Infrastructural landscape fragmentation versus occlusion: a sensitivity analysis

Original
Infrastructural landscape fragmentation versus occlusion: a sensitivity analysis / Ledda, Antonio; De Montis, Andrea. - In: LAND USE POLICY. - ISSN 0264-8377. - 83:(2019), pp. 523-531. [10.1016/j.landusepol.2019.02.035]

Published
DOI:10.1016/j.landusepol.2019.02.035

Ledda, A., De Montis, A. (2019). Infrastructural landscape fragmentation versus occlusion: A sensitivity analysis. Land Use Policy, 83, pp. 523-531. ISSN: 0264-8377. DOI: 10.1016/j.landusepol.2019.02.035

Abstract

Landscape fragmentation, i.e. the process where large habitat patches become smaller and more isolated, has often been accelerated by human activities, such as deforestation, agricultural land conversion, and urbanisation of natural areas. Transport and mobility infrastructures are a major cause of landscape fragmentation. The Infrastructural Fragmentation Index is a common measure of landscape fragmentation due to transport and mobility infrastructures and depends, inter alia, on the occlusion coefficient, which accounts for the obstruction to movement. The values of this coefficient mirror well-established conditions, which depend on type of transport and mobility infrastructure and traffic flow. Lack of data affects its values and generates uncertainty in the measurement of landscape fragmentation. In this study, we develop on a sensitivity analysis, by assessing how IFI varies when the occlusion coefficient changes in the case of six landscape units in Sardinia (Italy) and Andalusia (Spain). Our results demonstrate that the IFI is very sensitive to the elimination of national, provincial, and local roads. In addition, we verified that IFI varies linearly versus the occlusion coefficient, i.e. its elasticity is constant. Thus, we advance that, as the uncertainty cannot be eliminated, the most efficient strategy to reduce these biases is to dismiss the absolute values of IFI and adopt difference-based expressions.

Keywords: landscape fragmentation; transport and mobility infrastructures; fragmentation index; IFI; sensitivity analysis.

1 Introduction

In 2000, the European Landscape Convention (ELC) was adopted, aiming at promoting protection, management and planning of all European landscapes (Council of Europe, 2000). The ELC is the first legal instrument that has officially attributed the same importance to valuable landscapes and rural landscapes. According to the ELC, landscape means “an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors” (Council of Europe, 2000).

The transformation and degradation of landscapes has often been accelerated by human activities and infrastructures such as roads and railways, and new rules are called for to promote and achieve sustainable development, maintaining high natural value landscapes that meet the expectations of the public. In this respect, the ELC marked the beginning of a new planning season in Italy (De Montis, 2014, 2016; Gambino, 2003). In agreement with the ELC, the landscape dimension should be considered in the drafting of all land management policies to achieve best quality in safeguard, management and planning proposals. The possible impact of projects on the landscape, whatever their scale, should therefore be assessed beforehand (Council of Europe, 2008). A major cause of degradation for landscape is fragmentation, i.e. the process according to which large habitat patches become smaller and more isolated (EEA, 2011). Planning practice in some countries, including Italy, has paid little attention to the quantification of landscape fragmentation, henceforth LF (De Montis et al., in press). This phenomenon has rarely been described in landscape plans, since a qualitative approach is chiefly used by means of textual description, photos and satellite images. Thus, it is hard to give quantitative measure-based answers to questions concerning the degree of LF and put forward *ad hoc* mitigation measures capable of reconnecting habitats restoring -at least to a certain extent- the original habitat condition.

Methods apt to quantify LF are discussed at length in scientific literature. However, this study focuses on LF due to transport and mobility infrastructures (TMIs) and few methods have been proposed in literature for measuring this type of LF. In this regard, the Infrastructural Fragmentation Index (IFI) has largely been discussed in literature (De Montis et al. 2018; De Montis et al., 2017; Bruschi et al., 2015; Fabietti et al., 2011; Melis and Puddu, 2008; Battisti and Romano, 2007; Zanon et al., 2007; La Rovere et al., 2006; Romano and Tamburini, 2001) and used to measure such a type of fragmentation (De Montis et al., 2018; De Montis et al., 2017; Bruschi et al., 2015).

The IFI equation consists of five factors, including the so-called occlusion coefficient O_i, whose values have been defined by scholars and experts, according to well-established conditions. O_i is relevant to the absolute value of IFI in that it defines the weight of roads and railways in the IFI equation. However, the lack of data can affect the values of O_i and such a shortage generates uncertainty in the measurement of LF. In the light of the foregoing considerations, in this study we aim at answering two research questions (RQ_s). Firstly, we assess the variation of IFI when TMIs are added or removed from the IFI equation. Thus, we quantify the weight of each type of TMI that contributes to IFI (RQ_1). Secondly, we focus on the values of O_i, by studying the sensitivity of IFI when O_i varies (RQ_2).

We consider as case study the results discussed in De Montis et al. (2017), who measured the LF in six landscape units in Sardinia (Italy) and Andalusia (Spain). The regions show similar geographical and institutional contexts and De Montis et al. (2017) obtained comparable findings (further details in De Montis et al., 2017).

This paper unfolds as follows. In Section 2, we review the scientific literature on the LF and its measurement via IFI and on sensitivity analysis. In Section 3, we describe the method used to perform the sensitivity analysis and illustrate the case study. In Sections 4 and 5, we show and discuss the findings. In Section 6, we summarize the concluding remarks.

2 State of the art summary

In this Section, we report in subsection 2.1 on LF and its assessment and in subsection 2.2 on the multidisciplinary use of sensitivity analysis applied in several research fields, included LF assessment.

2.1 Landscape fragmentation due to transport and mobility infrastructures

The increased consumption of the resources of the planet and the changes in land use for human needs have led to severe impacts on habitats and considerable loss of biodiversity (Foley et al., 2011; Foley et al., 2005). In addition to natural catastrophic events such as volcanic eruptions and floods, and natural barriers such as rivers and canyons, LF is closely (and especially) related to the transformation of natural landscapes due to human activity (Harrisson et al., 2012). LF can be defined as the dynamic process by which larger patches, or fragments, tend to become smaller and more isolated than in their original condition (EEA, 2011; Jaeger, 2000). For the purposes of this paper, patches are understood as rural and peri-urban landscape areas constituting habitats. LF negatively affects biodiversity (see, for example, Gibson et al., 2013) and leads to important consequences including the decrease of connectivity, i.e. a higher difficulty for animal species to move across their habitats (Scolozzi and Geneletti, 2012). According to the same concepts, other authors confirmed that LF can jeopardize both ecosystem continuity and quality, and is one of the main factors that adversely affect biodiversity (Haddad et al., 2015; Battisti, 2004; Henle et al., 2004; Wilcove et al., 1986) contributing to the decline in population, due to the loss of functional connectivity (Harrisson et al., 2012) and of species richness (Collinge, 1996). In addition, LF can exacerbate the effects of climate change, as it may result in a reduced resilience of habitats, of the population per species and the variety of ecosystems (Kettunen et al., 2007). LF derives from deforestation, agricultural land conversion and urbanisation of natural areas and it is particularly evident in urban or intensively used areas, where it is caused by the network of TMIs (Igondova et al., 2016; EEA, 2011; Jongman, 2004; Saunders et al., 1991) and urban development (Battisti and Romano, 2007; Jongman, 2004; Serrano et al., 2002).

TMIs can be considered as one of the main causes of LF. Roads and railways have negative effects on ecological networks (Coffin, 2007; Smith, 2004) including loss of habitat and biota, increased mortality of plants and animals, the latter killed by vehicular traffic, reduced wildlife mobility (Rico et al., 2007), and habitat fragmentation, which in turn triggers habitat loss (Jaarsma, 2004; Smith, 2004; Spellerberg, 1998). According to Beckmann and Hilty (2010), "[r]oads are [...] a leading cause of habitat fragmentation and the resulting loss of connectivity for wildlife populations throughout the world [and the roads are also] one of the major causes of habitat fragmentation that are disconnecting once continuous habitat". Furthermore, Chester and Hilty (2010) argue that infrastructures (including roads) and human settlement "[...] are some of the main sources of breaks in natural connectivity" (Chester and Hilty, 2010). In addition, the rural road network also leads to LF, which depends on road features (Jaarsma and Willems, 2002).

A considerable part of landscape metrics and analytics includes tools able of monitoring LF in space and time. The interpretation of these assessments can be a key factor in the planning of adequate strategic measures to reduce and counteract LF and restore links between disconnected patches.

LF is measurable by using several indices proposed in literature, even though "few of these are useful for the transportation infrastructures design, as they often operate without considering the effect of each infrastructure or their different typology" (Bruschi et al., 2015). LF caused by roads and railways can be quantitatively assessed through the IFI, which has drawn the interest of some scholars over the last two decades. De Montis et al. (2017) study LF due to TMIs in Sardinia (Italy) and Andalusia (Spain) by using the IFI. De Montis et al. (2017) obtained comparable findings and pointed out higher LF in coastal areas than in the inland ones. Bruschi et al. (2015) have addressed the degree of habitat fragmentation caused by railways and roads. The authors applied IFI to 24 Italian national parks. They adopted weighted averages of IFI for all the national parks and reported on a high degree of LF in the parks of central and southern Italy and medium-low fragmentation in northern Italy. Neri et al. (2010) investigated a methodology useful for the location of an environmentally-sustainable transport infrastructure. As part of the study, the authors applied a modified IFI equation (Ifim), which is calculated with respect to a territorial area referred to a cell of one square kilometre, with a view to decoupling the IFI values from the territorial unit or landscape unit and obtaining comparable values of IFI to study areas having different extents. Neri et al. (2010) measured the Ifim in an area included between Marche and Umbria, two regions in Central Italy. La Rovere et al. (2006) report on the integration of eco-biogeographic parameters in spatial planning tools. As a set of parameters (indices), the authors considered: infrastructure density (ratio between the length of transport infrastructure and the area of a given territorial unit), IFI, urban density (ratio between the sum of the extents of urban areas and the extent of the territorial unit), weighted urban density, urban dispersion density (ratio between the number of urban settlements — converted in centroids — and the extent of a given territorial unit). The indices were validated after being tested in practice, and their relationships were analysed. The research was carried out in the province of Rome, Italy, and its focus was on the wealth of species of avifauna. La Rovere et al. (2006) pointed out that the avifauna was more vulnerable to urbanisation (biodiversity loss) than to linear infrastructure. Thus, IFI has several practical applications.

As for the LF caused by TMIs, in this research we focus on the method applied by, *inter alia*, De Montis (2018, 2017), Bruschi et al. (2015) and Romano and Paolinelli (2007), because it is widely discussed in literature, and its strengths and weaknesses are well-known. The IFI obeys to the following equation (1):

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

where: L_i stands for the length in metres of the road or railway traits, with the exclusion of discontinuities (viaducts, bridges, and tunnels); O_i for the (dimensionless) occlusion coefficient (Table 1); A for the extension in squared metres of the landscape unit area; P for the perimeter in metres of the landscape unit; N for the number of patches or fragments. IFI increases with the extent of the landscape unit (Bruschi et al., 2015; Romano and Tamburini, 2001), so it should be applied on areas of approximately the same size.

Type of TMIs	Code	Value	Description
National four (or more)-lane roads and railways	O_1	1.0	Side fences cause total occlusion
National and provincial roads	O_2	0.5	Noise and permanent movement cause high occlusion
Municipal and local roads	O_3	0.3	Disturbance conditions cause moderate occlusion

Table 1 Variations of the occlusion coefficient O_i: adapted from (Bruschi et al. 2015; Romano and Tamburini, 2001).

O_i depends on the type of TMIs and traffic flow, which can affect wildlife movement (Bruschi et al., 2015; Romano and Tamburini, 2006; Biondi et al., 2003; Romano, 2002; Romano and Tamburini, 2001). In this study, O_i has three values depending on the type of TMIs (Bruschi et al., 2015; Romano and Tamburini, 2001): national four(or more-lane) roads and railways, usually fenced, (O_1 = 1.0); national and provincial roads (O_2 = 0.5), where O_i depends on noise disturbance and vehicles movement; local roads (O_3 = 0.3), where O_i varies according to the "mean occlusion due to the disturbance conditions" (Bruschi et al., 2015). La Rovere et al. (2006), Battisti and Romano (2007) and Romano and Zullo (2013) refer to a simplest IFI equation where perimeter of landscape unit and number of patches are not considered, and suggest different values of O_i for national and regional roads with high traffic volume (O_i = 0.7), and provincial roads with average traffic volume (O_i = 0.5).

O_i appears as an element of uncertainty, because scholars and experts have defined its values according to well-established conditions. Lack of data about fenced TMIs, noise disturbance, traffic flows, and so on, can affect O_i. In such a scenario, IFI would provide overestimated or underestimated values of LF. In the case study discussed in this paper (Section 3), data about traffic flows and more accurate information concerning roads and railways were unavailable for Sardinia and Andalusia. Nevertheless, the IFI was calculated by adopting the values of O_i validated by Bruschi et al. (2015) and Romano and Tamburini (2001). So, in the hypothesis that the occlusion coefficient changes, the sensitivity of IFI with respect to O_i needs to be investigated.

2.2 Sensitivity analysis

Uusitalo et al. (2015) focus on methods for assessing uncertainty of deterministic models. Uncertainty can characterize the outcomes of environmental models and it is assessable through some methods, including model emulation, expert judgement, and model sensitivity analysis. Sensitivity analysis is commonly used to investigate "any model [and it aims at characterizing] how model outputs respond to changes in input, with an emphasis on finding the input parameters to which outputs are the most sensitive [...]" (Uusitalo et al., 2015).

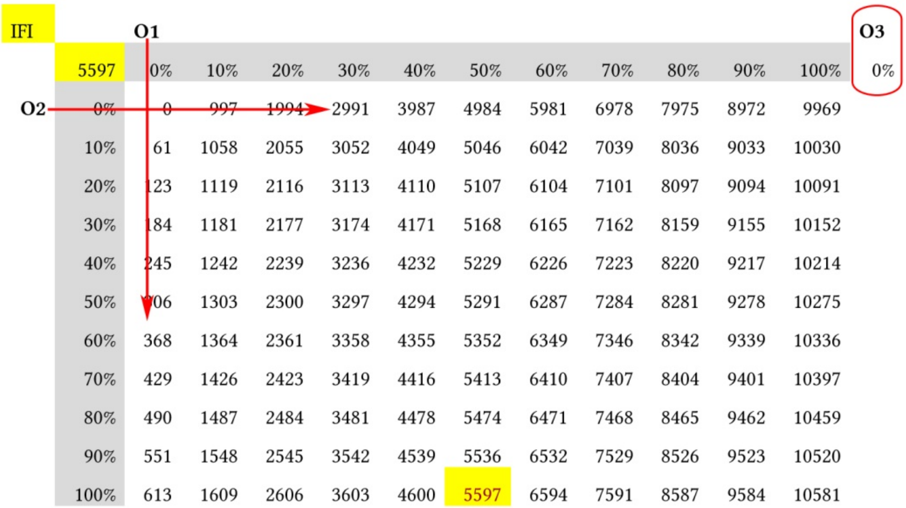
Scientific literature proposes several definitions of sensitivity analysis, although the main basic idea appears the same. According to McCuen (1973) "[s]ensitivity is a measure of the effect of change in one factor on another factor [and it] is potentially useful in all phases of the modeling process [...]". Sarrazin et al. (2016) argue that sensitivity analysis "is a diagnostic tool that can guide model calibration and verification, support the prioritization of efforts for uncertainty reduction, or help with model-based decision-making [...]". O'Connor et al. (2017) define sensitivity analysis as "a tool for performing quantitative risk assessments that evaluates the relationships between process parameters, material attributes, and product quality attributes".

In scientific literature, the interest in sensitivity analysis is remarkable in different fields (see, for example: Hornseth et al., 2014; Thabane et al., 2013), including decision-making process (Borgonovo and Peccati, 2008; Pannell, 1997; Clemen, 1996) and issues concerning LF (Bogaert et al., 2000; Davidson, 1998). Borgonovo and Peccati (2008) argue that "[s]ensitivity analysis is "an integral part [Clemen, 1996]" of any decision-making process accompanied by the creation of a decision-support model [...]", but "[n]o "optimal" sensitivity-analysis procedure exists for decision analysis" (Clemen, 1996). Pannell (1997) provides an overview on methodological and theoretical issues concerning sensitivity analysis. The author lists several uses of sensitivity analysis clustered in four macro categories and focuses mainly on one of them, namely 'decision making or development of recommendations for decision makers'. Then, the author discusses a theoretical framework about the use of sensitivity analysis for such a macro category, and reports on approaches and strategies to perform the analysis. Davidson (1998) discusses the quantitative analysis of LF and describes two approaches useful for measuring such a phenomenon. The author stresses strengths and weaknesses of the methods and recommends the use of sensitivity analysis "to see if analysis results are robust to changes in the scale of analysis, number of patch types, or patch definitions" (Davidson, 1998). Bogaert et al. (2000) point out the need for measuring LF to assess its consequences and define proper nature conservation policy. Then, the authors propose a fragmentation index that incorporates four key factors: "habitat loss, isolation, increased perimeter length, and occurrence of several patches" (Bogaert et al., 2000). Furthermore, a sensitivity analysis was performed by using artificial data, aiming to assess how the proposed index varied according to the variation of the four key factors.

The international scientific literature appears lacking in studies that quantitatively address the sensitivity of IFI with respect to O_i. Thus, we investigate on such a gap in order to provide findings, advice, and references that could be useful in practice and for further researches.

3 Method and case study

In response to RQ_1 concerning the assessment of the weight of each type of TMI, we assess the variation of IFI, when the influence of the various categories of TMIs is removed, i.e. the corresponding O_i is equaled to zero. In response to RQ_2 relating to the study of the elasticity of IFI versus the three types of occlusion coefficients, we focus on O_i considering the values suggested in Bruschi et al. (2015), validated in Biondi et al. (2003) and Romano and Tamburini (2001), and used *inter alia* in De Montis et al. (2018; 2017): $O_1 = 1.0$, $O_2 = 0.5$, and $O_3 = 0.3$. In this case, we perform a two-way sensitivity analysis, i.e. a nonstandard three-way sensitivity analysis, where -for easy of representation- we fix one occlusion coefficient and let the other two ones vary. Two-way sensitivity analysis allows us to better describe the variation of IFI versus two variables by using three dimensional tables and figures. The operational framework implies the use of 'What-If Analysis' and 'Data Validation' -two routines of Microsoft Excel 2010- for creating three-dimension data tables. In Figure 1, we report as an example a table where O_3 is fixed and equal to zero and O_1 and O_2 vary from 0 to 1 through 0.10 (i.e. 10%) intervals.



IFI		O1											O3
	5597	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	0%
O2	0%	0	997	1994	2991	3987	4984	5981	6978	7975	8972	9969	
	10%	61	1058	2055	3052	4049	5046	6042	7039	8036	9033	10030	
	20%	123	1119	2116	3113	4110	5107	6104	7101	8097	9094	10091	
	30%	184	1181	2177	3174	4171	5168	6165	7162	8159	9155	10152	
	40%	245	1242	2239	3236	4232	5229	6226	7223	8220	9217	10214	
	50%	306	1303	2300	3297	4294	5291	6287	7284	8281	9278	10275	
	60%	368	1364	2361	3358	4355	5352	6349	7346	8342	9339	10336	
	70%	429	1426	2423	3419	4416	5413	6410	7407	8404	9401	10397	
	80%	490	1487	2484	3481	4478	5474	6471	7468	8465	9462	10459	
	90%	551	1548	2545	3542	4539	5536	6532	7529	8526	9523	10520	
	100%	613	1609	2606	3603	4600	5597	6594	7591	8587	9584	10581	

Figure 1 O_1, O_2 and O_3 stand for occlusion coefficients. As an example, if $O_1 = 1.0$ (100%), $O_2 = 0.5$ (50%), and $O_3 = 0.0$ (0%) then the IFI has the yellow highlighted value.

In Figure 1, the values of IFI depend on the O_i variation. If O_1 is 1.0 (100%), O_2 is 0.5 (50%) and O_3 is 0.0 (0%), then the IFI is 5597.

We applied this methodological framework to the case studied by De Montis et al. (2017), which measured the IFI of six landscape units in two Mediterranean regions: Sardinia (Italy) and Andalusia (Spain) (Figure 2). The Sardinian landscape units are defined by the Regional Landscape Plan (Sardinia, 2006), while the Spanish ones by the Regional Government of Andalusia (Junta de Andalucia, 2016). The Sardinian landscape units consist of a coastal area (Golfo dell'Asinara) interested by relevant residential and productive industrial and agricultural settlements, and two much less developed inland areas characterized by the most relevant mountains of the island (Gennargentu and Mandrolisai) and upland basaltic plains (Regione delle giare basaltiche). The Andalusian landscape units include a Mediterranean mountain range (Las Lomas), a coastal area (Litoral Occidental Onubense), and a characteristic landscape with prevalence of olive groves (Sierra Bermeja).

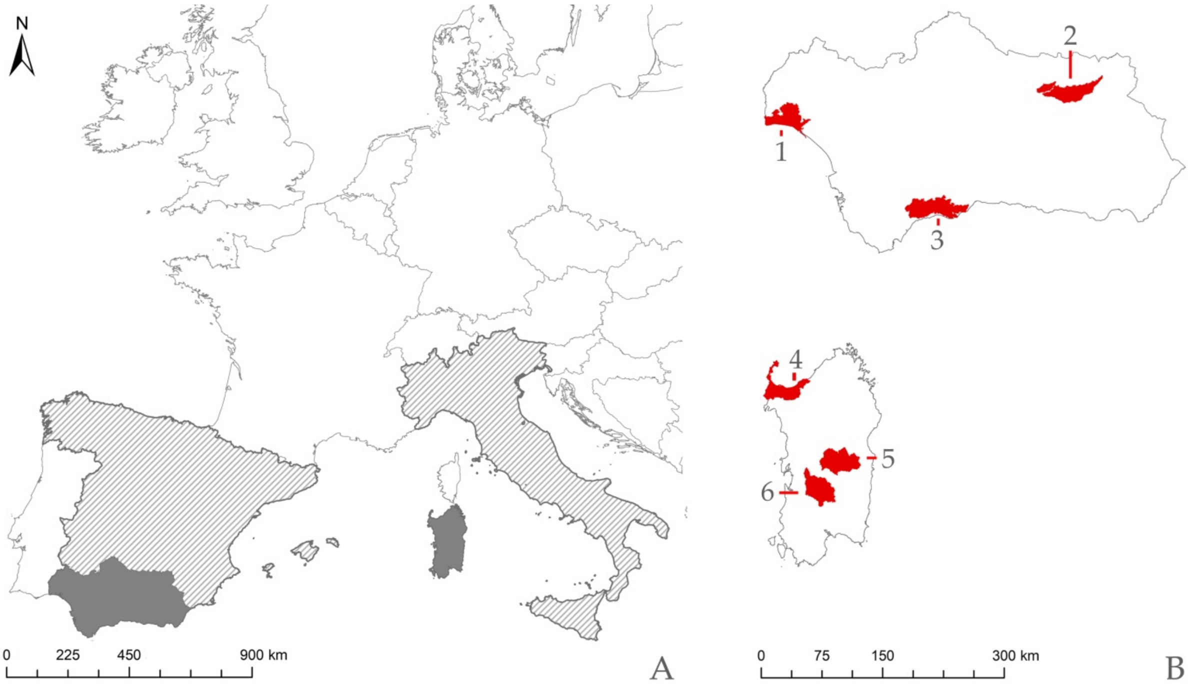


Figure 2 Geographical context. A: in dark gray, Andalusia (Spain) and Sardinia (Italy); B: in red, Litoral Occidental Onubense (1), Las Lomas (2), Sierra Bermeja (3), Golfo dell'Asinara (4), Gennargentu and Mandrolisai (5), and Regione delle giare basaltiche (6) (after De Montis et al., 2017).

Region	Landscape unit	IFI				
		2003	2008	2005	2009	Mean values
Sardinia	Golfo dell'Asinara	19655	21408			20531.5
	Regione delle giare basaltiche	8356	8439			8397.5
	Gennargentu and Mandrolisai	186	232			209.0
Andalusia	Las Lomas			7419	7760	7589.5
	Litoral Occidental Onubense			27354	29839	28596.5
	Sierra Bermeja			17797	18819	18308.0

Table 2 Sardinian and Andalusian landscape units: values of IFI (after De Montis et al., 2017).

Table 2 summarizes the values of IFI for the six landscape units. IFI was calculated for different time periods. Thus, in this exercise, we use the mean values reported in the last column. Litoral Occidental Onubense has the highest value of IFI and Gennargentu and Mandrolisai the lowest one.

4 Results

In this Section, we summarize the findings concerning (i) the effect of adding and removing the influence of TMIs on the final value of IFI, and (ii) the sensitivity of IFI to the variation of the occlusion coefficient.

4.1 Effect of TMIs removal on IFI

We are interested in ascertaining the variation of the IFI mean value, when TMIs are hypothetically removed from the landscape. In Table 3 and Figure 3, we focus on the results by reporting on and illustrating on the percentage variation of the IFI mean values for each landscape unit and region.

Regions	**Years**	**Landscape units**	**IFI**	**TMIs - weight in percentage**			
			Mean value	Railways	Four-lane roads	National or provincial roads	Local roads
Sardinia	2003-2008	Regione delle giare basaltiche	8397.5	7.2%	0.1%	59.6%	33.1%
		Gennargentu and Mandrolisai	209.0	0.0%	0.0%	66.5%	33.5%
		Golfo dell’Asinara	20531.5	23.0%	5.6%	41.7%	29.7%
Andalusia	2005-2009	Las Lomas	7589.5	9.9%	3.8%	65.8%	20.5%
		Litoral Occidental Onubense	28596.5	9.9%	21.1%	30.4%	38.6%
		Sierra Bermeja	18308.0	1.5%	12.9%	34.0%	51.7%
		Mean values	13938.7	8.6%	7.2%	49.7%	34.5%

Table 3 Contribution of each TMI to landscape fragmentation.

In Sardinia, the railways are relevant to IFI in Golfo dell’Asinara (23.0% of IFI), while are not significant in Gennargentu and Mandrolisai (0%). The four-lane roads have little impact on LF in Golfo dell’Asinara (5.6%). The national or provincial roads are relevant to IFI in Regione delle giare basaltiche (59.6%), Gennargentu and Mandrolisai (66.5%), and Golfo dell’Asinara (41.7%). The local roads are important in these three landscape units (about 30% of IFI). In Andalusia, the railways are more relevant to IFI in Las Lomas and Litoral Occidental Onubense (9.9% of IFI) than in Sierra Bermeja (1.5%). The four-lane roads have the highest effect on LF in Litoral Occidental Onubense (21.1%). The national or provincial roads are relevant to IFI in Las Lomas (65.8%), Sierra Bermeja (34.0), and Litoral Occidental Onubense (30.4%). In Sierra Bermeja and Litoral Occidental Onubense, local roads remarkably contribute to LF (51.7% and 38.6% of IFI, respectively).

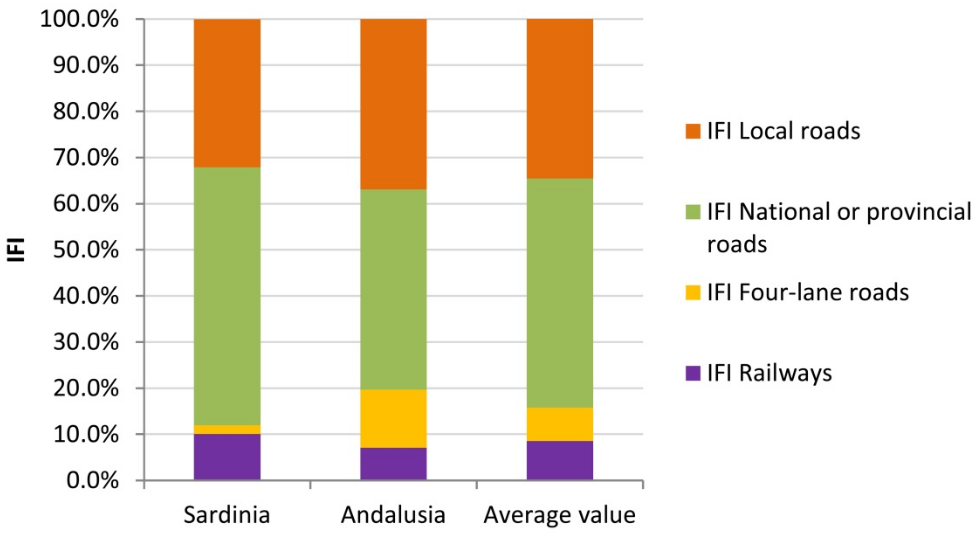


Figure 3 Relevance of the type of TMIs with respect to landscape fragmentation in Sardinia and Andalusia.

As clearly illustrated by the first on the right bar concerning the average values in Figure 3, the most relevant influence on the IFI is generally exerted by national or provincial roads. For Sardinian landscape units, the effect is visually much larger, while in Andalusia local roads show a slightly larger weight.

4.2 Sensitivity of IFI to the variation of the occlusion coefficient

The two-way sensitivity analysis yields result in form of tables, where IFI is mapped for each couple of possible discrete variations by 10% (i.e. 0.10) of two occlusion coefficients with the third one fixed. We obtained tables such as the Tables 4, 5, and 6, which report on the variation of IFI measuring LF of Golfo dell'Asinara in 2008. In Table 4, 5, and 6, O_1 and, respectively, O_2, and O_3 is set and fixed equal to zero. A variation of O_i from zero to one describes a transition from full permeability to maximum obstruction.

		O_3											O_1
		0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	0%
O_2	0%	0	1780	3560	5340	7119	8899	10679	12459	14239	16019	17799	
	10%	2150	3930	5710	7489	9269	11049	12829	14609	16389	18169	19948	
	20%	4300	6079	7859	9639	11419	13199	14979	16759	18538	20318	22098	
	30%	6449	8229	10009	11789	13569	15349	17129	18908	20688	22468	24248	
	40%	8599	10379	12159	13939	15719	17498	19278	21058	22838	24618	26398	
	50%	10749	12529	14309	16089	17868	19648	21428	23208	24988	26768	28548	
	60%	12899	14679	16458	18238	20018	21798	23578	25358	27138	28917	30697	
	70%	15049	16828	18608	20388	22168	23948	25728	27508	29287	31067	32847	
	80%	17198	18978	20758	22538	24318	26098	27877	29657	31437	33217	34997	
	90%	19348	21128	22908	24688	26468	28247	30027	31807	33587	35367	37147	
	100%	21498	23278	25058	26838	28617	30397	32177	33957	35737	37517	39297	

Table 4 Values of IFI for Golfo dell'Asinara. Fixed value: O_1 = 0%.

		O_1											O_2
		0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	0%
	0%	0	2150	4300	6449	8599	10749	12899	15049	17198	19348	21498	
O_3	10%	606	2756	4906	7055	9205	11355	13505	15655	17804	19954	22104	
	20%	1212	3362	5512	7661	9811	11961	14111	16261	18410	20560	22710	
	30%	1818	3968	6118	8267	10417	12567	14717	16866	19016	21166	23316	
	40%	2424	4574	6723	8873	11023	13173	15323	17472	19622	21772	23922	
	50%	3030	5180	7329	9479	11629	13779	15929	18078	20228	22378	24528	
	60%	3636	5786	7935	10085	12235	14385	16535	18684	20834	22984	25134	
	70%	4242	6392	8541	10691	12841	14991	17141	19290	21440	23590	25740	
	80%	4848	6998	9147	11297	13447	15597	17747	19896	22046	24196	26346	
	90%	5454	7604	9753	11903	14053	16203	18353	20502	22652	24802	26952	
	100%	6060	8210	10359	12509	14659	16809	18959	21108	23258	25408	27558	

Table 5 Values of IFI for Golfo dell'Asinara. Fixed value: O_2 = 0%.

		O_1											O_3
		0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	0%
O_2	0%	0	1780	3560	5340	7119	8899	10679	12459	14239	16019	17799	
	10%	606	2386	4166	5946	7725	9505	11285	13065	14845	16625	18405	
	20%	1212	2992	4772	6552	8331	10111	11891	13671	15451	17231	19011	
	30%	1818	3598	5378	7157	8937	10717	12497	14277	16057	17837	19617	
	40%	2424	4204	5984	7763	9543	11323	13103	14883	16663	18443	20222	
	50%	3030	4810	6590	8369	10149	11929	13709	15489	17269	19049	20828	
	60%	3636	5416	7196	8975	10755	12535	14315	16095	17875	19655	21434	
	70%	4242	6022	7802	9581	11361	13141	14921	16701	18481	20261	22040	
	80%	4848	6628	8408	10187	11967	13747	15527	17307	19087	20867	22646	
	90%	5454	7234	9013	10793	12573	14353	16133	17913	19693	21472	23252	
	100%	6060	7840	9619	11399	13179	14959	16739	18519	20299	22078	23858	

Table 6 Values of IFI for Golfo dell'Asinara. Fixed value: O_3 = 0%.

A graphical support provides a clearer overview on the variation of IFI. If we fix O_1 (0%) and let O_2 and O_3 vary (Table 4), we obtain a graph such as the one in Figure 4-A.

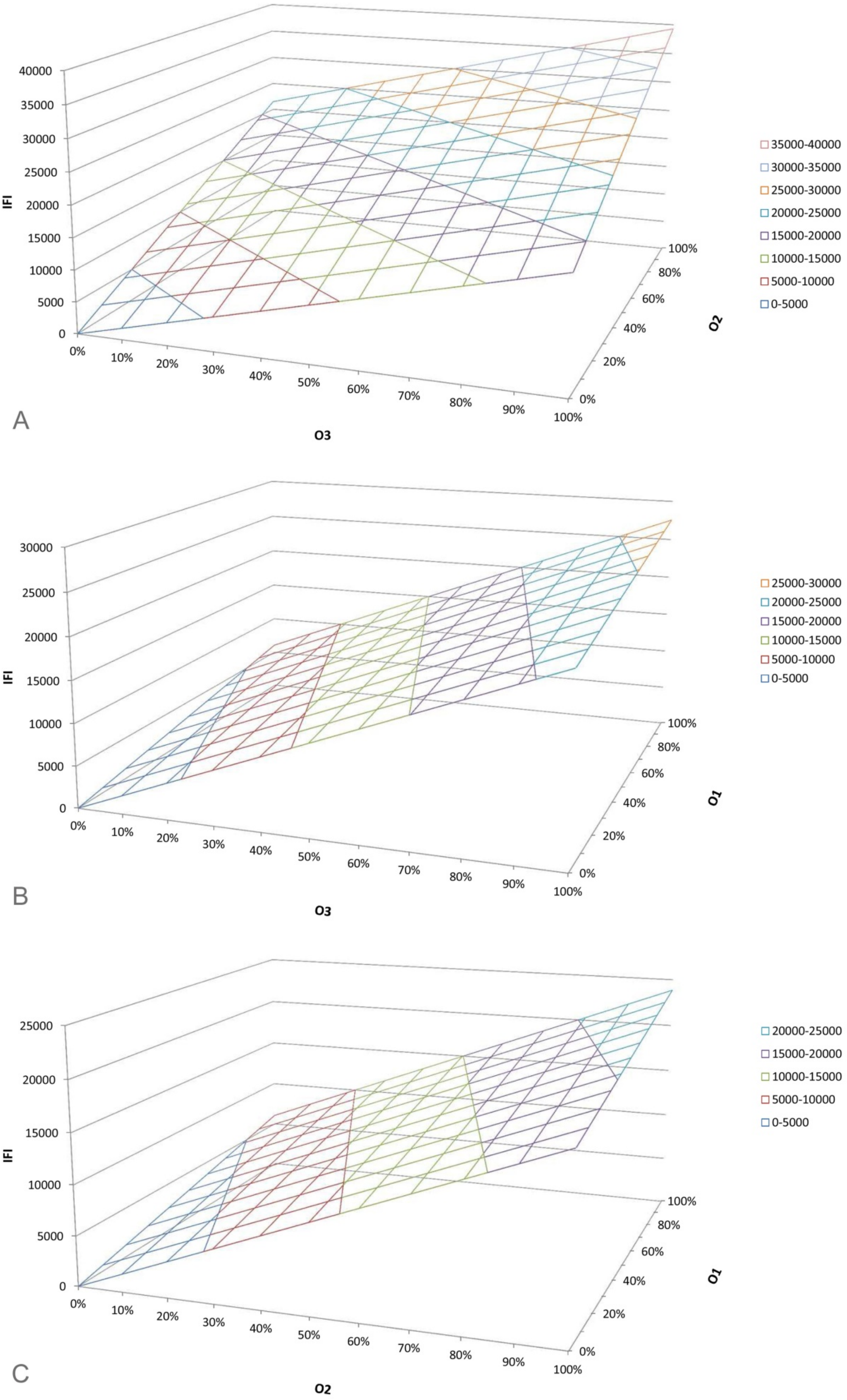


Figure 4 Three-dimension planar representations of IFI with respect to O_i for Golfo dell'Asinara in 2008. A: IFI versus O_2 and O_3 with O_1 = 0%. B: IFI versus O_3 and O_1 with O_2 = 0%. C: IFI versus O_1 and O_2 with O_3 = 0%.

The same holds for Table 5 and Figure 4-B, and Table 6 and Figure 4-C. The IFI varies in a quite regular way in that its values are arranged on inclined planes. This implies that the distribution of values shows a clear minimum (i.e. IFI=0) and maximum at a certain point; furthermore, the elasticity of IFI versus O_i does not change suddenly as O_i varies.

5 Discussion

The effect of adding and removing TMIs has consequences on IFI (RQ_1), which are especially due to national and provincial roads and local roads. Considering the six landscape units, according to the mean values of IFI, the national and provincial roads are the most relevant to LF in Sardinia and Andalusia. In general, the effects of railways and four-lane roads are less important in Sardinia than Andalusia, except for Golfo dell'Asinara, where the railways contribute about one fifth to the value of IFI. This implies also that the most efficient strategy to overcome LF (i.e. reduce the IFI) would be in both regions the construction over national and provincial roads of reconnecting buildings, such as wildlife crossing structures and green corridors. As far as RQ_2 is concerned, we note that the IFI provides a rough measure of LF and more information need to be known for *ad hoc* defragmentation measures planning. A more accurate assessment of LF requires information on traffic flows, noise disturbance, fences, seasons and tourist load, barrier effect (how specific target species perceive TMIs), and so on. Such factors affect O_i in the IFI equation and should be considered in the measurement of LF. For the sensitivity analysis of IFI versus O_i, we have applied a two-way sensitivity inspection to the IFI obtained for Golfo dell'Asinara in 2008. We found out that IFI varies in a quite regular way according to a well-defined geometric pattern, i.e. a planar surface. However, the values of O_i cannot be considered unchangeable and should be carefully chosen, in order to give proper weight to each type of TMI, avoiding overestimation or underestimation of LF phenomena. The example of sensitivity analysis performed for Golfo dell'Asinara is replicable in the other five landscape units. It provides us with more information on the value of IFI depending on the chosen values of O_i. The O_i calibrated for specific contexts would be desirable for a more realistic measure of LF, but the lack of data is often a barrier difficult to overcome, as for the six landscape units considered in this study. The graphical support concerning the variation of the three values of O_i (O_1, O_2, and O_3) is a critical issue of this research. Thus, we overcome this criticality and illustrated the sensitivity of IFI versus O_i by adopting a nonstandard three-way analysis and fixing a value (for example, O_1) and letting the other ones (O_2 and O_3) change. In the cases where the lack of information does not allow to obtain a reliable value of O_i, the calculation of IFI suffers of a certain degree of uncertainty. Given the pattern of variation, the most efficient way to eliminate or reduce these uncertainty biases is to avoid using absolute values of IFI and prefer difference-based expressions, such as the following equation 2:

$$\Delta IFI = (IFI_x + \varepsilon) - (IFI_y + \varepsilon) = IFI_x - IFI_y \tag{2}$$

where IFI_x and IFI_y measure IFI in two different years x and y, and ε stands for the constant error connected to the uncertain assessment of the occlusion coefficient.

6 Conclusions and outlook

The European Union encourages conservation and restoration of landscapes to achieve a good level of wildlife conservation. LF adversely affects landscape quality and wildlife conservation and is widely discussed in scientific literature. TMIs contribute to LF and the IFI proved a useful metric for quantifying it. The IFI allows us to measure fragmentation at landscape level and may be used to identify landscape units where mitigation measures would contribute to reconnecting habitat patches. The IFI obeys to an equation consisting of five factors, including an occlusion coefficient (O_i), whose values have been defined by scholars and experts according to well-established conditions. The absolute value of IFI is affected by O_i, which defines the weight of specific type of TMIs. An accurate knowledge of data about traffic flows, target species, type of habitats, and so on, should be desirable at operative level to calibrate O_i on realistic values. Thus, transportation planners would be able to (i) quantify LF considering more elements related to the effects of TMIs in specific contexts and (ii) define *ad hoc* defragmentation measures to improve landscape connectivity (or at least maintain the connectivity of the original scenario).

The lack of data can affect the values of O_i and such a shortage generates uncertainty in the measurement of LF. In the light of the above considerations, in this study we answered two research questions (RQ_s). Firstly, we assessed the weight of each type of TMI that contributes to IFI (RQ_1). Secondly, we focused on the values of O_i and assessed the sensitivity of IFI when O_i varies (RQ_2). We use as case study the findings discussed in De Montis et al. (2017), who measured the LF in six landscape units in Sardinia (Italy) and Andalusia (Spain). As for RQ_1, we considered the six landscape units and found out that IFI is particularly affected by national or provincial roads in both the regions. As for RQ_2, we focused on one landscape unit (Golfo dell'Asinara, year 2008) and pointed out that (i) IFI varies in a quite regular way, according to a well-defined geometric pattern, and (ii) the IFI equation provides predictable graphical results. In general, IFI appears sensible to variation of O_i but according to progressive and linear trend. The same approach used for Golfo dell'Asinara can also be extended to the other landscape units.

As for the relevance of this study, we stress that, for that we know, this work can be considered as one of the first researches that quantitatively dealt with the sensitivity of IFI with respect to O_i. We verified that IFI varies constantly with respect to O_i and, under some circumstances connected to lack of data and absence of context-specific calibration, its uncertainty cannot be eliminated. In these cases, we believe the most efficient strategy is to dismiss the absolute values of IFI and adopt difference-based figures. Last generation landscape plans could apply such an approach to provide quantitative measure of LF when data are available for two different years at least.

As concluding remarks, we stress critical issues of this research. We showed the findings of the sensitivity analysis through graphical support that has some limitations. In fact, we do not provide a four-dimensional chart where IFI varies according to the simultaneous change of O_1, O_2, and O_3, and that appears as an insurmountable barrier if we reason in purely graphical terms. In future research, we aim at addressing such a critical element and apply other methods for assessing the sensitivity of IFI versus O_i.

7 References

Battisti, C. 2004. Frammentazione ambientale, connettività, reti ecologiche. Un contributo teorico e metodologico con particolare riferimento alla fauna selvatica. Provincia di Roma: Assessorato alle politiche ambientali, Agricoltura e Protezione civile. ISBN 88-900297-6-5. In Italian.

Battisti, C., Romano, B. 2007. Frammentazione e connettività. Dall'analisi ecologica alla pianificazione ambientale Torino: CittàStudi. In Italian.

Beckmann, J. P., Hilty, J. A. 2010. Connecting Wildlife Populations in Fractured Landscapes. In J.P. Beckmann, A. P. Clevenger, M. P. Huijser, J. A. Hilty (Eds.), Safe Passages: Highways, Wildlife, and Habitat Connectivity (pp. 3-16). Washington DC: Island Press. ISBN-10: 1-59726-653-1.

Biondi, M., Corridore, G., Romano, B., Tamburini, G., Tetè, P. 2003. Evaluation and Planning Control of the Ecosystem Fragmentation Due to Urban Development. ERSA conference papers ersa03p15, European Regional Science Association, Jyväskylä, Finland, August 27-30, 2003.

Bogaert, J., Van Hecke, P., Salvador-Van Eysenrode, D., Impens, I. 2000. Landscape fragmentation assessment using a single measure, Wildlife Society Bulletin, 28 (4), 875-881.

Borgonovo, E., Peccati, L. 2008. Sensitivity Analysis in Decision Making: A Consistent Approach. In M. Abdellaoui, J. D. Hey (Eds.), Advances in Decision Making Under Risk and Uncertainty. Theory and Decision Library (Series C: Game Theory, Mathematical Programming and Operations Research), vol 42 (pp. 65-89). Berlin, Heidelberg: Springer.

Bruschi, D., Garcia, D. A., Gugliermetti, F., Cumo, F. 2015. Characterizing the fragmentation level of Italian's National Parks due to transportation infrastructures. Transportation Research Part D: Transport and Environment, 36, 18-28. https://doi.org/10.1016/j.trd.2015.02.006.

Chester, C. C., Hilty, J. A. 2010. Connectivity Science. In G. L. Worboys, W. L. Francis, M. Lockwood (Eds.), Connectivity conservation management: a global guide (pp. 22-33). London: Earthscan.

Clemen, R. T. 1996. Making hard decisions: An introduction to decision analysis. Belmont, Calif: Duxbury Press.

Coffin, A. W. 2007. From roadkill to road ecology: A review of the ecological effects of roads. Journal of Transport Geography, 15 (5), 396-406. https://doi.org/10.1016/j.jtrangeo.2006.11.006

Collinge, S. K. 1996. Ecological consequences of habitat fragmentation: implications for landscape architecture and planning. Landscape and Urban Planning 36 (1), 59-77. https://doi.org/10.1016/S0169-2046(96)00341-6.

Council of Europe. 2000. European Landscape Convention. Treaty No.176. Florence, 20/10/2000 — Treaty open for signature by the member States of the Council of Europe and for accession by the European Union and the European non-member States. https://www.coe.int/en/web/conventions/full-list/-/conventions/treaty/176?_coeconventions_WAR_coeconventionsportlet_languageId=it_IT Accessed 1 September 2018.

Council of Europe. 2008. Recommendation CM/Rec(2008)3 of the Committee of Ministers to member states on the guidelines for the implementation of the European Landscape Convention. https://rm.coe.int/16802f80c9 Accessed 1 September 2018.

Davidson, C. 1998. Issues in measuring landscape fragmentation. Wildlife Society Bulletin, 26 (1), 32-37.

De Montis, A. 2014. Impacts of the European Landscape Convention on national planning systems: A comparative investigation of six case studies. Landscape and Urban Planning, 124, 53–65. http://doi.org/10.1016/j.landurbplan.2014.01.005.

De Montis, A. 2016. Measuring the performance of planning: the conformance of Italian landscape planning practices with the European Landscape Convention. European Planning Studies, 24 (9), 1727-1745. http://doi.org/10.1080/09654313.2016.1178215.

De Montis, A., Martín, B., Ortega, E., Ledda, A., Serra, V. 2017. Landscape fragmentation in Mediterranean Europe: A comparative approach. Land Use Policy, 64, 83-94.

De Montis, A. Ledda, A., Ortega, E., Martín, B., Serra V. 2018. Landscape planning and defragmentation measures: an assessment of costs and critical issues. Land Use Policy 72, 313-324.

De Montis, A., Ledda, A., Serra, V. (in press). Landscape defragmentation policy and planning: An assessment of strengths and weaknesses. TeMA, Journal of Land Use, Mobility and Environment, 11.

EEA. 2011. Landscape fragmentation in Europe, Joint EEA-FOEN report. Copenhagen: European Environment Agency. ISBN 978-92-9213-215-6.

Fabietti, V., Gori, M., Guccione, M., Musacchio, M. C., Nazzini, L., Rago, G. 2011. Frammentazione del territorio da infrastrutture lineari. Indirizzi e buone pratiche per la prevenzione e la mitigazione degli impatti, ISPRA, Manuali e Linee Guida 76.1/2011. In Italian.

Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., Chapin, F. S., Coe, M. T., Daily, G. C., Gibbs, H. K., Helkowski, J. H., Holloway, T., Howard, E. A., Kucharik, C. J., Monfreda, C., Patz, J. A., Prentice, I. C., Ramankutty, N., Snyder, P. K. 2005. Global Consequences of Land Use. Science, 309 (5734), 570-574. http://doi.org/10.1126/science.1111772.

Foley, J. A., Ramankutty, N., Brauman, K. A., Cassidy, E. S., Gerber, J. S., Johnston, M., Mueller, N. D., O'Connell, C., Ray, D. K., West, P. C., Balzer, C., Bennett, E. M., Carpenter, S. R., Hill, J., Monfreda, C., Polasky, S., Rockström, J., Sheehan, J., Siebert, S., Tilman, D., Zaks, D. P. M. 2011. Solutions for a cultivated planet. Nature, 478 (7369), 337-342. http://doi.org/10.1038/nature10452.

Gambino, R. 2003. Progetto e conservazione del paesaggio. Ri-Vista. Ricerche per la progettazione del paesaggio, anno 1 - numero 0. Firenze: Firenze University Press. In Italian.

Gibson, L., Lynam, A. J., Bradshaw, C. J. A., He, F., Bickford, D. P., Woodruff, D. S., Bumrungsri, S., Laurance, W. F. 2013. Near-Complete Extinction of Native Small Mammal Fauna 25 Years After Forest Fragmentation. Science, 341 (6153),1508-1510. https://doi.org/10.1126/science.1240495.

Haddad, N. M., Brudvig, L. A., Clobert, J., Davies, K. F., Gonzalez, A., Holt, R. D., Lovejoy, T.

E., Sexton, J. O., Austin, M. P., Collins, C. D., Cook, W. M., Damschen, E. I., Ewers, R. M., Foster, B. L., Jenkins, C. N., King, A. J., Laurance, W. F., Levey, D. J., Margules, C. R., Melbourne, B. A., Nicholls, A. O., Orrock, J. L., Song, D.-X., Townshend, J. R. 2015. Habitat fragmentation and its lasting impact on Earth's ecosystems. Science, 1 (2), 1-9. https://doi.org/10.1126/sciadv.1500052.

Harrisson, K. A., Pavlova, A., Amos, J. N., Takeuchi, N., Lill, A., Radford, J. Q., Sunnucks, P. 2012. Fine-scale effects of habitat loss and fragmentation despite large-scale gene flow for some regionally declining woodland bird species. Landscape Ecology, 27 (6), 813-827. https://doi.org/10.1007/s10980-012-9743-2.

Henle, K., Davies, K. F., Kleyer, M., Margules, C., Settele, J. 2004. Predictors of species sensitivity to fragmentation. Biodiversity & Conservation, 13, 207-251.

Hornseth, M. L., Walpole, A. A., Walton, L. R., Bowman, J., Ray, J. C., Fortin, M.-J. E., Murray, D. L. 2014. Habitat loss, not fragmentation, drives occurrence patterns of Canada lynx at the southern range periphery. PLoS ONE, 9 (11), e113511. https://doi.org/10.1371/journal.pone.0113511.

Igondova, E., Pavlickova, K., Majzlan, O. 2016. The ecological impact assessment of a proposed road development (the Slovak approach). Environmental Impact Assessment Review, 59, 43-54. https://doi.org/10.1016/j.eiar.2016.03.006.

Jaarsma, C. F., Willems, G. P. A. 2002. Reducing habitat fragmentation by minor rural roads through traffic calming. Landscape and Urban Planning, 58 (2–4), 125-135. https://doi.org/10.1016/S0169-2046(01)00215-8.

Jaarsma, C. F. 2004. Ecological 'black spots' within the ecological network: an improved design for rural road network amelioration. In R. H. G. Jongman, G. Pungetti (Eds.), Ecological networks and greenways: concept, design implementation (pp. 171-187). Cambridge: Cambridge University Press.

Jaeger, J. A. G. 2000. Landscape division, splitting index, and effective mesh size: New measures of landscape fragmentation. Landscape Ecology, 15 (2), 115-130.

Jongman, R. H. G. 2004. The context and concept of ecological networks. In R.H.G. Jongman, G. Pungetti (Eds.), Ecological networks and greenways: concept, design implementation (pp. 7-33). Cambridge: Cambridge University Press.

Junta de Andalucia. 2016. Sistema de Información sobre Ocupación del Suelo de España en Andalucía (Land use Information System of Spain) (SIOSE).

http://www.juntadeandalucia.es/medioambiente/site/portalweb/menuitem.7e1cf46ddf59bb227a9ebe205510e1ca/?vgnextoid=fbec73f552215310VgnVCM2000000624e50aRCRD&vgnextchannel=637c545f021f4310VgnVCM1000001325e50aRCRD Accessed 1 September 2018.

Kettunen, M., Terry, A., Tucker, G., Jones, A. 2007. Guidance on the maintenance of landscape features of major importance for wild flora and fauna - Guidance on the implementation of Article 3 of the Birds Directive (79/409/EEC) and Article 10 of the Habitats Directive (92/43/EEC). Brussels: Institute for European Environmental Policy (IEEP), 114 pp. & Annexes.

La Rovere, M., Battisti, C., Romano, B. 2006. Integrazione dei parametri eco-biogeografici negli strumenti di pianificazione territoriale. XXVII Conferenza Italiana di Scienze Regionali, Impresa, Mercato, Lealtà Territoriale, Pisa, 12-14 October 2006. In Italian.

McCuen, R. H. 1973. The role of sensitivity analysis in hydrologic modeling. Journal of Hydrology, 18, 37-53. https://doi.org/10.1016/0022-1694(73)90024-3.

Melis, G., Puddu, G. 2008. Gli algoritmi di cost-distance come strumento di supporto per la pianificazione alla scala provinciale delle reti ecologiche. XII Conferenza Nazionale ASITA - L'Aquila, 21-24 October 2008. In Italian.

Neri, M., Menconi, M. E., Vizzari, M., Mennella, V. G. G. 2010. Propuesta de una nueva metodología para la ubicación de infraestructuras viarias ambientalmente sostenibles. Aplicación en el tramo viario de la pedemontana Fabriano-Muccia. Informes de la Construcción, 62 (517), 101-112.

O'Connor, T., Yang, X., Tian, G., Chatterjee, S., Lee, S. 2017. 2 - Quality risk management for pharmaceutical manufacturing: The role of process modeling and simulations. Predictive Modeling of Pharmaceutical Unit Operations, 15-37. https://doi.org/10.1016/B978-0-08-100154-7.00002-8.

Pannell, D. J. 1997. Sensitivity analysis of normative economic models: Theoretical framework and practical strategies. Agricultural Economics, 16 (2), 139-152. https://doi.org/10.1016/S0169-5150(96)01217-0.

Rico, A., Kindlmann, P., Sedláček, F. 2007. Barrier effects of roads on movements of small mammals. Folia Zoologica, 56 (1), 1-12.

Romano, B. 2002. Evaluation of urban fragmentation in the ecosystems. International conference on mountain environment and development (ICMED). CHENGDU, Sichuan, China, 15-19 October 2002.

Romano, B., Paolinelli, G. 2007. L'interferenza insediativa nelle strutture ecosistemiche: modelli per la rete ecologica del Veneto. Roma: Gangemi Editore. ISBN: 9788849213997.

Romano, B., Tamburini, G. 2001. Gli indicatori di frammentazione e di interferenza ambientale nella pianificazione urbanistica. Atti XXII Conferenza Italiana di Scienze Regionali, Venezia, 10-12 October 2001, AISRE, CNR Ipiget, Napoli. In Italian.

Romano, B., Tamburini, G. 2006. Urban Sensibility of Landscape Structures in Italy General Characteristics and Local Details. ERSA conference papers ersa06p400, European Regional Science Association, Greece.

Romano, B., Zullo, F. 2013. Valutazione della pressione insediativa: indicatori e sperimentazione di soglie. In C. Battisti, M. Conigliaro, G. Poeta, C. Teofili (Eds.), Biodiversità, disturbi, minacce (pp. 170-177). Udine: Forum Editrice Universitaria Udinese. ISBN: 978-88-8420-803-3. In Italian.

Sardinia. 2006. Piano Paesaggistico Regionale (Regional Landscape Plan). http://www.sardegnaterritorio.it/paesaggio/pianopaesaggistico2006.html Accessed 1 September 2018.

Sarrazin, F., Pianosi, F., Wagener, T. 2016. Global Sensitivity Analysis of environmental models: Convergence and validation. Environmental Modelling and Software, 79, 135-152. https://doi.org/10.1016/j.envsoft.2016.02.005.

Saunders, D. A., Hobbs, R. J., Margules C. R. 1991. Biological Consequences of Ecosystem Fragmentation: A Review. Conservation Biology, 5, 18-32.

Scolozzi, R., Geneletti, D. 2012. Assessing habitat connectivity for land-use planning: a method integrating landscape graphs and Delphi survey. Journal of Environmental Planning and Management, 55 (6), 813-830. https://doi.org/10.1080/09640568.2011.628823.

Serrano, M., Sanz, L., Puig, J., Pons, J. 2002. Landscape fragmentation caused by the transport network in Navarra (Spain): Two-scale analysis and landscape integration assessment. Landscape and Urban Planning, 58 (2-4), 113-123. https://doi.org/10.1016/S0169-2046(01)00214-6.

Smith, D. J. 2004. Impacts of roads on ecological networks and integration of conservation and transportation planning: Florida as a case study. In R.H.G. Jongman, G. Pungetti (Eds.), Ecological networks and greenways: concept, design implementation (pp. 73-93). Cambridge: Cambridge University Press.

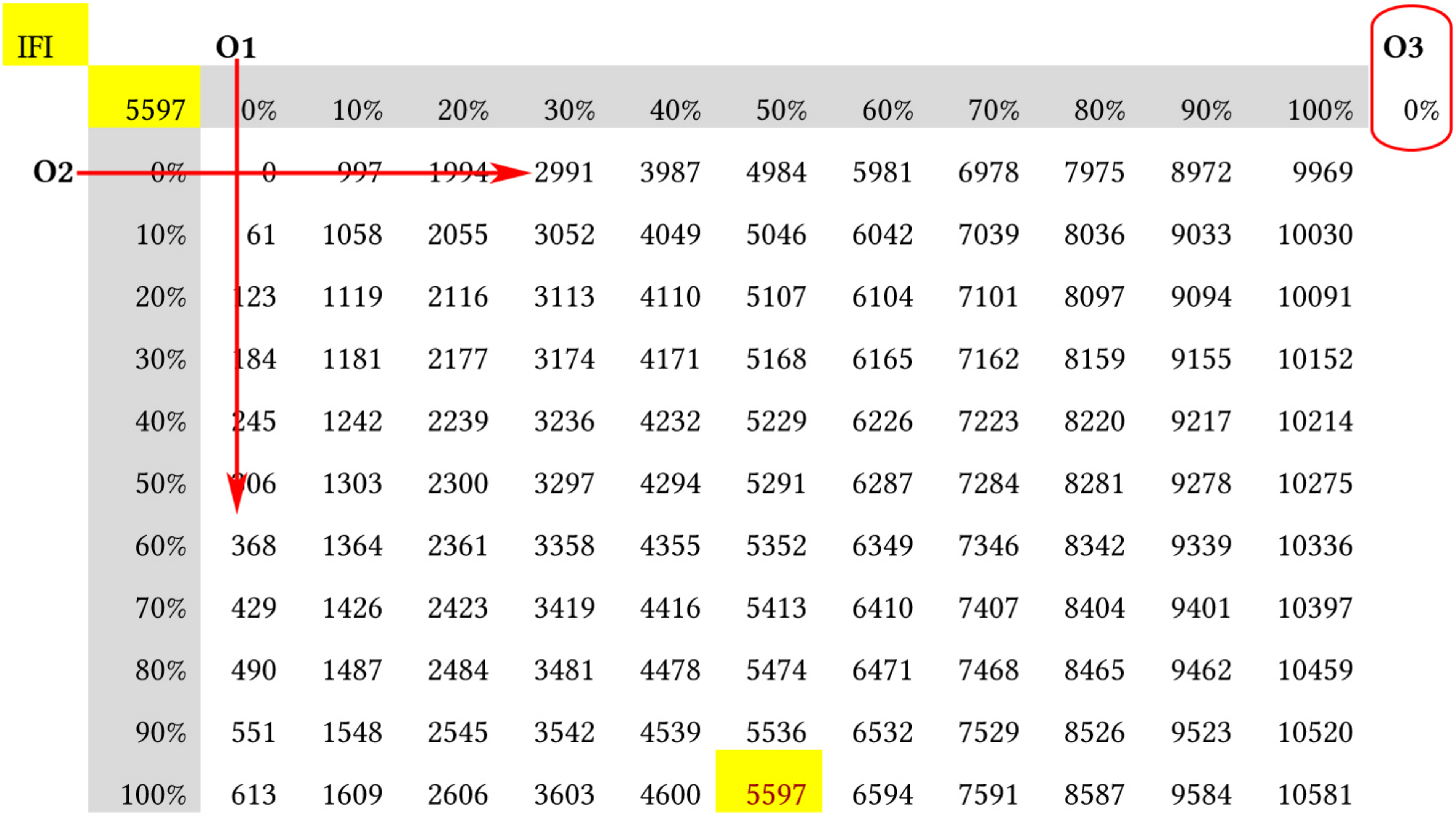
Spellerberg, I. 1998. Ecological effects of roads and traffic: a literature review. Global Ecology and Biogeography Letters, 7, 317–333.

Thabane, L., Mbuagbaw, L., Zhang, S., Samaan, Z., Marcucci, M., Ye, C., Thabane, M., Giangregorio, L., Dennis, B., Kosa, D., Debono, V. B., Dillenburg, R., Fruci, V., Bawor, M., Lee, J., Wells, G., Goldsmith, C. H. 2013. A tutorial on sensitivity analyses in clinical trials: The what, why, when and how. BMC Medical Research Methodology, 13 (1), 92. https://dx.doi.org/10.1186%2F1471-2288-13-92.

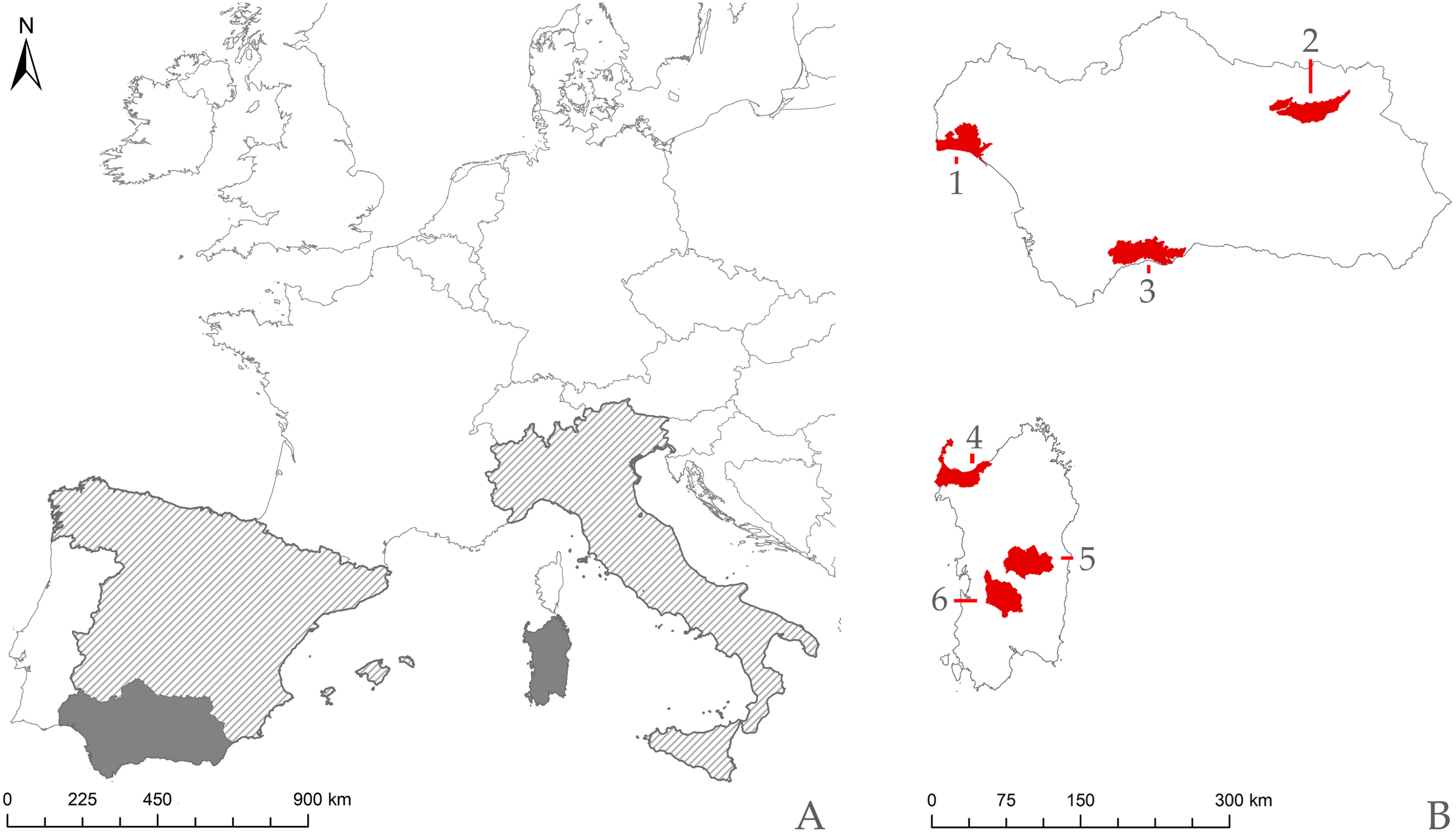
Uusitalo, L., Lehikoinen, A., Helle, I., Myrberg, K. 2015. An overview of methods to evaluate uncertainty of deterministic models in decision support. Environmental Modelling and Software, 63, 24-31. https://doi.org/10.1016/j.envsoft.2014.09.017.

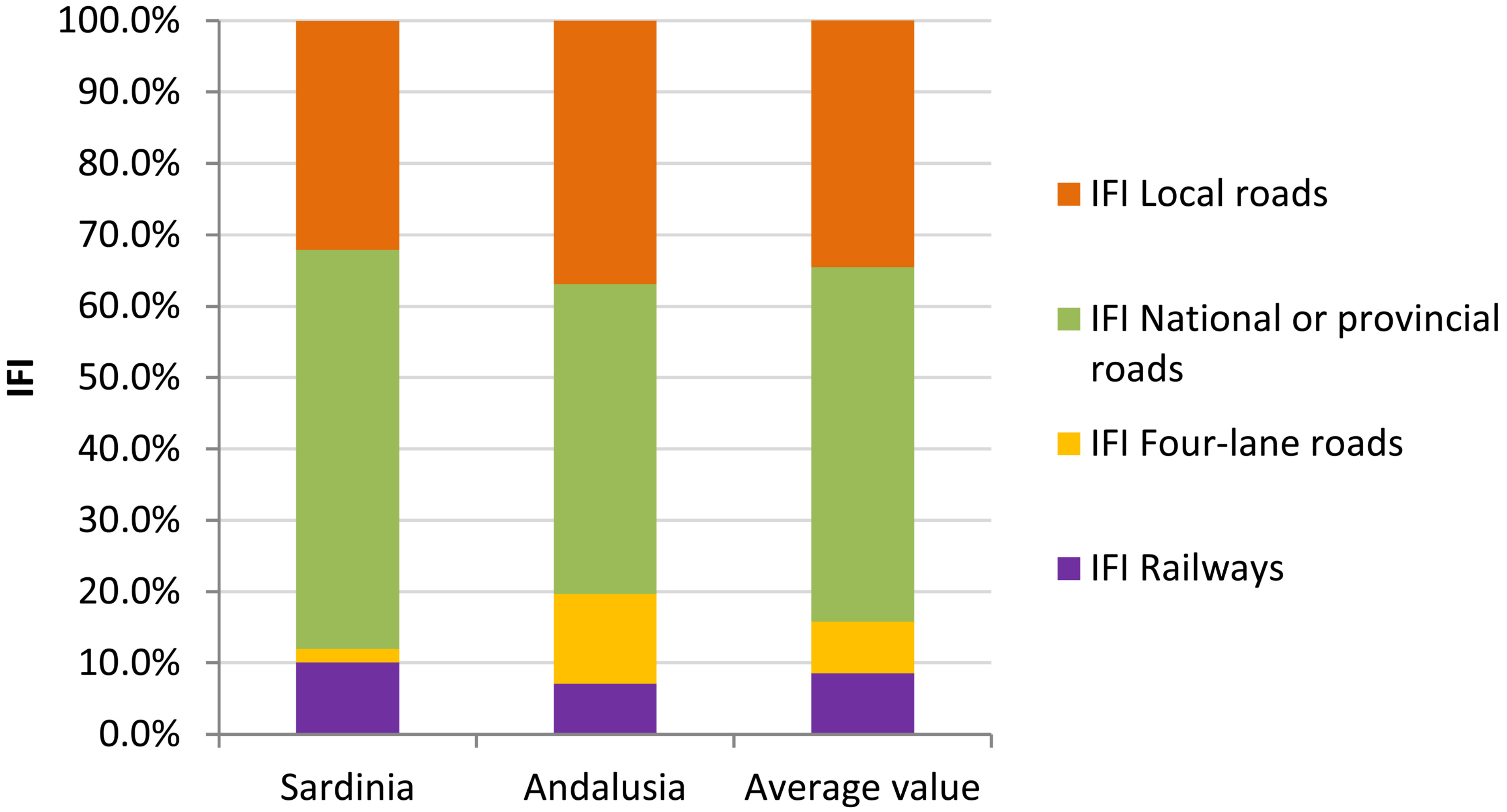
Wilcove, D. S., McLellan, C. H., Dobson A. P. 1986. Habitat fragmentation in the temperate zones. In M. E. Soulé (Ed.), Conservation Biology (pp. 237-256). Sunderland, Massachussets: Sinauer Associates Inc.

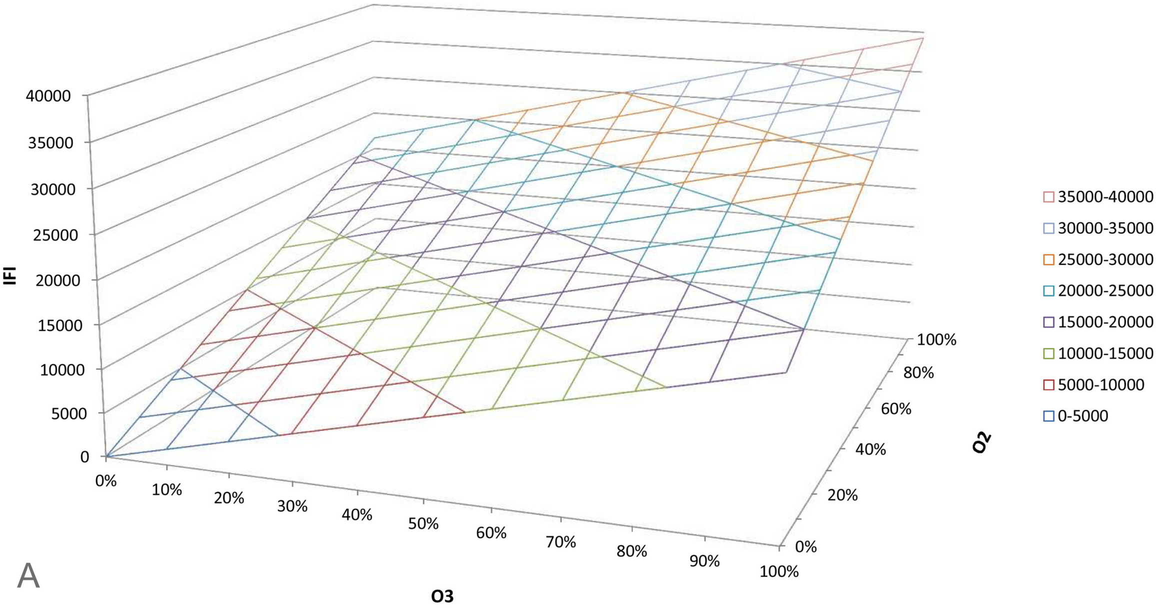
Zanon, B., Geneletti, D., Franceschini, A. 2007. L'integrazione dei valori antropici, visuali ed ambientali nella zonizzazione dei parchi naturali. Agribusiness Paesaggio & Ambiente 10 (2), 126-137. In Italian.



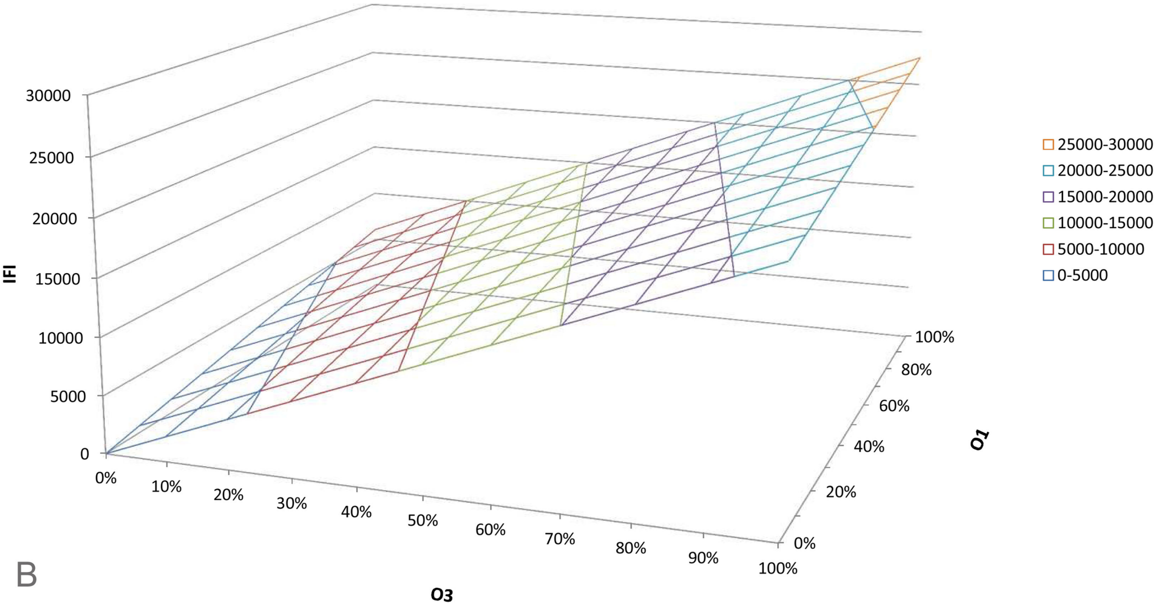
5597	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	0%
0%	0	997	1994	2991	3987	4984	5981	6978	7975	8972	9969	
10%	61	1058	2055	3052	4049	5046	6042	7039	8036	9033	10030	
20%	123	1119	2116	3113	4110	5107	6104	7101	8097	9094	10091	
30%	184	1181	2177	3174	4171	5168	6165	7162	8159	9155	10152	
40%	245	1242	2239	3236	4232	5229	6226	7223	8220	9217	10214	
50%	306	1303	2300	3297	4294	5291	6287	7284	8281	9278	10275	
60%	368	1364	2361	3358	4355	5352	6349	7346	8342	9339	10336	
70%	429	1426	2423	3419	4416	5413	6410	7407	8404	9401	10397	
80%	490	1487	2484	3481	4478	5474	6471	7468	8465	9462	10459	
90%	551	1548	2545	3542	4539	5536	6532	7529	8526	9523	10520	
100%	613	1609	2606	3603	4600	5597	6594	7591	8587	9584	10581	


N
0
225
450
900 km
A
2
1
3
4
5
6
0
75
150
300 km
B

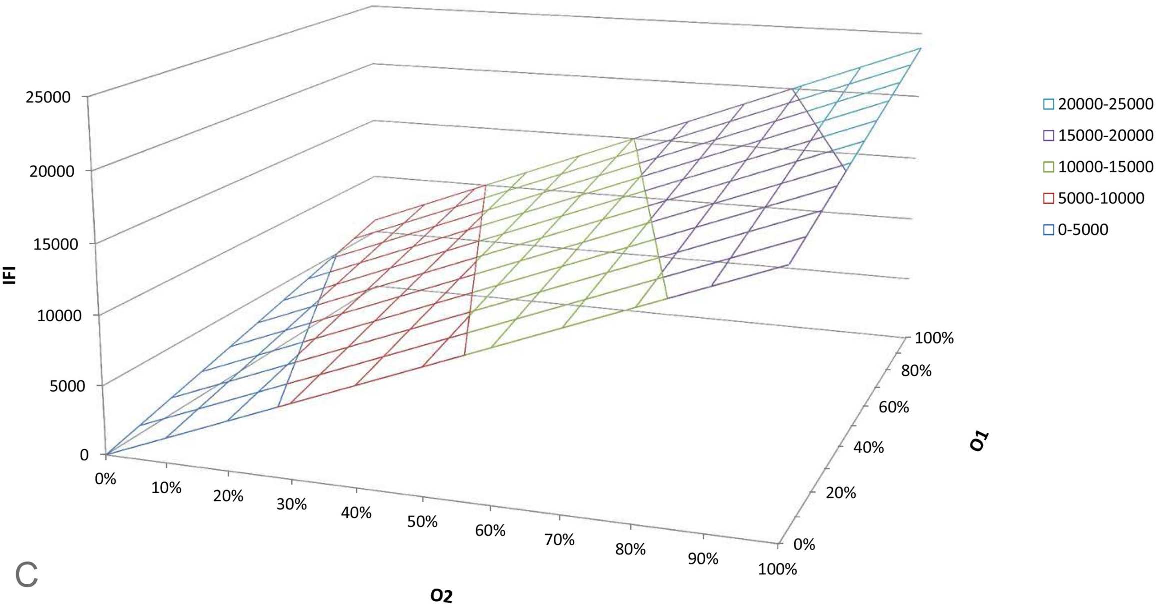

100.0%
90.0%
80.0%
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
IFI
Sardinia
Andalusia
Average value
IFI Local roads
IFI National or provincial roads
IFI Four-lane roads
IFI Railways


IFI
40000
35000
30000
25000
20000
15000
10000
5000
0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
O3
0%
20%
40%
60%
80%
100%
O2
35000-40000
30000-35000
25000-30000
20000-25000
15000-20000
10000-15000
5000-10000
0-5000

A


IFI
30000
25000
20000
15000
10000
5000
0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
O3
0%
20%
40%
60%
80%
100%
O1
25000-30000
20000-25000
15000-20000
10000-15000
5000-10000
0-5000

B


IFI
25000
20000
15000
10000
5000
0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
O2
0%
20%
40%
60%
80%
100%
O1
20000-25000
15000-20000
10000-15000
5000-10000
0-5000

C