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Ranking European regions as providers of structural riparian corridors for conservation and management purposes

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ABSTRACT

Riparian zones are of utmost importance in providing a wide range of ecological and societal services. Among these, their role in maintaining landscape connectivity through ecological corridors for animals and plants is of major interest from a conservation and management perspective. This paper describes a methodology to identify European regions as providers of structural riparian corridors, and to rank them with reference to conservation priority. Physical riparian connectors among core habitat patches are identified through a recent segmentation technique, the Morphological Spatial Pattern Analysis. A multi-scale approach is followed by considering different edge distances to identify core and peripheral habitats for a range of hypothetical species. The ranking is performed using a simple set of indices that take into account the degree of environmental pressure and the presence of land protection schemes. An example for environmental reporting is carried out using European administrative regions and major rivers to summarize indices value. The approach is based on freely available software and simple metrics which can be easily reproduced in a GIS environment.

1. Introduction

Riparian zones are considered among the most valuable environments due to the wide range of ecological and societal services they provide. They play key roles in stream non-point nutrient and pollution reduction (Zhang et al., 2010), like diffuse pollution due rainfall runoff. They stabilize river bank and control floods (Bennett and Simon, 2004), together with hosting highly valuable natural habitats with rich biodiversity (NRC, 2002; Whitaker et al., 2000). In fragmented landscapes riparian zones are elements of utmost importance in maintaining biological connections for animals and plants (Gillies and Cassady St Clair, 2008), representing ecological corridors for species dispersal and migration, and contributing toward maintaining landscape connectivity (Naiman et al., 1993). This latter ecological function is of major interest for policy makers and environmental managers in order to define and implement large conservation and restoration initiatives, such as the European Green Infrastructure (Sundseth and Silwester, 2009) or continental-wide habitat assessments (Estreguil and Mouton, 2009).

In general ecological terms connectivity can be defined as the degree to which species movement is facilitated along resources and territory (Taylor et al., 1993). Although various meanings have been attributed to this term (see Fischer and Lindenmayer, 2007), the distinction between *functional* connectivity and *structural* connectivity is widely recognized. In a functional approach, movement and dispersal dynamics through habitat and non-habitat matrices are modelled and evaluated under consideration of specific behaviour of the species with the environment (Adriaensen et al., 2003). For example, the species ability to move through heterogeneous and fragmented landscapes offering different degrees of resistance to crossing (Hanski, 1994). In contrast, structural connectivity focuses on habitat spatial contiguity and arrangement, without necessarily including species-specific behaviour or ecological processes (Freemark et al., 2002). Structural connectivity is based on the underlying assumption that ensuring physical linkages among habitat patches may provide connectivity for the more fragmentation-sensitive species, and consequently also for species with high dispersal capability (Saura et al., 2011). The presence of a structural connection, however, does not necessarily imply also a functional connection.

The main objective of this work is to present a methodology to identify regions as providers of structural connectivity for stream riparian environments, and to perform a preliminary ranking for conservation. This is achieved by: (i) identifying riparian corridors as physical linkages between larger habitat patches at multiple scales, and (ii) by assessing a set of simple indices to rank corridor regions based on the degree of environmental pressure and presence of protection schemes. Indicators are calculated for Europe at 1-km scale, and then summarized over administrative regions and

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major continental rivers. Relying on the study of structural connectors partly resolves the issues related to species-specific dispersal dynamics, by focusing uniquely on habitat contiguity and physical structures (Vogt et al., 2007a). An analysis of multi-species functional connectivity at continental scale would in fact be extremely difficult, requiring a vast amount of data on multiple dispersal dynamics in heterogeneous landscapes and a massive processing effort. The potential of the proposed method is strengthened by the use of simple indices and of freely available software to perform image segmentation.

2. Materials and methods

2.1. European riparian zones data

Information on European stream riparian zones distribution was derived from a database recently developed by the European Commission Joint Research Centre (Clerici et al., 2011), hereafter RZ2000. The data have continental Europe extension and include both ‘river-floodplain’ systems as well as ‘stream-riparian’ networks of minor and ephemeral watercourses. Clerici et al. (2011) mapping model exploited a combination of multiple Earth Observation data in order to derive spatial estimates of input variables relevant to map riparian zones (hydrological connection, natural and semi-natural land-cover, vegetation, etc.). The RZ2000 model exploited an information fusion system, which assigns a degree of belonging to the riparian zone class using fuzzy membership functions (Zimmermann, 2001). Any riparian zone in the RZ2000 output is characterized by two fuzzy indices representing water influence (μ_W) and presence of natural vegetation (μ_V), together defining the degree of belonging to the riparian zones class. The producer accuracy is reported to be $p_{PA} = 84.5\% \pm 1.3\%$ at 95% confidence level, while user accuracy $p_{UA} = 72.6\% \pm 5.8\%$. The accuracy was derived using locations of riparian zones from independent ecological datasets, visual validation points (VISVAL) and LUCAS2009 data (Eurostat, 2009). The data exploited have a spatial resolution of 50 m.

2.2. Identifying structural riparian corridors

Structural corridors are defined as those landscape features which physically connect through habitat contiguity two or more areas large enough to contain interior habitat, i.e. ‘hubs’ (Benedict and McMahon, 2002) or ‘core areas’. The identification of riparian structural corridors and core riparian zones was performed exploiting the *Morphological Spatial Pattern Analysis* (MSPA), a segmentation technique recently developed by Soille and Vogt (2009). MSPA is based on morphological image processing techniques, already used in the detection of landscape spatial elements like structural and functional corridors in forests (Vogt et al., 2007a,b) and the US Green Infrastructure (Wickham et al., 2010). MSPA performs a segmentation of image objects (binary raster images representing foreground-background, e.g. habitat-non habitat) into seven different and mutually exclusive geometric categories (Soille and Vogt, 2009). The seven MSPA classes have the following properties:

- *Core*, inner foreground pixels beyond a defined distance d from foreground-background boundary.
- *Edge*, transition pixels between core and external non-core.
- *Perforation*, transition from core to internal background.
- *Bridge*, foreground pixels connecting at least two disjoint core areas.
- *Islet*, foreground patch too small to contain core.
- *Loop*, foreground pixels connecting a core area with itself.

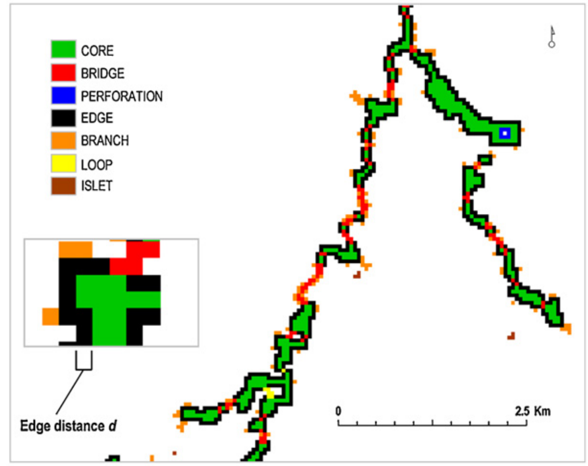

Fig. 1. Example of MSPA output from the riparian zones layer. The zoom to the left side of the image shows edge distance $d = 50$ m (1 pixel).

- *Branch*, foreground pixels linked to a core, but not connecting to another core.

These categories are obtained by computing a sequence of morphological operators (erosion, dilation, skeletonization) derived from mathematical morphology (Serra, 1982). The interpretation associated with the seven MSPA classes depends on the meaning of the input binary thematic layer.

In this study we focus on the *bridge* class, representing riparian corridors, and the *core* class (core riparian habitat). The identification of core pixels by MSPA is equivalent to applying an erosion operator to the foreground (riparian) pixels using a predetermined edge distance from the background (non riparian). Bridge pixels, instead, are identified under the geometrical property to connect two or more core areas (Fig. 1). All MSPA segmentation algorithms are explained in detail in Soille and Vogt (2009). The other structural categories identified by MSPA were not directly exploited for the purpose of this work. The MSPA segmentation was carried out using the software GUIDOS, freely available from the EC-JRC Forest Action website[1].

A key parameter which determines the assignment of the riparian pixels to the seven MSPA classes is the edge distance *d*. This distance, calculated beyond the riparian–non riparian boundary, controls the assignment to the core riparian areas and the edge pixels (edge habitat). Among others, it defines the minimum core size, and the internal (perforation) and external edge cells. In ecological systems the edge distance from core habitat is typically dependent on species: some perceive habitat edges at a smaller distance with respect to the non-habitat matrix, while others require a larger distance from the non-habitat to the inner core (Vogt et al., 2007a,b). Among the ecological edge effects we can mention changes in biotic conditions (humidity, illumination, etc.) or increased competition and predation (Tomimatsu and Ohara, 2004; Vaaland Burkey, 1993). From field studies on species dispersal dynamics, we can potentially derive estimates of ecological edge distances and minimum core area extension. In reality, this information is rarely available, and relying on empirical parameterizations to target hypothetical species is a widely followed strategy, especially in multi-scale analyses (Wickham et al., 2010; Saura et al., 2011). Three edge distances ($d = 50$, 100 and 200 m) were set in the MSPA multi-scale assessment. The interval covered by these values was

[1] http://forest.jrc.ec.europa.eu/download/software/guidos.

Table 1
Relative proportions (%) of MSPA classes by varying edge distance (Europe).

Edge distance d (m)	Core (%)	Islet (%)	Perforation (%)	Edge (%)	Loop (%)	Bridge (%)	Branch (%)
50	29.0	8.9	0.1	33.6	0.8	9.2	18.4
100	8.4	39.3	0.02	16.9	2.5	14.2	18.7
200	1.4	70.6	0.01	4.2	3.9	10.2	9.7

defined accordingly to the narrow lengthwise shape of riparian zones in Europe.

Requiring the MSPA a binary layer in input, the RZ2000 dataset, which is based on fuzzy indices, is processed to derive a dichotomic layer of riparian presence/absence. The riparian presence class is derived by applying the condition of positive values for both fuzzy indices ($\mu_W > 0$ AND $\mu_V > 0$). MSPA was run for the three edge distances considered, obtaining in input three MSPA mosaics for Europe at 50 m. An example of MSPA output is shown in Fig. 1.

2.3. Aggregated indices

The class bridge, which identifies structural riparian corridors, is extracted from the three MSPA mosaics and analyzed by means of aggregated indices (e.g. Nardo et al., 2005; Clerici et al., 2004). Combined information of multiple scales corridors aims at considering the perception of the environment from a number of hypothetical species, which perceive core and edge habitat at different scales. Aggregated indices provide valuable information by synthetizing ecological considerations for a larger set of species.

Calculations of aggregated indices to summarize and exploit the MSPA results were performed by means of simple metrics computed in a grid with 1 km × 1 km cells. A multi-scale structural corridors index (SC_c) is calculated per every grid cell c as a summation of the MSPA bridge class area (B_c) over the total of the cell area (S equal to 1 km^2), for the $n = 3$ scales analyzed:

$$SC_c = \sum_{i=1}^{n} \left(\frac{B_{c(n)}}{S} \right) \quad (1)$$

The index represents the total proportion of structural corridor presence in every cell c, as calculated for the three scales (edge distances) considered in this work.

The amount of multi-scales riparian corridors represented by SC_c is directly proportional to the extension of riparian zones present in the cell c. This means that high SC_c values will occur in areas with conditions that allow the presence of riparian zones, i.e. extended natural and semi-natural vegetated land and a dense river network.

Relevant information for management and conservation purpose should consider the presence of riparian structural corridors with respect to the level of neighbouring environmental pressure, i.e. stress from anthropogenic systems that negatively affect the natural environment. Riparian zones in regions with intense environmental pressure are more severely threatened, and play a crucial role in maintaining connectivity within a riparian network more prone to fragmentation (Gillies and Cassady St Clair, 2008). If we consider the proportion of urban and agricultural land-cover in the landscape as a reasonable proxy for anthropogenic pressure, it is possible to identify where significant presence of riparian structural corridors coexist with highly human-modified landscapes. The structural corridor metric SC_c can be integrated with information on the proportion of non-natural (artificial and agricultural) land-cover in the grid cell (A_c, expressed in %), as derived from the Corine Land-Cover 2000 dataset (Bossard et al., 2000). The structural corridors under pressure index (CP_c) is calculated for every cell c as:

$$CP_c = SC_c \cdot A_c \quad (2)$$

The value of CP_c is high with a large proportion of artificial and agricultural land-cover present in c. Consequently, higher cell rankings will indicate more critical situations towards a riparian conservation and management perspective.

Some of the riparian corridors analyzed are currently managed under a land protection scheme, such as natural parks or reserves. Therefore, it is of higher interest to identify and focus on those areas hosting corridors which are not located within the main European conservation network. Two pan-European datasets were exploited for this purpose: the Common Database on Designated Areas[2] (CDDA) and the Natura2000 network (EEA, 2011). The former considers the International Union for Conservation of Nature (IUCN) management categories, while the latter includes the EU-wide system of protected natural areas established under the Habitat Directive (92/43/EEC). The overall extension of main protected areas in Europe was derived by merging the two datasets. Using this layer it was calculated the proportion of protected

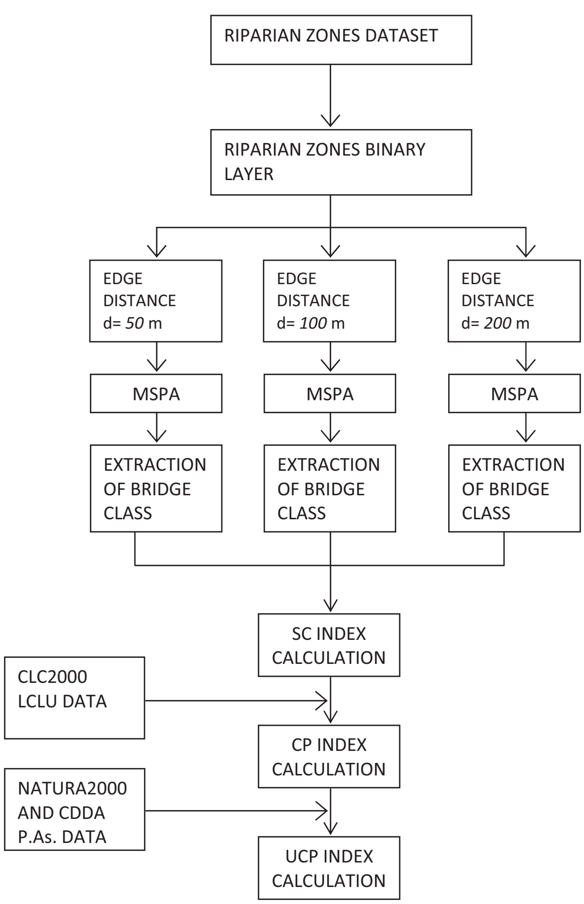

Fig. 2. Flow-chart representing the sequential operations in the riparian structural corridors assessment.

[2] Technical specifications available at EEA EIONET website. URL: http://dd.eionet.europa.eu/datasets/2445.

riparian zones with respect to their total amount in each cell (P_c). A new index was defined, which integrates CP_c with information on the degree of corridors protection:

$$UCP_c = \frac{CP_c}{P_c} \quad (3)$$

If P_c is zero (absence of protection schemes) it is assigned the same value of the minimum possible proportion, to avoid division by zero. A small proportion of protected riparian zones (denominator) will increase the overall value of the UCP_c index. High values of UCP_c correspond to a high ranking assigned to cell c, representing large presence of multi-scale riparian structural corridors, in condition of environmental pressure and with low degree of protection or complete lack thereof. In other words, cells with top UCP_c scores (higher cell ranking) represent potential priority regions with respect to conservation and management of riparian corridors.

A flow-chart representing the sequence of methodological operations is shown in Fig. 2.

In order to obtain a representation for European administrative units, the indicator values were summarized using the Europe Nomenclature of territorial units for statistics dataset, or NUTS (Regulation EC-N.1059/2003). NUTS level 3 (provincial) was adopted for most of the EU territory, however, for some countries (Germany, The Netherlands, Belgium, and United Kingdom) the NUTS 2 level was preferred to better harmonize for extension. The results were mapped applying a min–max standardization of the indices, to present rankings (scores) in a scale from 0 to 1 (Nardo et al., 2005):

$$I_i* = \frac{I_i - \min I_i}{\max I_i - \min I_i} \quad (4)$$

with I_i the index summation over NUTS i area and I_i^* the standardized value for i.

Major European rivers derived from the CCM dataset (Vogt et al., 2007c) were also used for reporting with the same procedure, and results presented.

3. Results and discussion

Landscape metrics are sensitive to spatial parameterization (Ostapowicz et al., 2008), like changes in pixel size (Wickham and Riitters, 1995) or edge distance. The change in edge value from 50 m till 200 m varied the relative abundances of the seven MSPA classes, and consequently also the amount and spatial arrangement of the corridors, represented by the bridge class (Fig. 3). The relative proportions of MSPA classes shows a notable decrease in the proportion of core and edge habitat, while the percentages of bridge cells does not show a monotonic behaviour (Table 1). Edges together with smaller core areas frequently combine to become bridges (e.g. Fig. 3). This is ecologically meaningful, considering that some riparian species need smaller extensions of interior habitat, associated to low d, to perform all necessary ecological functions. At the contrary, other species that need extended core areas and edge distance, can only exploit small riparian patches as corridors to reach larger core regions (Fig. 3c). The narrow structure and small dimension of the riparian zones is well reflected in the low relative proportion of core habitat at the three scales analyzed (29% to 1.4%, with increasing edge distance).

As expected, a large presence of riparian structural corridors is located in Northern European countries. Higher SC_c values occur in regions with a dense river network and extensive natural landscape (Sweden, Finland). Here the vast natural and semi-natural conditions present allow the formation of larger and denser riparian zone networks, increasing consequently the probability to find physical corridor structures. At the contrary, Ireland, England, northern Germany and Denmark particularly lack multi-scale structural corridors, due to the large presence of small and fragmented riparian zones (Clerici et al., 2011). The spatial distribution of the standardized SC_c index was resumed using NUTS administrative units (Fig. 4a).

The index CP_c shows a very dissimilar pattern from SC_c (Fig. 4b). Higher values are located in east Hungary, some provinces of Rumania and north Italy. In these regions large riparian zones and associated corridors occur in a landscape largely dominated by agriculture and artificial land-cover. At the contrary, Scandinavian countries are characterized by very low values due to the small amount of agricultural and urban land generally present. Top values of standardized CP_c for NUTS region are reported in Table 2.

The UCP_c indicator (Fig. 4c), which includes information on the protection of corridors, shows peak values in the Rumanian plains, provinces of northwest Italy and to a minor extent to Greece and France (Picardy, Champagne-Ardenne). Latvia also presents high values of this indicator. For this country, however, only 73.1% of the CCM2 river stream data used as input in the original riparian dataset

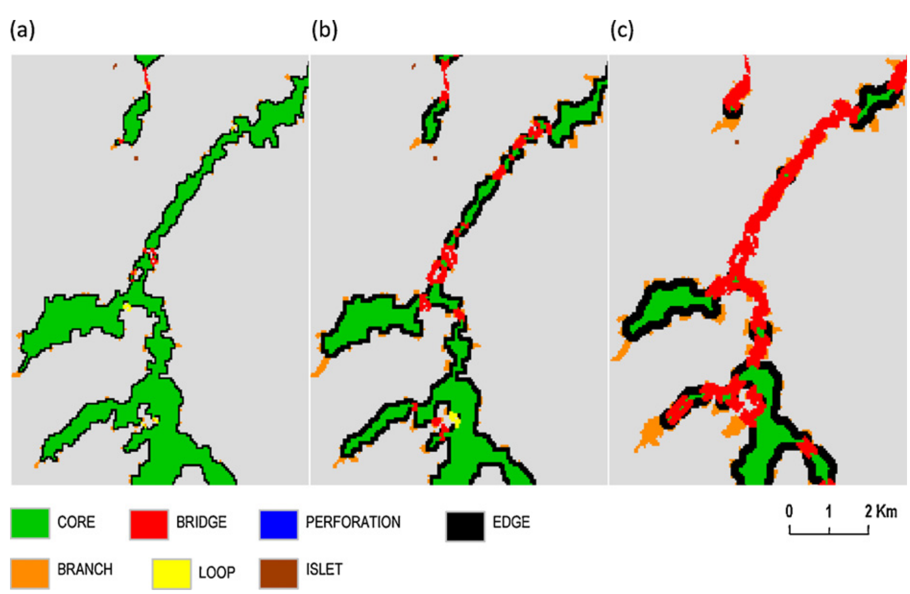

Fig. 3. Examples of MSPA output from the riparian zones layer, using three different edge distances: 50 m (a), 100 m (b) and 200 m (c). The changes in MSPA class assignment and bridge locations are evident.

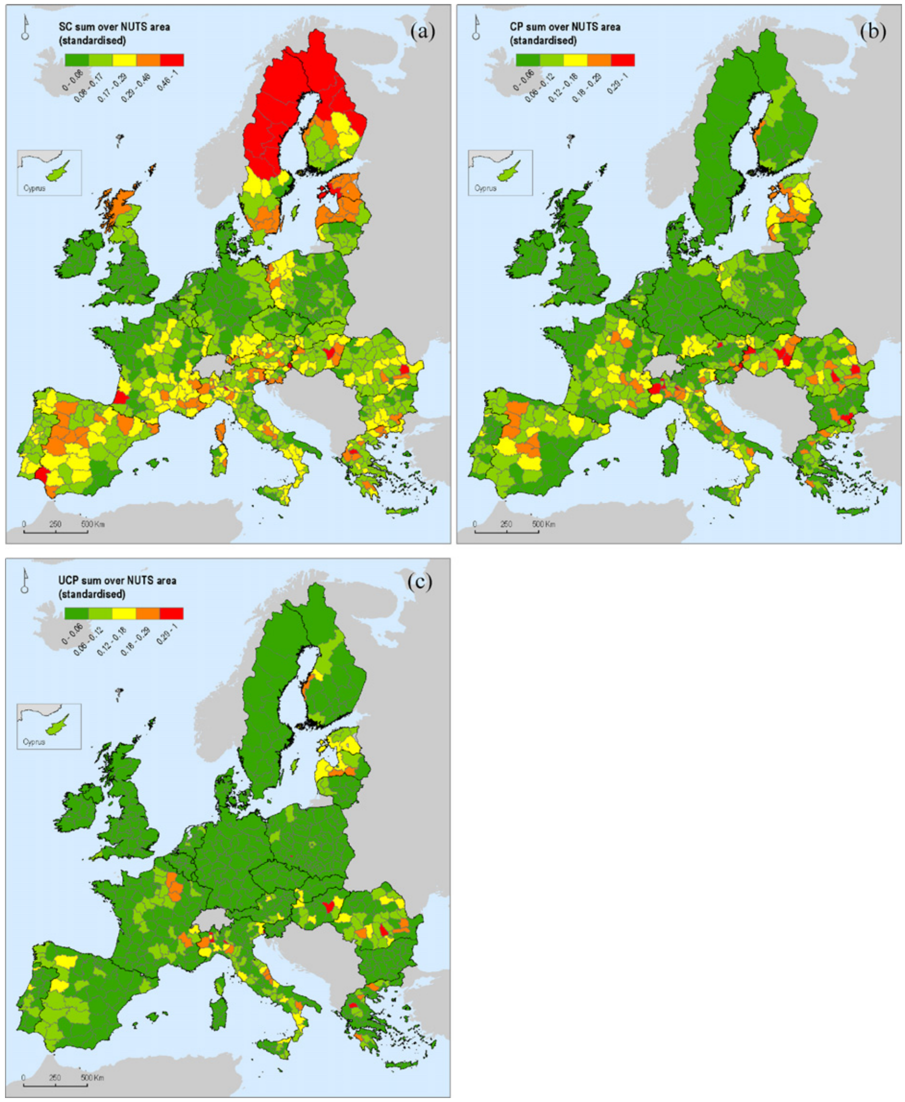

Fig. 4. Distribution of indices SC (a), CP (b) and UCP (c). Values refer to standardized sum over NUTS 2-3 area.

Table 2
Top CP and UCP values for NUTS 2–3 regions (standardized) and for the major European rivers.

Standardized CP sum		Standardized UCP sum	
NUTS code	NUTS Name (value)	NUTS code	NUTS Name (value)
ITD43	Gorizia (1)	ITD43	Gorizia (1)
HU322	Jasz-Nagykun-Szolnok (0.61)	RO313	Dâmbovita (0.45)
ITC49	Lodi (0.55)	ITC49	Lodi (0.42)
RO313	Dâmbovita (0.42)	HU322	Jasz-Nagygun-Szolnlk (0.34)
HU221	Gyor-Moson-Sopron (0.42)	ITC12	Vercelli (0.30)
HU332	Bekes (0.41)	GR131	Grevena (0.30)
SI011	Pomurska (0.39)	GR126	Serres (0.27)
BG422	Haskovo (0.35)	FI195	Pohjanmaa (0.25)
AT312	Linz-Wels (0.31)	ITC11	Torino (0.24)
ITC11	Torino (0.31)	ITF13	Pescara (0.24)
Standardized CP sum		Standardized UCP sum	
Country	River name (value)	Country	River name (value)
BG, GR	Maritsa (1)	RO	Ialomita (1)
HU, RO	Crisul,Koros (0.94)	E, PT	Zancara, Guadiana (0.71)
E, PT	Zancara, Guadiana (0.76)	HU, RO	Crisul, Koros (0.67)
F	Loire(0.69)	E, PT	Tajo (0.66)
E, PT	Tajo (0.68)	IT	Po (0.60)
IT	Po (0.56)	F	Arc, Isere (0.60)
RO,BG,HU,A,D	Donau (0.54)	RO	Arges (0.58)
F	Aube, Seine (0.51)	GR	Aliakmonas (0.52)
E	Ebro (0.50)	RO	Buzau (0.50)
HU, RO	Somesul Tysa (0.49)	E	Ebro (0.43)

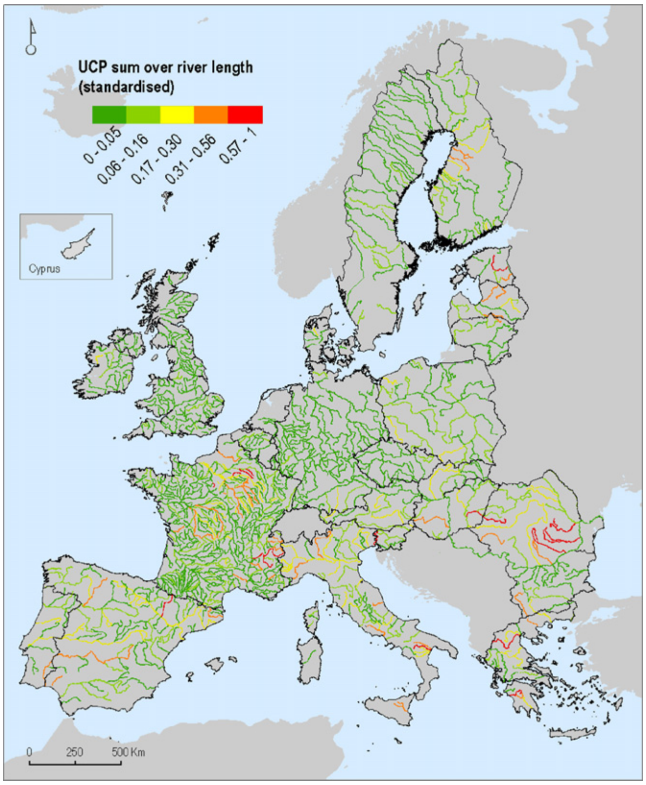

Fig. 5. UCP summation over river length for the major European rivers (min–max standardized).

are of high confidence (Vogt et al., 2007c), hence the indicator values should be here considered with caution. Pearson's correlation coefficient between CP_c and UCP_c is high (0.84), which suggests that a large part of European riparian zones is already under a major protection scheme.

Indices CP and UCP were also summarized over the major European rivers (Table 2). In this case a simple index sum along the water stream was calculated, as we considered the river as a single entity. The higher scores of the two indices, indicating more critical situations from a conservation perspective, are generally associated to large eastern European and Spanish rivers, with the significant addition of the Po river (Italy). However, depending on the application, a measure standardized for river length could result more meaningful. For illustration purposes the distribution of the UCP summation over river length is presented (Fig. 5). Romania results the country with the highest number of top scoring rivers.

4. Conclusions

Spatially explicit mapping and assessment of structural riparian corridors is of great interest from a natural resources management perspective. Preservation and restoration of connectivity in stream riparian habitats is a major concern in national and supranational projects that target conservation of biodiversity and ecosystem services. We presented a new method for multi-scale assessment of structural riparian corridors and a ranking of European regions as providers of corridors in relation to environmental pressure and degree of protection. The identification and extraction of structural corridors is based on a rapid and robust technique (MSPA), which makes use of freely available software. Ranking is defined based on simple indices, which exploit the MSPA bridge class. Overall, the method is easily reproducible for both software availability (free distribution) and the simplicity of the indices proposed, computable with any GIS software.

European administrative regions (NUTS) and major rivers were used for presentation purposes, but a more complex environmental stratification can be used depending on scale, boundaries of managed area, and study objectives. The results obtained cannot provide a comprehensive multi-scale assessment of riparian connectivity in Europe, but rather to illustrate valuable analysis tools and information with regard to its structural component (habitat physical linkages). Nevertheless, the proposed framework and methodology can be easily integrated with information on functional connectivity. For example, by exploiting graph theory considering grid cells as nodes (riparian patches) in connected graphs (river network), and evaluating graph-based indices of functional connectivity (e.g. Pascual-Hortal and Saura, 2006; Saura et al., 2011). The methodology can be applied to multi-temporal analysis, exploiting at least two datasets of riparian zones covering different dates. This information is currently not available, however, the new generations of Earth Observation sensors, like the European Space Agency Sentinel family (ESA, 2012), are expected to provide a large amount of new data to support environmental monitoring and habitat mapping at large scale. We believe that the analysis of habitat structural connectivity in Europe is of major importance for a biodiversity conservation perspective. This is currently witnessed at European level by the implementation of the new European Green Infrastructure (Sundseth and Silwester, 2009), which among its operational objectives has the support and improvement of landscape connectivity in Europe.

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