Measuring fragmentation in rural landscapes: the case of Sardinia, Italy

Andrea De Montis[a,*], Antonio Ledda [a,b], Vittorio Serra [a,b]

[a] Department of Agricultural Sciences, University of Sassari, Sassari, Italy

[b] Department of Civil and Environmental Engineering and Architecture, University of Cagliari, Cagliari, Italy

* Corresponding author. Email: andreadm@uniss.it

Abstract

Maintaining continuity of the ecosystem is becoming a central element in spatial planning policies. Several authors acknowledge the environmental fragmentation due to human action as one of the main causes which has negative effects on biodiversity. The environmental fragmentation is assimilated to the landscape fragmentation: the transformation of larger patches of habitat in smaller ones, or fragments, which tend to be more isolated than in the original condition.

Landscape fragmentation is extremely evident in urban areas, including settlements and various transport and mobility infrastructures. The main ecological effects due to the presence of a road network include loss of habitat, increased mortality of plants, and isolation of animal and vegetal species.

In this paper, we measure landscape fragmentation through two indices -the Infrastructural Fragmentation Index (IFI) and the Urban Fragmentation Index (UFI)- to assess the evolution of three landscape units of the island of Sardinia, Italy, in the time period 2003-2008. We find that the indices present coherent values confirming that in the three landscape units urban areas and transport and mobility infrastructure induce a similar level of fragmentation.

Keywords: landscape fragmentation, fragmentation indices, Infrastructural Fragmentation Index, Urban Fragmentation Index.

1. Introduction

In the last decades, the human needs caused an increase in planet's resources consumption and changes in land use, with tremendous impacts on habitats and considerable losses of biodiversity (Foley et al., 2011; Foley et al., 2005). In addition to natural processes such as catastrophic events (Lindenmayer and Franklin, 2002), landscape fragmentation (LF) is closely (and especially) related to ''[L]arge-scale conversion of natural landscapes for human use" (Harrisson et al. 2012), and recent studies (see, for example, Gibson, 2013) confirm the negative effects that LF has on biodiversity.

Some other authors (quoted by Battisti, 2004; Henle et al., 2004; Dobson et al., 1999; Wilson, 1993; Wilcove et al., 1986) argue that natural environment fragmentation is one of the main causes that has adverse effects on biodiversity such as the population decline due to loss of functional connectivity (Harrisson et al., 2012) and species richness declines (Collinge, 1996). Keeping in mind such background, maintaining ecosystem continuity is becoming a central element in spatial planning policies (Romano and Tamburini, 2001).

LF derives, inter alia, from deforestation, agricultural land conversion, and urbanization of natural areas, and it is extremely evident in urban areas, or in areas intensively used, where it is due, for example, to infrastructure network (Igondova et al., 2016; EEA, 2011; Saunders et al., 1991) and urban development (Battisti and Romano, 2007; Serrano et al., 2002). The main ecological effects produced by an infrastructure network include loss of habitat and biota, increased mortality of plants, death of animals killed by vehicular traffic and habitat fragmentation, which in turn triggers habitat loss (Spellerberg, 1998). Also the rural road network leads to LF, which depends on characteristics of the roads (Jaarsma and Willems, 2002).

A relevant part of LF analytics includes tools able to monitor the phenomenon in space and time. Information concerning the landscape evolution is key to planning adequate strategies to reduce and counteract the consequences of an higher fragmentation.

In this paper, we aim at developing on and applying two measures, i.e. the Infrastructural Fragmentation Index (IFI) and the Urban Fragmentation Index (UFI), to the assessment of LF for three landscape units (LUs) established by the regional landscape plan (RLP) of the Autonomous Region of Sardinia, Italy (RAS, 2006).

In the next section we present the methodology used. In the third section we show and discuss the results achieved, while in the fourth section we present the concluding remarks of this work.

2. Materials and Methods

According to the European Environment Agency (EEA, 2011), natural environment fragmentation, i.e. LF, is the transformation of larger patches into smaller ones, or fragments, where the fragments tend to be more isolated than in the original condition. In this work, for patches we mean rural and peri-urban landscape areas occupied by habitats.

In order to define a framework for investigating the LF in the LUs we have performed a research on Scopus and retrieved a series of publications through keywords such as 'landscape fragmentation', 'fragmentation [and] rural landscape', 'landscape fragmentation index', 'landscape fragmentation [and] roads', 'fragmentation [and] roads [and] loss of biodiversity', and so on. A series of methods have been used for quantifying the LF. Butler et al. (2004) examine forest fragmentation in the Pacific Northwest (Oregon and Washington west of the crest of the Cascade Range) through a forest fragmentation index combining three fragmentation metrics (percentage non-forest cover, percentage edge, and interspersion). Li et al. (2009) characterize forest spatial configurations in Alabama, the USA, using a historical record of 163 Landsat Thematic Mapper and select many indices (including core area index, edge density, largest polygon index, and mean polygon area) for assessing forest fragmentation. Li et al. (2010) quantify the forest fragmentation patterns in China and the USA through global land cover map and stress that the China's forests show an higher fragmentation than those of the USA.

LF caused by roads and railways can be assessed using indices, such as the IFI which is encountering some interest in research (Bruschi et al., 2015; Fabietti et al., 2011; Guccione et al., 2008; Melis and Puddu, 2008; Battisti and Romano, 2007; Zanon et al., 2007; La Rovere et al., 2006; Biondi et al., 2003; Romano, 2002; Romano and Tamburini, 2001). There are many ways to calculate the IFI (Bruschi et al., 2015; Fabietti et al., 2011; Melis and Puddu, 2008). In this study, we use the approach suggested by Bruschi et al. (2015), Biondi et al. (2003), Romano (2002), and Romano and Tamburini (2001), who proposed the following equation 1

$$IFI = \frac{\left(\sum_{i=1}^{i=n} L_i \cdot O_i\right) \cdot N \cdot P}{A} \qquad (1)$$

where L_i stands for the length in meters of the road or railway trait with the exclusion of discontinuities (viaducts, bridges, tunnels, etc.), O_i for the (adimensional) occlusion coefficient, A for the extension in squared meters of the LU area; P for the perimeter in meters of the LU, and N for the number of patches. We consider patches whose area is more than 0.2 hectares in order to eliminate the fictitious parts (Bruschi et al., 2015; Lega, 2004). O_i varies in the range 0.3-1.0 depending on the difficulty that the fauna has in crossing the transportation infrastructure (Table 1).

Table 1. The occlusion coefficient values for infrastructures type (Bruschi et al. 2015).

Types of transportation infrastructure	*O*i value
National road n. 131 and n. 131bis (Four-lane roads) and railway	1
National, regional, and provincial roads	0.5
Municipal and local roads	0.3

We stress that the IFI increases with spatial dimension of the LU, so it is mainly useful for comparing the LF of LUs with approximately the same extension (Bruschi et al., 2015; Romano and Tamburini, 2001).

Urbanization induces effects on ecological networks (De Montis et al., 2016) and causes fragmentation processes and soil consumption, which produce qualitative and quantitative effects on habitat, flora, and fauna (Astiaso Garcia et al., 2013). LF due to urban areas can be assessed through the UFI (Astiaso Garcia et al., 2013; Battisti and Romano, 2007; Biondi et al., 2003). According to Romano and Zullo (2013) and Battisti and Romano (2007), the UFI can be modeled by the following equation 2

$$UFI = \frac{\sum_{i=1}^{i=n} S_i}{A} \cdot \frac{\sum_{i=1}^{i=n} p_i}{2\sqrt{\pi \sum_{i=1}^{i=n} S_i}} \qquad (2)$$

where S_i stands for the extension in squared meters of the i-th urban area, p_i for the perimeter in meters of the i-th urban area. The first term of equation 2 quantifies the incidence of urbanized areas on the LU surface; the second term is the ratio between the perimeter of the urban area and the circumference of the equivalent circle (Romano and Zullo, 2013). UFI ranges between zero (for absence of urban areas) and the value of the second term of equation 2 (Battisti et al., 2013). In the next section, we illustrate the application of the two indices to the measurement of LF change from 2003 to 2008 for three LUs in Sardinia, Italy.

3. A case study in Sardinia

We have applied the two indices, IFI and UFI, to the study of three LUs, which are defined as 'Gulf of Asinara', 'Meilogu', and 'Gennargentu-Mandrolisai' by the RLP (RAS, 2006) and illustrated in Figure 1 and 2. In particular, we have obtained the IFI by considering transport infrastructures crossing rural and peri-urban areas, and calculated the UFI taking into account urban settlements, industrial and commercial areas, and outbuildings settlements.

Data on transportation infrastructures and urban areas consisted in the regional land cover maps corresponding to 2003 and 2008. We mainly use data available on-line in the official website of the Autonomous Region of Sardinia (RAS, 2016) as shapefiles based on Corine Land Cover classification and include: LUs; road and railway network; road and railway bridges, viaducts, and tunnels; urban settlements or other populated areas, industrial areas. Orthophotos are available on-line through the Web Map Service of the Region. We stress that data in shapefile format are not accurate. Recurrent pitfalls include: i) lacking or missing correspondence between satellite data and vector data, and ii) poor level of detail in the land cover map. We have spent some time to manually solve these errors.

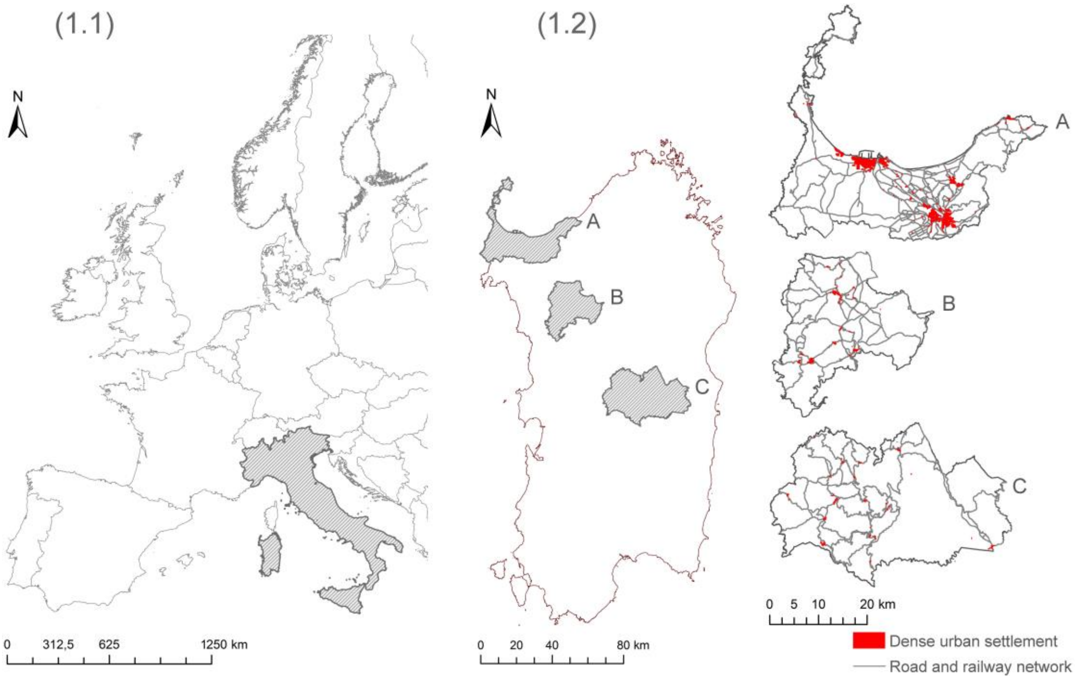

Figure 1. Geographical context. Figure 1.1: in gray, Italy; Figure 1.2: on the left, the island of Sardinia; on the right, the LUs Gulf of Asinara (A), Meilogu (B), and Gennargentu-Mandrolisai (C).

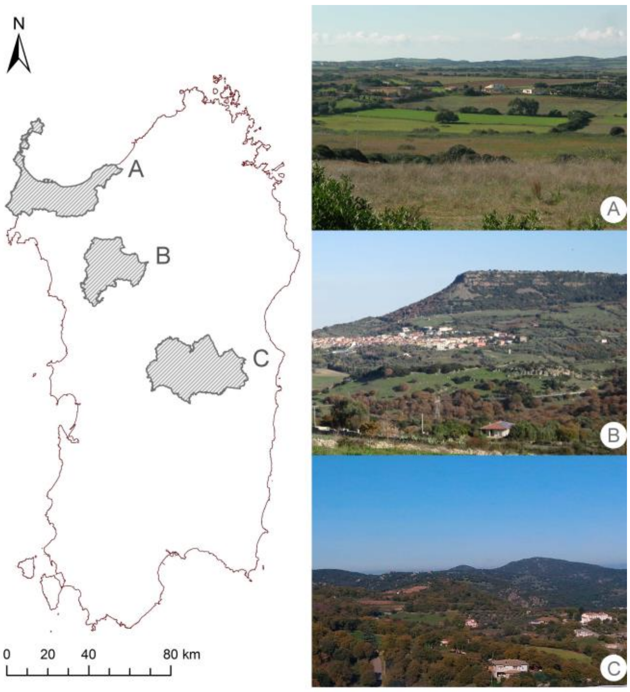

Figure 2. Typical rural landscapes of the selected LUs.

Table 2. Analysis of the IFI and UFI dynamic trend in the time period 2003-2008.

LUs	IFI			UFI		
	2003	2008	Variation	2003	2008	Variation
Gulf of Asinara	44,220	55,929	26.48%	1.42	1.79	26.06%
Meilogu	8051	9022	12.06%	0,13	0.15	15.38%
Gennargentu and Mandrolisai	8067	8133	0.82%	0.12	0.12	-

In Table 2, we report the values for both the indices in the time period considered. Gulf of Asinara is the most fragmented LU and Gennargentu-Mandrolisai the least one. In addition, Gulf of Asinara shows the highest LF increase in the period and Gennargentu-Mandrolisai the lowest one. Variation values show roughly the same size for the three LUs: LF increase of Gulf of Asinara is almost twice as much as the one of Meilogu.

4. Conclusions

In this preliminary study, we have estimated the level of LF in rural and peri-urban areas through two indices, namely the IFI and the UFI. Both these indices have been calculated for the years 2003 and 2008 and three LUs designed in the RLP of Sardinia. Results stress that the LU Gulf of Asinara has the highest LF, according to both the measures. This is due to a relevant presence of urbanized areas and transport infrastructures.

Further studies need to be developed in order to i) increase the accuracy of the data provided by the Region and re-calculate the IFI and UFI value, ii) calculate the IFI and UFI value for vulnerable domains (including natural areas and protected areas), iii) consider the daily average traffic and the impact of transport infrastructure on terrestrial wildlife, and iv) suggest ad hoc measures for preventing (and/or mitigating) the effects caused by landscape fragmentation in rural and peri-urban areas.

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