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Short communication

# Scale and ecological dependence of ecosystem services evaluation: Spatial extension and economic value of freshwater ecosystems in Italy

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ABSTRACT

Using land cover datasets derived from satellite imagery as a proxy for ecosystem services (ES) mapping and evaluation generates a series of technical problems mainly related to the resolution at which spatial data are acquired. Small sized and highly fragmented ecosystems such as wetlands, streams and rivers are particularly underestimated when coarse resolution land cover datasets are used. However, even at finer resolution, a large fraction of the economic value provided by freshwater ecosystems may not be adequately captured by remote sensed data because, other than technical and methodological problems, the provision of many freshwater services is strictly dependent on the interactions and contacts of these ecosystems with contiguous environments. The paper analyzes and discusses the effectiveness of the CORINE land cover (CLC) dataset to represent the spatial extension and, indirectly, the economic value of freshwater biomes in Italy, with emphasis on rivers and streams. Using a georeferenced national hydrographic network database and applying a stream buffer of variable width to more than 20,000 water courses, we demonstrated that less than 10% of the estimated surface is captured by the CLC dataset with heavy negative consequences on the overall evaluation of ES at local, regional and national scale. Our approach, easily applicable also to other geographical and spatial contexts, may contribute to improve proxy-based methodologies in ES mapping/evaluation and may help to limit errors in the estimation of freshwater services.



## 1. Introduction

The natural functions of ecological systems generate an interconnected series of processes that directly or indirectly produce goods (such as food) and services (such as climate regulation or soil formation) for the human society (MA, 2005). At the same time these processes sustain the equilibrium of the system itself and the equilibrium of the entire Biosphere (De Groot et al., 2002).

The ecosystems maintain natural capital stocks and flows which in part converge in human systems, often after various transformations. In this context, natural originated goods and services are not considered as an integrated part of the economic systems, but they are simply utilized (Daily, 1997).

Costanza et al. (1997) provided one of the most complete reviews of methods and values for the assessment of these "Ecosystem Services" (ES). Without entering in the complex debate on the methods used to assign a monetary value to non-marketable "goods and services" (De Groot et al., 2002; Spangenberg and Settele, 2010), we simply remark that once all services provided by an ecosystem or biome are identified and a monetary value (per unit area) is assigned to each service, the total value of natural capital associated to a territory is strictly dependent on the spatial extension of constituent biomes. In other words, we can use land cover attributes as a proxy for ES valuation (Konarska et al., 2002; Feng et al., 2010; but see Eigenbrod et al., 2010).

However, using land cover datasets derived from satellite imagery in ES valuation, may generate a series of technical problems mainly related to the scale dependence of the spatial extension of some biomes. For example, Konarska et al. (2002) demonstrated that the overall economic value of ES for the conterminous United States increased by 200% when comparing national land cover datasets derived from 1-km (NOAA–AVHRR) and 30-m (Landsat ETM) satellite imagery resolution. They also stated that the spatial extension of small sized, highly fragmented and almost linear extending ecosystems such as streams, rivers and wetlands is greatly underestimated at the coarser resolution (−56% for Lakes/Rivers; −5155% for wetlands).

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Based on the conclusions of Konarska et al. (2002), we hypothesized that, in the context of a heterogeneous and highly fragmented land cover mosaic, the spatial extension of some biomes is still highly underrepresented also when fine-resolution satellite imageries are used. Furthermore, other than the uncertainty of the "measure" influenced by the resolution of land cover datasets, the economic evaluation of goods and services provided by rivers, streams and fresh waters in general, poses another conceptual problem. The "open system" nature (Allan, 1995) and the extreme heterogeneity in space and time of running water ecosystems suggest that their structure and functions are strictly dependent on contacts and exchanges with contiguous environments (Ward, 1989; Thorp et al., 2006). For example, the provision of many freshwater services is strictly dependent on the functional linkage with the riparian zone (Allan, 2004; Gregory et al., 1991; Naiman and Decamps, 1997; Naiman et al., 2005; Tabacchi et al., 1998). However, the exact extension of the buffer necessary to ensure a full functionality to freshwater systems is still a matter of debate (Barker et al., 2006; Lees and Peres, 2008; Parkyn, 2004; Spackman and Hughes, 1995; Vidon and Hill, 2004; Wenger, 1999), though almost all researchers agree that relatively large buffer widths (>200 m) are needed to sustain multiple ecosystem services (Jones et al., 2010).

These considerations clearly suggest that the boundaries of freshwater biomes extend well over the physical limit defined by the aquatic habitat and that their extension/evaluation is not adequately captured by satellite imagery.

These inherent and methodological problems consequently cause a documented distorted evaluation of the role of rivers and wetlands for the human well-being and particularly exposes these ecosystems to unsustainable policies and management (Thorp et al., 2010).

This paper is thus aimed (i) to test the effectiveness of a 30-m resolution land cover dataset to assess the spatial extension of Italian freshwater ecosystems with emphasis on rivers and streams, (ii) to estimate the economic value of freshwater biomes in Italy and (iii) to demonstrate that a large fraction of this natural capital is not captured by the methods currently employed in national and regional based ES evaluation.

## 2. Methods

We utilized the CORINE land cover 2006 dataset (CLC-2006) to represent the land cover mosaic of terrestrial biomes in Italy. The CLC-2006 dataset (EEA, 2007) is based on satellite imagery data (SPOT-4 and Landsat-7 ETM+, resolution 20/30-m) which are interpreted and converted into 44 different classes of cover types (APAT, 2005), represented and mapped at a scale of 1:100,000 with a minimum mapping unit of 25 ha and minimum width of 100 m for linear elements. The CORINE classes were grouped and classified into seven principal biomes (Table 1) following Costanza et al. (1997) and Konarska et al. (2002). We used this modified land cover dataset for all analyses and considerations. For each biome we then calculated the absolute and relative spatial extension. The economic value of each biome was estimated by multiplying the total extension in hectares and the unit value (dollars per year per hectare) assigned to biomes on the basis of the services they provide. We followed the "benefit transfer" approach (but see Plummer, 2009; Wilson and Hoehn, 2006) and used the unit values of Costanza et al. (1997) after conversion to equivalent dollars 2009 by applying the Consumer Price Index (US Bureau of Labor Statistics, http://www.bls.gov/cpi/#tables, accessed 30.06.11).

Data concerning the spatial extent of the national hydrographic network were extracted from a georeferenced database of the Italian Ministry of the Environment (ISPRA, 2009), available online at: http://www.mais.sinanet.isprambiente.it/. In this dataset, Italian watercourses are represented by lines and segments of variable length and are divided into10 categories or orders which are not comparable with the Strahler classification system (Strahler, 1957). For example, with order 1 are indicated all watercourses discharging directly into the sea; order 2 are all watercourses discharging into streams of order1; streams and rivers of order 3 join with those of order 2 and so on. In this manner, size and length of streams within a given order are extremely variable. In our analysis we considered only streams belonging to the first six orders (98% of the total network length) and >2 km in length. To convert lines into polygons we added a strip buffer of variable width to all water courses using the "buffer" command in ESRI-ArcGIS 9.3 (ESRI, 2008). The width of stream buffers (Table 2) was chosen after an accurate revision of the literature and was mainly based on values published in: Castelle et al. (1994), Jones et al. (2010), Narumalani et al. (1997), Parkyn (2004), Pert et al. (2010) and Wenger (1999). We then calculated and mapped the total areal extent of the Italian hydrographic network. To estimate the total extension of terrestrial biomes and the overall economic value of ES in Italy we overlapped the modified CLC-2006 layer with the newly created hydrographic network buffer layer. To avoid double counting, land cover polygons intersected by stream buffers were cut off using the "erase" command in ESRI ArcGIS 9.3. We finally compared the results from the modified CLC-2006 dataset with those obtained after fusion with the hydrographic network buffer dataset.

## 3. Results and discussion

From the CLC-2006 dataset, the category "Lakes/Rivers" in Italy extends for 218,730 ha, representing about 1% of the total surface

**Table 1**
Aggregation scheme of terrestrial CORINE land cover classes (only the first two levels are reported) and ES Biomes, as defined by Costanza et al. (1997).

| CORINE land cover classes | | Biomes |
|---|---|---|
| Level 1 | Level 2 | |
| 1. Artificial surfaces | 1.1 Urban fabric | Urban |
| | 1.2 Industrial, commercial and transport units | Urban |
| | 1.3 Mine, dumps and construction sites | Urban |
| | 1.4 Artificial, non agricultural vegetated areas | Urban |
| 2. Agricultural areas | 2.1 Arable land | Croplands |
| | 2.2 Permanent crops | Croplands |
| | 2.3 Pastures | Croplands |
| | 2.4 Heterogeneous agricultural areas | Croplands |
| 3. Forests and seminatural areas | 3.1 Forests | Forests |
| | 3.2 Shrubs and/or herbaceous vegetation associations | Shrub/grasslands |
| | 3.3 Open spaces with little or no vegetation | Ice/Rock |
| 4. Wetlands | 4.1 Inland Wetlands | Wetlands |
| | 4.2 Coastal Wetlands | Wetlands |
| 5. Water bodies | 5.1 Inland Waters | Lakes/Rivers |