environmental policies in order to protect vulnerable ecosystems and assign a conservation priority rank that takes into account the presence of diversity both in terms of species and ecosystems.

1. Introduction

Habitat degradation is the major causes of biodiversity loss in recent times (Duraiappah et al., 2005; Cazzolla Gatti, 2016a). This could be exacerbated in a near future by the global climate change (Battipaglia et al., 2015; Banerjee et al., 2017). More than half of the estimated original extent of temperate broadleaf forests had already been converted to agriculture, forest plantations and urban areas prior to 1950 (Duraiappah et al., 2005). In contrast, deforestation and land-use change accelerated in the tropics after 1950 (Vaglio Laurin et al., 2016). The use of freshwater ecosystem services is now well beyond levels that can be sustained even at current demand (Tilman et al., 1997; Gleick et al., 2009; Cazzolla Gatti, 2016b). The Mediterranean Ecoregion was identified (Bulgarini et al., 2007) among the Global 200 as one of the areas with the highest presence of biodiversity (Purvis and Hector, 2000). Within the Italian territory, WWF selected priority areas for the conservation of natural habitats that deserve special protections. Because this area is affected by different stressors (logging, desertification, fires, urbanization, etc.), a complete survey of biodiversity and an analysis of its spatial patterns from the field shall, evidently, be associated with satellite imagery (Corsi, 2004), which can provide a synoptic observation in space and time of the territory. In order to improve this issue, detailed maps of land cover and its changes over the years have been created for the main

* Corresponding author.
E-mail address: robertocazzollagatti@mail.tsu.ru (R. Cazzolla Gatti).

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vegetation classes of the study area. The satellite data used in this work cover the last 30 years and were acquired by multispectral sensors applied on board of the LANDSAT satellites that provide a resolution varying between 30 m and 60 m.

Within the Mediterranean Ecoregion, in the South-East Murgian area, in Apulia (Italy), a 3-years research project (Cazzolla Gatti, 2010) was carried with the main aim to draft a preliminary biodiversity checklists, to identify species distribution and habitats, to check the presence of species considered locally extinct or endangered, to detect changes in species seasonal and temporal diversity (Messina et al., 2016) and identify anthropogenic threats (Banerjee et al., 2017).

Within the framework of this research, we collected information on the biological diversity of the ecoregion with the synergic use of satellite imagery (to monitor the land use and changes) and field surveys. In the framework of this research project, here we present a proposal for a novel Multilevel Biodiversity Index (MBI), which derives from a combination of a land use index of ecosystem rarity, related to rare species found on the ground, and rarity index of land cover classes derived from multitemporal satellite images. The approach we present here to calculate the Multilevel Biodiversity Index (MBI) can be extended to other different ecosystems and research programmes by following specific guidelines.

2. Materials and methods

2.1. Study area

The priority area in the Apulia region (Italy) includes south-east Murge has been inserted into Global 200 territories identified by WWF (Fig. 1). The area lies in the two provinces of Bari and Taranto, where a carbonate platform occupies the

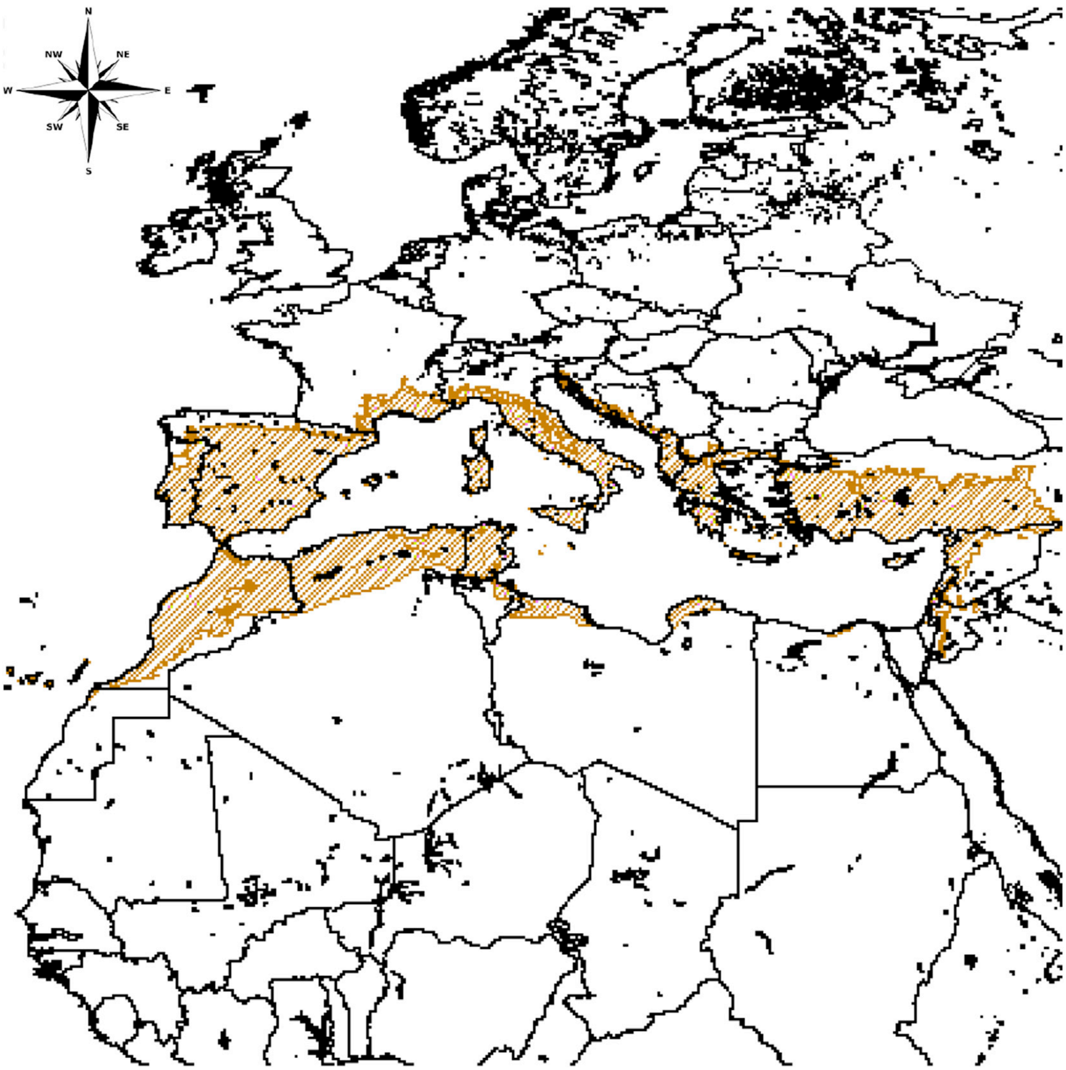

Fig. 1. Priority area of “Murge e Valli fluviali lucane” in the Central Mediterranean Ecoregion.

hilly areas of Minervino Murge, Gioia del Colle, Martina Franca and Mottola. The Murge area preserves a rich fauna of insects related to arid environments and many bird species of European interest (Petretti, 1991), including Lesser Kestrel, Egyptian Vulture, Red Kite, Stone-curlew and many sparrows. The main factors interfering with biodiversity in this area are pollution of water bodies, coastal erosion, desertification due to various factors, including deforestation, depletion of soil and water resources and the application of improper agricultural practices, resulting in degradation and loss of soil fertility and forest fires (Bulgarini et al., 2007).

2.2. Data collection and analysis

The research activities were divided into five phases that spanned over a research period of three years (Cazzolla Gatti, 2010).

2.2.1. First phase: area selection for field survey

During this first phase, the information derived from satellite images LANDSAT (high resolution, from 30 m to 60 m) was used in combination with orthophotos (0.5 m resolution) to identify areas that would have become sites for the field survey. Forest areas, steppe pastures of Murgia and shrublands (which are the residual wild lands of the site) were selected in order to ensure a good representation of the biological characteristics of different biomes in the study area.

2.2.2. Second phase: field data collection

In the second phase, three research campaigns for each of the selected sites were carried out in order to collect biodiversity information during two years. Five transects per site were randomly placed and during each field survey, we carried a comprehensive census of species (occurrence data of flora and fauna; Table 1) together with ancillary data, such land use, environmental features, geomorphology, threats etc.

2.2.3. Third phase: field data analysis

After each research survey (phase 3) the whole data and the samples collected were transferred to the laboratories, catalogued and analysed. Each checklist was cross-checked to verify the correctness of taxonomic nomenclature and the matching of the species detected with the bibliographic information available and the spatial distribution of species. Samples of animals and plants were subjected to preliminary direct analysis, then were analysed by a stereomicroscope. A geo-referenced photographic database was created, differencing species per area.

2.2.4. Fourth phase: satellite data processing

During the fourth phase, field surveys were combined with satellite image analysis to identify different ecosystem types. Detailed maps of land cover and its change over the years were analysed for each class of vegetation identified (Landsat images acquired in 1979, 1989, 1999, 2002 and 2007). For the classification procedure, a semi-automatic approach was adopted, based on the algorithm of the Maximum Likelihood (Schowengerdt, 1997). The standard nomenclature CORINE (EC, 1993) was only partially modified and adapted to the characteristics of the area, characterised by extensive areas of arable lands, pasture trees, olive-almond, and natural formations such as woods, scrublands and grassland steppes (Ivone, 1997). The accuracy of the images classification process was higher than 90%, except from the 1979 image, where the spatial resolution was lower than 60 m and the presence of only four spectral bands made the different classes difficult to be identified.

2.2.5. Fifth phase: database generation and index derivation

Finally (phase 5), the results were analysed in order to create a geo-referenced species database (Cazzolla Gatti, 2010) and to develop a Multilevel Biodiversity Index (MBI) which is described in the next section.

3. Results and discussion

3.1. Assessment of biodiversity

The analysis of biodiversity led to identifying three main levels of differentiation: biomes, ecosystems and species (Owens et al., 1999).

For the first level it was observed that in a relatively small area (400 km^2), as the extension of our study site, there are five differentiated biomes: deciduous forest, conifer forest, Mediterranean vegetation, garìga and pasture steppe (Murgia). The whole territory locates also some exceptional habitats shaped by geological forces: an intricate drainage network with a considerable erosion phenomena associated with the formation of "*gravine*", "*lame*", sinkholes and caves. In addition to biodiversity at the biome level, an analysis of biological diversity at ecosystem level was carried out. The presence of areas of deciduous not-coppice forests guarantee the survival of specific communities well-structured and allow the presence of particular biocenosis and rare species (such as *Cerambix cerdo* in *Quercus pubescens* forests), which in turn enhances the diversification of ecological niches and, therefore, allow the presence of a greater number of species (Cazzolla Gatti, 2011, 2016c; Cazzolla Gatti et al., 2017). Moreover, at the ecosystem level, it was also noted, linking satellite analysis to field surveys, that the presence of ecotones between two ecosystems creates the conditions to increase biodiversity (as primary

Table 1
Taxa surveyed and sampling methods.

Taxa	Sampling methods	No of species detected
Mosses	• Quadrats on trunks and ground along parallel transects; • field microscopes identification; • samples collection for lab identification.	6
Lichens	• Grids on trunks and rocks along parallel transects; • field microscopes identification; • samples collection for lab identification	12
Ferns	• Transects (parallel).	5
Macrofungi	• round quadrats along the transects; • direct observation with a field microscope (in selected areas).	46
Vascular plants	• Transects (parallel) for trees and shrubs; • ground quadrats along the transects for herbs and grasses.	300
Arthropods (Arachnids, Crustaceans, Myriapod, Insects) and Molluscs (Gastropods)	• Pitfall traps; • light traps; • entomological umbrella; • Berlese funnel; • butterfly nets; • net for freshwater invertebrates; • direct observation (naked-eyes and field microscopes); • telephoto identification.	226
Amphibian and Reptiles	• Direct observation (visual encounter surveys along parallel transects); • dipnetting and sweep sampling in selected ponds and channels; • kick sampling; • egg mass detection.	20
Fish	• Nets on channels; • direct observation (in selected areas).	1
Birds	• Distance sampling (along parallel transects); • indirect detection (songs, nests, droppings and feathers identification); • telephoto identification; • night vision IR monoculars; • hiding and camouflage tents.	97
Mammals	• Distance sampling (along parallel transects); • photo-trapping; • indirect detection (footprint, droppings, hairballs, pellets and bones); • bat detectors; • snap/flick non-killing traps (small mammals); • night vision IR monoculars; • hiding and camouflage tents.	30

observed by Armstrong and McGehee, 1980). We detected, for example, a greater number of species of orchids than in other not ecotonal areas. As a further proof, in a barren rocky marginal area between an oak forest and a grazing steppe three nesting pairs of the rare and threatened (IUCN Redlist) Eurasian Thick-knee, *Burhinus oedicnemus*, were identified, confirming the importance of that ecotonal environment for the survival of a species that otherwise would not have available site where to nest in the surrounding ecosystems.

In terms of species rarity, 26 rare species considered locally extinct (in the south-east Murge area) or endangered (IUCN Red List), and included in the lists of communitarian directives Habitats 92/43/EEC and Birds 79/409/EEC (D'Antoni et al., 2003) were collected in the study area: *Cerambix cerdo, Saga pedo, Melanargia arge, Coenargion mercurialem, Euplagia quadripunctaria, Zerynthia polixena, Bufo viridis, Rana lessonae, Testudo hermanni hermanni, Lacerta bilineata, Podarcis sicula, Coluber viridiflavus, Elaphe longissima, Elaphe situla, Circus macrourus, Falco naumanni, Falco peregrinus, Bubo bubo, Milvus milvus, Burhinus oedicnemus, Rhinolophus ferrumequinum, Hyspugo savii, Pipistrellus pipistrellus, Hystrix cristata, Asyneuma limonifolium* and *Dictamnus albus*. The importance of such a high number of rare and endangered species in a narrow area confirmed the importance to have included this site within areas of high biodiversity within the Central Mediterranean Ecoregion.

A total of 843 species (Table 1) of which 300 are vascular plants, 6 mosses, 5 ferns, 12 lichens, 46 macrofungi, 226 invertebrates, 20 amphibian and reptiles, 1 (introduced) fish, 97 birds, and 30 mammals were collected (lists of species are reported in Supplementary Table 1). Of them, 26 species were detected only at one time (singletons). Species occurrence and distribution is reported in Cazzolla Gatti (2010).

3.2. Association between land cover and field data of rare species

The map of rare species found in the study sites was associated with a land cover map of the area (Fig. 2) and the rarity index of the major ecosystems found through the land use analysis (Fig. 3). The rarity index is based on the percentage of areas of interest (in this case classes of deciduous, conifer, scrubland, grassland, and steppe) in the total surveyed area (400 km^2) and was calculated for the map of land use of 1979 and 2007 (Angelini et al., 2009). Surveys of rare species were overlapped on these maps in order to identify how they were located in comparison to the changes in land use. For each detection point a range of 5×5 pixel area was considered (750 m^2) and the rare class to which they belong was found. This preliminary analysis indicates that many rare species are confined to areas that were substantially reduced in the percentage of territory over the period 1979 to 2007. Furthermore, the fragmentation of the environment, often a cause of the loss of the structure of biomes (Pignatti et al., 2005), can be observed from Fig. 2. The decline of community because the physical barrier which prevents the natural progression from ecological successions and the interruption of the continuity of ecosystems with roads, agricultural fields, industrial areas, etc. creates the conditions for genetic isolation and the impoverishment of species communities (Schulze and Mooney, 1993), making them more vulnerable to environmental changes and to inbreeding. An example map of ecological corridors that would reduce the ecosystem fragmentation of the region was also created (Fig. 4; for detailed methodology see Cazzolla Gatti and Notarnicola, 2009).

3.3. A novel Multilevel Biodiversity Index (MDI)

Based on this analysis, one of the main aims was to identify an index, which may summarise both the ground survey results and the analysis carried out with satellite imagery.

For this purpose, we developed a Multilevel Biodiversity Index (MBI) and we tested it with data collected both from satellite and field analyses during the abovementioned research project. This index allows the quantification of the “whole site biological diversity” and could be used in other different contexts to survey whole biomes, manage protected areas, quantify the value of natural ecosystems, etc.

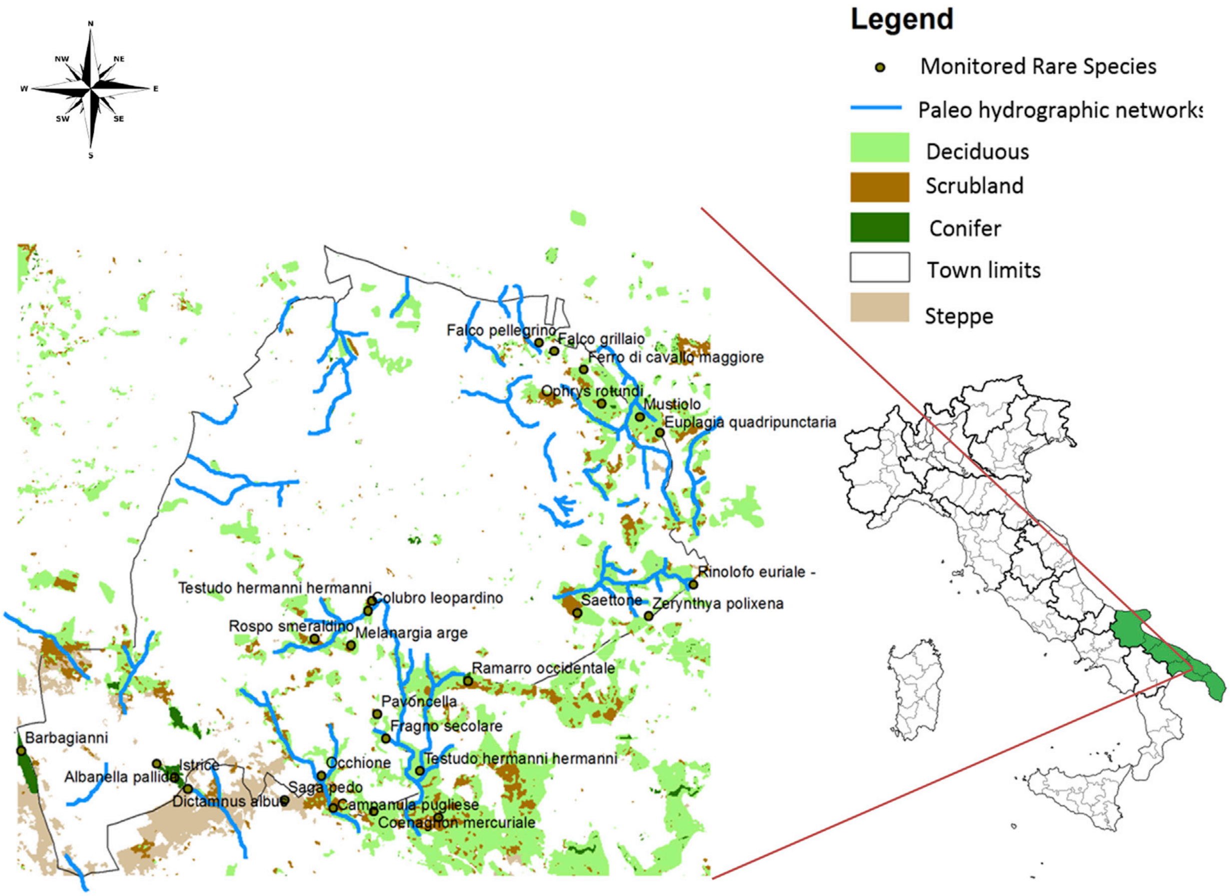

Fig. 2. Map of the sample area with the references to rare species found during field survey and respective land cover classes analysed (Cazzolla Gatti R. & Notarnicola C., 2009).

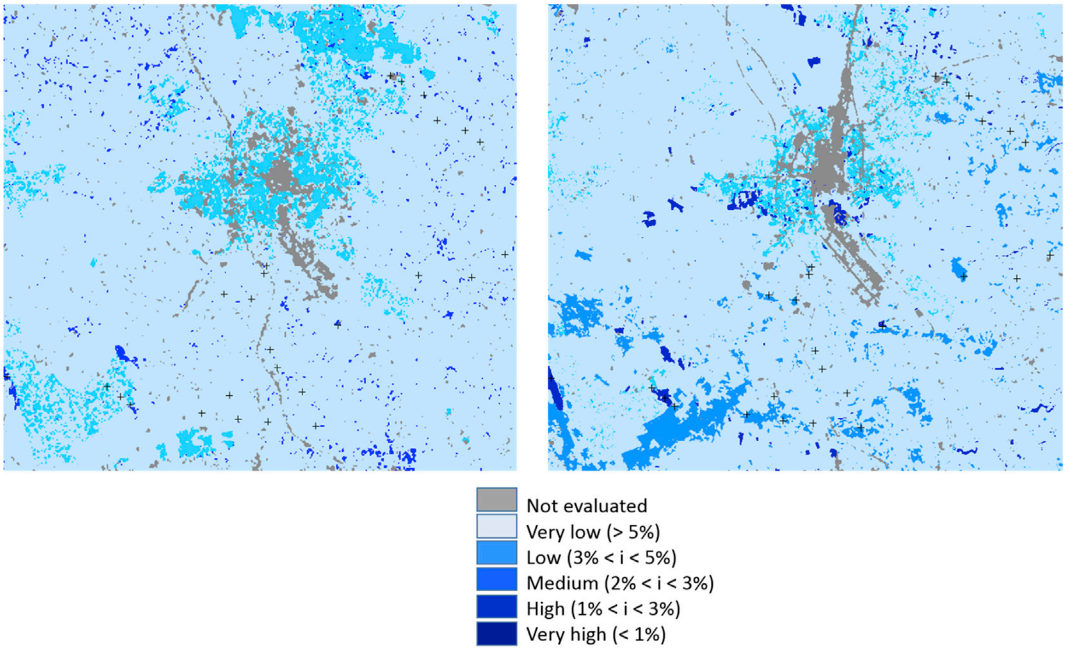

Fig. 3. Map of land cover classes rarity index (the percentage of occupation of each class compared to the total area). The lesser is the % of occupied area of a class, the higher the value of the index is (as well as the colour intensity) (Adapted from Cazzolla Gatti R. & Notarnicola C., 2009). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

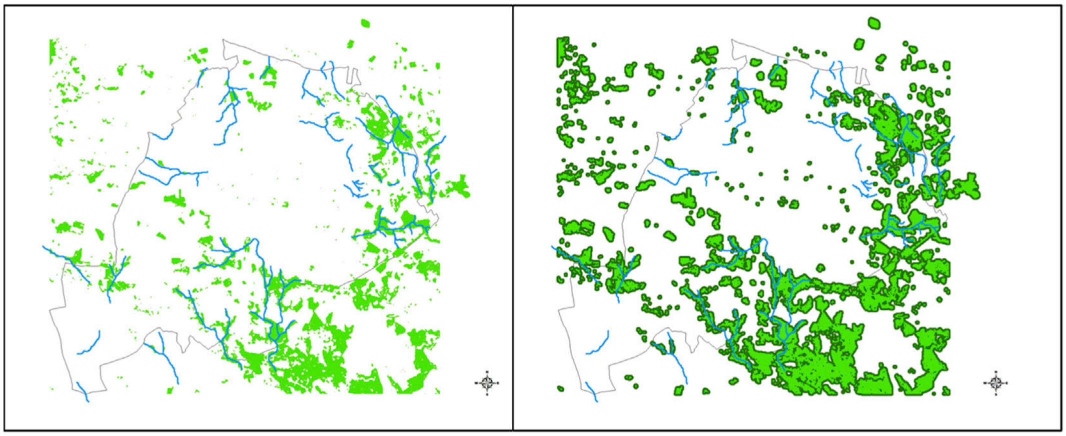

Fig. 4. Map of the ecological corridors (in the area shown in Fig. 2; left), individuated as buffer areas after satellite and field analysis (right).

The MBI has the simple form of (S*LC)/A, where S is the "true" species richness (effective number of species), LC is the "true" land cover richness (effective number of land cover classes) and A the sampled area. This formulation considers the effective species and land cover richness as multiplicative factors that increase the biodiversity of an area. They are, then, normalised by dividing for the surveyed surface (in km^2).

Considering r_1 and r_2 the number of rare species (species collected once, such as singletons, or twice, such as doubletons, respectively) and S_{obs} the total number of species collected in the field (species richness observed), the new Multilevel Biodiversity Index (MBI) is formulated as follows:

$$MBI = \left(\frac{\left(S_{obs} + \frac{r_1^2}{2r_2}\right) * \left(LC_{obs} + \frac{c_1^2}{2c_2}\right)}{A_{km^2}} \right) \tag{1}$$

where LC_{obs} is the number of land cover classes observed in the area surveyed by satellite, c_1 and c_2 is the index of class rarity (n° of land cover classes whose surface is <1% and <3% of total area respectively) and A (measured in square km) is the total area surveyed.

Although common species have a greater effect on observed geographical patterns of species richness than do rare ones (Vázquez and Gaston, 2004), the typically larger numbers of rare species (Gaston, 1994), the positive correlations between the numbers of rare species and the overall numbers of species in an area (Berg and Tjernberg, 1996; Gaston and Blackburn, 2000) and the evidence of nested species distributions (Wright et al., 1998) emphasized the importance of rare species (Lennon et al., 2004). Moreover, rare species and ecosystems are usually the main targets for conservation (Purvis and Hector, 2000). In this proposed MBI we adopted a "Chao-like" effective number of species metric (Chao, 1984) to relate both species richness/land cover classes and their rarity. Then, the product of species and ecosystem diversity is divided by the study area extent, resulting in a combined ground/satellite richness density index. The Chao1 index uses mark-release-recapture (MRR) statistics-like ratio to estimate richness by adding a correction factor to the observed number of species (Chao, 1987).

The value of the index MBI fluctuates from 0 to $+\infty$. Because the total number of species/land cover classes is multiplied by the proportion of rare species/classes, we have an estimation of richness and rarity within the same index relative to the sampled area. The normalisation against the sampled area allows an easy comparison of the index among different sites.

For instance, considering our study site, with an area (A) of 400 km^2 and 5 land cover classes, whose just 1 with a surface <1% and 2 with a surface <3% compared to the total area and 843 species collected, whose 26 singletons and 38 doubletons, we calculate an MBI as follows:

$$MBI = \left(\frac{\left(843 + \frac{26^2}{2*38}\right) * \left(5 + \frac{1^2}{2*2}\right)}{400} \right) = 205.31$$

In the case of a sampling of a similar area (400 m^2), but with half of the species (421) and their rarity (13; 19) and the same land cover classes and their rarity, the MBI would have accounted for a value of 30.4; in the case of the same area and species richness and rarity, but with only 3 land cover classes of which 1 with a cover <1% and 1 < 3%, the MBI would have a value of 119.76.

Thus, we can derive that because species/land cover richness and their rarity are functions of the sampled area (Magurran and McGill, 2011), the larger the area, the higher its diversity (until it reaches a plateau) and the lower its rarity. However, this effect has been balanced to get a more reliable result by the proposed index [Eq. (1)] because the area size (A) is the denominator of the formula and even small areas with high species and land cover diversity may still account for high values. Considering constant values of rarity, the MBI in poor biodiversity sites, with both a low or a high number of land cover classes, is quite different in small sampling areas, but it becomes similar to the sampled area increases (Fig. 5). At the same time, when biodiversity is higher, the MBI shows more evident differences at a low or high number of land cover classes, along with the increase of area (Fig. 5). This reflects the fact that, as the sampled area increases, the contribution of the number of land cover classes is more evident (being a multiplicative and limited in number factor) if species richness rises accordingly. The contribution of species richness and rarity is averaged by the complexity of the biome (ecosystem diversity). To the MBI, the number of species and their rarity has a heavier weight than the number of classes. However, the ecosystem diversity is

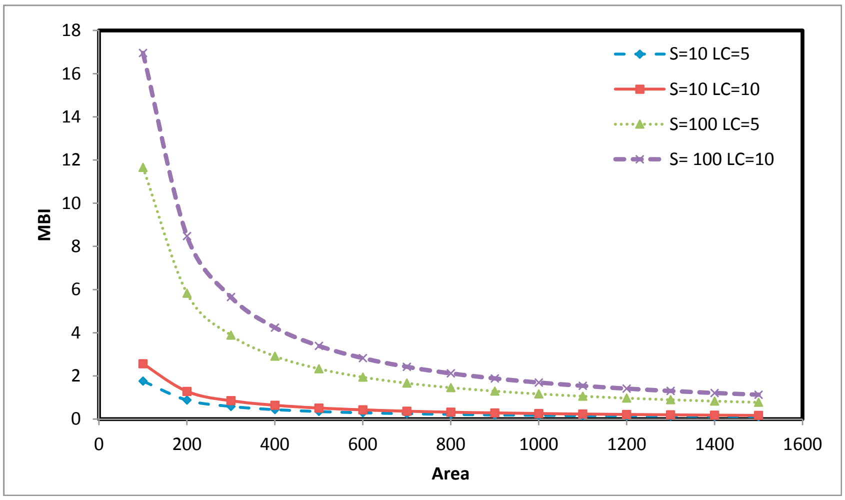

Fig. 5. Dependency of the MBI index from the area, the number of sampled species (S_{obs}) and the Land Cover Classes (LC_{obs}). In the plot, $r_1 = 2$, $r_2 = 3$ and $c_1 = 2$, $c_2 = 3$ have been assumed.

important in the overall estimate of biological diversity and it is considered here, for the first time in a biodiversity metric, as an important factor contributing to species diversity (and not just as an external feature of it). Although rarity makes sense as a basis for prioritizing species and not necessarily for ecosystems, the MBI is able to take into consideration rare, recent, low-diversity and anthropogenic land cover classes. In fact, in our study area the map of land cover classes rarity index (Fig. 3), which is the percentage of occupation of each class compared to the total area and can be considered as a proxy of the $\left(LC_{obs} + \frac{c_1^2}{2c_2}\right)$ in the MBI formula, is based on the principle that the lesser is the % of occupied area of a class, the higher the value of the index. This allows the inclusion into the index of rare ecosystems (i.e. rare land cover classes).

Similar calculations, which show interesting results in the comparisons at a regional scale in the Mediterranean, may be applied to other terrestrial biomes and to marine environments when global and marine cover classes (e.g. as coastal, coralline, mangroves, deep cold ocean, salt water, etc.) will be more standardised and developed.

Taking into account this general consideration, an algorithm/protocol to calculate the MBI index can be suggested:

1. Select the sample area (A) and measure its extent. We recommend a minimum A of 200 km^2 because (see the analysis in Fig. 5) areas <200 km^2 could bias the index;
2. Detect the number of land cover classes (LC_{obs}) from standard classification scheme, such as the CORINE Land Cover (https://www.eea.europa.eu/publications/COR0-landcover), that characterise the study site. It is very important to ensure an adequate sample size (A≥200 km^2 as suggested in point 1) and a standardization of the sampling effort (in particular for the kind of taxa sampled and the land cover classes considered) for better comparisons;
3. Quantify the area covered by each class compared to the total area;
4. Count the number of classes that have an area <1% (c_1) and <3% (c_2) compared to the total surface (A);
5. Track 4 transects that follow the diagonals of the square sample area;
6. Select the target taxa to collect;
7. Start the field survey and, following the 4 transects, detect all the species (S_{obs}) the research group is able to collect; mark all species whose only one individual and two individuals are detected at the end of the survey; leave unmarked all the others;
8. count the total number of species (S_{obs}) and the n° of rare species (singletons, r_1 and doubletons, r_2);
9. Use these values to calculate the index (MBI);
10. It is possible to compare the index results to values obtained in other sample areas, but it is fundamental to ensure that sampling protocols (both in the field and from satellite), the sampled taxa and the land cover classes definition are the same;
11. From the MBI values, it could be possible to draw a map of vulnerability (Edwards et al., 2007) in terms of biological and ecosystem diversity.

4. Conclusion

The study of biodiversity is a young science because only in recent times the value of biological diversity has received attention, particularly because of the recognised importance of human being wellness and the maintenance of ecosystem services upon which humanity depends. The work presented here proposes a new approach to qualitatively and quantitatively analyse biodiversity at various levels. The Multilevel Diversity Index can be easily adapted to study areas of different ecoregions on Earth. The ease of adapting the experimental protocol and the preliminary results derived using this procedure with a top-down (verification by satellite to the ground) and bottom-up (from the ground to the satellite) approach allows picturing with details the biological diversity of an area. As shown by the results obtained for this research by the comparison between the land cover map of the studied area (Fig. 2) and the rarity index of the major ecosystems found through the land use analysis (Fig. 3) the MBI could certainly be useful for future studies and to address environmental policies in order to protect vulnerable ecosystems and assign them an economic value that takes into account the presence of diversity both in terms of species and ecosystems. This, for instance, would improve the assessment and identification of ecological corridors that would reduce the ecosystem fragmentation of biodiverse regions, as shown in Fig. 4.

However, since this index is expected be very sensitive to the taxa surveyed, the sampling effort, which will determine the numbers of singletons and doubletons, and the number of land cover classes considered we stressed the importance of a priori standardisation and of the development of a common global for land cover classification (which is a long time aim of the FAO-UN; see, for instance, Di Gregorio, 2005) to better compare the values obtained by its calculation. In a historical period when one of the most important priority is to protect the environment from the anthropogenic impacts and to develop strategies to face the global changes, providing adaptation and resilient solutions, this new index could represent a further fundamental tool.

Acknowledgments

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.gecco.2017.e00361.

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