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TITOLO TESI

ASSESSMENT OF RIVER ECOSYSTEMS BY A MULTITEMPORAL AND MULTILAYERED LANDSCAPE APPROACH. THE SEMIAQUATIC OTTER (*LUTRA LUTRA* L) AS A PARADIGMATIC SPECIES.

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1) Preface

Among wetlands, fluvial habitats represent key ecosystems for maintaining the general equilibrium of the entire landscape (Ward et al., 2002a) since they contribute to sustain a high level of biodiversity (Naiman et al., 1993), act as environmental corridors (Knutson & Klaas, 1998), and are depurating organisms with many functional links with the surrounding territory (Brunet & Astin, 1997; He et al., 2000; Ingegnoli, 2002; Sponseller et al., 2001; Stewart et al., 2001). Nevertheless, in the last 30 years, river ecosystems have been severely menaced by many anthropogenic pressures (Tockner et al., 2010; Schinegger et al., 2011), such as channelization and bank stabilization (Ward, 1998), erosion (Montgomery, 1999), land use (Allan, 2004), pollution (Ormerod et al., 2010) and so on.

In order to maintain the crucial role of river ecosystems in keeping the equilibrium of the entire landscapes, the European Union adopted the Water Framework Directive 60/2000/CE, that aims at the recovering of a satisfactory functional level of European water bodies within the year 2015. The main environmental objectives of the Water Directive are the protection, the improvement and the restoration of water bodies. For reaching this aims, specific monitoring campaigns must be implemented and a correct management of each river basin based on those monitoring information must be drawn. For the achievement of Water Directive objectives, scientifically based strategies that take into account the multilayered structure of the river/landscape systems are mandatory. River basins, in fact, are dynamic mosaics of spatial elements and ecological processes hierarchically organised (Frissell et al., 1986; Schumm et al. 1988, Lowe et al., 2006; Huang et al., 2007).

In a stream ecosystem it is possible to recognise at least three major layers, such as stream channel, floodplain, and transitional upland areas; all these layers interact and work dynamically in the landscape basin (Ward, 2002a). The interactions between these layers are essential for preserving the natural functionality and biodiversity in the river basin: e.g. cycling nutrients, filtering possible contaminants from runoff, absorbing and gradually releasing floodwaters, supporting fish and wildlife habitats, recharging ground water, maintaining stream flows and go further. The connections between the river courses and their surrounding and upland areas have been well acknowledged in literature (Richards et al., 1996; Bis et al., 2000; Snyder et al., 2003), which define a stream and its involved landscape as a continuous and integrated hydro-system (Ward et al., 2002a). In this context a disturbed landscape influences the river ecosystem and vice-versa (Hem, 1985; Norris and Thoms, 1999; Davies et al. 2000, Miltner et al., 2004; Ahearn et al., 2005; Bunner et al., 2010).

In order to provide efficient scientific tools for the monitoring, management and/or restoration of a river/landscape system, a more dynamic assessment, based on the knowledge of key ecological aspects of the different layers, is needed.

The general aim of the research work was to identify and test a kit of scientifically sound indicators of fluvial basin function and disturbance (criticalities) able to synthesize the multi-layered structure of a river/landscape system.

With this aim in mind we focused on the diverse layers of the river landscape by applying and integrating different approaches.

As a synthetic indicator of the entire basin environmental status we used the distribution of suitable habitats for a river key species, provided by the application of an inferential Habitat Suitability Model (Chapter 1).

Next we described the existing links between the river channel and its upland areas by measuring a fine scale index of Fluvial Functionality. Results from both Habitat Suitability model of a key species and Fluvial Functionality analyses were integrated in order to identify the main critical sector of the river basins.

Successively we test the results derived from this integration by calculating a set of landscape ecology Metrics (LM). For this purposes we chose two different river basins showing high (High Agri River, Chapter 2) and low levels of anthropogenic influence (High Sinni River, Chapter 3) respectively. In the more natural/functional river basin additional landscape analysis was performed aimed to identify further links between the water course criticalities and the territory of the entire basin (Chapter 4).

Considering that ecological systems are dynamic and that river systems tend to change in considerable short time we also implemented a multi-temporal HS model approach. In particular we produced two inferential Habitat Suitability Models concerning different periods (years 1985 and 2006) and we compared them in order to identify the environmental factors that accompanied the natural expansion of the key species (Chapter 5).

A schematic representation of the research work is depicted in Figure 1, which follows a detailed introduction of the treated topics along with the relative scientific articles.

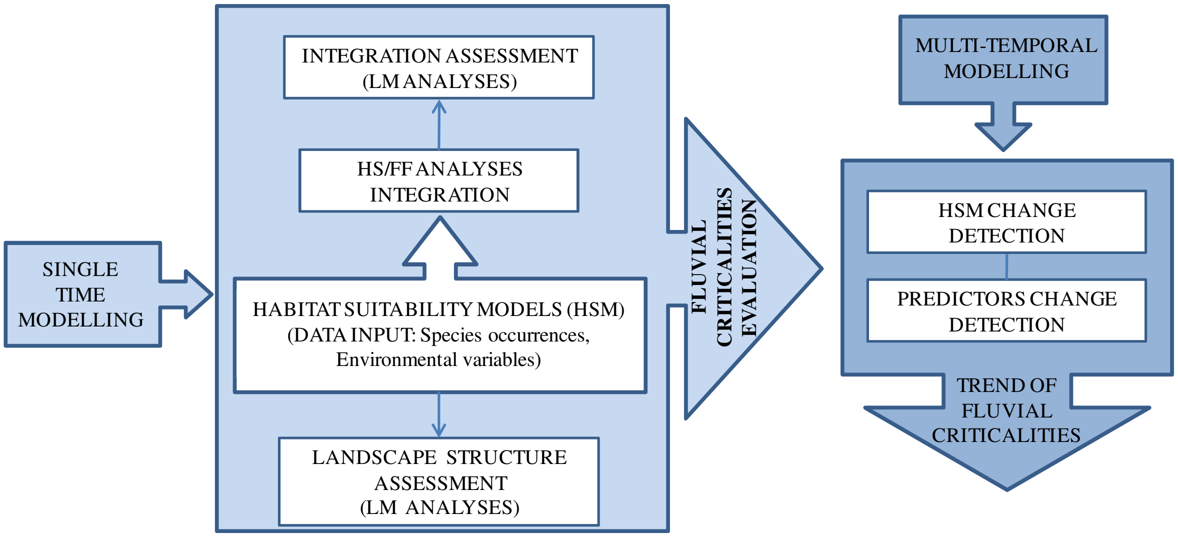

Figure 1: Flow-Chart of the proposed approach: in light blue the single-time step modelling regarding the different performed analyses and providing fluvial criticalities at a specific time; in blue the multi-temporal step modelling providing the fluvial criticalities trend. HS (Habitat Suitability), LM (Landscape Metrics), FF (Fluvial Functionality).

For the research we used the spatial distribution of a wide-ranging key species, particularly vulnerable to the environmental quality and equilibrium of fluvial habitats, as a broad scale surrogate of good ecological functioning of the river basin: the Eurasian otter (*Lutra lutra* L.). This species relies on the river course and on the riparian vegetation for feeding, for resting and for reproductive activities (Chanin, 2003; Kruuk, 2006). It is also linked to the presence and structure of natural and semi-natural elements in the terrestrial matrix for inter-catchment dispersal movements and gene flow (Carranza et al., 2012). In Italy, the species was distributed over the whole country till the 70's when it started to decrease (Spagnesi et al., 2000). In the 90's otters resulted relegated to a Southern Italy range, geographically isolated from the European population, and for this reason it was listed as critically endangered (CE IUCN category - Bulgarini et al., 1998). The causes of Otter decline included illegal hunting, food shortages (mainly fish), and the destruction of riparian vegetation (Loy et al., 2010). At present, the Otter's Italian population consists of two isolated sub-populations that are slowly recovering: a core area represented by the Campania, Basilicata, Calabria and Apulia regions and an outlying area in the Molise region (Loy et al. 2010).

2) Study area and Methods

The research was carried out in Basilicata Region (Southern Italy) that comprises the following five river catchments: Sinni, Agri, Cavone Basento and Bradano (Figure 2).

This area played a crucial role for the survival of the Italian remnant Otter population in the period 1970-1990, and it represents a consistent sector of its current range.

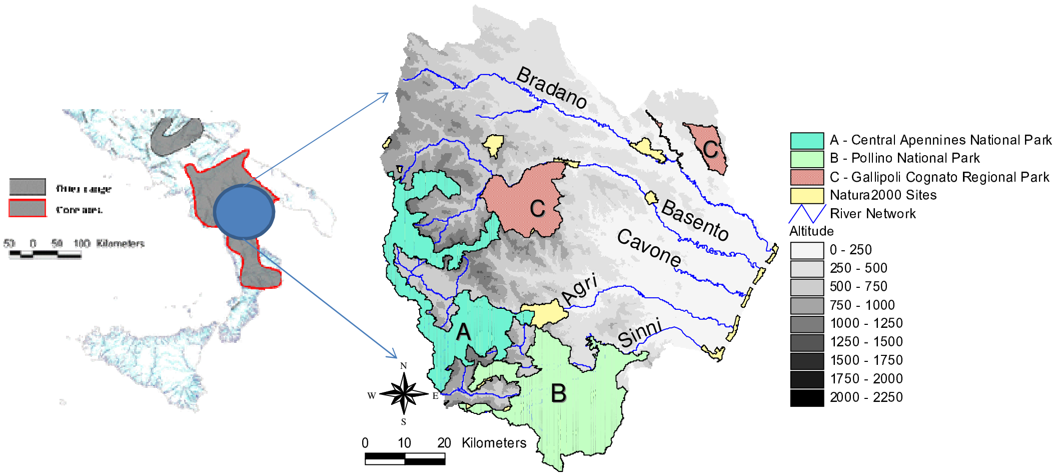

Figure 2: Left: study area. Right: the rivers included in the study region along with the Natura 2000 Sites and the EUAP areas. In yellow Natura 2000 Sites; in light blue, A, Central Apennines National Park; in light green, B, Pollino National Park; in pink, C, Gallipoli-Cognato Regional Park.

To describe the spatial distribution of the Otter, we used Habitat Suitability Models (HSMs) and maps. Otter Habitat Suitability maps, describing the quality and distribution of river habitats, can be considered a proxy of the functions and critical aspects on river ecosystems. HS models, generating maps of species suitable habitats distribution, are a powerful instrument for the description of the species environmental niche (Hirzel et al., 2002; Araújo & Guisan, 2006) and can be considered fundamental for providing a geographic perspective on supporting conservation strategies both for the chosen species and for the ecosystem that enclose them (see e.g. Mladenoff et al., 1997; Guisan & Zimmermann, 2000). Many HSMs have been produced for a variety of common species (Guisan & Zimmermann, 2000, Elith et al., 2006; Guisan & Thuiller, 2005; Jiménez-Valverde et al., 2008 and reference therein), but their use for modelling the distribution of endangered species has not been sufficiently exploited yet (Elith et al., 2006; Engler et al., 2004; Guisan et al., 2006, Lomba et al., 2010). Furthermore, the integration of HS models with environmental indices describing other ecological levels of organization (as ecosystems and landscape) has been quite unexplored.

We used two different HS modelling approaches: the ENFA model (Hirzel et al., 2002), and the multi-modelling BIOMOD platform (Thuiller, 2009).

We first selected the ENFA model because it produces reliable results by using only-presence data (Cianfrani et al., 2010).

On this subject see Chapter 1:

- "Carone M.T., Simoniello T., Loy A. e M.L. Carranza et al (2010): Individuation of fluvial areas needing restoration through the analysis of a target species, the Eurasian otter (*Lutra lutra* L.). Extended abstract 7th European Conference on Ecological Restoration, Avignon, France. SER Europe Knowledge Base (www.ser.org/europe).

Habitat Suitability Models produced with ENFA were then integrated with fine scale information derived from Fluvial Functionality analysis.

Considering the river as an "organism", the Fluvial Functionality describes the health of its metabolic functions due to both: the living structure (e.g. trophical chain) and the environmental frame (e.g. fluvial contributions to the environmental biodiversity, solid transport loads, etc) (Vannote et al., 1980). Many Fluvial Functionality Indices have been developed in different environmental situations and countries (e.g., AUSRIVAS - Australian River Assessment System, Parsons et al., 2002; ISC - Index of Stream Condition, Ladson et al., 1996; RHS - River Habitat Survey Raven et al., 1997; IFF – *Indice di Funzionalità Fluviale,* Siligardi et al., 2003a) all of them aimed to provide an efficient and synthetic description of fluvial metabolic functions. Being the Fluvial Functionality indices operational tools for the assessment of the river metabolic functions (e.g. Ladson et al., 1996; Raven et al., 1997), they can support the evaluation of river criticalities at the local scale. In Italy, Balestrini et al. (2004), have demonstrated that the IFF is more adapt for evaluating the functionality of rivers than other Fluvial Functionality indices, such as the Buffer Strip Index, and the Wild State Index (Braioni & Penna, 1998). At present the IFF is adopted by the Italian Governmental Agency of Environmental Protection, ISPRA (Siligardi et al., 2003a) and a wide scientific literature underlined that it is a robust tool for the assessment of fluvial functioning (e.g. Comiti et al., 2009; Mazza et al., 2011; Munafò et al., 2005; Renai et al., 2006; Siligardi et al., 2003b; Siligardi & Cappelletti, 2006). For all the above mentioned reasons in the present research we used the Italian protocol for Fluvial Functionality (IFF - Siligardi et al., 2000; Siligardi et al., 2003a).

The integration of FF parameters with maps of HS for fluvial key species (Otters) was used for identifying the river sectors with different vulnerability levels (VU), providing a prioritization that is essential for individuating the river tracts needing urgent specific restoration actions. In order to integrate HS and FF data, both suitability and functionality values were categorized into three levels (low, medium, and high suitability/functionality) and combined in a GIS environment to obtain three levels of river Vulnerability (VU). In this way, each Vulnerability level synthesizes information coming from both the broad (HS) and the fine scale (FF) of river system and for this reason gives an efficient description of the river health status. Then we analyzed land-cover fragmentation inside each original (Functionality, Suitability) and derived map (Vulnerability).

In particular we concentrate our attention on natural cover types because its fragmentation strongly modifies the river ecological functions at different scales (e.g. Lindenmayer & Fischer, 2006 and references therein) and it influences the entire fluvial ecosystems (King et al., 2005; Carone et al., 2009; Karaburun & Demirci, 2009). Furthermore, although there is an open debate about the significance of Landscape Metrics in absolute terms (e.g. Dramstad et al., 2002), the efficacy of such indices in terms of relative values is widely accepted in literature (e.g. Dramstad et al., 2002; Peng et al., 2010; Renetzeder et al., 2010; Zhou et al., 2011) and their effectiveness on describing landscape structure is acknowledged (see e.g. Leitão & Ahern, 2002; Peng et al., 2010; Colson et al., 2011).

In our specific case for each thematic map (HS, FF and VU) classified in three levels (low, medium, and high) we performed a fragmentation analysis based on land cover distribution.

Then we compared the behaviour of the analyzed Landscape Metrics (McGarigal et al., 2002) on the different thematic levels.

On this subject see Chapter 2, and Chapter 3:

- “Carone M. T., Simoniello T., Loy A., Carranza, M. L. (2011) Integration of Ecological Niche Factor Analysis and Fluvial Functionality in vulnerability assessment for supporting restoration strategies in fluvial habitats. Submitted to Ecological Indicators” (data: authors sent a revised version concerning a minor/major revision);
- “Carone M. T., Simoniello T., Loy A., Carranza, M. L. (2011) Combining habitat suitability models and fluvial functionality data for a multilayer assessment of riverine vulnerability: a second study case. In: Jørgensen S.E. and Jordán F. (Eds.) “Models of the Ecological Hierarchy: From Molecules to the Ecosphere” Series on Developments in Environmental Modelling, Elsevier”. (data: authors sent a revised version concerning a minor revision);

An extra landscape pattern analysis was realized on the more natural test area (High Sinni River), oriented to further investigate on the structure and functioning of the entire river basin (Freeman and Ray, 2001; Rob et al., 2002; Ward et al., 2002a,b,c; Wiens, 2002; Wozniak et al., 2009; Tockner et al., 2009). We obtained in this way stronger basis for an adequate management and restoration of fluvial habitats (Poudevigne et al., 2002, Cote et al., 2009).

On this subject see Chapter 4:

- "Carone M.T., Simoniello T., Coppola R., D'Emilio M., Lanfredi M., Proto M., Carranza M.L., Loy A., Macchiato, M., 2010. Analysis of landscape structure and connectivity at watershed scale. Fresenius Environmental Bulletin, 19(10a): 2361 – 2366."

In the last research period we performed multi-temporal habitat suitability models for the Eurasian otter. Considering that land use change constitutes one of the most severe causes of habitat loss for wildlife (Sala et al., 2000), we used past and current otter presence data and land use changes in time to model the otter distribution and to identify critical areas for the survival and expansion of the species. We were specifically interested in accounting for shifts in the distribution of otter occurred between the past contraction period and the current expansion phase (Loy et al., 2009). The basic idea was that insights on environmental predictors driving past and current species distribution would likely allow to better identify the limiting factors for the otter survival at a regional scale, and contribute to raise the accuracy and reliability of the model itself.

The habitat suitability for the European otter was assessed in the Italian core area of the species in a 21 years interval (from1985 to 2006), using an ensemble niche modelling approach (BIOMOD Thuiller, 2009). Such an approach was applied in order to test previous modelling results and, as suggested by many authors (e.g. Araújo and New, 2007; Elith et al, 2006; Le Lay et al., 2010; Pearsons et al., 2002; Thuiller, 2004), to improve the final product.

On this subject see Chapter 5:

- "Carone M.T., Simoniello T., Cianfrani, C., Loy A., Guisan A., Carranza, M.L.: Habitat suitability for the endangered species Eurasian otter in Southern Italian river basins. A multi-temporal approach".

Since all the results provided by the analyses described so far can be produced as maps, the use of GIS technologies and remote sensing data represent the most appropriate tools for the various steps implementation. In particular, remote sensing data allows for a satisfactory discriminating ability, coherent with the purposes of the approach, and provide the possibility to easily repeat the modelling in time (map update) and to test the territory changes over large areas at relatively low cost (Simoniello et al., 2004; Carone et al., 2009).

For the present study we chose to produce land-cover maps derived from a fuzzy supervised classification (Schowengerdt, 2007) of a high resolution satellite image acquired by the Landsat-TM sensor, taking into account that this sensor offers a good compromise between the area coverage (~180 square kilometers) and the spatial resolution (30 m), and proved to be useful for the land cover characterization at basin scale in the study area (Carone et al., 2009; Liberti et al., 2009).

3) Final remarks

The obtained results demonstrated that distribution models for a key aquatic species can be considered as robust indicators of the fluvial health status. In particular the choice of the European otter as target species correctly capture the complexities of the ecosystem, which is crucial for defining indicators aiming to monitoring purposes, as underlined by Dale & Beyeler (2001).

The integration of Habitat Suitability models with information on Fluvial Functionality and its successive combination with parameters of fragmentation, effectively synthesized the relation between the functionality of the water courses, the landscape structure and the distribution of the studied key species. This integration represents a helpful tool for understanding the effect of anthropogenic pressures on the river functionality. Furthermore this approach resulted very effective for the identification of the most vulnerable fluvial tracts, allowing for a correct planning of the necessary restoration interventions. Since the prioritization of fluvial conservation interventions represents a crucial challenge for defining a sustainable environmental management (see e.g. Mainstone, 2010; Thompson, 2010; Suding, 2011), the proposed approach provides a basis for an interesting perspective that should be further explored.

The multi-temporal analysis of Otter distribution evidenced that the improvement of Otter population is coherent with the recovering of natural land covers on the studied territory, as indicated, but not tested by precedent studies (see e.g. Remonti et al., 2008; Loy et al., 2009; Loy et al., 2010). In particular the results confirm the essential role of riparian vegetation along the river courses (Loy et al, 2010) and the widespread natural inter-catchment matrix (Carranza et al, 2012) for the Otter survival and expansion.

Finally, considering that, at present, the conservation of biodiversity represents an urgent challenge (see e.g. Rands et al., 2010; European Directive 92/43/CE, European Directive 97/62/CE; European Directive 2006/105/CE; www.iucnredlist.org) and a correct management of endangered species is the most effective way for preserving a satisfactory biodiversity level (see e.g. Lopez-Toledo et al., 2011; Scott et al., 2010; Strayer & Dudgeon, 2010), the proposed approach represents a concrete answer, among the others, for dealing with the conservation of river's biodiversity and function.

4) Strengths of the approach and elements of novelty compared to existing literature

- <u>HSM on single data and multi-temporal data</u>: we built two HSM for two data (1985 and 2006) based on a multi-temporal dataset (otter surveys and land cover data), we assessed, then, the relation between landscape change, suitable habitat distribution and real presence data. While the predictions of species expansion on virtual scenario are widely challenged (see e.g. Rushton et al., 2004; Elith & Leathwick, 2009), model validations based on real multi-temporal data have not been addressed so far.
- <u>Test region in a core area</u>: the approach has been tested in the Italian Otter core area. This aspect is particularly important because 1) generally core areas represent key source regions for the conservation of remnant populations; 2) for the studied species such areas represents its only possibility to recover and spread again (in Italy reintroductions are not possible, since the genetic pool of the populations breaded in captivity include elements from areas abroad the Italian territory); 3) the natural recover of the species in Italy starts from the core areas and is actually going on in their borders (Loy, 2009);
- <u>Single and Multi-models approach</u>: the analysis utilized both a single-model (ENFA; Hirzel, 2002) based on presence data, and a multi-model approach (BIOMOD; Thuiller, 2009), based on presence/pseudo-absence data. The results will give the possibility to make, as a further exploration, a comparison between the different applied methods, which have great differences on hardware and time consuming. Such a comparison, unlike others realized among ENFA and different modelling approaches (see e.g. Tsoar et al., 2007), has been rarely addressed (Elith & Leathwick, 2009);

- Multi-layered approach: the method takes into account the multi-layered structure of the studied system and integrate indicators referring to each existing layer. An integration of general indicators relying on Fluvial Functionality and Habitat Suitability is still unexplored;
- Test with Landscape Metrics: the landscape ecology analyses give the opportunity to point out the main criticalities on the structure of the studied landscapes (e.g. the eventual increasing of fragmentation). If the use of Landscape metrics (McGarigal et al., 2002) for the analysis of environmental mosaic structure is widely addressed, their application for the assessment of other approaches (here the assessment of the proposed approach) is still quite unexplored;
- Use of Satellite data: the elaboration of the environmental data concerning land use has been realized by means of high resolution satellite data; this choice provides the possibility to easily repeat the modelling in time (HS map update), testing the territory changes over large areas at relatively low cost.

5) Forthcoming perspectives

The proposed approach can be further exploited taking into account the following :

1) *Habitat Suitability (HS) Analyses*
   a. For building HSM of a core area also real absence data should be taken into account in order to better describe the realized spatial niche;
   b. the examination of other environmental variables, not available at the moment (e.g. fish diversity and abundance, surface runoff), should be considered in order to improve the method;
   c. by considering the existing consistent difference between ENFA and BIOMOD time and hardware commitment, a focused comparison of their results should provide a helpful basis for choosing the right modelling tool in cases of specific requested analysis time or held technical equipment.
2) *Integration between HS and Fluvial Functionality (FF) analyses*
   a. The application of the HS and FF integration at fluvial basins showing more consistent anthropogenic influences would represent a further test on its reliability and then, an eventual strengthening of its exportability and efficacy.
3) *Landscape Ecology analyses*

a. Further assessments by means of the application of Landscape Metrics can be provided for the additional application of HS and FF integration;
b. Landscape metrics analyses should be realized both on the studied landscapes and on the obtained HS maps, with the aim to point out the existing links between these two structures.

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CHAPTER 1

INDIVIDUATION OF FLUVIAL AREAS NEEDING RESTORATION THROUGH THE ANALYSIS OF A TARGET SPECIES, THE EURASIAN OTTER (LUTRA LUTRA L.)

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Abstract: Fluvial habitats are key ecosystems in maintaining landscape biodiversity for their role as corridors and filtering organisms. Since they are functionally linked to the surrounding territory, the health of riverine fauna populations depends on river/landscape equilibrium. Thus, due to the anthropic pressures that in last decades have damaged many fluvial environments, the identifying of scientifically based management strategies devoted to restore the river environmental sustainability has become urgent. Efficient restoration strategies may be valuable performed by analyzing the environmental needs of target species whose survival depends on the entire basin conservation status, e.g. the Eurasian otter (Lutra lutra). In this work we use a Habitat Suitability model (Ecological Niche Factor Analysis) for the Otter to evaluate the river basin functionality and to identify sectors needing restoration measures. The input data have been land covers (from LANDSAT-TM images), a DEM and a derived SLOPE map; the model was performed in the Otter core area of its Italian range, within a riparian buffer of 300 m, producing a HS final map, categorized into three levels (unsuitable, suitable, optimal). The unsuitable areas represent unbalanced sites in term of ecological equilibrium for Otter habitats and can be used to locate restoration interventions having a general character as well as to refine the analysis for specific restoration activities. In conclusion, the combined use of HS models/satellite data represents a helpful support for management policies efficiently suitable to improve the whole river functionality and to recreate balanced habitats for an endangered species as the Eurasian otter.

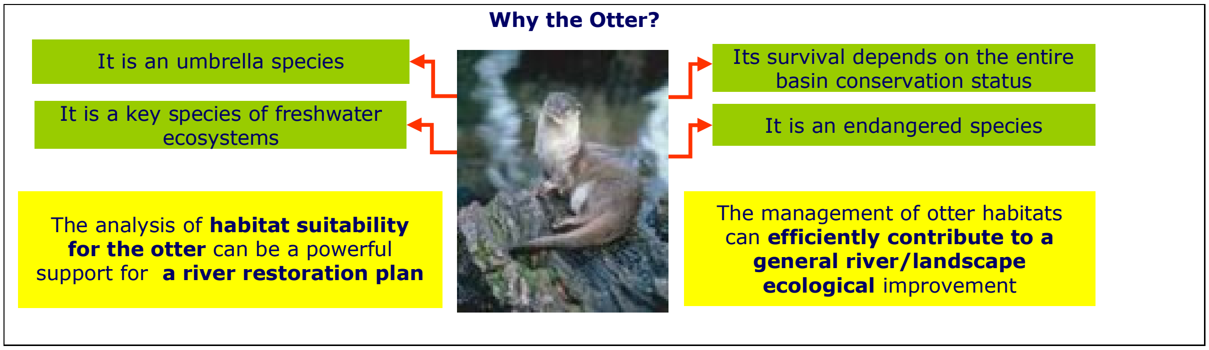
Keywords: freshwater habitats, Eurasian otter, appropriate restoration objectives.

Introduction

Among wetlands, fluvial habitats represent key ecosystems for the general balance of landscapes: they contribute to maintain a high level of biodiversity, act as environmental corridors, are depurating organisms with many functional links with the surrounding territory.

In the last decades such a role has been severely deteriorated because of anthropic pressures, thus the need to restore those crucial environments has become urgent. By considering that there are several aspects involved in preserving a satisfactory river ecological equilibrium, a correct individuation of fluvial criticalities indicators aiming at restoration is not easy.

A significant help can be taken by analyzing key species whose survival is strictly linked to the various characteristics of river ecosystems. In this paper we present a study that analyzes the environmental needs of a target species, the Eurasian otter (*Lutra lutra*) (Figure 1), in order to identify scientifically based management strategies mainly devoted to fluvial habitat restoration.



Why the Otter?

It is an umbrella species

It is a key species of freshwater ecosystems

Its survival depends on the entire basin conservation status

It is an endangered species

The analysis of **habitat suitability for the otter** can be a powerful support for **a river restoration plan**

The management of otter habitats can **efficiently contribute to a general river/landscape ecological** improvement

Figure 1. Relevant traits of the Eurasian Otter (*Lutra lutra*) for river management tools.

Materials and methods

The studied territory is represented by the main axis of the five principal rivers of the Basilicata region (Southern Italy) and by their tributaries showing Otter presences, Figure 2; such an area represents a consistent portion of the Italian Otter core area.

In order to identify the suitable/unsuitable sites for the Otter presence, we applied on this study area a Habitat Suitability Model, the Ecological Niche Factor Analysis (ENFA, Hirzel et al., 2002). This model, developed on the basis of the Hutchinson (1957) ecological niche concept, compares in a multidimensional space the presence distribution of the studied species with a data set of environmental variables describing the whole study area.

The input data for the model are represented by topographic data, derived from a DEM of the Basilicata Region, and land covers data, derived from a supervised classification of a satellite image, acquired by the sensor Landsat-TM. Satellite data proved to be very useful to evaluate the river basin status (Carone et. al, 2009), in such a context they were selected in order to reduce the cartography elaboration time, improving the performance of the chosen approach, since only aerial photos have been used for such purposes so far. The acquisition time of the satellite image (19/07/2006) was chosen consistently with the monitoring period for the Otter presences (2002-2006). In particular, the use of a summer image improved the identification of the different land cover classes present over the territory, particularly for shrubs and sclerophyllous vegetation. On the whole, sixteen classes plus water bodies were classified.

Figure 2. Area of interest; the studied rivers flow into the Ionian Sea and are: Bradano, Basento, Cavone, Agri and Sinni, from North to South respectively.

Since the model requires only continuous input, topographic data could be used directly, where the land cover data needed to be transformed in frequency maps. For topography, information on slope and convexity were also considered in addition to the altitude. In order to consider a large area close to the rivers, all the investigations were extended within a fluvial buffer of 300 mt.

The model predictive accuracy was calculated by means of the Boyce index (Boyce et al., 2002), which ranges between 0 and 1. The final product is a Habitat Suitability Map for the Otter, categorized into three levels (unsuitable, suitable, and optimal), which, in our case, represent sites from a high need of prioritization, in term of ecological restoration intervention, to a low need of prioritization.

A general scheme of the approach is reported in Figure 3.

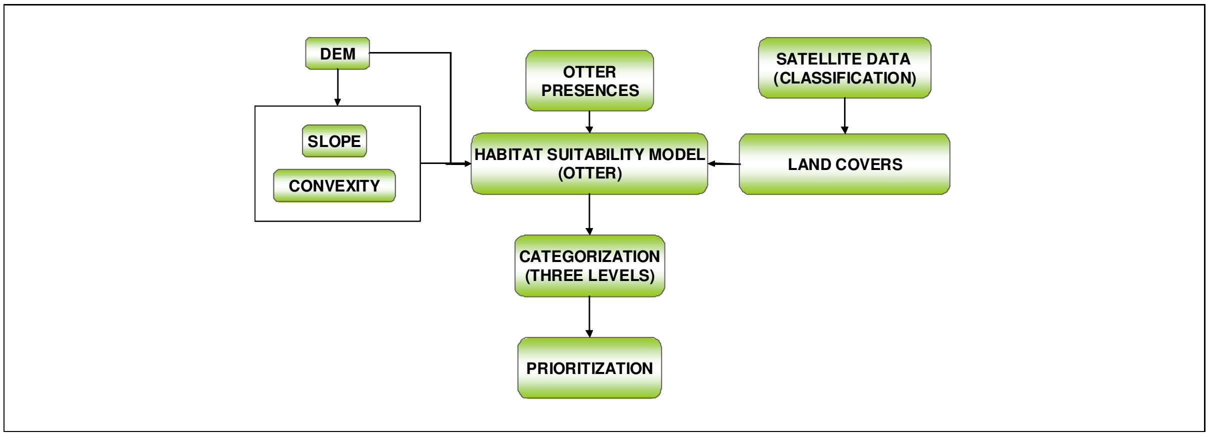


Figure 3. Scheme of the utilized approach.

Results and discussion

Figure 4a summarizes results obtained from the application of the ENFA Habitat Suitability Model; a zoom in the map for the Sinni River is shown in figure 4b. The calculated Boyce index value for the elaborated suitability map was equal to 0.80.

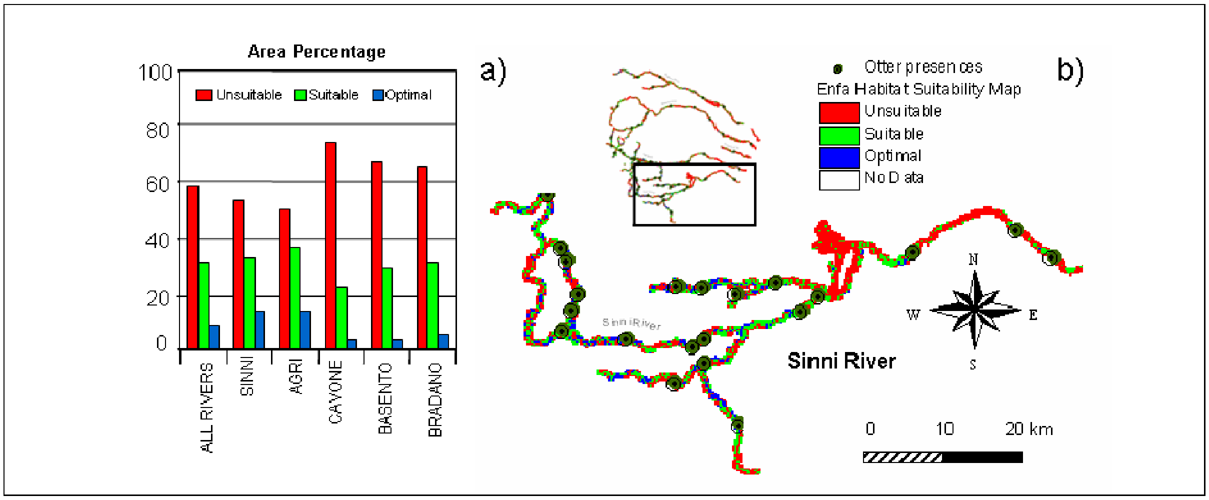
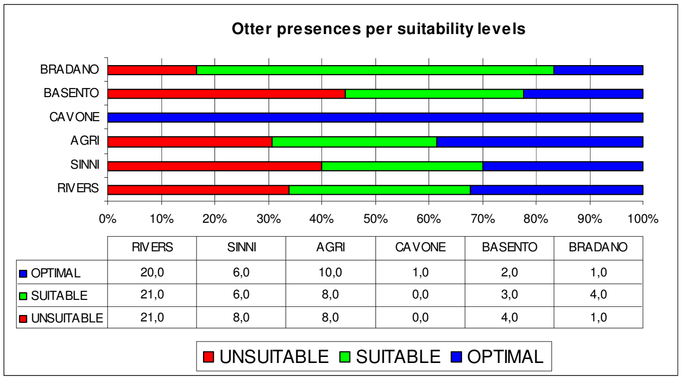


Figure 4. Distribution of the categorized areas for the investigated rivers (a) and a detail of the Habitat Suitability Map for the Otter corresponding to the black box: Sinni River (b).

By observing the distributions, it is possible to see as all rivers do not overcome the 50% of suitable/optimal areas. Optimal areas, in particular, have very low values, except for Agri and Sinni Rivers, which, in general, show the highest extension of both suitable and optimal sites. This result is coherent with the general characteristics of the studied riverine landscapes. In fact, the anthropogenic pressures are higher for the Bradano and Basento rivers and lower for the Sinni River, whose basin is partially included in the territory of a National Park; the Agri watershed presents an intermediate condition.

By considering the distribution of the Otter occurrence is evident that the species is more or less homogeneously dispersed among the three suitability levels (Figure 5); only for Bradano River it is possible to observe more presences in suitable sites. This condition however, can be considered predictable, in case of few presences, as for the Bradano basin, because of the low level of inter-individual competition. On the other hand, by observing the structure of suitable/unsuitable patches distribution, we noted an evident fragmentation of such sites.



	RIVERS	SINNI	AGRI	CAVONE	BASENTO	BRADANO
🟦 OPTIMAL	20,0	6,0	10,0	1,0	2,0	1,0
🟩 SUITABLE	21,0	6,0	8,0	0,0	3,0	4,0
🟥 UNSUITABLE	21,0	8,0	8,0	0,0	4,0	1,0

Figure 5. Otter occurrence per suitability level.

This structure is confirmed by the fact that the presence sites located within unsuitable patches are generally very close to suitable/optimal areas, or included in them, suggesting an influence of those last on the occurrence distribution within unfavourable sites and a general instability of the Otter habitats.

Conclusions

From the obtained results it is possible to consider that the Otter habitat in the study area shows a high level of fragmentation, as testified by the Otter presence in unsuitable sites surrounded by suitable/optimal sites. Such a fragmentation regarding suitable areas can be considered a critical stressor for the maintaining of the Otter populations mainly in view of surface covered by those favourable sites, which do not overcome the half of the studied area. By taking into account that the Eurasian otter is a key species linked to all the different aspects of a watershed, and based on the assumption that unfavourable habitats for such species are ecologically unbalanced sites for the fluvial ecosystem we can use the obtained information for suggesting restoration ecology strategies, which can be efficient for the whole river functioning. The categorization of the Habitat Suitability Map for the Otter, in particular, allows for a prioritization of eventual river restoration interventions giving the outmost importance to the unsuitable river stretches showing Otter occurrences. Furthermore, in case of planned interventions, those can be also used for refining the study in view of other more specific restoration activities.

Finally, the combined use of HS models/satellite data gives the possibility to repeat in time the analysis, over large areas, allowing for an efficient monitoring of realized interventions. Thus it represents a helpful support for management policies suitable to improve the whole river functionality and to recreate balanced habitats for an endangered species as the Eurasian otter.

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CHAPTER 2

Integration of Ecological Niche Factor Analysis and Fluvial Functionality in vulnerability assessment for supporting restoration strategies in fluvial habitats

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Abstract

In this paper we propose an integrated approach for the investigation of fluvial vulnerability. We used general indicators linked to different layers of the river system combining analyses of environmental suitability for the Eurasian otter, *Lutra lutra L.*, a keystone species whose survival depends on the entire basins conservation status, with field data on fluvial functionality.

The investigation was performed in a portion of the Agri river basin, located in the Otter core area of Southern Italy (Basilicata region). The test area was chosen for its peculiarities in term of anthropogenic pressures and environmental characteristics. The Habitat Suitability model for the Otter was developed through the Ecological Niche Factor Analysis (ENFA). The analysis of fluvial functionality was carried out through the fieldwork application of the Italian Fluvial Functionality Index (IFF). The final result is represented by a map that integrates the information obtained from the two fluvial and watershed data sets and categorizes the river buffer into three levels of vulnerability. The elaborated suitability, functionality and vulnerability maps were further analyzed by means of Landscape Metrics giving information on fragmentation. Such pattern analysis underlined that, even if the disjointed habitat suitability and fluvial functionality levels are not proportionally linked to the metric values, the integrated vulnerability levels increase from the low to the high values with the fragmentation strength providing also useful ecological information on landscape pattern arrangements. The approach contribute to an efficient characterization of the fluvial vulnerability by summarizing the ecological criticalities related to the different layers. The provided vulnerability levels allow for prioritizing the river segments in term of intervention needs. The method, then, may be considered a robust scientific tool for both management and restoration activities involving fluvial habitats.

Key Words: ecological vulnerability, habitat suitability models, fluvial functionality, satellite images, comprehensive indicators, river management.

1. Introduction

For the general balance of landscapes a key role is played by fluvial habitats; they contribute to maintain a high level of biodiversity, act as environmental corridors, and are depurating organism with many functional links with the surrounding territory (Brunet and Astin, 1997; He et al., 2000; Ingegnoli, 2002; Knutson and Klaas, 1998; Naiman et al., 1993; Sponseller et al., 2001; Stewart et al., 2001; Ward et al., 2002).

In order to maintain such a crucial role, the Water Framework Directive 60/2000/CE establishes that the European water bodies have to recover a satisfactory functional level by 2015. The environmental objectives of this Directive are the protection, the improvement and the restoration of water bodies by applying specifically devoted monitoring campaigns and also by performing management plan at a river basin scale.

Considering the several aspects involved in preserving a satisfactory river ecological equilibrium, a correct identification of fluvial criticalities indicators is very difficult.

A significant contribution can be provided by the analysis of ecological requirements of wide-ranging species whose survival is strictly linked to the various characteristics of the river ecosystems. From this point of view, the Eurasian otter (*Lutra lutra* L.) can be considered an ideal target species. This medium sized carnivore is strictly dependent upon pristine freshwater ecosystems, relying on the river for its feeding needs and on the riparian vegetation for its resting and reproductive activities (Chanin, 2003; Kruuk, 2006). Thus, studies based on the analyses of the habitat suitability for this species may be very helpful for identifying scientifically based management strategies mainly devoted to fluvial habitat restoration.

Such an assumption can be particularly true where the Otter shows populations in territories characterized by high anthropogenic pressures as it is the case of Italian river basins. In Italy, in fact, the general deterioration of riverine habitats seems to have heavily affected Otter populations, and now the species survives only southward, with an outlying area in Molise and a core area in Campania, Basilicata, Calabria and Apulia regions (Loy et al., 2010).

The utilization of habitat suitability models for such semi-aquatic species can represents a good strategy to assess the environmental quality at watershed scale (broad scale). Since the fluvial basin is a multilayered system in which the river shows many fine-scale functional links with its surrounding territory, information at a more detailed scale are also necessary. For this reason, in order to include crucial information at river ecosystem scale (fine scale) and to obtain an efficient characterization of the environmental criticalities of such ecosystems, also data concerning fluvial functionality are mandatory.

The fluvial functionality can be described as the well working of the river system, and considers both the trophic relationships between the living organisms and the non-trophic fluvial contributions to the landscape, such as environmental biodiversity, solid transport loads, etc. (Vannote et al., 1980).

Since analyses taking into account the characteristics of a fluvial system at these different scales and from these points of view have not been realized so far, in this work we tried to combine information derived from Habitat Suitability (HS, hereafter) data for a keystone species (the Otter) with Fluvial Functionality (FF, hereafter) data. The aim of such an integration is to provide a vulnerability assessment (VU, hereafter) of the river system in order to identify the most critical fluvial segments and to suggest priority sites for restoration strategies.

Absence data can be often misleading when analyzing HS, therefore we choose to use the Ecological Niche Factor Analysis (ENFA) model that demonstrated to be robust also in case of database providing only presence data (Cianfrani et al., 2010; Hirzel et al., 2002). For the analysis of the FF, which represents the river ecological equilibrium at ecosystem scale, we choose to apply the Italian Fluvial Functionality Index (IFF) (Siligardi et al., 2003a). This index is widely used for fluvial functionality evaluation both for research studies and for operative assessments (see e.g. Comiti et al., 2009; Mazza et al., 2011; Renai et al., 2006; Siligardi et al., 2003b; Siligardi and Cappelletti, 2006).

Since fragmentation processes heavily influence the ecological equilibrium of landscapes as well as ecosystems and their biological communities (see e.g. Lindenmayer and Fischer, 2006 and references therein), a fragmentation analysis based on a specific set of landscape metrics (McGarigal et al., 2002) can provide precious information on the ability of an indicator to describe the ecosystem vulnerability related to the ecological fragmentation (e.g. Colson et al., 2011; Leitão and Ahern, 2002; Peng et al., 2010).

The work received a further strength by the use of satellite data for the elaboration of the environmental variables related to land use. Satellites allow for gathering information on large areas at relatively low costs. In addition, by exploiting the update frequency (e.g., bi-weekly, monthly) of high-resolution satellite data, it is possible to support the post-intervention monitoring for evaluating the effectiveness and the evolution of implemented activities.

The article is structures as follows: first, the study area (2.1) and the methods adopted to implement the proposed integrated approach (2.2-2.5) are presented, jointly with the metrics selected for testing the capability of the methods to represent fragmentation processes (2.6). Then, the results of the separated components at broad and fine scale (3.1-3.2) are shown, followed by the results of data integration and vulnerability assessment (3.3). This section is closed by the fragmentation analysis tests (3.4). Finally are reported the conclusions, from both a practical and an academic point of view, with some suggestions for exporting and testing the approach in different fluvial environments.

2. Methods

2.1 The study area

The study has been realized in the Basilicata County (Southern Italy), which includes most of the Otter Italian core area (Figure 1). The region is characterized by a very high differentiation of its landscapes, with wide mountainous and hilly areas showing different characteristic in terms of anthropogenic pressures. Such a differentiation is reflected on the structure of the five main rivers that were considered for the implementation of the HS model. All the five rivers show a hydraulic regime primarily torrential, which strongly characterizes the fluvial morphology showing large riverbed in the level areas.

The major anthropogenic influence, with a scarce presence of forest vegetation and a diffused coverage of cultivations, characterizes Cavone and Bradano Rivers and the medium areas of Basento River. The most natural structure is present along the Sinni River, whereas the Agri River is characterized by a mixed alternation of natural portions, included in a National Park, and areas with important anthropogenic pressures: long sections of the river main axis are managed in concrete, and an important industrial site related to an oil-drilling activity is also present.

On the basis of this particular landscape structure the High Agri sub-basin (blue hatched area in figure 1) was chosen for assessing and testing the proposed HS-FF integrated analysis.

Figure 1 about here

2.2 The Integrated Approach

In order to obtain synthetic information on the vulnerability of the river-watershed multilayered system, the proposed approach integrates habitat suitability (HS) and fluvial functionality (FF) analyses following the flowchart depicted in Figure 2. The HS analysis discriminates the territory in term of general ecological equilibrium (broad scale) on the basis of the existing links between a wide-ranging species (the Otter) and its habitat. The FF analysis provides information on the environmental sensitivity of fluvial ecosystems (fine scale). Results obtained from HS and FF analyses are reclassified into the same number of classes to elaborate the final vulnerability (VU) map. The different levels of vulnerability represent a different priority degree in term of intervention need, i.e. areas showing high vulnerability related to poor habitat suitability and fluvial functionality conditions require more urgent interventions compared to less vulnerable areas.

Figure 2 about here

2.3 Analysis of Habitat Suitability (HS)

The HS analysis was implemented in order to discriminate the territory in areas showing good environmental characteristics (optimal/suitable) for the studied species, i.e. territory portions in which Otter can live and improve its population, from those having adverse characteristics (unsuitable). For the identification of suitable/unsuitable sites for the Otter presence was applied the Ecological Niche Factor Analysis (ENFA, Hirzel et al., 2002).

The ENFA model, developed on the basis of the Hutchinson (1957) ecological niche concept, compares in a multidimensional space the presence distribution of a species with a data set of environmental variables describing the whole study area. The method demonstrated to be robust for predicting Otter distribution using only presence data (Cianfrani et al., 2010), as it is the case of the present work. For the implementation of the ENFA model, the software Biomapper ver. 4.0.6.370 (http://www.unil.ch/biomapper) was adopted.

2.3.1 Ecological Niche Factor Analysis (ENFA)

The ENFA model quantifies the species' ecological niche by comparing the environmental characteristics of the sites where it is present with the environmental characteristics of the whole study area (Hirzel et al., 2002). The set of the elaborated environmental variables jointly with the Otter presence distribution were used to implement the model for the study area.

The predicting power of the model was evaluated using the index proposed by Boyce et al. (2002) and modified (continuous index) by Hirzel et al. (2006). The index measures, through a Spearman rank correlation, the monotonicity of the function that gives the information on the accuracy of the model. Such a function (F) is built by partitioning the HS range into b bins (classes) and evaluating for each bin (i) the Predicted/Expected ratio:

$$F_i = P_i/E_i$$

where, P_i is the percentage of predicted validation points for a given i bin, and E_i is the expected percentage of validation points estimated as the proportion of the area corresponding to the considered i bin on the total area of the HS map. Since low suitability classes should contain fewer validation presences than expected ($F<1$), whereas high suitability classes should have a higher number ($F>1$), a good model is expected to show a monotonically increasing curve, i.e. the function increases as suitability increases ($F = 1$ testify a completely random map).

The Boyce index measures just such a monotonic increase ranging between 0 (null predictive power) and 1 (best predictive power).

By applying a k-fold cross-validation, k estimates of the Boyce index are produced, allowing the assessment of its central tendency and variance. For our implementation k=4, therefore the index was estimated on 25% samples randomly distributed four times.

The evaluation of the relevant bin limits allows for the reclassification of the HS map on different levels; in this case the final map was categorized into three suitability levels: low, medium and high suitable. For further information on the subject see Boyce et al. (2002) and Hirzel et al. (2006) and the manual of the software Biomapper (http://www.unil.ch/biomapper).

2.3.2 The Input Data for the ENFA model

The input data for the application of the Ecological Niche Factor Analysis were represented by a dataset of Otter occurrences and a set of Environmental Variables (EV) related to land use and morphological characteristics of the area.

The Otter occurrences were collected during a standard survey covering the period 2002-2006 (Panzacchi et al., 2010).

The EV concerning the land use were derived from a satellite image acquired by the Landsat-TM sensor. The choice of a Landsat-TM satellite image takes into account that this sensor provides a good compromise between the area coverage (~180 square kilometers) and the spatial resolution (30 m), and proved to be useful for land cover characterization at basin scale in the study area (Carone et al., 2009; Liberti et al., 2009). The image acquisition time (19/07/2006) was selected consistently with the monitoring period of Otter presences. A fuzzy supervised classification (Schowengerdt, 2007), was performed to get the land use map depicted in Figure 3.

Figure 3 about here

As it is possible to observe, in the studied territory, the agricultural land covers increase from south to north. The whole landscape matrix gives indication of strong anthropogenic influences, which seem more evident in the north-eastern areas and close to the coast. In these areas, an inappropriate land management coupled with adverse climatic conditions largely reduced the ecosystem resilience (Simoniello et al., 2008). The most natural basins, with a larger extension of shrubs and forests, are the Sinni and Agri watersheds.

From the obtained seventeen classes, we chose the natural vegetated land cover types located close to the main river axes. The land cover types selected as proxies for the description of main habitat types that might affect Otter presence/absence (Cianfrani et al., 2010; Loy et al., 2009) were the following: water bodies, natural grasslands, sparsely vegetated areas, shrubs, sclerophyllous, transitional woodland-shrubs, broad-leaved forests, riparian vegetation, annual and mixed cultivations, riverbeds.

For the implementation in the ENFA model, it is required the use of continuous data. Therefore, we transformed the categorical information of the land cover map into continuous variables. We first transformed each selected land cover type into a Boolean map of presence/absence (value per pixel=1 for the presence and value=0 for the absence of a given land cover type, respectively).

For each Boolean map, we derived a frequency map for the whole area by counting the number of pixels with value equal to 1 within a considered radius (300m).

The EV related to the morphological characteristics of the area were derived from a DEM (Digital Elevation Model) of the Basilicata region having a resolution of 20x20 m. In order to overlay all the EV maps, the DEM was resampled at the same Landsat pixel resolution and then used to elaborate the Slope, Aspect, and Convexity variables. Since such data are in continuous form, they do not need transformation.

All the maps were lastly clipped in a fluvial buffer of 300 m, coherent with the ecological behaviour of the Otter, which is rarely found far from water, and with the resolution of the utilized satellite sensor. A scheme of the whole process for the EV preparation is reported in Figure 4.

Figure 4 about here

2.4 Analysis of Fluvial Functionality (FF)

The information concerning the FF for the interested sub-basin were obtained by applying the Italian Fluvial Functionality Index (IFF) (Siligardi at al., 2000; Siligardi et al., 2003a) during a field campaign performed in Summer 2003.

The index is derived from the RCE-I (Riparian Channel Environmental Inventory) (Petersen et al., 1987), which was specifically modified to be coherent with the Italian river characteristics. It has been officially adopted by the National Environmental Protection Agency since 2000; indeed, it demonstrated to be more suitable than other indices, such as Buffer Strip Index and Wild State Index, for the functionality evaluation of Italian rivers (e.g., Balestrini et al., 2004).

The IFF index provides information on the comprehensive status of the FF and the possible estrangements from an ideal condition of maximum functionality; it is suitable for all river typologies, excluded transitional areas such as river mouths and steady waters, and it was adopted for different environmental studies (Comiti et al., 2009; Mazza et al., 2011; Siligardi and Cappelletti, 2006).

Operatively, the index is obtained by walking along the main river axis and filling a Standard Data Form organized in 14 questions regarding various aspects of the fluvial habitat (e.g. land use, buffer of riparian vegetation, biological characteristics, hydrological and hydraulic characteristics). For each homogeneous river segment a different form is completed.

The questions included in the data form can be summarized, on the basis of their different ecological mean, in the following four complexes:

- Questions 1–4: dimension and typology of riparian vegetation buffer, land use of the nearby landscape;
- Questions 5–6: hydrological and hydraulic characteristics of a stream cross-section;
- Questions 7–11: morphological structure of the stream;
- Questions 12–14: biological characteristics of the stream (presence of *periphyton* and organic matter, structure of *macrobenthos* populations).

The detailed questions of the IFF Standard Data Form are reported in Figure 5. As it possible to notice, for each considered ecological aspect the score have to be selected among the given 4 values representing different levels of functionality. The differences in scores for the questions are linked to the different importance that each specific topic has for the global fluvial functionality.

Figure 5 about here

The sum of all that scores indicates the total stream functionality value, which ranges from 14 to 300. To such a total stream value, the functionality level is associated from the functionality classification that ranges from Very Good (I class) to Very Poor (V class) (Figure 6). Intermediate classes are also admitted in order to better graduate the transition from one level to another.

The classification provided by the protocol also includes different colours and symbols for a user-friendly mapping of IFF. By considering that the IFF information are carried out at the scale of the data collector, it can be mapped at various scales, from very fine (e.g. 1:10.000 or less) to coarse grain (e.g. 1:50.000) (Siligardi et al., 2003a).

Figure 6 about here

Finally, to make possible the overlap and the integration of FF data with the HS map in a GIS environment, the IFF was rasterized over the fluvial buffer at the same resolution of suitability model output (30x30 m); and then it was reclassified into three functionality levels by taking into account the score distribution of IFF classes as follows: low (14-120: from very poor to mediocre-poor), medium (121-200: from mediocre to mediocre-good), and high (201-300: from good to very good).

2.5 Integration of HS and FF levels into the analysis of Vulnerability (VU)

The analysis of vulnerability was implemented on the upper portion of the Agri watershed by integrating, in a GIS environment, the results provided by the ENFA model (HS map) and by the IFF field survey (FF map).

Since HS and FF maps provide three levels of environmental quality specifically linked to the suitability and functionality, we can consider each of them as a level of ecological equilibrium: for instance, to low levels of HS and FF, an equal low level of ecological equilibrium can be associated.

Therefore, each of these levels represents a different importance in term of ecological vulnerability: the lower the HS/FF value, the higher the ecological vulnerability.

On the basis of such a consideration, HS and FF data were combined to obtain the final vulnerability (VU) map by assigning more importance to the level showing the higher ecological vulnerability, as follows:

- we assigned to a low ecological vulnerability level all the segments where both HS and FF show a high value;
- we assigned to a medium ecological vulnerability level all the segments where both HS and FF show a medium value, or at least one of them;
- we assigned to a high ecological vulnerability level all the segments where both HS and FF show a low value, or at least one of them.

Since a high ecological vulnerability underlines the need of management attention, each of the provided VU levels gives a different priority in term of necessity (high/medium/low) for conservation or re-naturalization actions. From the point of view of ecological restoration/management, then, such VU levels can be considered as ”priority levels” in term of intervention need, i.e. where both FF and HS have the lowest values, there is the highest vulnerability, and then the utmost priority of intervention, and vice-versa.

2.6 Fragmentation Analysis

Since fragmentation represent a crucial aspect for both the survival of Otter populations and the natural equilibrium of fluvial habitats, a specific set of Landscape Metrics was applied to each of the three elaborated categorical maps (HS, FF and VU) to assess their capability in describing such process.

The chosen set concerns different features of fragmentation by taking into account: the patch contagion/interdispersion, i.e the spatial aggregation and patch/class type intermixing, (CONTAGION and DIVISION); the class diversity, i.e. the richness and evenness of patch types (SHDI and SHEI); and the area/density characteristics of patches (NP) (McGarigal et al., 2002). Details on the formulas of the selected metrics and on their behaviour are shown in Table 1.

Such metrics were calculated on land covers included within the sub-landscapes that the different functionality, suitability and vulnerability levels delineate.

In order to identify the relationships between the fragmentation indexes and the disturbance pressure, the metrics were calculated at landscape level, considered as more appropriate for the purposes of the work.

For such an identification, we are interested to explore the proportionality of the HS, FF, or VU levels with the continuous increase or decrease of the corresponding landscape metric values (e.g., moving from low to high HS values the corresponding metric values should be always increasing or decreasing).

Although there is an open debate on the significance of landscape metrics in absolute terms (e.g. Dramstad et al., 2002), their representativeness in term of relative values is widely accepted also in very recent works (e.g. Dramstad et al., 2002; Peng et al., 2010; Renetzeder et al., 2010; Zhou et al., 2011). Therefore, being interested in relative increments/decrements of metrics with the different levels, the adopted landscape analysis represents more than a qualified and effective tool for assessing the performances of the elaborated categorical maps.

The values derived from each level of the three analyzed sub-landscapes, represented by the HS, FF, and VU maps, were finally compared.

Table 1 about here

3. Results and Discussion

3.1 Analysis of Habitat Suitability (HS)

The ENFA model implemented by including both topographic characteristics and land cover information provided a good predictive power of HS respect to the Otter presence (Boyce index = 0.801 ± 0.039).

The final HS map obtained by segmenting the suitability values (ranging from 0 to 1) into three levels is shown in Figure 7 (top).

Areas having an optimal suitability level are quite few and scattered on the HS map; larger clusters are present on the south-west part of the region (along Agri and Sinni) and at a source segment of Bradano River. On the whole, they cover about 10% of the investigated basins and the percentage is particularly low for Cavone, Basento and Bradano Rivers (Figure 7, bottom). The eastern side is mainly characterized by unsuitable areas intermixed with clusters of suitable level. In such eastern areas there is a larger presence of cultivations (see Figure 3) that represent the 51% of unsuitable sites; whereas the optimal sites are mainly found in correspondence of more developed vegetation (broad-leaved forest and transitional woodland-shrubs) covering more than 50% of the total area with optimal habitat (Table 2).

In general, the percentage of the area per suitability level decreases going from the unsuitable to the optimal level (Figure 7, bottom). For each river, suitable/optimal areas generally do not overcome the 50%; Agri and Sinni Rivers show the highest extension of both suitable and optimal sites.

Figure 7 about here

Table 2 about here

The majority of the observed Otter presence is mainly located in the south-western part of the area just along the Agri and Sinni Rivers. For such rivers, the total Otter presences are 26 and 20, respectively (Figure 8, top) and the distribution per suitability level show the highest values in optimal sites (38% and 30% respectively), with the exception of Cavone River, where the only one observed presence falls just in an area characterized by optimal habitat.

The Otter distribution per HS level also highlights a quite high percentage of presence in unsuitable sites for all rivers (corresponding to 34% of the total presence). Generally, the lower the total presences, the lower the relative number of presences in unsuitable sites. By excluding the shorter river (Cavone) with a single observation, Bradano shows the lowest percentage of presence in unsuitable sites and the highest value in the optimal-suitable ones; in particular, the presence in suitable areas is higher than in those identified as optimal.

Such a characterization of presence distribution can suggest two main explanations. The first is the noticeable high fragmentation of optimal and suitable sites that can justify the Otter presences in clusters qualified as unsuitable; in fact, such sites have always little dimensions and often they are included in bigger suitable clusters, and the relative major importance of the suitable vs. the optimal sites. The second is related to the actual expansion of Otter population (Loy et al., 2009; Loy et al., 2010): when a species occupies a new territory it first colonizes sites having more suitable habitat and, then, it spreads in the less suitable ones (Begon et al., 1990). Both such explanations can justify the distribution of the Otter occurrences among the three identified suitability levels and in particular for Bradano, which shows a quite recent colonization since no presences were detected in the past (Loy and Racana, 1986). Therefore, it shows a major importance of suitable sites being the more accessible compared to the few and scattered optimal areas. Robitaille and Laurence (2002) also underline the importance of the landscape structure on the Otter distribution; in particular, the lack of territorial connectivity can have a fundamental role in Otter habitat recolonization (Remonti et al., 2008).

To better point out the peculiarity of Bradano colonization, we reported the presences in suitable sites versus the total presences for all the rivers (Figure 8, bottom). While the other rivers seem to be distributed on straight line, Bradano appears to diverge from the behavior of the other rivers.

Figure 8 about here

The scattered distribution of optimal and suitable levels is more evident by zooming on the HS map. At the scale of the High Agri sub-basin (Figure 9), it is possible to observe Otter occurrences in areas very close and with different suitability levels.

Such a configuration, jointly with the particularly heavy anthropogenic pressures characterizing this river sub-basin, represents the main reason for selecting the High Agri to test the proposed approach based on the integration of Habitat Suitability (HS) and Fluvial Functionality (FF) analyses (see Figure 2).

Figure 9 about here

3.2 Analysis of Fluvial Functionality (FF)

The findings of the 2003 IFF campaign on the selected test area (High Agri sub-basin) confirm a landscape configuration in which anthropogenic characteristics alternate natural structures. In particular, the analyses of the IFF standard data forms, filled walking along the river, shows large portions of the Agri main axis highly modified by anthropogenic activities and some others that preserve a structure with a high natural level.

By observing the obtained FF levels, the river segments showing the best class in functionality (I class, Very Good) are only two: the first one is located toward the river source, and the second is situated immediately before the only water body present in the area (Figure 10a).

The functionality strongly decreases along segments managed with concrete banks, in the central part of the basin, reaching the lowest level found (intermediate III-IV class, Mediocre-Poor). Notwithstanding, such a river sector, despite the strong alteration of its hydraulic section due to the concrete profiles, shows Otter presences thanks to a diffuse riparian vegetation recolonization into the riverbanks limits, which simulates a natural riverine structure. The presence/absence of riparian vegetation, in fact, is one of the most important factors in determining Otter presence/distribution (Loy et al., 2010 and references therein).

In the remnant river segments, accordingly with the surrounding landscape structure, the functionality keeps a medium level.

The IFF map reclassified into three levels for the data integration step is shown in Figure 10b.

Figure 10 about here

3.3 Data Integration and Vulnerability Analysis (VU)

The integration of habitat suitability and fluvial functionality was performed by applying the rule of major ecological vulnerability (see section 2.5) on the combination of HS (Figure 9) and FF (Figure 10b) maps.

The obtained vulnerability (VU) levels (Figure 11) take into account the information of the separated analyses at broad (HS) and fine (FF) scale and are able to summarize the ecological criticalness of both the layers (compare figures 9, 10b, and 11).

In particular, the VU map underlines the crucial vulnerability of river segments heavily affected by anthropogenic activities in the central part of the sub-basin, that shows a predominance of suitable areas for HS analysis, whereas it reach the lowest found functionality level for FF data.

Such segments, managed in concrete more than 20 years ago, were left undisturbed until now, leading to a riparian vegetation recolonization inside them. Such a recolonization favoured the actual Otter occurrence (HS results), but it represents a noteworthy condition standing for a remarkably unstable equilibrium. In fact, for reasons of channel hydraulic maintenance, the existing vegetated patches can be removed at any time, causing, thus, the complete disappearance of the suitable habitats and then a consequent decreasing of Otter presence. Conversely, in the upper part of the area (close to the river source), even if there is the best level of functionality, the VU map is able to highlight the territory portion unsuitable for Otter habitat by showing clusters with a high level of vulnerability.

Figure 11 about here

From an ecological management point of view, the VU levels provide information on the present criticalities giving a different priority in term of necessity (high/medium/low) for conservation or re-naturalization actions. Therefore, the areas showing a high vulnerability represent the areas where restoration activities have to be prioritized. This is particularly necessary if the high vulnerable areas are compacted and extended, such as in the case previously shown of concrete banks.

A medium level of vulnerability is well spread in the remnant part of the river, suggesting a less urgent intervention need (lower prioritization of interventions). Notwithstanding, inside these medium critical clusters, many small portions highly vulnerable are present.

Few non-vulnerable clusters (low VU values) are found in the central part of the area towards the source and in the river portions close to the Pertusillo Lake (absence of intervention need).

The capability of VU to resume and emphasize the ecological criticalness related to habitat suitability and fluvial functionality confirms the hypothesis that for a multilayered system, such as the river-watershed system, an integrated approach is more efficient than separated analyses.

3.4 Fragmentation Analysis

In order to evaluate the performances of the proposed approach to also represent fragmentation processes, we computed the selected landscape metrics (see Table1) on VU map obtained from the integration (Figure 11) as well as on the separated HS and FF maps (Figures 9 and 10b, respectively). In Figure 12 are depicted the charts of the metrics evaluated at landscape level on the land cover arrangement (sub-landscapes) delimited by the respective vulnerability, suitability, and functionality levels. In the figure, the suitability and functionality levels are expressed in term of criticalness (e.g., high functionality means low criticalness, and vice-versa) to make the information easily comparable with the vulnerability levels.

The histograms show that there is no a strict correspondence between the HS and FF levels (low, medium, high) and the continuous increase or decrease of the corresponding landscape metric values. As an example, for the number of patches (NP), which is considered the simplest and more understandable indicator of fragmentation, both FF and HS do not show a monotonic increase of NP values going from the low to the high level of criticalness.

Thus, a pattern analysis on the single HS or FF parameter is not able to provide clear information on the fragmentation degree of the studied territory.

On the contrary, the analysis of the VU sub-landscapes highlighted a clear relationship between vulnerability and fragmentation relative strength. For all the considered metrics, there is a correspondence between the increase of vulnerability and the increase of fragmentation. By moving from the low to the high vulnerability level, we found an increase of patch disaggregation (Contagion reduction) and landscape repartition (Division increase). Shannon Diversity (SHDI) and Evenness (SHEI) indexes confirm such a behaviour as well. Generally, such indices provide high values in presence of good ecological conditions and tend to lower values for small territory portions since they are sensitive to the landscape extension (Nagendra, 2002; Ramezani and Holm, 2011; Wu et al., 2002). In this case, in spite of the small dimension of the considered sub-landscapes, the Shannon indices show quite high values that increase with the increase of vulnerability. Such a result is possible only in presence of a very high number of patches belonging to different land covers, which support the picture of fragmented territories (Diaz-Varela et al., 2009; Fischer and Lindenmayer, 2007; McGarigal et al., 2002) and the relationship with the considered vulnerability levels.

The landscape pattern analysis shows up that VU, computed as the integration of HS and FF, is able not only to resume and emphasize the ecological criticalness of the single information, but it also provides additional information related to the territorial fragmentation, a very relevant aspect for the ecological vulnerability assessment.

The obtained results are strictly in agreement with the “Emergent Property Principle” of the classical ecology that highlights “as components, or subsets, are combined to produce larger functional wholes, new properties emerge that were not present at the level below” (e.g., Odum and Barret, 1971).

Figure 11 about here

4. Conclusion

Management tools for complex multilayered systems, as the river-watershed, require a detailed characterization of the various aspects that can induce criticalities for the ecological equilibrium. Due to the many functional links existing between the fluvial habitats and the surrounding territories, the main difficulty lies in deriving correct information able to describe and combine the different quality levels concerning the different layers.

The proposed integrated approach showed a good capacity to evaluate the vulnerability of the system by emphasizing criticalities for the ecological equilibrium at both broad-scale (watershed) and fine-scale (river ecosystem). At watershed scale, the implementation of a habitat suitability model (HS) for a keystone species of riverine habitats, as the Eurasian otter, provides the possibility to differentiate the analyzed territory in term of general ecological equilibrium. On the basis of the existing links between the studied species and its habitat, territory portions suitable for the otter presence can be considered as areas with a satisfactory environmental equilibrium; whereas the unsuitable ones can be accounted as ecologically unstable. At river ecosystem scale, the analysis of the fluvial functionality (FF) gives evidence of crucial phenomena acting locally. The integration of both such information (HS and FF), pointing out a comprehensive territorial vulnerability (VU), represents a good support for management activities, as it was confirmed by the fragmentation analysis. Such findings respond to gaps individuated by previous works that underline the relevance of taking also into account the lack of territorial connectivity in Otter habitat recolonization, especially for management purposes (Remonti et al., 2008) and, at the same time, the necessity of individuating large scale descriptors for better addressing the Otter management (Robitaille and Laurence, 2002). From a practical point of view, the integration output, a map that discriminate different level of vulnerability (low, medium, high) that are also coherent with the fragmentation degree, can be practically used for the prioritization of fluvial habitats restoration interventions.

Such a prioritization can be fundamental for two crucial aspects of the environmental management aiming at fluvial habitat restoration. The first one is related to a correct localization of the intervention sites, which is mandatory for a successful strategy; the second one is related to the possibility to comprehensively evaluate the effectiveness of already implemented activities, providing a robust tool for hypothesizing feedback actions. Both such points can be considered helpful supports for fluvial management policies.

From an academic point of view, the results obtained on the test area (High Agri sub-basin) confirms the hypothesis that for a multilayered system, such as the river-watershed system, an integrated approach is more efficient than separated analyses in agreement with the ecological principle of emergent property.

The approach can be easily exported for the analysis of other river basins by specifically tuning the factors that influence the Otter presence/absence (Kemenes and Demeter, 1995) or by considering different semi-aquatic species with similar links between the river and its basin as the studied endangered Eurasian otter. Since the method was implemented in a test area with specific peculiarities (fluvial characteristics and anthropogenic pressure), further implementations, both taking into account other types of functionality indices and river-watershed systems with different ecological stressors, should give additional information on the effectiveness of the approach.

Acknowledgments

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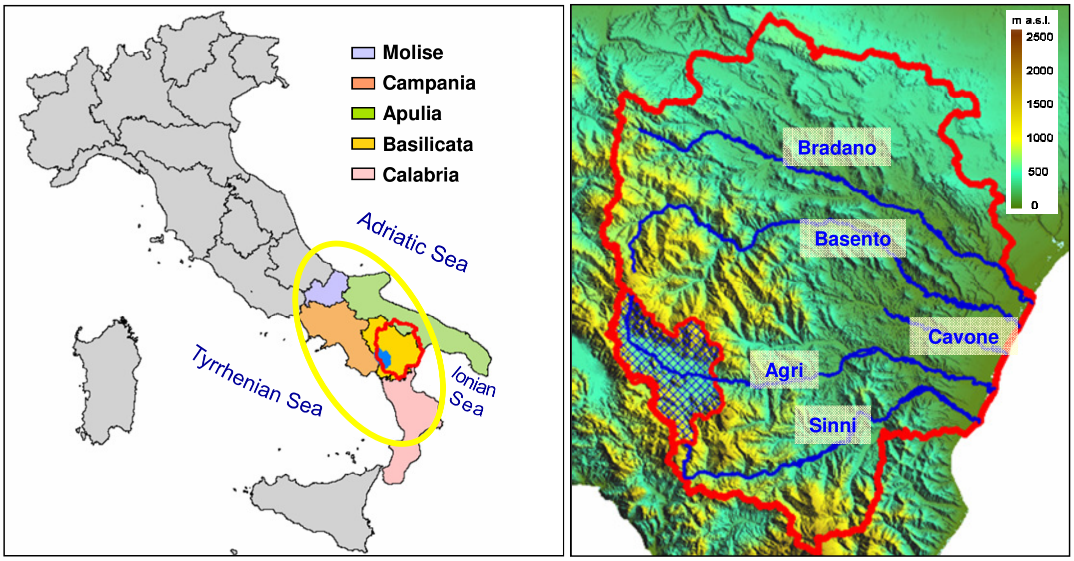


Figure 1 – Study area. On the left, the Italian Otter range with the indication of the investigated areas for HS implementation (red contour) and the test area for the HS-FF integration (blue hatched area); on the right, a zoom on the five investigated rivers overlapped to the digital elevation model.

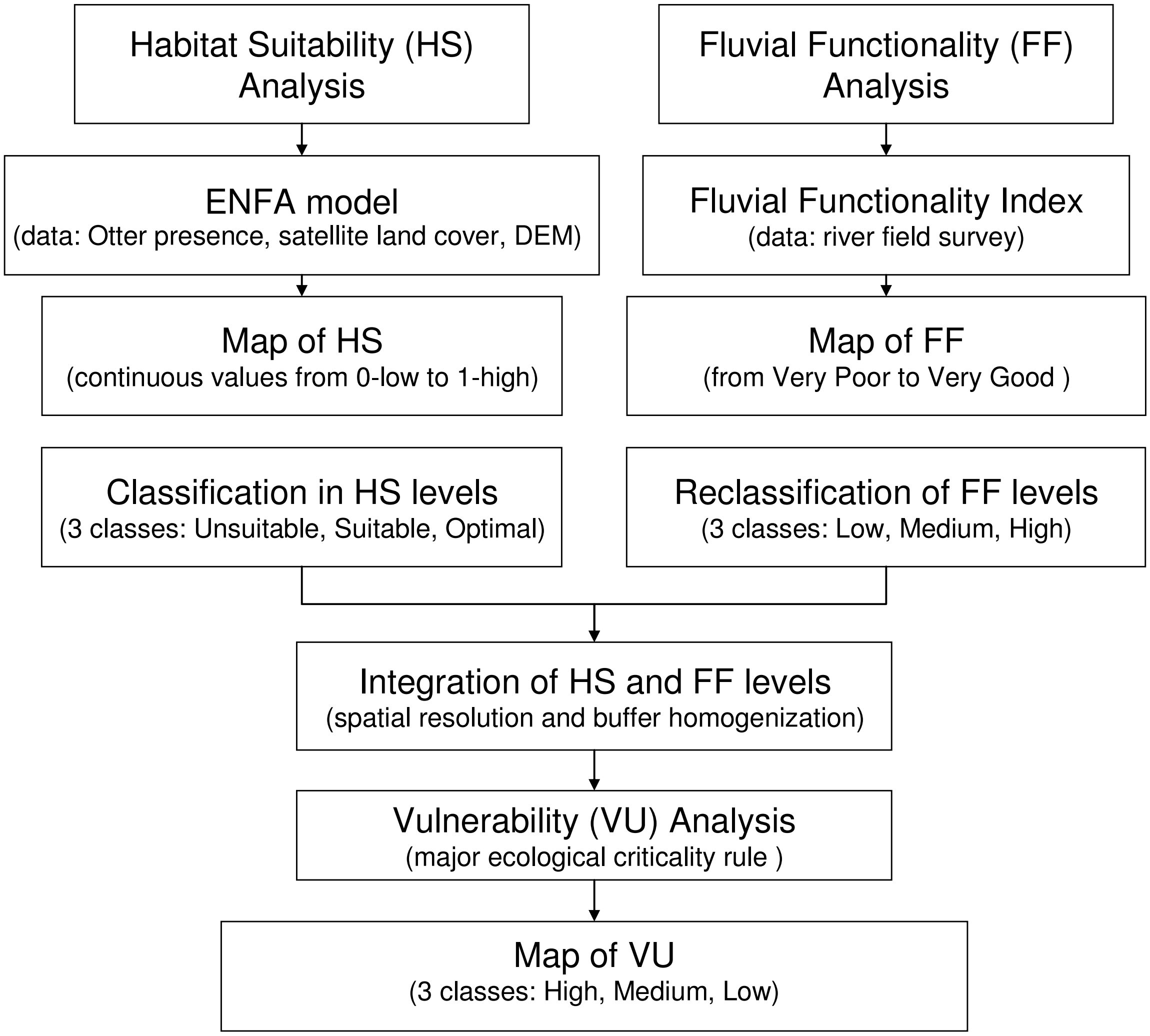


Figure 2 - Flow-chart of the proposed approach. Data coming from the HS and FF analyses, reclassified into the same ranges, are integrated to obtain synthetic information (VU) contemporaneously linked to the watershed and the ecosystem layers. The VU is categorized into three level of ecological vulnerability, each of them represent a different priority level in term of needed intervention.

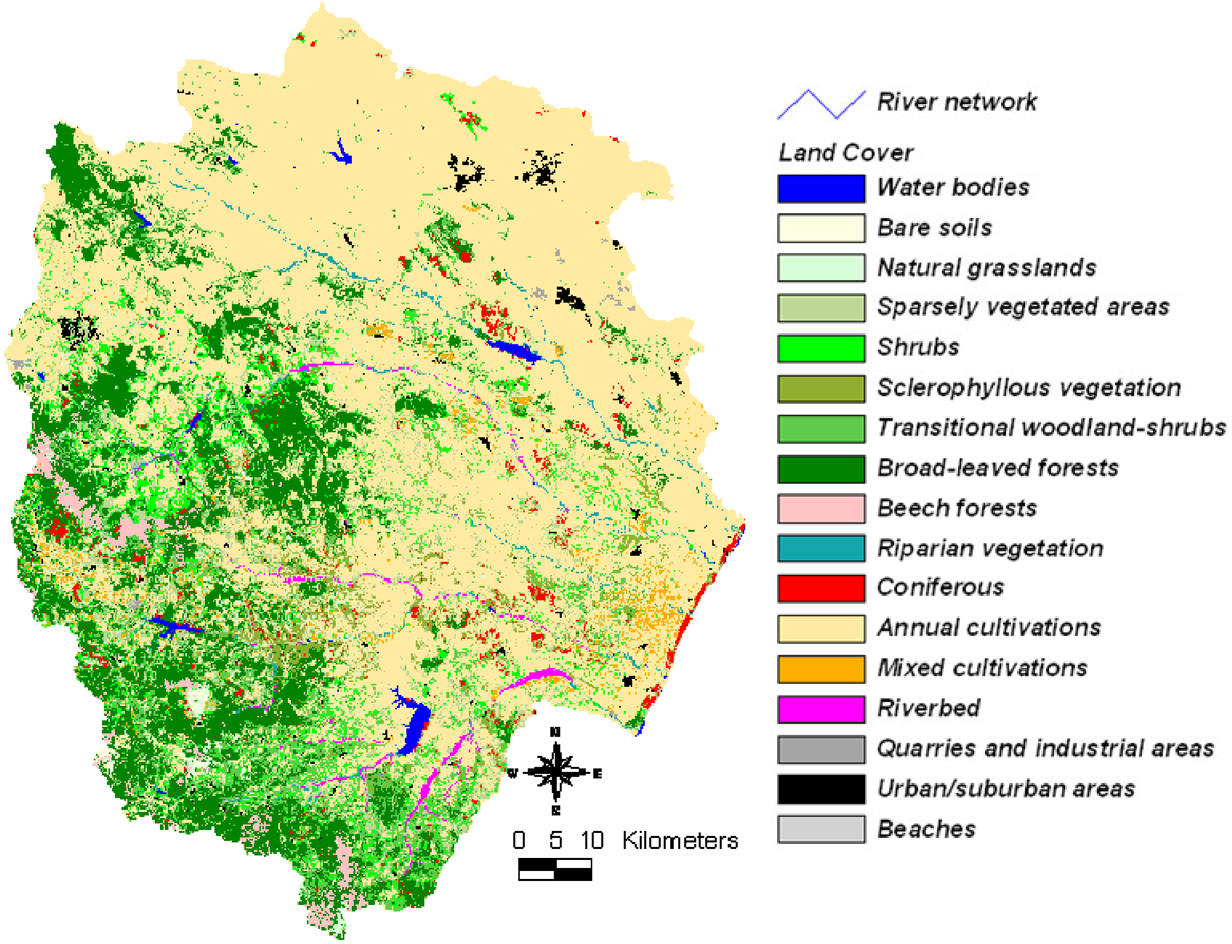


Figure 3 – Land Cover map. The map was obtained by implementing a fuzzy classification on the selected Landsat-TM image (19/07/2006). To derive the Environmental Variables for the Habitat Suitability analysis, classes coherent with the Otter habitat buffer (waters bodies, natural grasslands, sparsely vegetated areas, shrubs, sclerophyllous, transitional woodland-shrubs, broad-leaved forests, riparian vegetation, annual and mixed cultivations, riverbeds) were selected from the elaborated map.

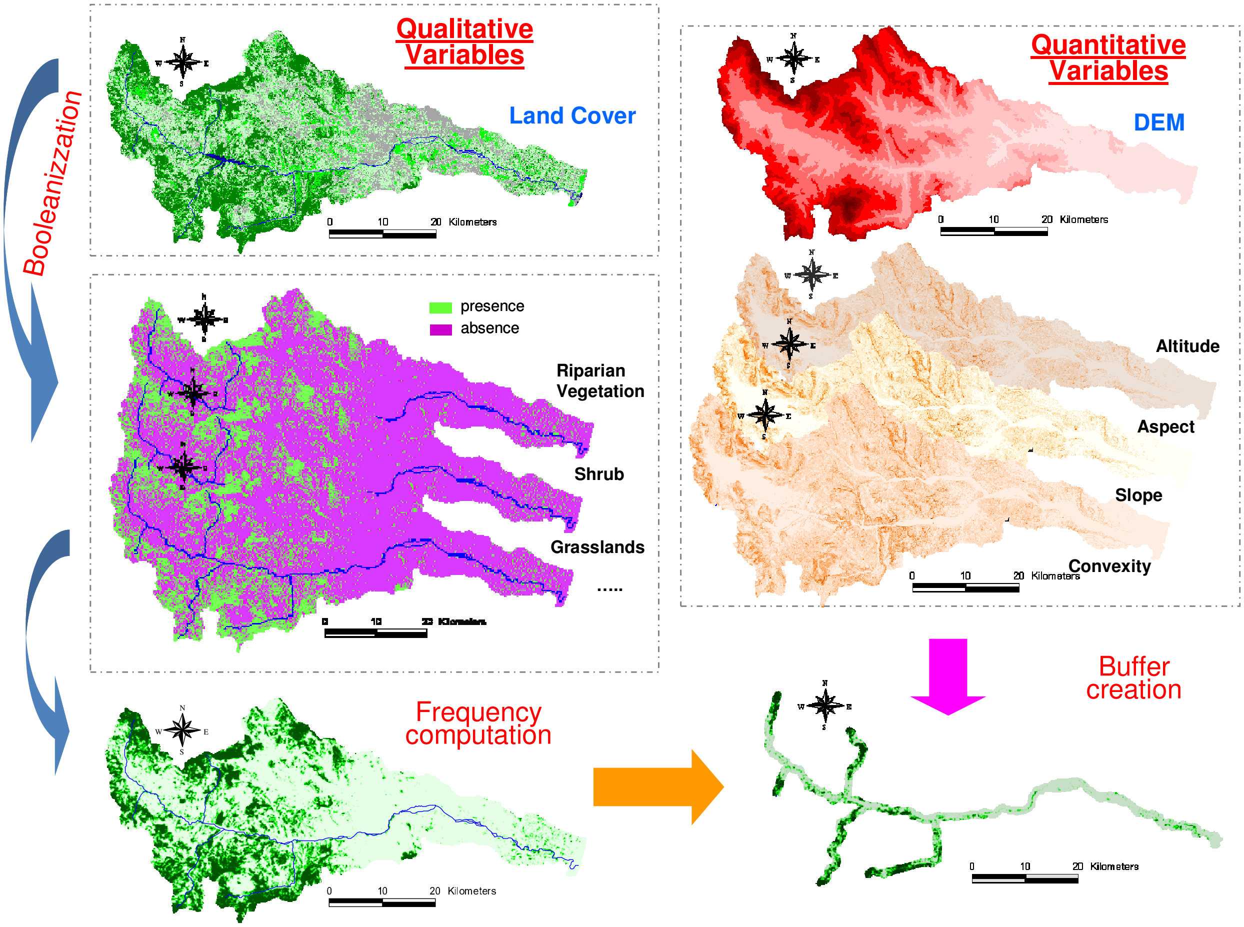


Figure 4 - Scheme of the environmental variables (EV) preparation (shown for the Agri watershed). For the land cover variables (categorical data/discontinuous) three steps are needed: 1) each cover type is transformed into a Boolean map (presence/absence map); then 2) the cover frequency is evaluated, over the whole area, within a radius of 300 metres; and finally, 3) the frequency map is clipped into the river buffer area (two-side 300 m). For the topographic variables (quantitative data/continuous), once the relative maps are derived from the DEM, they are directly clipped in the river buffer area. On the whole, for the current implementation, 11 land cover frequency maps and 4 topographic maps were elaborated as EV for the ENFA model.

Watershed		**River**		**Locality**		**Code**			
Data		**File N.**		**Photo N.**		**Altitude**		**Tract (mt)**	
Riverbed width (m)		**Flow**	LAMINAR		TURBULENT				
Substratum	CALCAREOUS		SILICEOUS		MIXED				

Bank	L		R
1) Main composition of the surrounding landscape			
a) Forests and woods ecotopes	25		25
b) Meadows and pastures	20		20
c) Cultivated ecotopes and/or scattered urbanisation	5		5
d) Urbanised ecotopes and industrial suburban areas	1		1
2) Vegetation of the natural peri-fluvial belt			
a) Arboreal riparian plant formations (dominant)	30		30
b) Shrubby riparian plant formation and/or reed thickets	25		25
c) Non-riparian arboreal formations	10		10
d) Non-riparian shrubby or herbaceous plant formations (or absent)	1		1
2bis) Vegetation within the artificial riverbanks			
a) Arboreal riparian plant formations (dominant)	20		20
b) Shrubby riparian plant formations and/or reed thickets	15		15
c) Non-riparian arboreal formations	5		5
d) Non-riparian shrubby or herbaceous plant formations (or absent)	1		1
3) Breadth of the vegetation peri-fluvial belt (trees and/or shrubs)			
a) Vegetation belt > 30 mt	20		20
b) Vegetation belt 5 – 30 mt	15		15
c) Vegetation belt 1 – 5 mt	5		5
d) Absence of vegetation belt	1		1
4) Continuity of the vegetation peri-fluvial belt (trees and/or shrubs)			
a) Without interruptions	20		20
b) With interruptions	10		10
c) Frequent interruptions or only herbaceous	5		5
d) Bare soil or rare herbaceous	1		1
5) Water conditions of the riverbed			
a) Moderate flow width < triple of the wetted riverbed		20	
b) Moderate flow width > triple of the wetted riverbed (seasonal)		15	
c) Moderate flow width > triple of the wetted riverbed (frequent)		5	
d) Wetted riverbed very reduced or absent (or waterproofing)		1	
6) Riparian morphology			
a) Presence of arboreal vegetation and/or rocks	25		25
b) Presence of shrubs and herbs	15		15
c) With thin herbaceous coating	5		5
d) Bare shores	1		1
7) Trophic input retention			
a) Riverbed with rocks and/or embanked trunk or reeds and hydrophytes		25	
b) Rocks or branches with sediment or reeds and hydrophytes		15	
c) Retention structures dependent only on floods (or reeds absent)		5	
d) Sand sediments without algae		1	

Bank	L		R
8) Erosion			
a) Non-evident and non-relevant	20		20
b) Only in curves and narrows	15		15
c) Frequent, with riparian excavation	5		5
d) Very evident, with excavations and landslides	1		1
9) Transversal section			
a) Natural		15	
b) Semi-natural (few artefacts)		10	
c) Semi-artificial (few natural remnants)		5	
d) Artificial		1	
10) Structure of the riverbed bottom			
a) Stable and diversified		25	
b) Partially movable		15	
c) Easily movable		5	
d) Artificial or with concrete		1	
11) Scrapings, puddles or meanders			
a) Clearly distinguished and recurrent; distance between scrapings (or meanders)/riverbed length = 5-7:1		25	
b) With irregular succession (7-15:1)		20	
c) Few meanders, or long puddles and short scrapings (15-25:1)		5	
d) Absence of meanders, scrapings and puddles (canalised) (>25:1)		1	
12) Waters vegetation			
a) Very scarce periphyton and tolerant macrophytes		15	
b) Some presence of periphyton and tolerant macrophytes		10	
c) Discrete periphyton and high presence of tolerant macrophytes		5	
d) High presence of periphyton and tolerant macrophytes		1	
13) Debris			
a) Vegetal fragments (recognisable and fibrous)		15	
b) Vegetal fragments (fibrous and pulpous)		10	
c) Pulpous fragments		5	
d) Anaerobic debris		1	
14) Macrobenthic community			
a) Well structured and diversified, in accordance with the river type		20	
b) Quite diversified but with altered structure		10	
c) Badly balanced community with pollution tolerant taxa		5	
d) Absence of community, few pollution tolerant taxa		1	
Total Score			
Functionality Level			

Figure 5 – The Standard Data Form for the application of the Italian Fluvial Functionality Index. A different score is given to each considered ecological aspect. The Total Functionality level is obtained by summing the scores of all 14 questions. The form is compiled by moving from the mouth to the source per fluvial homogeneous segment; therefore the number of forms for a given river depends on the homogeneity of its characteristics. For the questions related to vegetation and bank conditions, a separate score is assigned for the left (L) and the right (R) hydrographic river side.

IFF Score	Functionality Class	Functionality Level	Mapping Colour
261 - 300	I	Very good	🟦
251 - 260	I – II	Very good – good	🟦🟩
201 - 250	II	Good	🟩
181 – 200	II – III	Good – Mediocre	🟩🟨
121 – 180	III	Mediocre	🟨
101 – 120	III – IV	Mediocre – Poor	🟨🟧
61 – 100	IV	Poor	🟧
51 – 60	IV – V	Poor – Very poor	🟥🟧
14 - 50	V	Very poor	🟥

Figure 6 – IFF standard classification. The Standard Protocol (Siligardi et al., 2003) provides the categorization of IFF scores into functionality classes and levels; it also includes colours and symbols for the elaboration of standardized functionality maps.

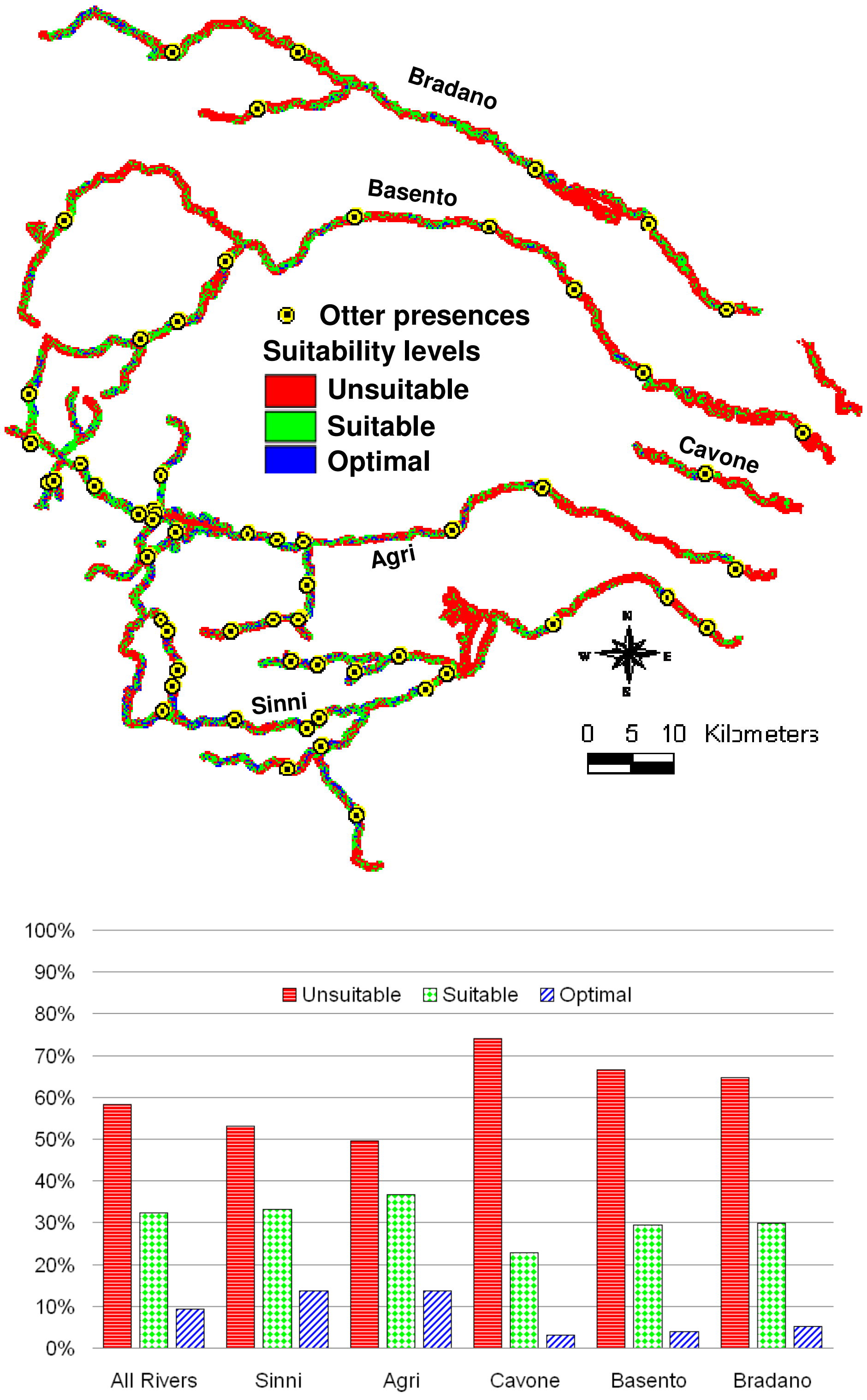


Figure 7 – Habitat Suitability analysis results. Top: Habitat Suitability Map and Otter presences for all the rivers of the studied territory. Bottom: relative extension of the suitability levels (expressed in percentage of covered area) for all the rivers collectively (whole area) and individually (per river).

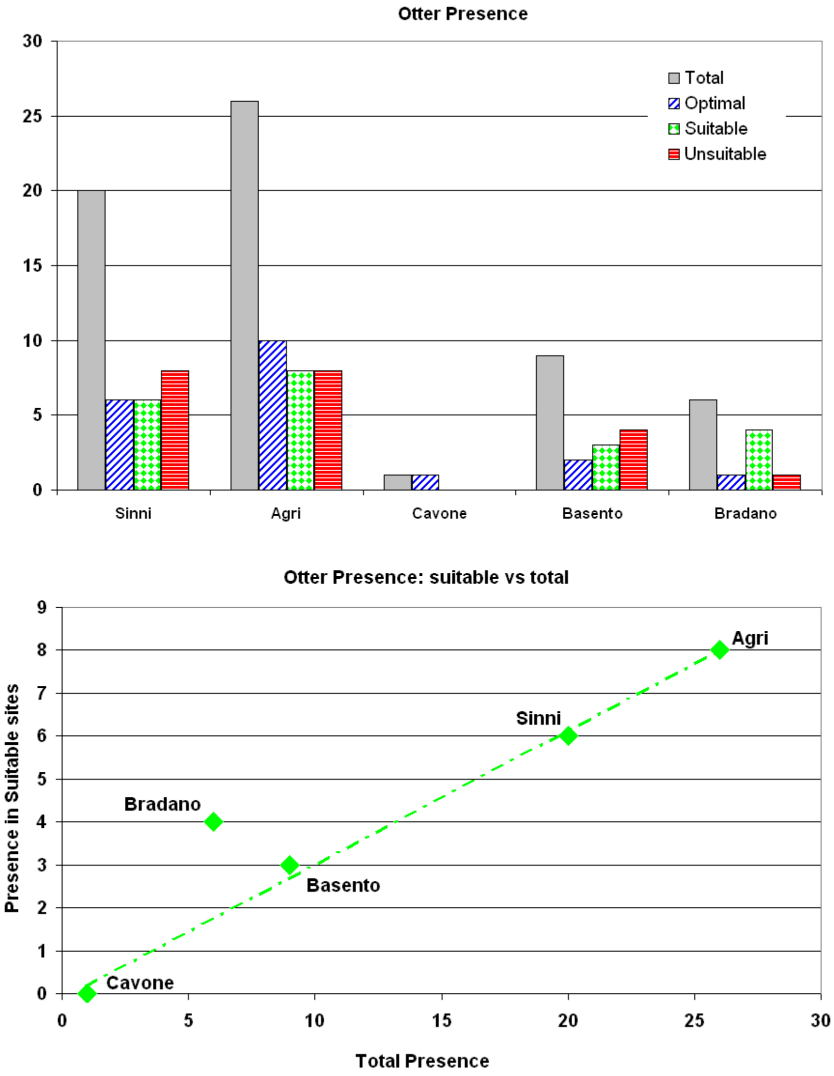


Figure 8 – Distribution of the Otter presences. On the top, total presences and presences per HS levels for each river; on the bottom, Otter presences in suitable sites vs total presences.

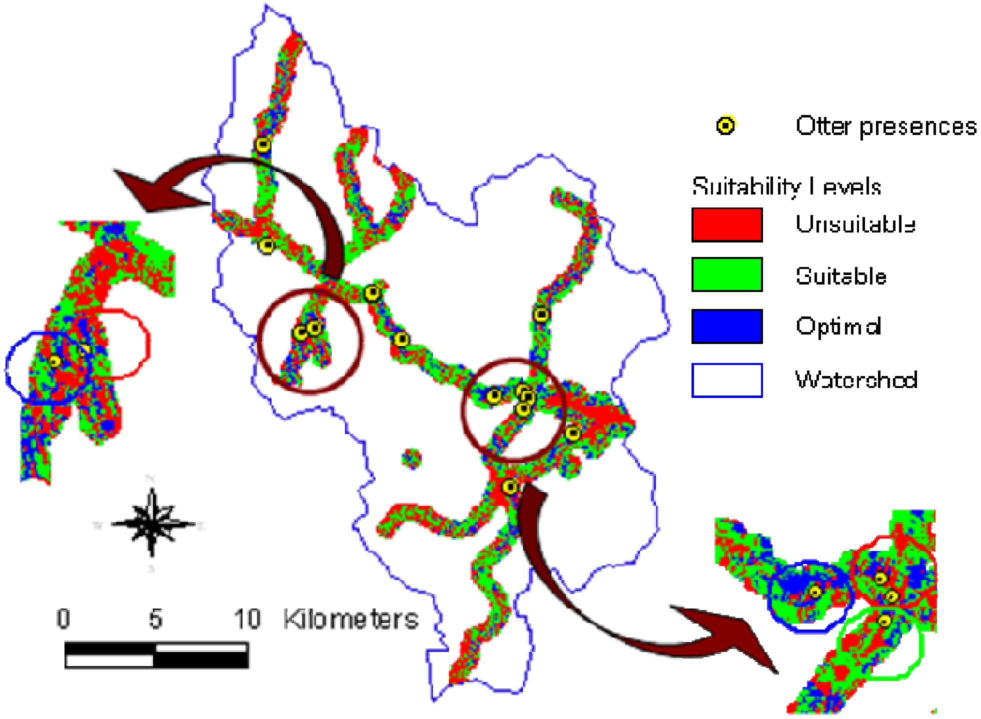


Figure 9 – Habitat Suitability (HS) map and Otter presences for the High Agri River. The zoom-in areas on the left and on the right emphasize Otter presences very close together, but placed in sites with different levels of suitability.

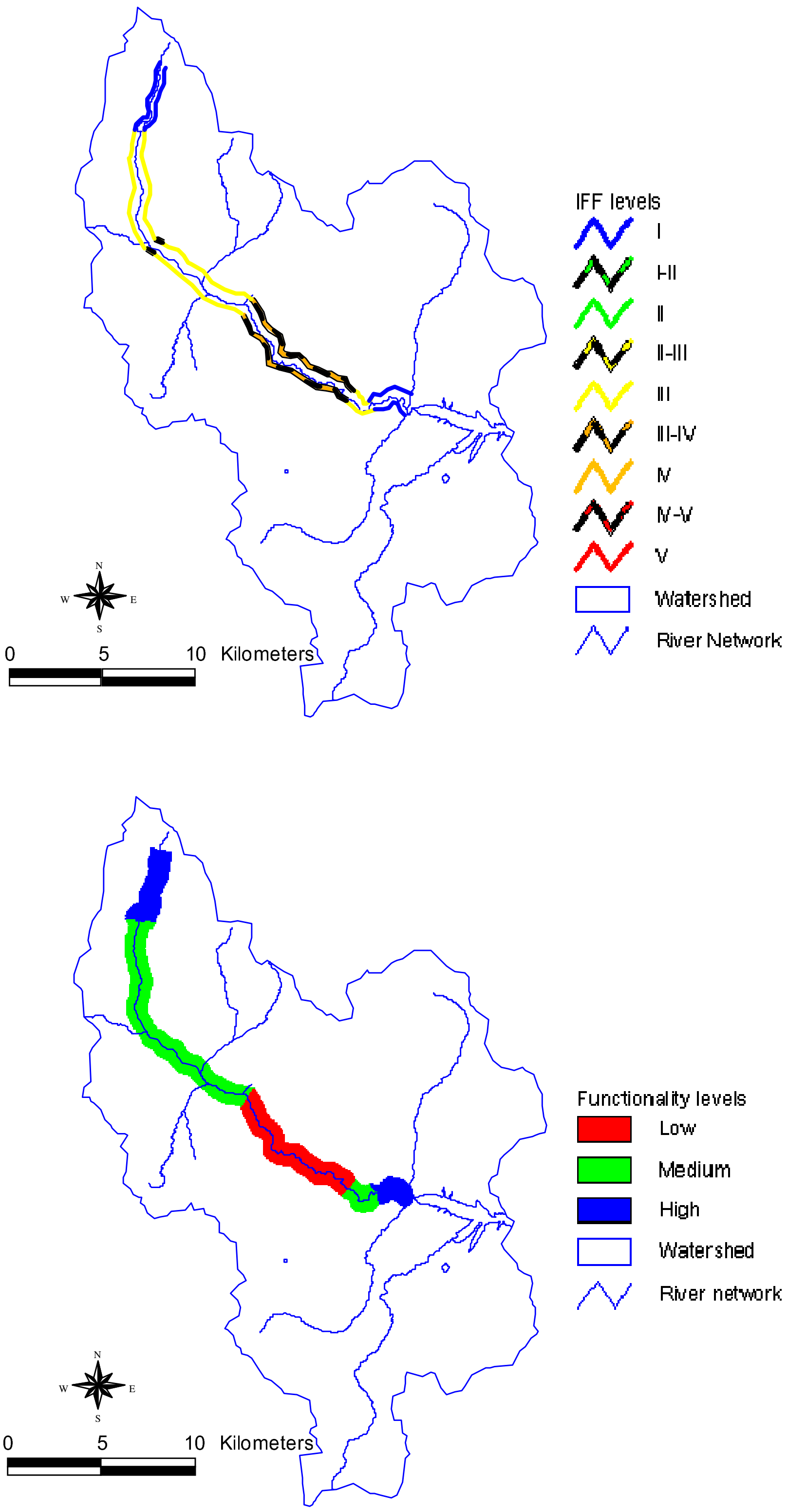


Figure 10 – Fluvial Functionality (FF) for the High Agri River. On the top (a), the IFF map plotted following the standard protocol symbols (see Figure 6); on the bottom (b), the same IFF map reclassified into three functionality levels for the integration with the HS map.

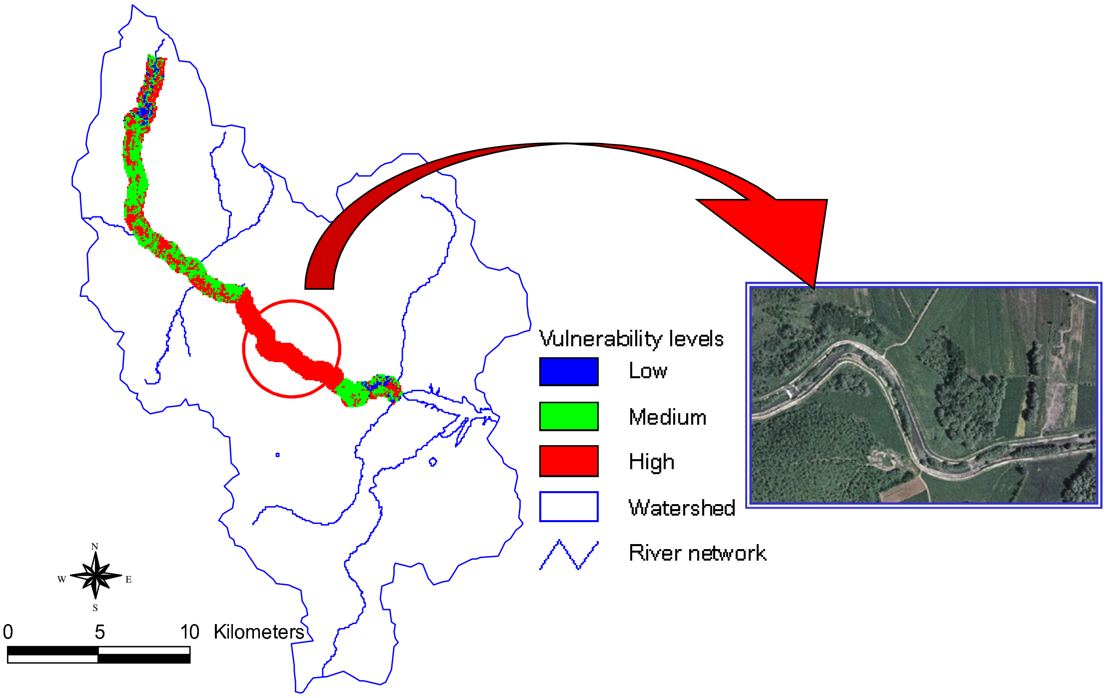
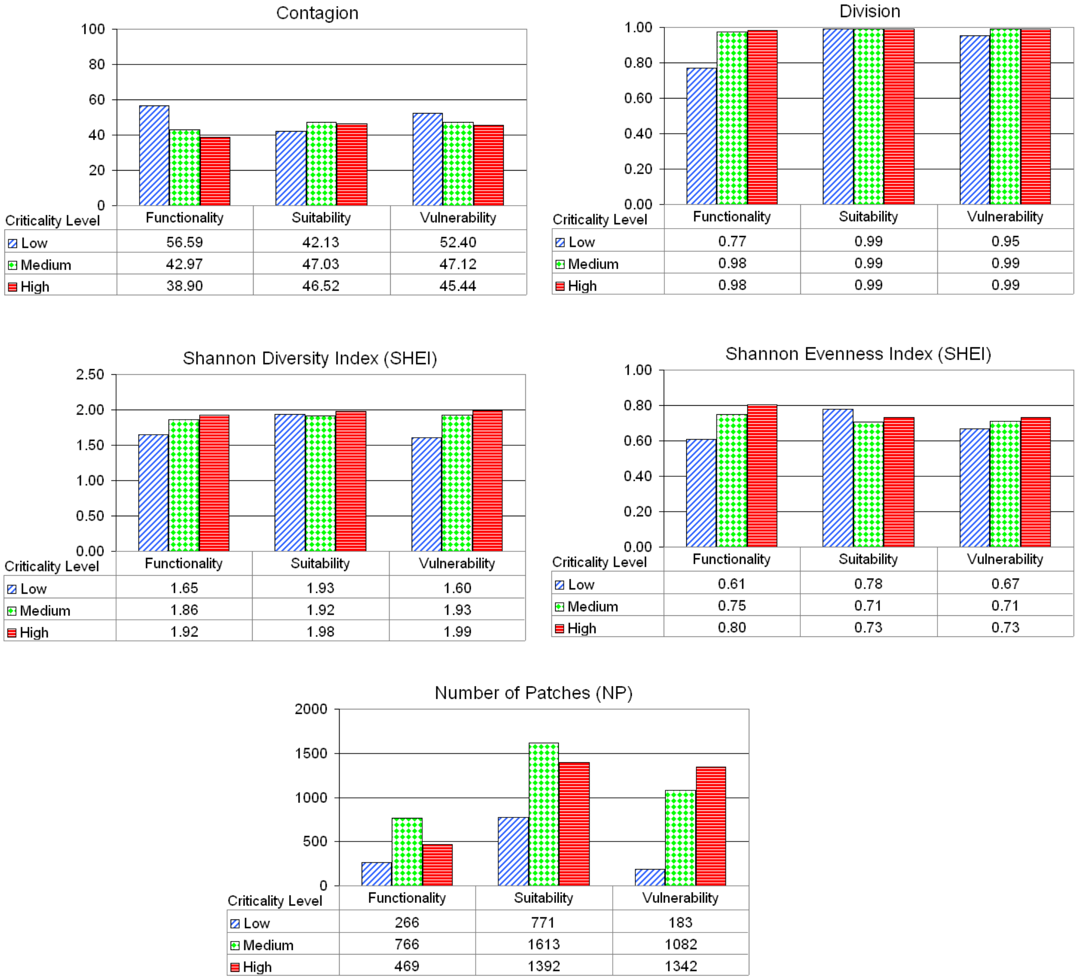


Figure 11 – Map of Vulnerability (VU) for the High Agri River. VU results from the integration of the suitability (HS) and functionality (FF) maps. Each level of vulnerability requires a different priority in term of intervention needs, i.e. the areas with a high VU level require more urgent interventions, and then they need the highest priority. The photo on the right shows the particularly critical environmental situation emphasized by the VU map: a riparian vegetation recolonization inside the riverbanks in concrete represents a highly unbalanced temporary habitat.



Contagion

Criticality Level	Functionality	Suitability	Vulnerability
▨ Low	56.59	42.13	52.40
⊞ Medium	42.97	47.03	47.12
▤ High	38.90	46.52	45.44

Division

Criticality Level	Functionality	Suitability	Vulnerability
▨ Low	0.77	0.99	0.95
⊞ Medium	0.98	0.99	0.99
▤ High	0.98	0.99	0.99

Shannon Diversity Index (SHEI)

Criticality Level	Functionality	Suitability	Vulnerability
▨ Low	1.65	1.93	1.60
⊞ Medium	1.86	1.92	1.93
▤ High	1.92	1.98	1.99

Shannon Evenness Index (SHEI)

Criticality Level	Functionality	Suitability	Vulnerability
▨ Low	0.61	0.78	0.67
⊞ Medium	0.75	0.71	0.71
▤ High	0.80	0.73	0.73

Number of Patches (NP)

Criticality Level	Functionality	Suitability	Vulnerability
▨ Low	266	771	183
⊞ Medium	766	1613	1082
▤ High	469	1392	1342

Figure 12 – Fragmentation analysis results. Landscape metrics were evaluated on the sub-landscapes represented by the three levels of suitability (HS, Figure 9), functionality (FF, Figure 10b), and vulnerability (VU, Figure 11) for the High Agri River test area. Note that the HS and FF levels are reversed to express them in term of criticality for similarity with VU. Contagion/Interspersion features are represented by Contagion and Division metrics; the diversity is evaluated by Shannon Diversity and Evenness indices, and the area/density metrics is represented by the Number of Patches (NP).

Landscape Characteristics	Formula
Contagion/Interspersion	$\mathbf{CONTAGION} = \left[1 + \dfrac{\sum_{i=1}^{m} \sum_{k=1}^{m} \left[(P_i) \left(\dfrac{(g_{ik})}{\sum_{k=1}^{m} g_{ik}} \right) \right] \left[\ln(P_i) \dfrac{(g_{ik})}{\sum_{k=1}^{m} g_{ik}} \right]}{2\ln(m)} \right] (100)$ $0 \leq \mathrm{CONTAGION} \leq 100$ *Contagion* is affected by both the dispersion and interspersion of patch types. It has low values when the patch types are highly disaggregated (i.e., every cell is a different patch type) and interspersed (equal proportions of adjacencies), and vice-versa.
	$\mathbf{DIVISION} = \left[1 - \sum_{i=1}^{m} \sum_{j=1}^{n} \left(\dfrac{a_{ij}}{A} \right) \right]$ $0 \leq \mathrm{DIVISION} < 1$ *Division* is the probability that two random pixels not belong to the same patch. Low values are associated with landscape minimally subdivided. It has a great similarity with Simpson's diversity index, but the sum is across the proportional area of each patch.
Diversity	$\mathbf{SHEI} = \dfrac{- \sum_{i=1}^{m} (P_i * \ln P_i)}{\ln m}$ $0 \leq \mathrm{SHEI} \leq 1$ *Shannon's evenness index* is expressed such that an even distribution of area among patch types results in maximum evenness.
	$\mathbf{SHDI} = - \sum_{i=1}^{m} (P_i * \ln P_i)$ $\mathrm{SHDI} \geq 0$, without limit *Shannon's diversity index* is a popular measure of diversity in community ecology applied to landscapes. It is determined by both the number of different patch types and the proportional distribution of area among patch types.
Area/ Density	$\mathbf{NP = N}$ $\mathrm{NP} \geq 1$, without limit *Number of patches*

Table 1 - Algorithms of the applied Landscape Metrics (from McGarigal et al., 2002).

	Habitat Suitability Level		
Land cover	**Optimal**	**Suitable**	**Unsuitable**
Water bodies	0.7	1.7	6.2
Natural Grasslands	0.7	1.8	2.0
Sparsely Vegetated Areas	12.9	10.3	6.0
Riparian Vegetation	7.6	8.4	3.5
Shrubs	5.7	7.3	4.5
Sclerophyllous	2.9	2.2	2.6
Transitional woodland-shrubs	16.2	10.6	4.9
Broad-leaved Forests	36.7	20.0	14.1
Annual Cultivations	12.1	31.9	51.0
Mixed Cultivations	1.6	2.5	2.6
Riverbeds	3.0	3.3	2.8

Table 2 – Distribution of Land Cover Environmental Variables per HS level, expressed as percentage of covered area.

CHAPTER 3

Combining habitat suitability models and fluvial functionality data for a multilayer assessment of riverine vulnerability: a second study case.

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Abstract

For studying the criticalities of river basins it is mandatory to take into account the multilayered structure of the river/landscape system. We propose an integrated analysis that combines habitat suitability maps for a riverine key species (the endangered Eurasian otter) with data on fluvial functionality as an instrument to reveal more vulnerable fluvial portions in need of restoration. The approach was tested on two river catchments with different anthropogenic pressures, both falling within the Otter core area in Italy. Results showed that the integration allows for a satisfactory prioritization of river criticalities, suggesting the method as useful tool for river environmental management.

Keywords: habitat suitability models, fluvial functionality, key species, river vulnerability.

X.1 Introduction

River/landscape systems are characterized by a complex multilayered structure (Poole, 2002; Brown et al., 2011) with many functional links and feedback processes, which makes difficult the correct individuation of river criticalities to suggest management and/or restoration strategies. A detailed modelling able to take into account such links and processes can be very complicated, even for merely selecting the right variables for the whole system representation.

A possible solution to overcome this problem, especially in operative contexts, can be represented by comprehensive indicators having links with all the system layers.

In order to obtain concise information on both landscape and fluvial ecosystem layers and to provide a tool for the assessment of the river vulnerability suitable for supporting management and/or restoration activities, we propose the integration of Habitat Suitability (HS) models for a wide-ranging key species of riverine habitats (the Eurasian otter, Lutra lutra) with Fluvial Functionality (FF) analyses based on indicators of riverine ecosystem equilibrium (index of Fluvial Functionality).

Habitat Suitability models are widely considered as robust tools for the description of species' environmental niche and for a number of different ecological implications being it able to generate maps of suitable habitats for the studied species (see e.g. Guisan and Zimmermann, 2000; Mladenoff et al., 1997). For our model implementation, we considered the Otter for obtaining information at a broad scale (landscape layer) since the survival of such a species is strictly dependent on the environmental quality and equilibrium of fluvial habitats and on the good ecological functioning of their links with the surrounding territory.

Indices of Fluvial Functionality (e.g., AUSRIVAS - Australian River Assessment System, ISC - Index of Stream Condition, RHS - River Habitat Survey) represent operational tools for the assessment of the well working of river metabolic functions linked to the trophic relationships between the living organisms as well as to the non-metabolic functions, such as fluvial contributions to the environmental biodiversity, solid transport loads, etc. (e.g. Ladson et al., 1996;

Raven et al., 1997). Therefore, they can support the evaluation of river criticalities at the local ecosystem scale (river layer). In particular, for this purpose we accounted the Italian standard protocol for Fluvial Functionality (Siligardi et al., 2003) since it was specifically adapted for Italian river characteristics and widely tested and adopted at operational levels by the agencies for environmental protection. Moreover, it proved to be useful for other integrated approaches for fluvial assessment (e.g. Comiti et al., 2009; Munafò et al., 2005).

The effectiveness of the integrated information concerning fluvial vulnerability was evaluated by performing a Landscape Ecology analysis focused on fragmentation. Such a process influences the ecological equilibrium at different scales (e.g. Lindenmayer and Fischer, 2006 and references therein) and Landscape Metrics analyses revealed a satisfactory reliability for providing information on landscape structure (e.g. Peng et al., 2010; Colson et al. 2011).

The approach, recently developed and tested in the Italian otter core area on a river sub-basin showing a heavy anthropogenic influence, revealed a good capability to provide concise information for the fluvial vulnerability prioritization (Carone et al., 2011). Since such a prioritization still represents a crucial challenge for the environmental management, here we present a further test of the method in order to evaluate its exportability. The investigation was realized on a river sub-basin presenting a lower anthropogenic presence, and so a more natural river/landscape structure, than the sub-basin analyzed for the setting up of the approach. All the procedural steps applied to both the sub-basins were compared in order to assess the methodology response in systems having different levels of anthropogenic pressures.

X.2 Methods

X.2.1 Study area

The study area is located in a portion of the Otter core area, which hosts an important part of the Italian southern Otter population (Basilicata region); it is represented by two river sub-basin with different anthropogenic pressures: the High Agri River and the High Sinni River (Figure X.1).

Figure X.1 – Localization of the study area. Top right, little picture: representation of the Otter range with indication of Basilicata region (red circle). Main picture: the Basilicata Region, internal portion of the areal with the highlighting (red circles) of the two river sub-basin, utilized for the integration.

The studied river sub-basins are similar for their morphology (mountainous areas) and hydraulic regimes, which is characterized by heavy winter water loads alternate by drought summers; conversely, they are highly different for the anthropic pressure.

The high part of Agri watershed shows a wide presence of agricultural covers, mixed to natural portions interested by a National Park (Lucanian Appennine NP); long sections of the river main axis are managed in concrete, and an important industrial site related to an oil-drilling activity is also present.

On the contrary, the High Sinni River shows a less important anthropogenic pressure than the High Agri River: larger sectors are interested by a National Park (Pollino NP), the urban areas are smaller and more scattered, and the land cover structure presents larger forested patches.

X.2.2 The integrated approach

In order to provide a tool able to assess river vulnerability and to classify such a vulnerability in different priorities of intervention need, the proposed approach integrates information on the environmental criticalities coming from the river/landscape system layers. In particular, the different pieces of information take into account:

- the landscape layer, by evaluating the Habitat Suitability (HS) for the endangered Otter species, and
- the river layer, by analyzing the Fluvial Functionality (FF).

The Habitat Suitability (HS) analysis for the Otter was performed by using the ENFA (Ecological Niche Factor Analysis) model that compares in a multidimensional space a set of environmental variables describing the presence sites of a species with the whole study area characteristics (Hirzel et al., 2002). On the basis of such a comparison, the model identifies the fractions of the investigated area where there are good (optimal sites), quite good (suitable sites), and poor (unsuitable sites) environmental characteristics for the Otter survival. The model accuracy was determined by following the method of Boyce et al. (2002) and further modified by Hirzel et al. (2006). All the model steps were performed by using the software Biomapper 4.0 (http://www.unil.ch/biomapper).

Input data for the model implementation include: Otter occurrences derived from a standard survey concerning the 2002-2006 period (Panzacchi et al., 2010), environmental variables related to topography (Altitude, Slope, Aspect and Convexity) and land cover types. Topographic data were selected as proxy variables for food availability (Remonti et al. 2009), whereas land cover data give indications on resting and reproductive sites (Kruuk, 2006). To obtain the required land cover data representative of the Otter sampling period, a supervised classification (Schowengerdt, 2007) was performed on a Landsat-TM image (pixel resolution 30x30m) acquired in summer 2006 (19 July). From the obtained land covers (Figure X.2), 11 classes were chosen as more significant for the Otter's ecology (Loy et al., 2009). For each of the selected cover, to obtain continuous variables as required by the ENFA model, a frequency map was elaborated by evaluating the presence of the given cover within a circular window of 300m radius.

Topographic variables were originated from a Digital Elevation Model having a pixel size of 20x20m and resampled at the same spatial resolution of the satellite-derived land cover maps.

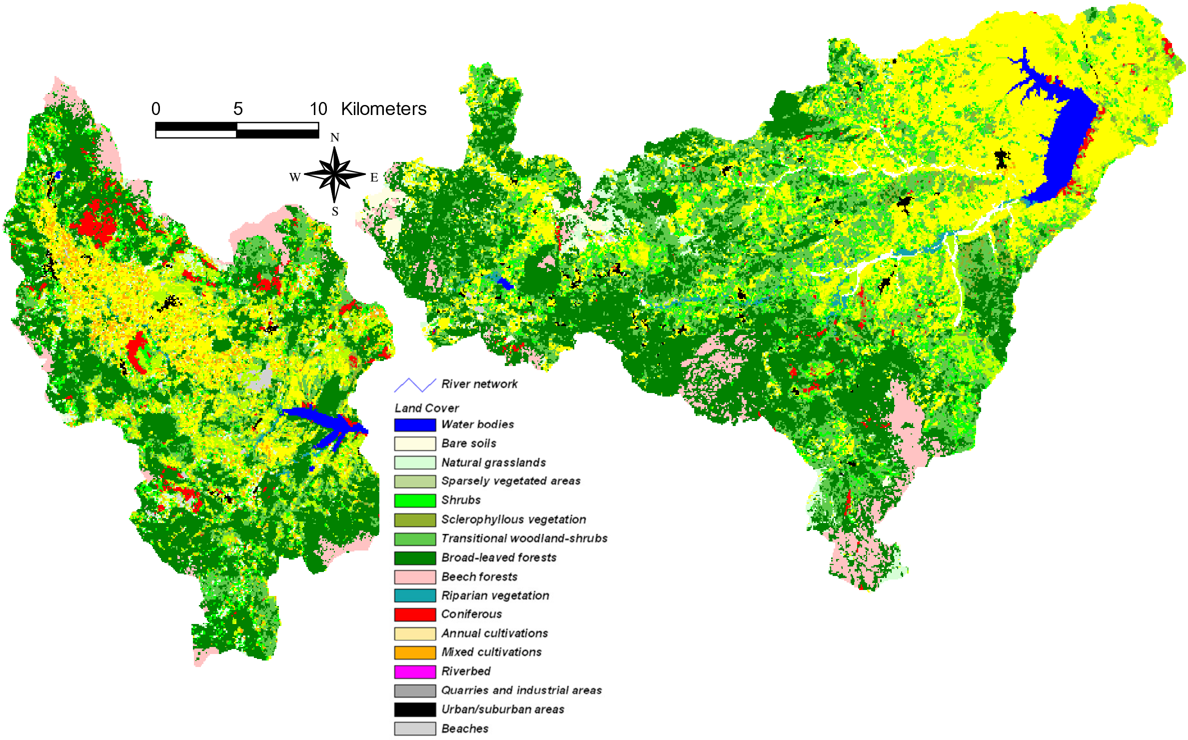

Figure X.2 – Land cover maps of the studied sub-basins, provided by a classification of a Landsat-TM summer image.

Finally, all the variables were clipped on a fluvial buffer 300 m wide since the studied species is rarely found far from the water.

Fluvial Functionality values (FF) were derived from field data collected in a 2003 summer campaign by following the Italian standard protocol (Siligardi et al., 2003), which is based on the evaluation of various river basin aspects (riparian vegetation, hydrology, fluvial morphology, etc.) at the operator scale.

The protocol has been defined, starting from the Riparian Channel Inventory (RCE-I) (Petersen et al., 1987), through different applications and modifications (Siligardi and Maiolini, 1993; Siligardi et al., 2000) which made it specific and more reliable than other indices for the Italian river characteristics (Balestrini et al., 2004). The index is adopted as a standard tool for the analysis of fluvial functionality by the Italian Environmental Protection Agency.

In order to integrate HS and FF data, both suitability and functionality values were categorized into three levels (low, medium, and high suitability/functionality) and combined in a GIS environment (ArcView 3.2) to obtain three levels of river Vulnerability (VU), as follow: 1) low ecological vulnerability level, where the integration indicated that both HS and FF provide the highest values; 2) medium ecological vulnerability level, where the integration indicated that both HS and FF provide a medium value, or at least one of them; 3) high ecological vulnerability level, where the integration indicated that both HS and FF provide the lowest values, or at least one of them. The integrated VU map is representative of environmental criticalities related to both landscape and fluvial ecosystem layers, and it can be read as map of priority in term of needed intervention since the higher the vulnerability, the higher the pressing for intervention activities.

The provided prioritization was assessed by performing a further analysis based on landscape metrics. A specific subset of landscape indices concerning fragmentation processes (Table X.1)

(McGarigal et al., 2002) was calculated at landscape level on land cover arrangements included within each sub-landscape delineated by the functionality, suitability and vulnerability levels.

Table X.1 – Algorithm and description of the applied Landscape Metrics (from McGarigal et al., 2002).

Contagion/Interspersion metrics
They refer to the overall texture of the landscape, which is a fundamental aspect for many ecological processes. They specifically describe the habitat fragmentation, since this phenomenon involves the disaggregation and subdivision of contiguous habitat into disaggregated and/or disjoint patches. As habitat fragmentation proceeds, habitat contagion decreases and habitat subdivision increases.
$\mathrm{CONTAG} = \left[1 + \frac{\sum_{i=1}^{m} \sum_{k=1}^{m} \left[(P_i) \left(\frac{(g_{ik})}{\sum_{k=1}^{m} g_{ik}} \right) \right] \left[\ln(P_i) \frac{(g_{ik})}{\sum_{k=1}^{m} g_{ik}} \right]}{2\ln(m)} \right] (100)$ $0 \leq \mathrm{CONTAG} \leq 100$ *Contagion* is affected by both the dispersion and interspersion of patch types. It has high values when a single patch occupies a high percentage of the landscape and vice-versa.
$\mathrm{DIVISION} = \left[1 - \sum_{i=1}^{m} \sum_{j=1}^{n} \left(\frac{a_{ij}}{A} \right) \right]$ $0 \leq \mathrm{DIVISION} < 1$ *Division* is the probability that two random pixels not belong to the same patch.

It has a great similarity with Simpson’s diversity index, but the sum is across the proportional area of each patch.

Diversity Metrics

Diversity measures have been applied by landscape ecologists to measure the landscape composition. They are influenced by two components: Richness and Evenness, where Richness refers to the number of patch types present and Evenness to the distribution of area among the different types. Both aspects are generally referred to as the compositional and structural components of diversity, respectively.

$$\mathbf{SHEI} = \frac{-\sum_{i=1}^{m} (P_i * \ln P_i)}{\ln m}$$

$$0 \leq \mathrm{SHEI} \leq 1$$

Shannon’s Evenness Index is expressed such that an even distribution of area among patch types results in maximum evenness.

$$\mathbf{SHDI} = -\sum_{i=1}^{m} (P_i * \ln P_i)$$

$$\mathrm{SHDI} \geq 0, \text{ without limit}$$

Shannon’s Diversity Index is a popular measure of diversity in community ecology, applied to landscapes.

Area/Density Metrics

The group represents all metrics dealing with the patches’ number and size. Specifically, Number of Patches can be considered the most basic aspect of landscape pattern that can affect a multitude of processes linked to fragmentation.

$$\mathbf{NP = N}$$

$$\mathrm{NP} \geq 1, \text{ without limit}$$

Number of Patches

X.3 Results and Discussion

The evaluation of the predictive power for the implemented ENFA model provided good values of the Boyce index (0.801 ± 0.039). In Figure X.3 are shown the final HS maps of the two test areas, obtained by segmenting the suitability values (ranging from 0 to 1) into three levels (unsuitable, suitable, optimal).

In both areas, it is possible to observe a mixed structure of optimal and suitable sites that cover half of the territory, with the same relative percentage of the optimal level (15%). Despite its structure more defined by the anthropogenic activities, the High Agri River shows a higher proportion of suitable areas (43%) compared to the High Sinni River (34%), and a lower relative presence of unsuitable clusters (42% for High Agri River and 51% for High Sinni River). Such percentages of suitability levels appears to be strongly linked to the wider incidence for High Agri River vs High Sinni River of covers with wooded vegetation (broad-leaved forests, riparian and transitional vegetation) that are present on 48.5% of the sub-basin. The presence of vegetation cover jointly with its spatial distribution seems to characterize the noticeable high fragmentation of optimal and suitable sites, and consequently the Otter occurrence per HS level (Table X.2). A high percentage of presences in unsuitable sites was found; such sites have always little dimensions and are often included in bigger suitable clusters. This percentage is higher in the High Agri River, which shows also in the high suitable level a more consistent percentage of Otter presences than in the medium level.

Conversely, the High Sinni River evidences homogeneously distributed occurrences between medium and high suitable clusters.

Table X.2 – Relative Otter distribution in the different levels of suitability

Suitability Levels	High Agri sub-basin	High Sinni sub-basin
Low	47%	41%
Medium	20%	30%
High	33%	30%

The structure of such presence distribution can be also linked to the dynamics of the Otter population in the study area. When a species is recovering, as the Otter demonstrated to be in the last two decades in the studied territories (Loy et al., 2009, Loy and Racana, 1986), once saturated the most suitable sites it proceeds to colonize also the less suitable ones (Begon et al., 1990). However, the unsuitable habitats colonized can act as ecological traps (Battin, 2004), leading to a future decreasing of the species population.

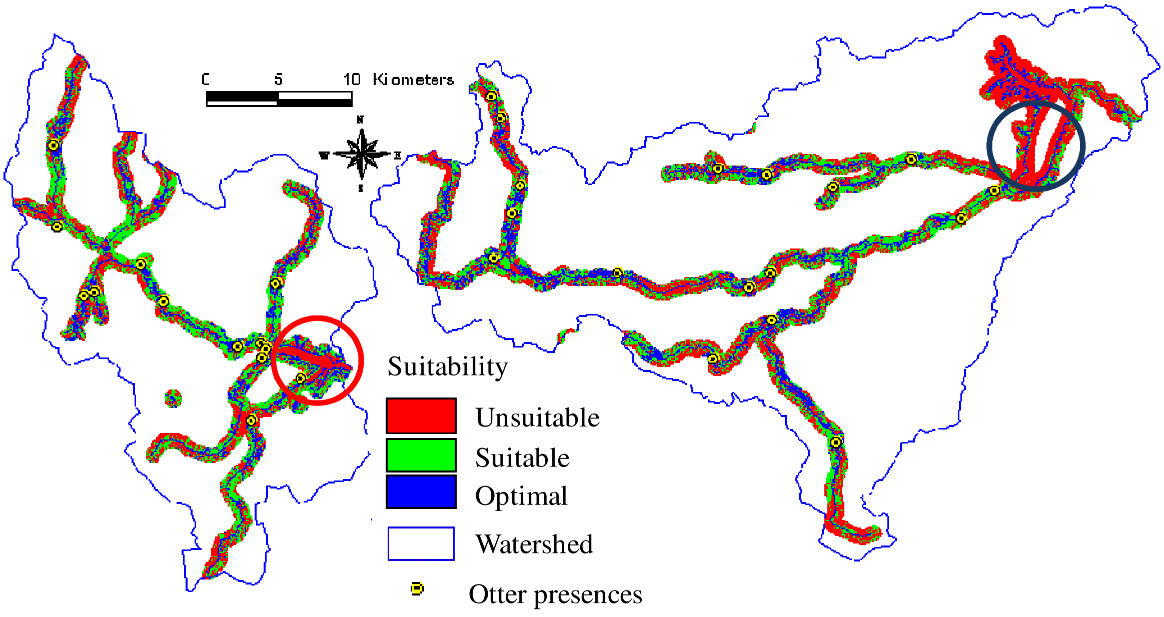

Figure X.3 – Habitat Suitability Map for the two test areas. On the left the High Agri River on the right the High Sinni River: in the red circle the Pertusillo Lake, in the blue circle the Monte Cotugno Lake.

The FF analysis (Figure X.4a) shows for the High Agri River a structure that clearly denotes an anthropogenic influence. The highest functionality levels are located along short segments in proximity of the river source and close to the Pertusillo Lake (areas with a lower agricultural and urban presence). On the contrary, a long river segment having low functionality is present in the territory portion with the highest urbanization and agricultural activity (see Figure X.2). Such a segment is regulated with riverbanks in concrete; notwithstanding, due to a diffuse riparian recolonization inside the artificial riverbanks, it corresponds to a mixed structure in term of Habitat Suitability allowing for the Otter presence. The High Sinni River (Figure X.4a, right) shows a different structure, coherent with the more natural texture of its territory. The river axis belongs for the major part to the highest functionality classes. Segments of medium level (classes II-III and III) are located close to the two Lakes (at the extremities of the river sector), where are concentrated the bigger urbanized areas and along the river portions characterized by a large scarcely vegetated riverbed. The functionality maps reclassified for the integration step (Figure X.4b) better highlight the differences between the two sub-basins.

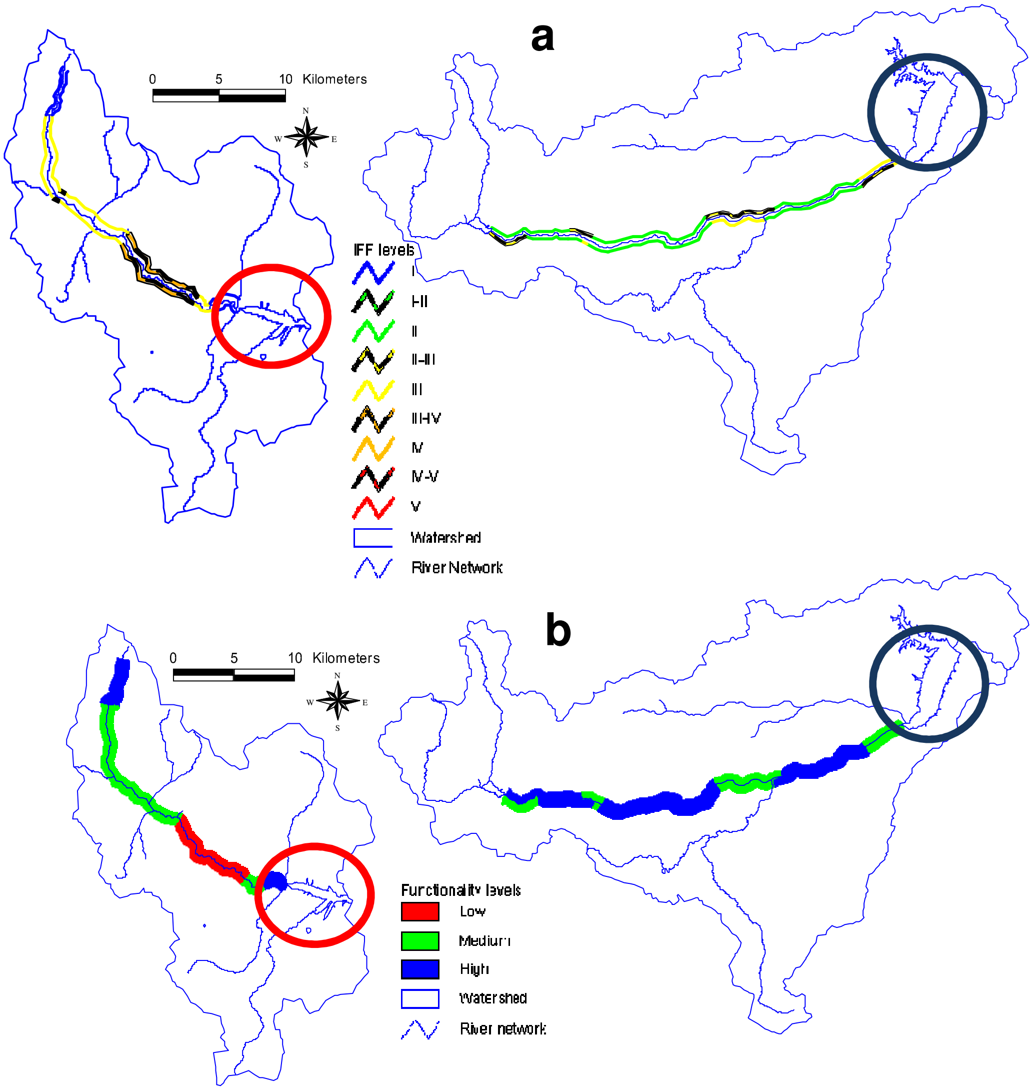

Figure X.4 - Fluvial Functionality Map for the two test areas. On the left the High Agri River on the right the High Sinni River: in the red circle the Pertusillo Lake, in the blue circle the Monte Cotugno Lake. On the top of the figure (a) are depicted all the classes provided by the application of the Italian standard protocol for FF; on the bottom (b), are shown the relative maps reclassified into three levels of functionality from the lowest to the highest.

The integrated vulnerability analysis taking into account information coming both from the broad-scale HS analyses and the fine-scale FF analysis summarizes the fluvial ecological criticalness of the two layers. The obtained vulnerability levels are shown in Figure X.5. The VU results underline for the High Agri River, in spite of the actual riparian vegetation presence, the crucial vulnerability of the central part of the sub-basin managed in concrete emphasizing the influence of the local aspects (see FF analysis) in this portion. In addition, even if the medium level is well spread in the remnant part of the river, it is possible to observe many highly vulnerable small portions inside it. In this case the major influence in enhancing the vulnerability level is given by the presence of patches unsuitable for the Otter habitat.

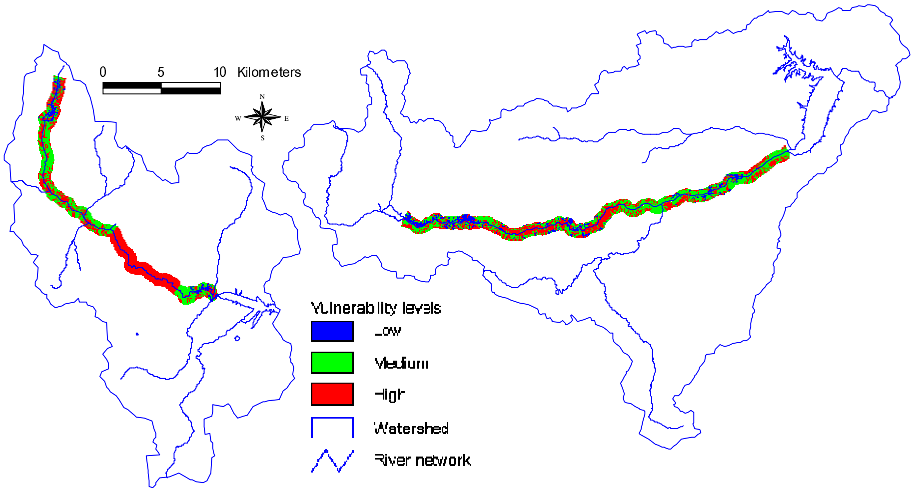

Figure X.5 - Map of Vulnerability (VU) for the two test areas. On the left the High Agri River on the right the High Sinni River: in the red circle the Pertusillo Lake, in the blue circle the Monte Cotugno Lake. Each level of vulnerability corresponds to a different priority in term of intervention needs.

Such an aspect seems to be the most important in regulating the vulnerability in the High Sinni River, since fluvial functionality does not give evidence of criticalness (see Figure X.4). In this territory, the percentage of unsuitable habitats represent a relevant weight in determining the overall increasing of the fluvial vulnerability (Figure X.5 on the right); as already underlined, it shows the major percentage of low suitability sites in spite of the more natural land cover structure. The map shows long compacted clusters with high VU levels and a heavy mixed structure of the three different levels in the remnant part of the river.

The obtained results allows for considering the information obtained by the proposed integrated VU analysis a useful tool in term of prioritization for intervention needs. In other words, where a high vulnerability is found the interested area must take precedence in term of intervention and/or management activities.

The assessment of this provided prioritization was also evaluated in term of fragmentation representativeness. The results of the Landscape Metrics analysis are shown in Figures X.6 and X.7 where is represented the relative behaviour of landscape metric values moving from the low to the high level of vulnerability.

Since a wide literature underlines that fragmentation is a major threats for the environmental equilibrium and may significantly alter ecological processes and biological communities (see e.g. Collinge, 1996; Marvier et al., 2004; Laurance, 2008), we expected that the higher the vulnerability, the higher the fragmentation suggested by the metrics. For a comparison, the evaluation was also performed on the separated suitability and functionality components.

For both the sub-basins, there is not a strict correspondence between the HS (Figure X.3) and FF (Figure X.4b) levels and the continuous increase or decrease of the corresponding landscape metric values. This is particularly evident for HS levels, which clearly shows a non continuity in the relative increase or decrease. On the contrary, a clear relationship between vulnerability and fragmentation degree relative strength is observed.

In detail, metrics related to Contagion/Interspersion describe an increasing disaggregation (Contagion reduction) and subdivision (Division increase) of the sub-landscapes from low to high

VU levels (Figure X.6). Similarly, there is an increase of the number of patches, even if it is less pronounced for the less vulnerable and more natural High Sinni River. Shannon Diversity Index (SHDI) and Shannon Evenness Index (SHEI) also corroborate the representativeness of fragmentation (Figure X.7). Such indices are sensitive to the landscape extension (see e.g. Fischer and Lindenmayer, 2007; McGarigal et al., 2002; Ramezani and Holm, 2011) and normally tend to lower values for small landscapes as the analyzed ones. High values of these indices, then, testify the presence of a corresponding high number of patches belonging to different land covers (presence of fragmentation).

A small deviation from the expected behaviour was only found for the diversity index (SHDI) related to the Sinni sub-basin, where the metric for the high VU level is only related to the structure of low suitability areas.

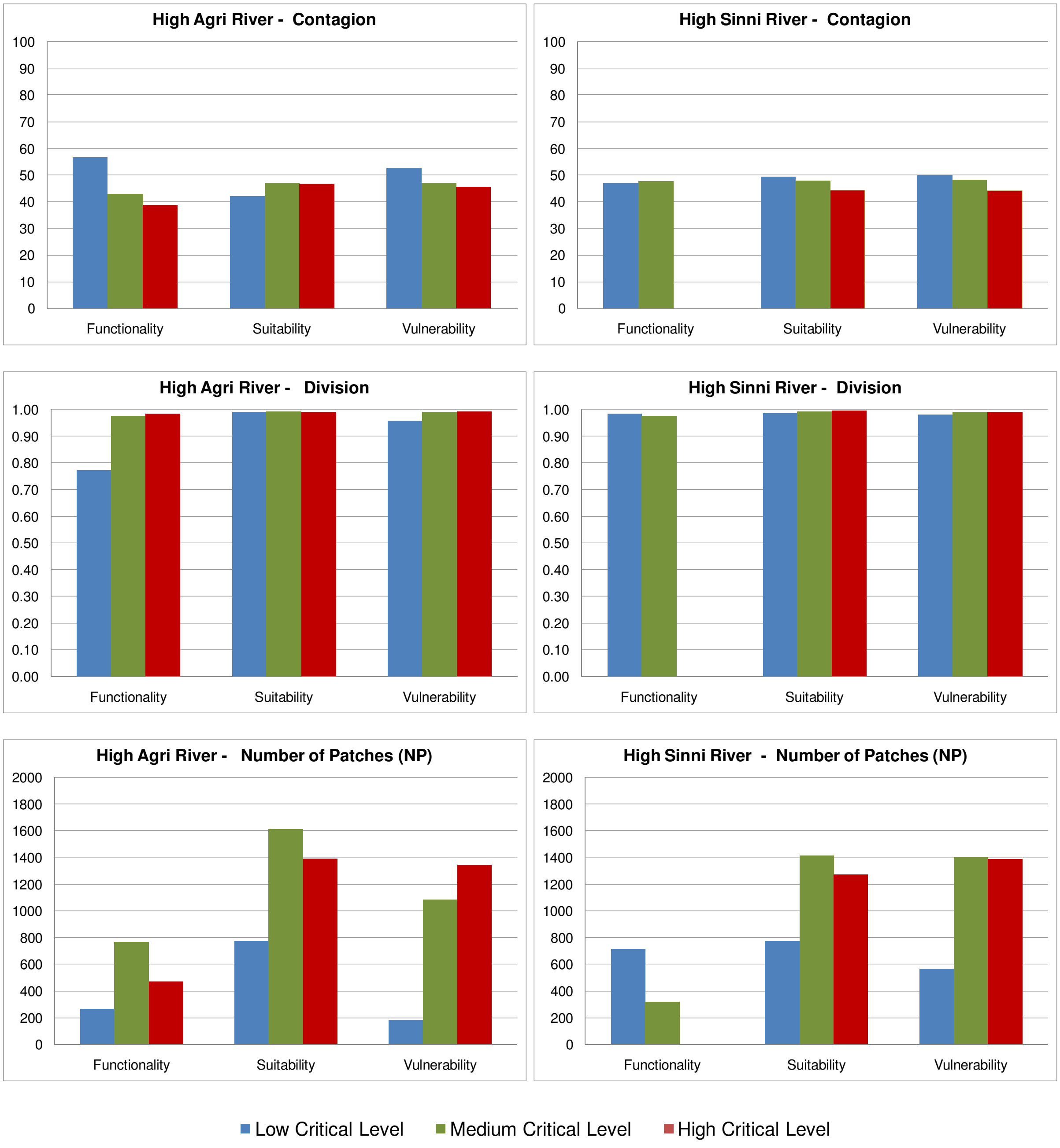

Figure X.6 – Contagion/Interspersion and Area/Density Landscape metrics performed for the sub-landscapes represented by the three levels of suitability (HS), functionality (FF), and vulnerability (VU), respectively.

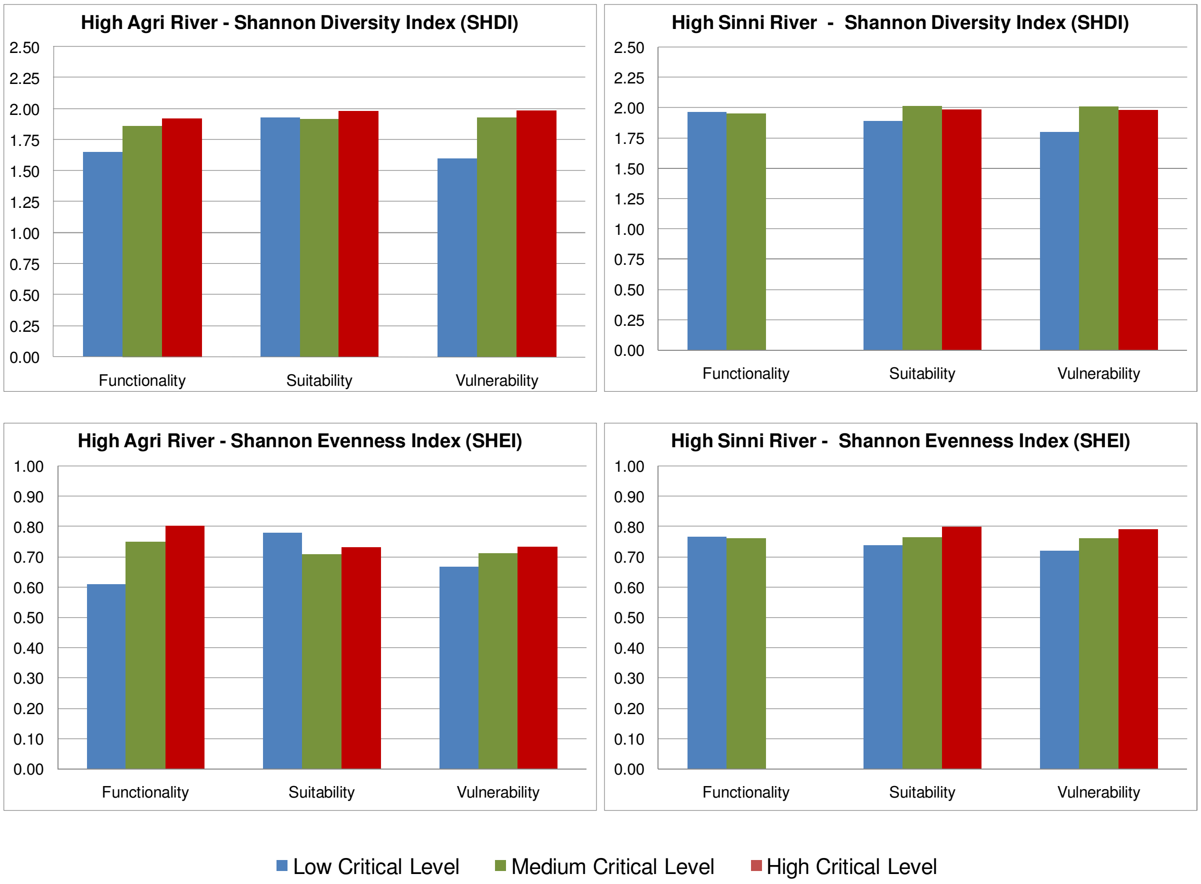

Figure X.7 – Diversity Landscape metrics performed for the sub-landscapes represented by the three levels of suitability (HS), functionality (FF), and vulnerability (VU), respectively.

X.3 Conclusions

The proposed methodology, based on the integration of information deriving from both watershed (HS) and river ecosystem (FF) layers, demonstrated to provide concise and effective information on the prioritization of fluvial vulnerability (VU), spatially located and classified in different levels. Since such a prioritization still represents a crucial challenge for the environmental management (see e.g. Mainstone, 2010; Thompson, 2010; Suding, 2011), the method effectively contributes to that debate and allows for calibrating management activities and for evaluating the urgency of environmental restoration interventions.

The capability of VU to resume and emphasize the ecological criticalness related to habitat suitability and fluvial functionality confirms the hypothesis that for a multilayered system, such as the river-watershed system, an integrated approach is more efficient than separated analyses, in agreement with the “Emergent Property Principle” (Odum and Barret, 1971) of the classical ecology.

The comparison of the results obtained on the two sub-basins (one with more human presence, and the other with more natural structure) confirm the usefulness of the proposed integrated approach in different environmental conditions. Further tests on other river basins, also in other countries (using different fluvial functionality indices), and on wider set of landscape metrics are needed to provide the necessary objectivity to consider the proposed methodology a powerful tool for final stake-holders.

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CHAPTER 4

ANALYSIS OF LANDSCAPE STRUCTURE AND CONNECTIVITY AT WATERSHED SCALE

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ABSTRACT

From a holistic perspective, a river ecosystem and its surrounding landscape can be considered as a unique and continuous system where the status of each element strongly conditions the healthiness of the others: e.g. in presence of a landscape with mature vegetation fragmented and low connected and also of a degraded riparian buffer, the river auto-depurating functioning results heavily compromised.

The assessment of fluvial functionality jointly with vegetation cover structure and connectivity, therefore, become fundamental in order to point out different levels of watershed vulnerability.

For analyzing the vulnerability of a fluvial basin at different hierarchical levels (patch and class), we propose an approach that integrates satellite and field data. It was tested on the upper Sinni River watershed (about 1,600 km^2) in Southern Italy.

The assessment of landscape vegetation cover structure and connectivity was performed on a detailed land cover map derived from multispectral satellite data and elaborating different landscape metrics. At river ecosystem level, we evaluated the fluvial functionality by performing field surveys based on the assessment of the Riparian Channel Inventory index adapted for Italian environments (IFF).

The landscape metrics analysis revealed that the portions of the territory closest to the river show a high level of fragmentation mainly concerning the transitional vegetation. The IFF values underlined a river functionality strongly influenced by both the riparian vegetation status and the watershed land cover structure. By classifying and integrating in a GIS environment the obtained results, we implemented the watershed vulnerability map suitable for supporting monitoring and management activities at basin scale.

KEY WORDS: landscape metrics, satellite data, IFF, vulnerability, watershed.

INTRODUCTION

The European Directive 2000/60/EC clearly establishes the importance of an integrated communitarian policy about waters, which must take into account the fragility of aquatic ecosystems in general and highlights that all the instruments have to be applied at watershed level because of the links existing inside such systems.

From this perspective, it is important to consider the role played by rivers in landscapes. For example, the presence/absence of riparian forests affects species habitat and movements, enhances species diversity, improves water quality, etc [1], [2]. All these functions are strictly related to the fluvial structure; moreover, such ecosystems are considered as dynamic mosaics of spatial elements and ecological processes hierarchically organised. Rivers and their surrounding territories have to be considered as integrated ecological systems and not only as "corridors" for the landscape [3]. It is also enhanced that for such an interaction a degraded landscape causes a damaged river and vice versa [4]. Landscape transformations are regarded as a very important threat for the river health; moreover, recent studies have underlined the influence of land cover arrangements on fluvial ecosystems [5], [6], [7].

Starting from the considerations quoted so far, it is intuitive the importance of an evaluation of vegetation cover structure and connectivity for assessing the ecological status of a fluvial basin as well as of analyses which take into account the aspects of functionality of the river ecosystem.

In this paper we propose an approach that integrates satellite and field survey data analyses in order to point out the fragility of a watershed from a holistic perspective. The information carried out can be read on levels of watershed vulnerability giving an efficient support for monitoring and management activities at basin scale.

MATERIALS AND METHODS

The investigation was performed on the upper Sinni River basin (about 1,600 km2), located in Basilicata Region, Southern Italy (Figure 1). The South-Western part of the basin presents a landscape with typical mountainous characteristics and a quite low anthropical presence; it is characterized by few patches of pastures and by very large areas covered by forests and transitional woodland shrubs, mainly belonging to the Pollino National Park, and showing a positive persistence in vegetation activity [8], [9]. In the level areas, the man made patches become slightly larger mainly representing cultivated areas arranged with sparsely vegetated areas and natural grasslands.

Northwards such areas border badlands formations characterized by strong erosional processes largely affecting natural vegetation [10], [11], [12].

Along the river, many interesting environments are present: places with turbulent and fast running waters, mainly populated by *Salmo trutta* spp., as well as sites with a very luxuriant vegetation and wider riverbed where we can found rare species such as *Lutra lutra* and *Ardea cinerea*.

The Landscape Ecology analyses

The assessment of landscape vegetation structure and connectivity was performed on a detailed land cover map obtained by classifying a multispectral satellite summer image acquired from the Landsat 5 TM (Thematic Mapper) sensor (spatial resolution of 30 m). To perform the classification a hybrid classification approach was used, since we experienced as very useful for high heterogeneous territories [13].

A preliminary unsupervised classification was performed by using the ISODATA algorithm to obtain a set of unsupervised training sites. Other training areas were identified based on field territory knowledge obtaining thus the complete set of training signatures. By using the Maximum Likelihood supervised procedure, we performed the final classification (Figure 2).

The land cover map obtained from this procedure has been the basis for landscape metrics calculation. Since the aim of the work is to evaluate the general vulnerability of the landscape vegetation structure, among the several existing metrics we choose a subset of them which gives information about the aspects of landscape structure considered more critical, such as the shape, the connectivity, the interspersion.

We calculated at patch level the FRAC (Fractal Dimension Index) and SHAPE (Shape Index) and at class level the IJI (Interspersion Juxtaposition Index), PLADJ (Percentage of Like Adjacencies) and COHESION (Patch Cohesion Index) indices. For the class level, the calculation was performed for the more structured vegetations: forested areas, transitional woodland-shrubs, shrubs.

All the computations were executed by using the software FRAGSTATS [14].

In a GIS environment the elaborated indices were reclassified into three ranges from 0 (null) to 3 (maximum) in term of vulnerability meaning.

Such classified indices were mapped and integrated by taking into account the maximum frequency at class level and the majority at patch level. The vulnerability maps at patch and class level have been further integrated by using the geometric mean to obtain the final vulnerability map.

The IFF field data

At river ecosystem level, we evaluated the fluvial functionality by performing field surveys based on the assessment of the Riparian Channel Inventory index adapted for Italian environments (IFF). The IFF index derives from the RCE-I (Riparian Channel Inventory), conceived at the end of the 80's by R. C. Petersen, of the Limnology Institute of the Lund University in Sweden and has been defined for the Italian rivers based on its application on several different Italian typologies. In the present study, we utilized the index version published on 2000 [15].

The IFF index considers all the features of a fluvial or stream habitat: land use, vegetation riparian buffer, biological characteristics, hydrological and hydraulic characteristics and has been widely applied in Italy to all river typologies. Such an index is carried out by walking along the entire river from the mouth to the source and observing the variations in the different characteristics of interest. The IFF is obtained assigning different functionality scores by answering to 14 questions regarding the various aspects of the fluvial habitat.

The total score of the index provides a value, which corresponds to different levels of functionality ranging from the best (I class) to the worst (V class); also four interclasses are present, e.g., I-II, II-III, etc., (Table1).

Each class can be mapped along the two riverbanks providing a user-friendly interpretation also for non-experts and thus it is really useful for final decision-makers in fluvial resource management. For the present work, also the relative weight of the different aspects considered by the index was calculated (Table2).

RESULTS AND DISCUSSION

In Figure 3 and 4 is possible to see the elaborated maps at patch level (SHAPE and FRAC) as well as the indices calculated at class level (IJI, PLADJ, COHESION).

The analysis of patch structure and perimeter regularity allows for the identifying of two types of vulnerable areas. The first ones correspond to natural vegetation (e.g. forested and transitional areas) showing a higher regularity that suggests an involution of the interested patches and, therefore, a degradation of such natural habitats. The second ones concern anthropic land covers (e.g. agricultural areas) showing a lower regularity and suggesting the presence of colonization phenomena, which act against more natural surroundings (increasing anthropic pressure).

At class level, it is possible to notice that the most vulnerable areas can be identified mainly in correspondence to the sclerophyllous vegetation; transitional and forested areas show a general medium and low level of the vulnerability respectively.

From the integration of the maps described so far, we obtained the final vulnerability map (Figure 5). By analyzing the vulnerability levels jointly with the original indices, it is possible to observe that the forested areas generally confirm a low level of vulnerability, but also present large areas with a medium level. Such areas are those influenced by the higher shape regularity at patch level, corroborating the hypothesis of an anthropical influence on the sites.

In particular, in the north-western area of the studied territory we found a very large forested patch (Malboschetto Wood within the Pollino National Park), located in proximity of the main fluvial axis, which shows a very regular shape of its perimeter.

Schlerophyllous coverages confirm what already found at class level; in addition, also transitional woodland-shrubs have numerous portions that belong to the most critical levels. Many high vulnerable patches of such covers are located in the neighbourhoods of the river and very often in correspondence to its critical segments in term of functionality (see IFF lines), especially along the right bank of the river, which also presents a functionality level considerably lower than that showed along the left river bank. Furthermore, very long segments of lower functionality are localized in correspondence to forested areas increasing the vulnerability of those portions of the territory.

Such a situation is confirmed by the analysis of IFF questions (Table 2) underling that the functional group of questions related to the riparian vegetation status and the land use of the watershed close to the river contributes for about the 55% in term of negative scores on the total of the detected negative answers.

CONCLUSIONS

The proposed approach based on the integration of satellite and field data seems to be promising for supporting monitoring and management activities at basin scale.

For our test area, the landscape metrics analysis revealed that the portions of the territory closest to the river show a high level of fragmentation mainly concerning the transitional vegetation; such a configuration decreases the depurating power of structured vegetation. The obtained IFF index values confirm that the River functionality is strongly influenced by both the riparian vegetation status and the watershed land cover structure.

The main peculiarity of the proposed approach is represented by the easy exportability to other environments by selecting the most suitable protocol for measuring the river functionality and by a user-friendly interpretation also for non-experts of the produced vulnerability map, which can represent a precious support for final decision-makers involved in fluvial resource management.

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TABLE 1

IFF Score	Functionality level classes	Functionality	Colours
261 – 300	I	Very good	Blue line
251 – 260	I – II	Very good - Good	Green/Blue line
201 – 250	II	Good	Green line
181 – 200	II – III	Good – Mediocre	Yellow/Green line
121 – 180	III	Mediocre	Yellow line
101 – 120	III – IV	Mediocre – Poor	Orange/Yellow line
61 – 100	IV	Poor	Orange line
51 – 60	IV – V	Poor – Very poor	Red/Orange line
14 – 50	V	Very poor	Red line

TABLE 2

Functional Group of Questions	**Characteristics**	**Relative Weight (%)**
1 – 4	Watershed land use and riparian vegetation status	54,9
5 – 6	Hydrological and hydraulic elements	16,1
7 – 11	Stream morphology	21
12 – 14	Biological elements	8

FIGURE 1

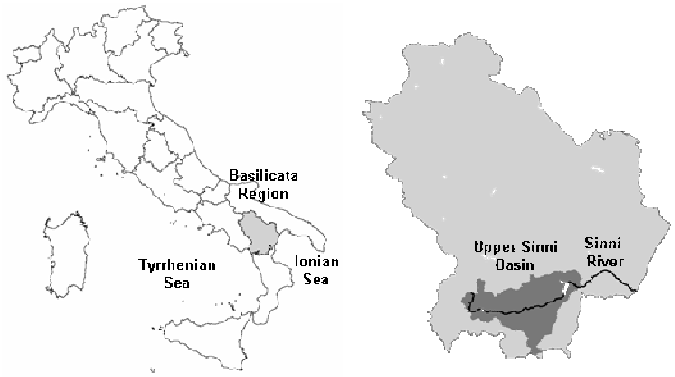

FIGURE 2

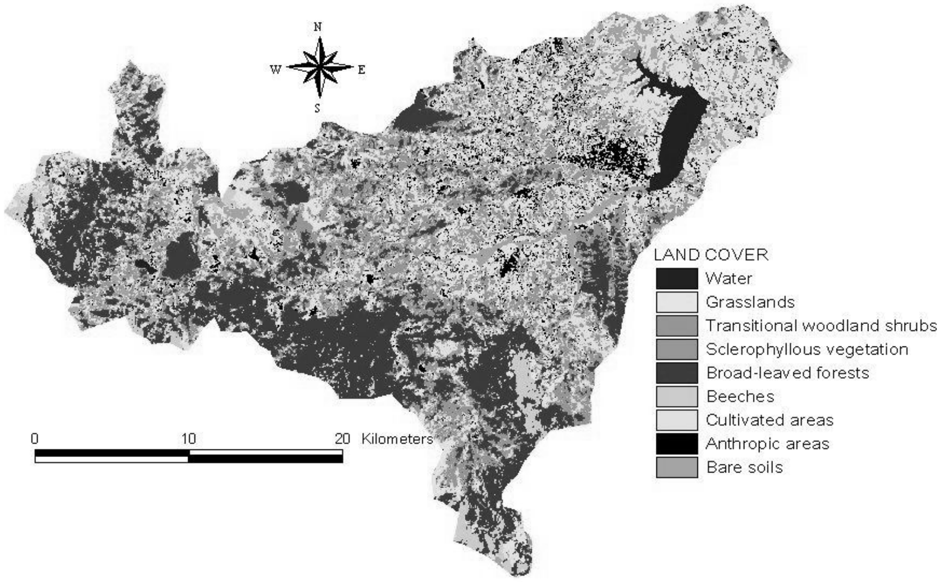

FIGURE 3

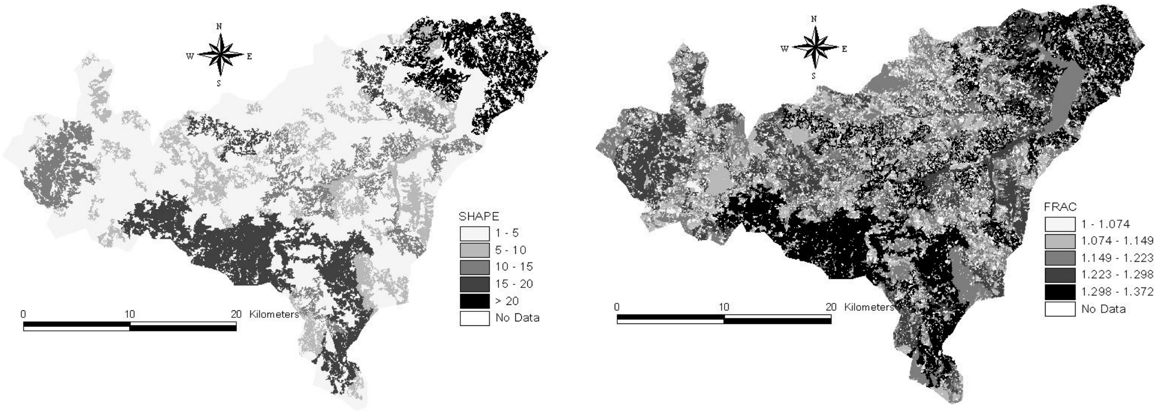
N
W
E
S
SHAPE
1 - 5
5 - 10
10 - 15
15 - 20
> 20
No Data
0
10
20
Kilometers
N
W
E
S
FRAC
1 - 1.074
1.074 - 1.149
1.149 - 1.223
1.223 - 1.298
1.298 - 1.372
No Data
0
10
20
Kilometers

FIGURE 4

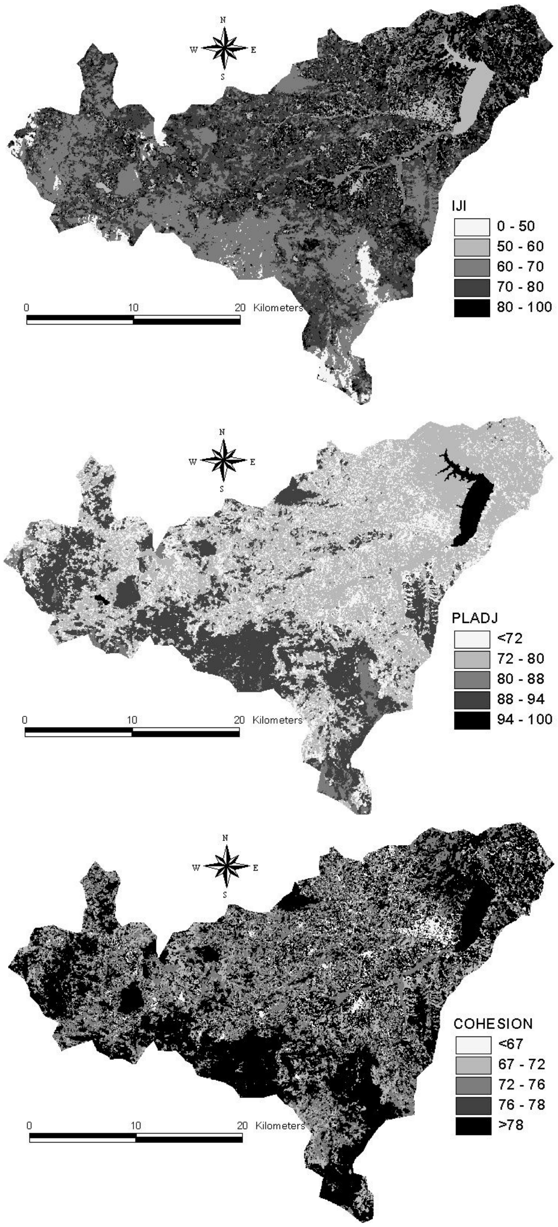
N
W
E
S
IJI
0 - 50
50 - 60
60 - 70
70 - 80
80 - 100
0
10
20 Kilometers
N
W
E
S
PLADJ
<72
72 - 80
80 - 88
88 - 94
94 - 100
0
10
20 Kilometers
N
W
E
S
COHESION
<67
67 - 72
72 - 76
76 - 78
>78
0
10
20 Kilometers

FIGURE 5

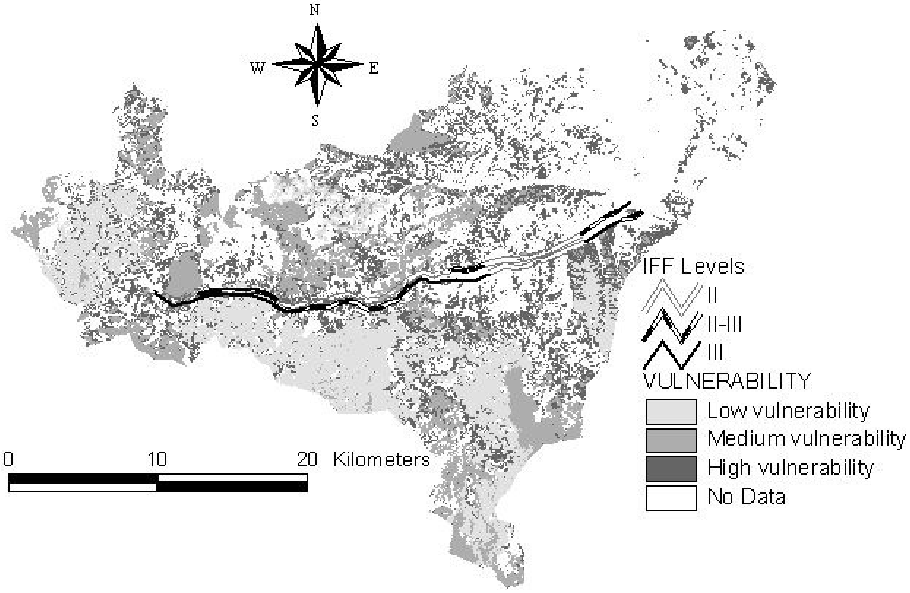
N
W
E
S
IFF Levels
II
II-III
III
VULNERABILITY
Low vulnerability
Medium vulnerability
High vulnerability
No Data
0
10
20
Kilometers

TABLE CAPTIONS

Table 1: Protocol of application of the Italian IFF index.

Table 2: Relative weight of the negative contributions per functional groups of IFF questions.

FIGURE CAPTIONS

Figure 1: Study area location: the upper Sinni River watershed

Figure 2: Land cover map of the upper Sinni River watershed

Figure 3: SHAPE (Shape Index) map (on the left) and FRAC (Fractal Dimension Index) map (on the right) calculated at patch level

Figure 4: Landscape Metrics calculated at class level. On the top the IJI (Interspersion Juxtaposition Index) (measure of interspersion), on the middle the PLADJ (Percentage of Like Adjacencies) (measure of dispersion) and on the bottom the COHESION (Patch Cohesion Index) (measure of physical connectedness).

Figure 5: Vulnerability map, obtained by integrating the information deriving from landscape metrics at class and patch level; the IFF classes are overlaid.

CHAPTER 5

HABITAT SUITABILITY FOR THE ENDANGERED EURASIAN OTTER IN SOUTHERN ITALIAN RIVER BASINS. A MULTI-TEMPORAL APPROACH

Introduction

Biodiversity is changing at an unprecedented rate as a complex response to several human-induced changes in the environment, and a correct management of endangered species is the most effective way for preserving satisfactory biodiversity levels (see e.g. Lopez-Toledo et al., 2011; Scott et al., 2010; Strayer & Dudgeon, 2010). It is widely acknowledged that habitat reduction is one of the major causes of species extinction (e.g. Ewers & Didham, 2006 and reference therein). Among the outmost important action for the in-situ conservation of endangered species are therefore the preservation/restoration of the species habitats and species reintroduction or restocking. When reintroductions or restocking are not possible the habitat protection/restoration plays the major role. This is the case of the semiacquatic Eurasian otter, *Lutra lutra* L., one of the most endangered mammals in Italy (Loy et al., 2010; Panzacchi et al., 2010). Decline of otter populations throughout Europe during the ’80 and the ’90 has been ascribed to pollution, direct persecution, habitat degradation (Conroy & Chanin, 2000; Kruuk, 2006; Macdonald & Mason 1994; Mason & Macdonald, 1986). Compared to other populations in Europe, the Italian population is recovering rather slowly (Prigioni et al. 2007). At present, the otter’s Italian range is confined to the southern part of the Italian peninsula. The residual population is relatively small and it is geographically isolated and genetically differentiated from other European populations (Prigioni et al. 2006a,b; Randi et al., 2003; Panzacchi et al, 2011). Given the current expansion trend of the species, it is important to identify rivers that can potentially host otters in the area and also to identify the rivers and land areas through which the species could disperse to better target conservation actions aimed at promoting the recovery of the species. A number of habitat suitability models predicting the distribution of the otter at different spatial scales have been proposed in the last decade (Boitani et al. 2002; Cianfrani et al., 2010; Cianfrani et al., 2011; Loy et al, 2009; Prenda & Granado-Lorencio, 1996). These models were either based on an expert based (Boitani et al., 2002; Loy et al., 2009) or inferential (Cianfrani et al., 2010; Cianfrani et al., 2011; Prenda & Granado-Lorencio 1996) approaches. The latter used current presence data to model the species niche.

Past distribution of this endangered species was not considered in any of these studies, and the consequences of landscape change in time on habitat suitability of menaced rare species (Demaría et al., 2004) is currently quite unexplored (Holmes & Sherry, 2001; Knick & Rotenberry, 2000).

As land use change constitutes one of the most severe causes of habitat loss for wildlife (Sala et al., 2000), we used past and current otter presence data and land use changes in time to model the otter distribution and to identify critical areas for the survival and expansion of the species. We were specifically interested in accounting for shifts in the distribution of otter occurred between the past contraction period and the current expansion phase (Loy et al., 2009). The basic idea was that insights on environmental predictors driving past and current species distribution would likely allow to better identify the limiting factors for the otter survival at a regional scale, and contribute to raise the accuracy and reliability of the model itself.

Methods

The habitat suitability for the European otter was assessed in the Italian core area of the species in a 21 years interval (from1985 to 2006), using an ensemble niche modelling approach (Le Lay et al., 2010; Thuiller, 2009). The model was based on two standard survey data (1985 and 2002-2006) and on land cover maps referred to the same periods.

Study area

The study area, included in the southern sub-population of the Italian otter range, is located in the Basilicata region and comprises five river catchments: Sinni, Agri, Cavone Basento and Bradano (Figure 1). This area played a crucial role for survival of the remnant otter population in the 70’-90’, and it still represents the most consistent part of its current range. Compared to present, otters in the 1985 were more scarce (Loy & Racana 1986; Loy et al., 2009; Loy et al., 2010; Panzacchi et al., 2010), occurring in only three over the five rivers cited above.

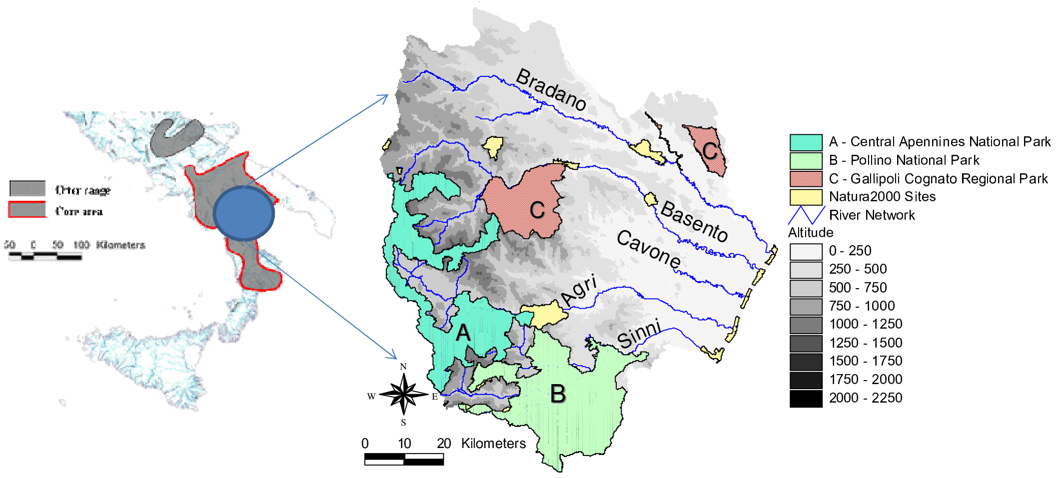

Figure 1: Left: study area. Right: the rivers included in the study region along with the Natura 2000 Sites and the EUAP areas. In yellow Natura 2000 Sites; in light blue, A, Central Apennines National Park; in light green, B, Pollino National Park; in pink, C, Gallipoli-Cognato Regional Park.

Input data

We used multi-temporal species occurrences across the study area collected during two standard surveys carried out on the years 1985 and 2006. The 1985 survey was run in 70 sites, 14 of which (20%) were found positive for the presence of otters (Loy and Racana, 1986). The 2002-2006 was run, for the interested area, on 86 sites, and 62 were found positive (72%) (Panzacchi et al., 2010) (Figure 2).

Since semiacquatic species are rarely found far from a crucial parameter as the water availability (Beja, 1992), the model was developed on a 300m buffer area along the main river stretches and lakes of the study area. Following previous studies (Prenda & Granado-Lorencio 1996, Boitani et al. 2002, Loy et al, 2009; Cianfrani et al., 2010; Cianfrani et al., 2011) land cover and topographic data (altitude, slope and aspect) were used as proxies of the ecological requirements of the otter (Table 1). Land-cover maps, related to the two survey periods, were derived from a supervised classification of high resolution satellite data (sensor Landsat-TM) (time acquisition for the images 10/08/1985 and 19/07/2006 respectively). Natural land cover classes (forests, shrubs, and sparse vegetation) were transformed into frequency maps computed on a moving circular window having the same diameter of the chosen buffer.

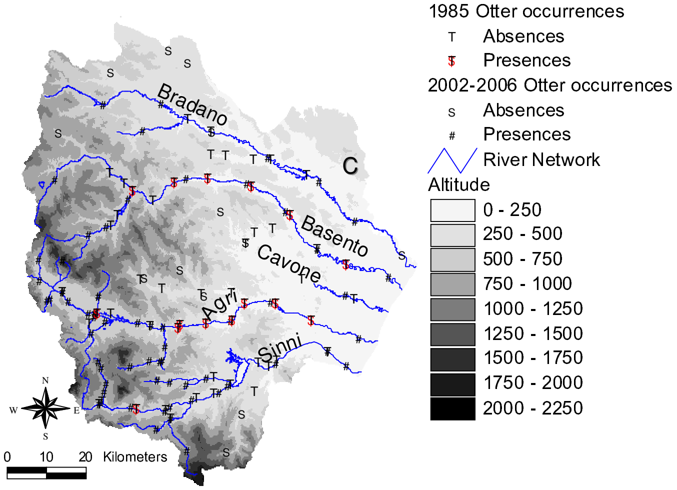

Figure 2: Presence absence data derived from otter surveys in 1985 (triangles) and 2006 (circles).

All the environmental predictors were tested to avoid the presence of autocorrelations. Input data were prepared as maps in a Geographic Information System (Arc-view 9.3; ESRI, Redlands,USA).

Modelling protocols

As the number of otter's presences in 1985 was very small and so low number of observations could produce over fitting of the multivariate model, we tested the multi-modelling ensemble (Guisan & Thuiller, 2005; Guisan et al., 2006; Thuiller, 2009) applying both a full-variable and a bivariate approach (Lomba et al., 2010). As suggested by MacKenzie et al (2003) and by Cianfrani et al. (2010), and in order to avoid the possibility of unreliable data, we did not consider the collected absences, but we used pseudo-absences randomly generated and appropriately weighted (Ferrier et al., 2002; Gibson, et al., 2007).

In the BIOMOD modelling platform (Thuiller, 2009) we fitted seven modelling techniques: (1) Artificial Neural Networks (ANN), (2) Generalized Linear Models (GLM), (3) Generalized Boosting Models (GBM), (4) Generalized Additive Models (GAM), (5) Classification Tree Analysis (CTA), (6) Multivariate Adaptive Regression Splines (MARS), and (7) Random Forest (RF). All models are implemented in the BIOMOD R package (version 2008.06.01; Thuiller, 2009). All seven techniques were used to fit the models for the full variables assembly and for the bi-variate combinations of the selected predictors (seven models for each of the 21 bi-variate combinations of predictors, giving 147 models for each year).

The performance of each model was evaluated by measuring the area under the curve (AUC) of the receiver-operating characteristic (ROC) (Fielding & Bell, 1997; Pearce & Ferrier, 2000). We used a split sample procedure based on 70% of the sample for calibration and the 30% left out for validation (see Thuiller, 2009). The AUC values were compared in order to choose and adopt the most accurate approach for the following analyses. In order to take into account the maximum of possible variance, the number of repetitions was set to 100.

The single ensemble models, both for the full variables and bivariate approaches, were obtained for each time period (1985 and 2006) using a weighting approach based on AUC values (Elith & Leathwick, 2007; Marmion et al., 2009).

For each modelling parameterization the BIOMOD platform provided a ranking of the variable importance (see the BIOMOD package documentation: http://r-forge.r-project.org/projects/biomod/). As reported in the software manual, variable importance is determined as 1 minus the correlation score between the original prediction and the prediction made with a permuted variable, and ranges between 0 (no importance) and 1 (high importance) (Thuiller, 2009).

Output suitability maps were reclassified as binary values (unsuitable and suitable) and final HS map were produced for each time period (1985 and 2002-06).

Land cover and Habitat suitability change in time

Multi-temporal analyses of land cover predictors and suitable habitat changes were performed by comparing HS maps produced for 1986 and 2006. Changes were described as changes in frequency of suitable areas that remained stable over time, areas where suitability increased, and areas where suitability decreased over time. Also, land cover maps produced for the two time periods were analyzed to evaluate changes over the 20 years in the main land cover classes (forests, cultivations, shrubs, and sparse vegetation).

Table 1: Environmental predictors used in the habitat suitability models and their link with otter requirements or disturbances

Variable Name	Ecological otter requirement /disturbance factor	Source	Resolution
Topographic factors	Food availability and hunting capacity	Digital Elevation Model (Basilicata region)	20 mt resampled at 30 mt
Cultivations	Anthropogenic pressure	Landsat-TM image (1985 and 2006)	30 mt
Forests	Riparian vegetation cover	Landsat-TM image (1985 and 2006)	30 mt
Shrubs	Riparian vegetation cover	Landsat-TM image (1985 and 2006)	30 mt
Sparse vegetation	Absence of riparian vegetation cover	Landsat-TM image (1985 and 2006)	30 mt

Results

The Area Under the Roc Curve (AUC) (Table 2) for the calibration of full-variables model was high for both years (AUC 1985= 0.83 ± 0.03; AUC 2006= 0.85 ± 0.02), while the performance of the bivariate model on both data sets was not as good as the full variable (AUC 1985 = 0.78 ± 0.05; AUC 2006 = 0.72 ± 0.03). Following these results we will describe and discuss in details the results from the full-variables ensemble model only.

Figure 3 shows the Habitat Suitability Maps obtained from 1985 and for 2006 data sets. In 1985 the suitable areas (total ha: 17885,97) were mainly located on the middle and low tracts of the river courses, and, some suitable patches were also present on vacant (Bradano) or scarcely populated (Sinni) river basins. The most important variables affecting otter's distribution in the year 1985 were altitude and slope, while land cover variables were weakly important (max value 0.341 for sparse vegetation class) (Table 2).

The extension of suitable areas increased in the year 2006 (total ha: 21213,72) and these were concentrated in the higher sectors of the river courses. The relative importance of topographic factors (altitude, slope and aspect) decreased while land cover predictors, such as cultivations and forests, became more important (Table 2).

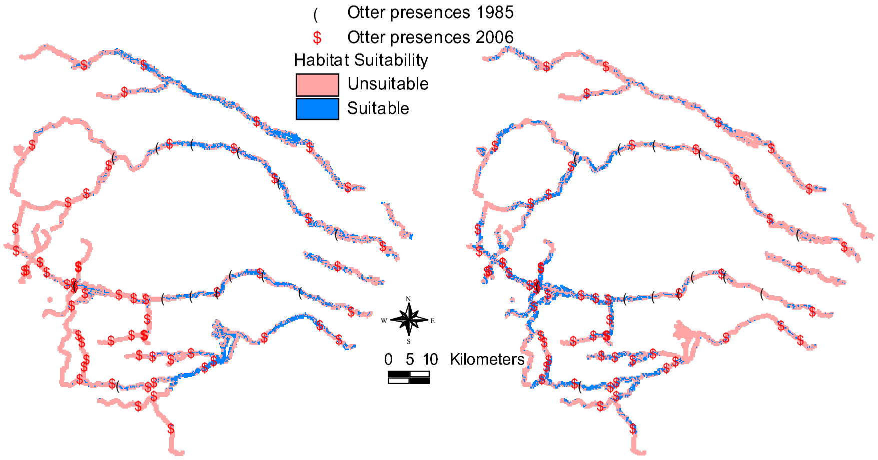

Figure 3: Suitable habitat distribution obtained for 1985 (left) and 2006 (right) survey periods.

Table 2: Coefficient vectors that describe the relative importance of each environmental predictor (see Table 1) used for full-variables calibration model. The values correspond to 1 minus the correlation score computed between the prediction made with all the variables and the predictions made by deleting the focal variable.

1985: AUC = 0.83 ± 0.03							
MODELS	Aspect	Slope	Altitude	Cultivations	Forests	Shrubs	Sparse vegetation
ANN	0.774	0.076	0.947	0.000	0.000	0.000	0.000
CTA	0.000	0.980	0.000	0.000	0.000	0.000	0.000
GAM	0.061	0.482	0.271	0.103	0.090	0.226	0.034
GBM	0.015	0.541	0.160	0.040	0.017	0.050	0.137
GLM	0.000	0.992	0.000	0.000	0.000	0.000	0.000
MARS	0.682	0.595	0.000	0.000	0.000	0.000	0.341
RF	0.231	0.292	0.058	0.069	0.040	0.012	0.149
2006: AUC = 0.85 ± 0.02							
MODELS	Aspect	Slope	Altitude	Cultivations	Forests	Shrubs	Sparse vegetation
ANN	0.547	0.272	0.342	0.287	0.001	0.004	0.011
CTA	0.297	0.000	0.387	0.611	0.237	0.000	0.000
GAM	0.207	0.165	0.175	0.313	0.122	0.000	0.022
GBM	0.207	0.050	0.062	0.340	0.115	0.036	0.015
GLM	0.298	0.226	0.000	0.642	0.000	0.000	0.000
MARS	0.304	0.423	0.274	0.253	0.000	0.214	0.000
RF	0.184	0.074	0.106	0.089	0.114	0.106	0.073

The comparison between the 1985 and 2006 HS maps suggests a considerable stability of the system, with the 63% of the territory that remained suitable in time. In addition, there was an improvement of suitability in the 20.5% of the modelled area, and only a small portion of the territory (16.5%) downgraded to unsuitable in the 20 years time span. Areas that became suitable in the 2006 were mainly represented by continuous patches in upper sectors of the river courses, and by small patches widespread all over the river stretches. The comparison between the actual distribution of otters and changes in suitability over time (Figure 4), evidenced a preferential expansion toward river sectors where suitability recently increased. In fact 76% of actual presences were included in areas that became only recently suitable, 21% in stable areas, and only 5% (n=3) in portions with decreasing suitability (Figure 4).

As topographic factors could not change over time, changes in suitability were related to changes in land cover. Comparison of land cover maps produced for years 1985 and 2006 revealed that in the last 20 years the 33% of the area showed land cover modification (Table 3). The main changes were represented by the expansion of forests, which increase on 12% of the area, and by the reduction of cultivated lands, which vanishes on 14% (Figure 4).

Table 3: Percentage of change per land cover category inside each river basin; the variations are reported as positive (+ increase), negative (- decrease) and absent (0).

LC % variations	**Cultivations**			**Sparse vegetation**			**Shrubs**			**Forests**		
	-	0	+	-	0	+	-	0	+	-	0	+
Bradano	22	70	8	4,2	94	1,8	0,29	99,7	0,01	16,1	74,3	9,6
Basento	29,1	54,5	16,4	22,7	63,1	14,2	6	77,3	16,7	8,7	75,22	16,1
Cavone	31,8	48	20,2	10	82	8	10	88	2	10	75,6	14,4
Agri	31	57	12	6,7	62,1	31,2	29	60	11	9,2	58	32,8
Sinni	25,5	58,5	16	17	70	13	6,3	75,7	18	8,6	64,7	26,7

Land cover changes, especially increment of forests, were concentrated in the south-western part of the region, including the first sectors of Agri, Sinni and Basento rivers, whereas cultivations decrease mainly concerned the Bradano river basin (Figure 4 and Table 3).

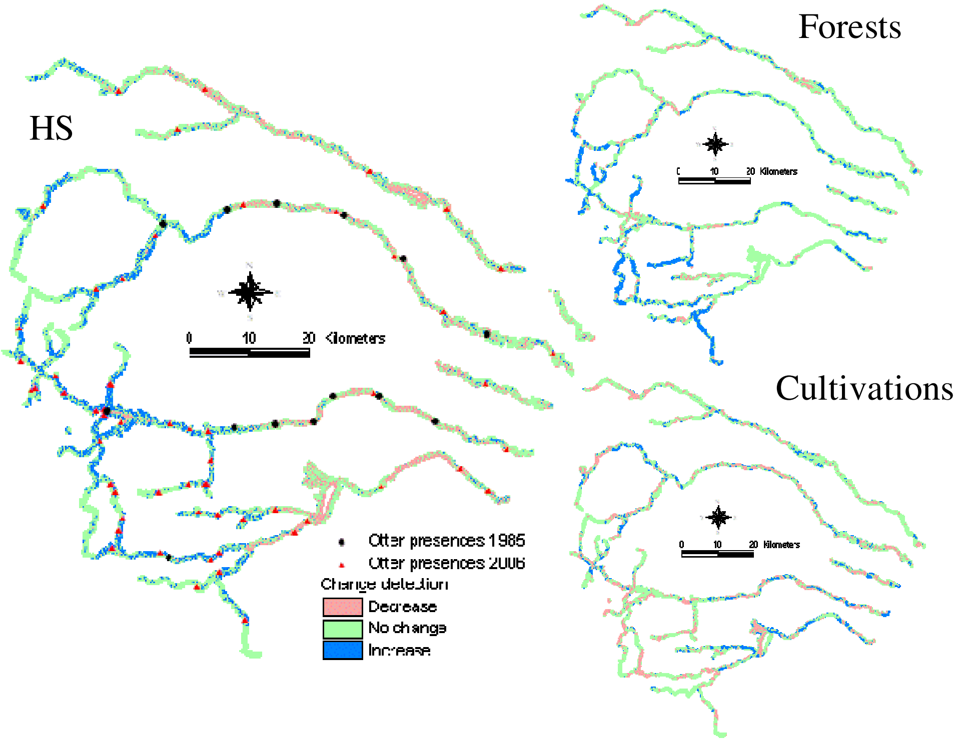

Figure 4: changes in otter habitat distribution and land cover between 1985 and 2006.

Discussion

Where the full variables approach produced accurate habitat suitability models the bi-variate approaches provided only fair results; furthermore, the bivariate approach was less accurate than the full variables one and very much time consuming (147 bivariate models to be performed instead of 7 full variable). Contrary to expectations, the multivariate full-variable model was more efficient in forecasting the present and past distribution of the otter in the study area, even with small occurrences past data set. This result stresses the possibility of applying such analyses for rare and endangered species, for which the availability of a large occurrences data represent the main constraint (Aitken et al 2007, Lomba et al. 2010).

More important, the multi temporal approach allowed to distinguish between different phenomena implied in the new expansion phase of the otter in the study area. It allowed to distinguish between the fraction of suitable vacant areas that were still suitable in the ’80, areas that became recently suitable, and suboptimal areas that were recently occupied by the expanding otters. The presence in the 1985 model of wide sectors of suitable habitat that resulted vacant, confirm the Italian otters decline that was at its maximum in the ’80. As described by Prigioni et al (2007), in the 80’ the species was disappearing from most of its former range, due to multiple threats, including direct persecution, food shortage, water pollution, and habitat destruction.

Legal protection, reduction of water pollutants determined a new expansion phases throughout Europe (Conroy & Chanin 2000; Kruuk, 2006; Macdonald & Mason 1994; Mason & Macdonald 1986), including Italy (Panzacchi et al., 2010). The recent expansion of the otter in areas that only recently became suitable stresses the importance of habitat restoration and conservations policies in favouring range and populations increase of endangered species in the last 20 years.

Finally, the small fraction of unsuitable areas recently occupied by the otter in the study area suggests that the species has reached its carrying capacity, filling all suitable habitats in the region, and that it is now expanding in suboptimal habitat. This results could be interpreted as an indirect sign that the core Italian otter population is now a source population for the neighbouring vacant basins, that could likely be colonized in the short term, on condition that it will find favourable habitats.

These evidences indicate the need to extend habitat modelling to the neighbouring vacant river basins, allowing to identify critical areas and evaluate the potentialities of expansion and habitat restoration that could promote otter range expansion, in accordance to the national action plan (Panzacchi et al., 2010; Loy et al., 2010).

Changes occurred in the land cover scenarios between 1985 and 2006 helped in identifying critical factors that can be managed to increase habitat suitability for otters. Being the topographic factors stable in time, it is reasonable to assume that the expansion of suitability was mainly driven by the expansions of forested areas, that provided shelters, increased the water quality (filter effect) and improved the connectivity among river basins (land matrix) (Carranza et al. 2012). This phenomenon is particularly evident in the Bradano basin, where the recent colonization by otters was likely driven by the replacement of agricultural areas with forests.

Specifically, the land cover multi-temporal analysis clearly highlighted that otter habitat quality highly improved through an expansion/restoration of forests and the reduction of cultivated fields in riparian belts, and suggest that little changes in land cover can have a large effect on the future expansion or local extinction of the species, by both increasing/reducing habitat availability.

The analysis of land cover change in time also provided important information about the efficiency and midterm consequences on the environmental planning. For example: the highest part of the Sinni River, that was included in 1987 in the Pollino National Park, showed a striking increase of suitable habitats for otters; while a long stretch of the Agri river, that was unsuitable in 1985 because of heavy riverbank managements in concrete, was recently colonized by otters likely following the recolonization by natural vegetation occurred inside such artificial riverbanks.

The relevance of vegetation cover on riverbanks is related to its multiple ecological roles in river ecosystems. It is important for providing resting and reproductive sites for otters, but it also can be considered an indirect indicator on food availability (Remonti et al., 2009), since we did not have reliable data on fish occurrence/density.

Limits of the present study are mainly related to the lack of direct data on feeding resources availability for otters, as fish biomass could not be included in the model, as it did not reveal any relation to otter occurrence (Cianfrani and Loy, unpublished data), likely due to the high variability in relation to sampling season and sampling site.

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