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BIODIVERSITY AS A TOOL: QUANTITATIVE ASSESSMENT OF SPECIES RICHNESS FOR ENVIRONMENTAL PLANNING

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Abstract – Biodiversity is recognised as one of the main factors causing ecosystem stability and the existence of several ecosystem functions. In consequence, species richness can be a reliable state variable, useful to assess an ecosystem status or to identify highly valuable areas in a landscape. Here we present two applications in which species richness assessment allowed respectively the boundaries redesign of a part of the Natura 2000 network and an *ex-post* BACI (Before-After-Control-Impact) assessment as enforced by an infringement procedure for action against Article 4 of the Birds Directive. In the first case study, the boundaries of 16 Natura 2000 sites were redefined, identifying genuine scientific errors and expunging low species richness areas and incorporating high biodiversity areas whose value was not possible to assess when the sites were instituted. The overall balance involved a minimal surface area change (+1.5% SPAs, +1.6% SCIs) but a net gain in high quality habitats in the redesigned sites network. The second case presents a small scale *a posteriori* impact assessment, where an exact quantification of habitat and species loss allowed not only reporting the European Commission as requested, but also to individuate a new Natural Reserve with identical ecological traits as measure of compensation, positively resolving the pending infringement procedure.

Keywords: species richness, Natura 2000, protected areas design, wildlife monitoring, biodiversity assessment

Introduction

In the last years, the role of biodiversity as a determinant of ecosystem functionalities has been demonstrated in several cases (Loreau et al., 2001; Hooper et al, 2005; Cardinale et al., 2006; Hector & Bagchi, 2007; Reiss et al., 2009; Schmid et al., 2009), and species richness is widely recognized as relevant for the existence of a number of key ecosystem functions. Furthermore, species richness is nowadays identified, almost axiomatically as an "insurance form", granting ecosystem resilience and eventually persistence of ecosystem services provision (Srivastava & Vellend, 2005; Hector & Bagchi, 2007; Mooney, 2010).
On these premises, species richness (i.e. measures of β- and γ-biodiversity) can be used as a "state variable" to indirectly monitor changes in ecosystem (and in ecosystem processes as well, Pereira et al., 2013). In particular, in the context of conservation planning, a quick and reliable assessment of "landscape values", is often needed, as an instrument to orient the decision-making process and choices, and the production in a spatially explicit fashion of species richness maps can be a tool of remarkable value.
Here we present two case studies in which a species richness assessment, i.e. the production of a (potential) species richness map has been used as a key instrument influencing decision-making on parts of the Natura 2000 Network.

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MATERIALS AND METHODS

Study areas

Both case studies involve areas in the "Alps conifer and mixed forests" ecoregion (European Environment Agency, 2012), covered by parts of the Natura 2000 network.
In detail, the Verbano-Cusio-Ossola Province case study area (8.261° E, 46.175° N, Figure 1a) contains 5 SPAs (Special Protection Areas, IT1140016, IT1140021, IT1140018, IT1140019, IT1140020) and 3 SCIs (Sites of Community Importance, IT1140004, IT1140003, IT1140016), whereas the "Parco Nazionale dello Stelvio - Valfurva" case study area is located in Stelvio National Park (Sondrio Province, Figure 1b) and includes the SPA IT2040044 (10.200° E, 46.667° N) as well as several other neighbouring and partially overlapping SCIs (among which IT2040010, IT2040013, IT2040014 and IT3120003).

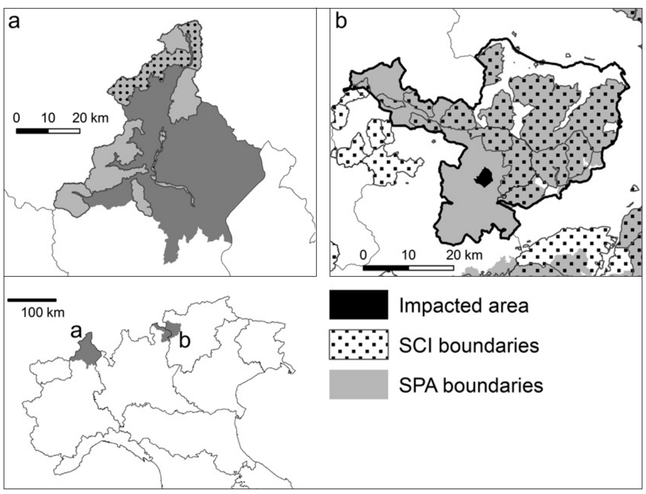

Figure 1. Location of the two case study areas (light grey) in North Italy. a) Verbano-Cusio-Ossola province (dark grey); b) Stelvio National Park (thick line). The black area indicates the area impacted. Natura 2000 network sites are indicated respectively in light grey (SPAs) and with a dotted hatching (SCIs).

Case study "Verbano-Cusio-Ossola"

This case study is a wide-area planning effort, aimed at a critical evaluation and redesign of Natura 2000 site boundaries, as indicated by the European Commission (Doc. Hab. 05/06/02, European Commission, 2005) and by the Italian Ministry of the Environment (note DPN/5D/2005/18772). In this case, a network of 9 SPAs and 7 SCIs was analysed with the help of two different species richness maps, one for birds only (SPAs) and one for Annex I and II habitats and species (SCIs). An unsupervised procedure was applied to each species richness map, in order to identify both high species richness areas in the vicinity of Natura 2000 sites, but left out of the Network itself, and low richness areas erroneously included, due to inaccurate data on the natural values of the sites (i.e. "demonstrable genuine scientific errors" *sensu* European Commission, 2005), at the time of first compilation of the Standard Data Forms.

Species richness mapping and automated boundary identification

Two species richness map were prepared, one for SPAs and one for SCIs boundaries verification, starting from species distribution data available on a local basis,. In the Verbano-Cusio-Ossola case the local Provincial Administration already possessed a bird distribution data base, used to realize the Provincial Bird Atlas (Bionda & Bordignon, 2006) as well as a more general wildlife distribution database, with both systematic and opportunistic presence records of both invertebrates and invertebrates. The base data collection activities also provided for the realization of an habitats map. From these base distribution data, two series of MAXENT potential species distribution models (Elith et al., 2011) were produced, one for birds and one for Habitats Directive Annex I and II habitats and species (Figure 2). In both cases, indicator maps (Isaaks & Srivastava, 1989) for each species group were summed up, producing two separate species richness maps. Data harmonization and batch-mode MAXENT modelling were carried out using a dedicated program written for the R analysis environment (R Core Team, 2013) using the *dismo* (Hijmans et al., 2013) and *raster* (Hijmans, 2013) packages.
The following step involved (both for SPAs and SCIs separately) the application of a dedicated threshold analysis procedure, developed for the GRASS GIS (GRASS Development Team, 2012a, b). The aim of the procedure is to "cut" a biodiversity map, at a given relative species richness threshold, identifying "richness islands" and comparing the surface areas of the "islands" with a reference area (i.e. the current surface area of either a SPA or a SCI). The threshold procedure is developed as a spatially-explicit bisection algorithm (Burden & Faires, 2005) and can be constrained to a given buffer distance from an existing polygonal boundary. In the case here described, new potential boundaries were searched in a 1 km radius from the existing boundaries, and a further constrain was imposed, i.e. the new boundaries surface area must be at least equal or in any case not exceeding the 5% of the current SCI or SPA area.
The threshold analysis procedure yielded a boundary indicator map, that was used to define and assess the new SCI/SPA boundaries. A further feature in the SCI boundary

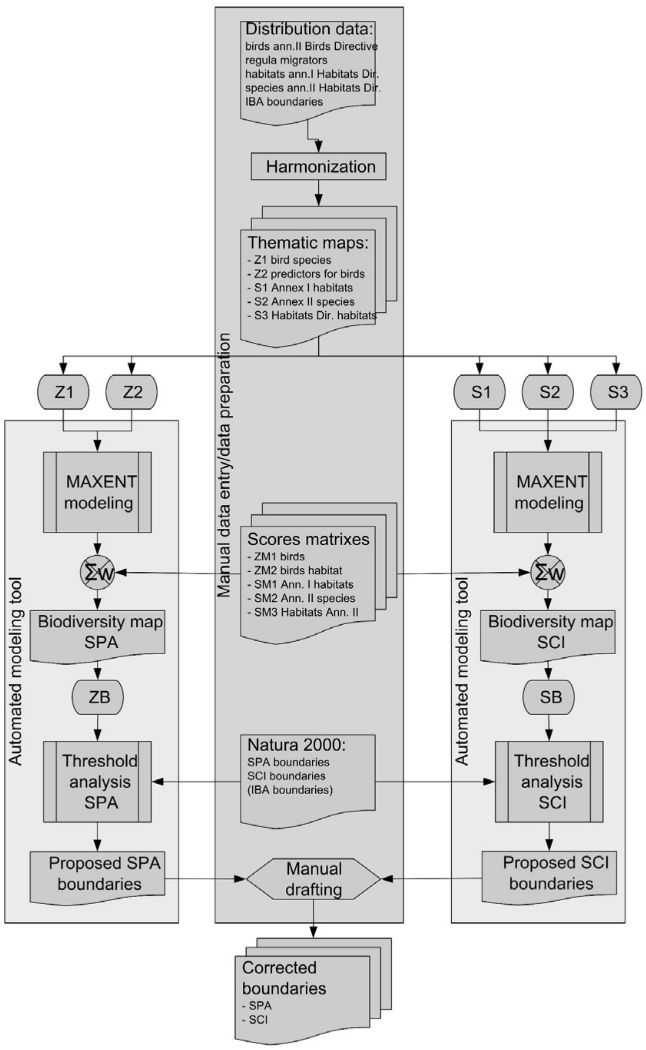

Figure 2. Logical flow chart of the modeling procedure developed for the semiautomated Natura 2000 sites boundary redesign used in case study Verbano-Cusio-Ossola (see text for details).

assessment case took into account the amount of change in the proportion of surface area covered by Annex I habitats, allowing for no habitat losses.

Case study "Parco Nazionale dello Stelvio - Valfurva"

In this case, biodiversity assessment played a crucial role in the formulation of a contingency response plan to answer to an infringement procedure (case 2003/5046, Court of Justice of the Eropean Union cause C-304/05), as a consequence of the loss of about 2.5 ha of mature Alpine forest (EIONET code 9410 - Acidophilous *Picea* forests of the montane to alpine levels (*Vaccinio*-*Piceetea*)) inside the IT2040044 SPA (Figure 1b, black area). Species richness was limited to birds, since the infringement procedure was targeted at a SPA and the European Union requested an estimate of the losses and the proposal of compensation measures proportional to the damage occurred, in a sort of *ex-post* assessment (European Commission, 2002), as requested by the European Commission note C(2008)7108. This case study thus configures as a small-scale (and as a consequence, high-resolution) biodiversity assessment for a BACI analysis (Before-After-Control-Impact Analysis, *sensu* Wiens & Parker, 1995), targeted at the appraisal of losses. both in terms of habitats and number of individuals and at the proposal and implementation of compensation actions for an equivalent (or higher) amount.

Impact area mapping and biodiversity loss quantification

A first data collection and harmonization step involved the integration of all the available materials (mostly Computer Aided Drafting blueprints, in arbitrary coordinate reference systems) related to all the intervention and works executed in the Santa Caterina Valfurva area.

This preliminary phase allowed to identify the exact surface area vulnerable to impacts (called "potential perturbation area"), as well as the possible specific impacts ranging from species and habitat direct losses caused by forest clearing or digging to indirect impacts linked to water catching for artificial snow making.

A second data collection phase involved the identification and mapping of all Habitats Directive Annex I habitats and Annex II species present in the area, as well as direct census of bird species.

Due to the fact that the impact assessment has been carried out *after* the realization of the infrastructures, it was not possible to know the pristine site status: a comparison of aerial photographs and land cover maps made before the site alteration allowed a reconstruction of the pre-existent conditions for the vegetation. As land cover maps, the DUSAF (Regione Lombardia, 2010) digital cartography was used, namely versions 1.1 (2000) and 2.0 (2006). The land cover cartography was supported by two set of aerial imagery, available from the National Geoportal (Ministero dell'Ambiente e della Tutela del Territorio e del Mare , 2013), i.e. the IT2000 and IT2006 orthophotos.

A direct estimate of the pre-existing wildlife component was not possible, but thanks to the availability of the above cited land cover maps, a site selection procedure allowed to identify other not perturbated areas inside the IT2040044 SPA having similar land cover, elevation and aspect traits, assuming no difference in the communities present. In these

areas, a series of census campaigns allowed the definition of a species checklist, as well as the estimation of population density for birds, using standard methodologies (Sutherland, 1996; Bibby et al., 2000). Furthermore, Sondrio Provincial Administration made available species distribution data that allowed to calculate potential species distribution and density models (Provincia di Sondrio, 2011), using standard logistic and multiple regression techniques (see Hutson, 2002; Rushton et al., 2004; Austin, 2007 for a review). Census data and model prediction allowed an estimate of the number of animals "lost".
A final GIS-based siting procedure allowed to identify high value, yet unprotected areas inside IT2040044 SPA eligible as Natural Reserve areas, thus starting the process to create a new Natural Reserve inside the SPA as a compensation for the losses suffered.

Results

Case Study "Verbano-Cusio-Ossola"

The semi-automated boundary revision procedure allowed, as a first result, to produce potential distribution models for 3 invertebrates species, 5 fish species, 1 amphibian species (*Pseudepidalea viridis*, (Laurenti 1768)), 2 reptiles (*Lacerta bilineata* Daudin 1802, *Podarcis muralis* (Laurenti 1768)), 52 bird species (of which 28 non-migratory) and 15 mammals (among which *Canis lupus* Linnaeus 1758 and *Lynx lynx* Linnaeus 1758, plus 13 species of bats). Thus, maximum species richness in the area would amount to 78 species. This value has been set as the maximum potential species richness and arbitrarily taken as 1. Thus, a site with e.g. 20 species achieved a 25.6% relative richness score.
At the wide area scale, the previous surface area covered by Natura 2000 SPAs changed from 74619.00 ha to 75753.95 ha (+1.5%). The apparently negligible increase in surface area involved instead several sizeable rearrangements, included the transfer of about 3400 ha from SPA IT1140017 to the neighbouring SPA IT1140021, since a clear species richness "gap" actually seemed to break the former IT1140017 site in two parts, one of which in perfect contiguity with IT1140021. Similarly, the SCIs original surface area passed from 21608.00 ha to 21954.52 (+1.6%). Again, a small change in quantity that involved a substantial change in the quality of protected habitats: in fact, for the 23 habitat classes (*sensu* Annex I Habitats Directive) recorded as present in the wide area, often with extremely localized distribution (such as habitats 7110* - Active raised bogs, or 7230 - Alkaline ferns) no change occurred except for four classes, that underwent a surface area increase (4060 - Alpine and Boreal heaths: +86.2 ha; 6170 - Alpine and subalpine calcareous grasslands: +24.5 ha; 6230 - Species-rich *Nardus* grasslands, on siliceous substrates in mountain areas: +228.9 ha; 7240 - Alpine pioneer formations of *Caricion bicoloris-atrofuscae*: +31.0 ha; 8110 - Siliceous scree of the montane to snow levels (*Androsacetalia alpinae* and *Galeopsietalia ladani*): +116.36 ha).
These surface area increases happened although several portions of the existing Natura 2000 network were dismissed, due to genuine mapping errors (e.g. portions of a SCI falling in Switzerland, outside European Union boundaries, 40.6 ha for SPAs and 20.73 ha for SCIs) or more appropriately for scarce species richness (i.e. genuine scientific error, 1112.24 ha for SPAs and 237.80 ha for SCIs, Figure 3).

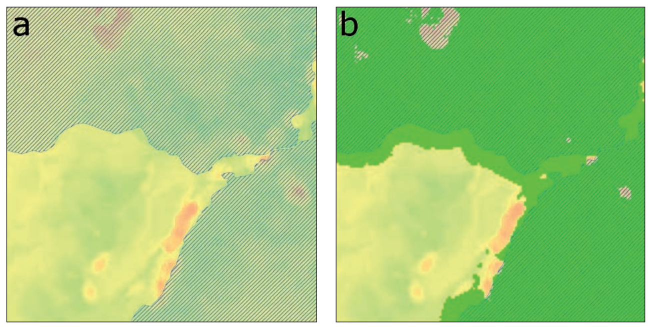

Figure 3. Example of the boundary changes proposed by the threshold analysis procedure. a) Current Natura 2000 boundaries (blue hatch), superimposed to a species richness map. Red areas indicate low species richness, yellow to green indicate higher species richness. b) Dark green area represent the proposed boundary. Note that the boundary extension is not uniform, excluding a low richness zone, whereas low richness zones inside the Natura 2000 site has been marked as "outside" (top left, middle right).

Case Study "Parco Nazionale dello Stelvio - Valfurva"

The potentially perturbated area was estimated as a 68.35 ha surface, taking into account the results from the mosaicking of all the infrastructures blueprints. This surface suffered irreversible habitat loss due to excavations and/or land cover alteration.
More into detail, land cover changes (Figure 4) caused a degradation of 14.02 ha of natural habitats, 5.32 of which belonged to Annex I habitat classes (Natura 2000 habitats 8210/8110/8120: -1.05 ha; 9410/9420: -3.22 ha; 4060: -1.05 ha). Indirect impacts (i.e. no irreversible loss) were also taken into account, both in the infrastructure building and exercise phases. In this case, the perturbated area covered 110.92 ha, of which 25.75 belonging to Annex I habitat classes.
These results allowed to state that at least 110.92 ha of IT2040044 SPA were lost, i.e. approximately 3.1% of Natura 2000 habitats present in the wide area: a small proportion that

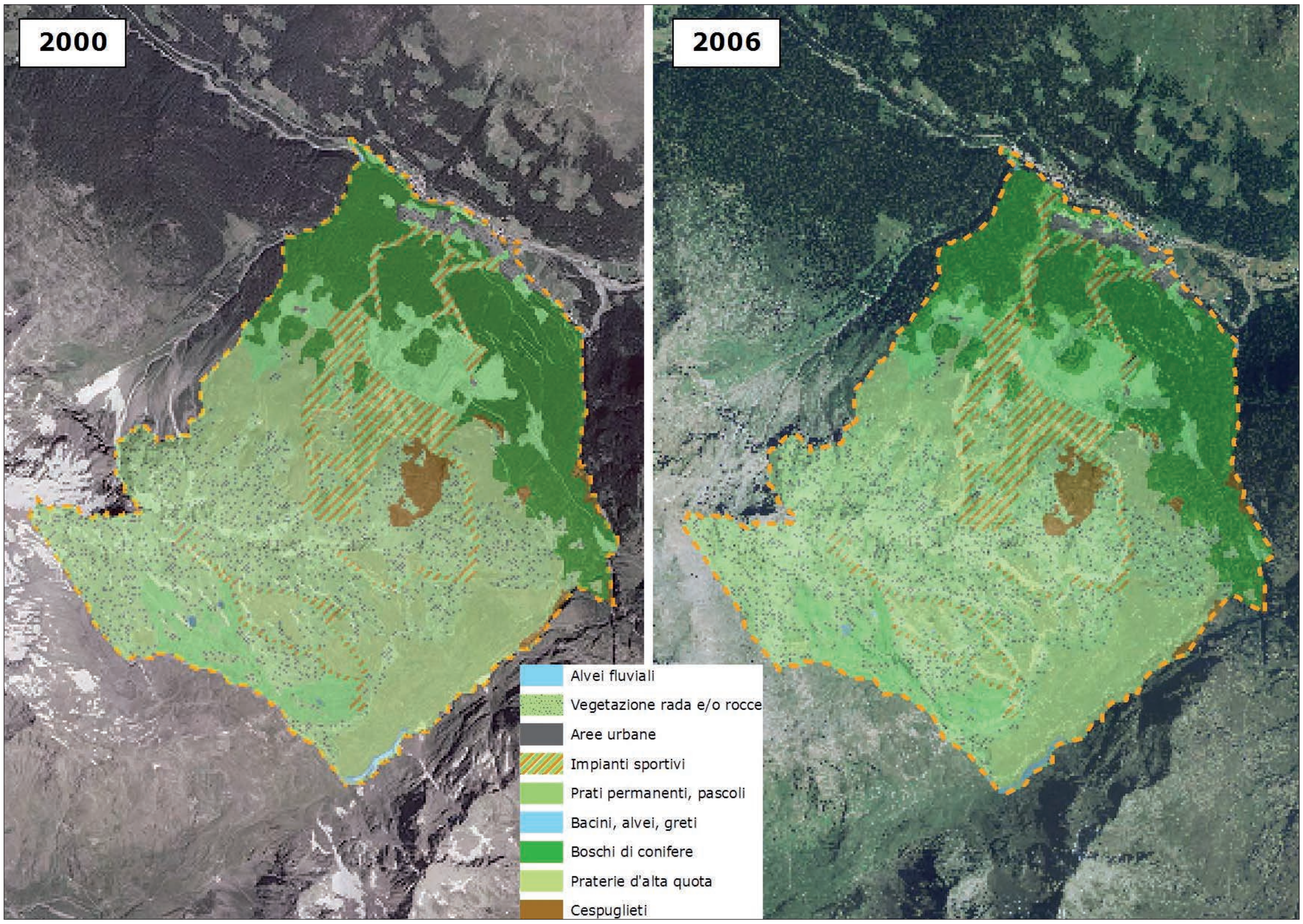

Figure 4. Before-and-after comparison of land cover changes. Left: land cover in 2000, before the beginning of works. Right: Land cover after the conclusion of works. Notice the fragmentation increase in the forested areas at top center.

in any case can involve a loss of habitat functionality, for instance in terms of increased fragmentation.

At the species level, extrapolations from species abundance models allowed a direct loss estimate in terms of individual, that can be summarized as follows, for some bird target species whose potential density has been estimated: *Lagopus muta* (Montin 1781): -13.8 breeder males; *Lyrurus tetrix* (Linnaeus 1758): -37.4 breeder males; *Alectoris graeca* (Meisner 1804): -8,1 breeder males; *Tetrastes bonasia* (Linnaeus 1758): -2,0 breeder males; Picidae: -13.3 refuge trees; Strigidae: -11.8 territorial males for both *Glauciduim passerinum* (Linnaeus 1758) and *Aegolius funereus* (Linnaeus 1758). The whole bird community (estimating from potential presence models) suffered an estimated loss accountable as two species (from 16 to 14) for forest species and 3 species (from 16 to 13) for grassland species. In these last two cases, a conservative approach suggested not to consider those changes as exclusively caused by the infrastructures realized, not taking into account the species loss itself (which is negligible), but the loss of habitat available to the two birds communities.

The forest stand density known for the area allowed to estimate a loss of about 2800 mature trees (*Picea abies* (L.) Karst., *Larix decidua* Mill. and *Pinus cembra L.*).

Summing up, since average population densities for the bird target species listed above were known for the area, the numbers of “lost” individuals was converted in hectares of species habitat, yielding a total species habitat loss of in the range between 2300 and 3500 ha.

These results, together with the identification of similar unperturbated areas inside the SPA, allowed the proposal of a new Natural Reserve, whose boundaries have been identified as to contiguous zones with a total surface area included in the limits stated above and with the same habitat composition of the habitat lost. The Natural Reserve “Tresero - Dosso del Vallon” has thus been instituted with the Decree 2/12/2010 of the Ministry of the Environment (Ministero dell’Ambiente e della Tutela del Territorio e del Mare, 2010).

Discussion

Doing an overall balance in terms of surface area changes for the Verbano-Cusio-Ossola case study, we can affirm that no substantial alteration of the existing Natura 2000 sites occurred, since the total surface area change was +1.5% and +1.6% for SPAs and SCIs respectively, on a prefixed maximum allowed change constrain ranging from 0 to +5%. The structure, functionality and conservation status of the Natura 2000 network portion present in the Verbano-Cusio-Ossola province did not change, from a qualitative point of view, and the parts of the Network dismissed due to their low species richness were abundantly balanced by high-value areas added to the Network

As for the Parco Nazionale dello Stelvio - Valfurva case study, a detailed, high-resolution habitats and species mapping not only allowed the *a posteriori* reconstruction of an ecosystem altered by human impact in a BACI framework, but also made it possible to precisely define (and locate in the neighbouring areas) the principal characteristics (minimum surface area and habitat composition) of a proposed - and then instituted - new protected area as a compensation measure.

Actually, the area affected constituted a small (about 3%) fraction of the whole IT2040044 SPA, but the small extent of the impact did not imply the impact magnitude, rendering instead more difficult to assess the effective magnitude (Hewitt et al., 2001). The availability of high resolution distribution data, as well as the capacity to activate small-scale intensive field monitoring, allowed sub-hectare precision estimates of habitat and species loss, ultimately answering the European Union with the requested detail and positively solving an infringement procedure.

Comparing the biodiversity assessment frameworks used in the two cases, scale differences influenced and accounted for the methodology used (Bunnell & Huggard, 1999, Hewitt et al., 2001). On a small spatial scale, in fact, direct sampling designs can be affordable and can give, if appropriately planned, high-quality, high-detail information on species distribution (Huston, 2002; Kroll, 2009), whereas on a provincial-to-regional scale existing species atlases begin to play a fundamental role as baseline knowledge repositories (Rodríguez et al., 2007). In this case, the incompleteness of "presence only" data, or the scarceness of presence records do not constitute a problem anymore, since several well-proven species distribution modelling techniques are readily available (Guisan & Zimmermann, 2000; Guisan & Thuiller, 2005; Elith & Leathwick, 2007).

Conclusions

The two examples discussed here showed how species monitoring, both done systematically on wide areas, as well as targeted and intensively done at a small scale, can be used with currently available spatially explicit modelling techniques to produce species richness maps. The two case studies can have general value since the methodology used to prepare species richness map is in fact applicable in almost any case dealing with natural resources management. Used as a proxy of habitat and/or landscape biodiversity, species richness maps proved to be an useful tool in activities related to the management of the Natura 2000 network, in the first case, causing the inclusion of high quality habitats in a network of 9 SPAs and 7 SCIs with only a slight surface area increment; in the second case allowing a coherent and detailed (as well as pro-active) answer to the European Community, solving a case of infringement.

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