

Federica Isola, Sabrina Lai,  
Federica Leone, Corrado Zoppi

# Green Infrastructure and Regional Planning

An Operational Framework

territorio sostenibilità governance



**FrancoAngeli**

*Territorio sostenibilità governance*  
*Collana diretta da Manlio Vendittelli*

*Comitato scientifico:* Pier Paolo Balbo (urbanistica), Fulvio Beato (sociologia del territorio), Maurizio Imperio (sistemi informativi), Massimo Paci (sociologia), Roberto Palumbo (tecnologia), Sandro Pignatti (ecologia), Edo Ronchi (sostenibilità), Benedetto Todaro (architettura)

La collana, suddivisa in tre sezioni (saggi, ricerche, quaderni), analizzando le trasformazioni territoriali, la sostenibilità ambientale e il governo dei processi, vuole contribuire alla costruzione di una nuova concezione del progetto in una cultura multiscale attraverso tre concetti chiave: complessità sistemica, limite, progetto. Il primo è legato ai risultati strutturali ed estetici che le trasformazioni hanno prodotto e che devono essere governati nella loro complessità; il secondo è definito dalle leggi della sostenibilità; il terzo è frutto della razionalità del fare.

Territorio, sostenibilità e governance diventano pertanto i tre elementi di interazione economica e sociale essenziali nei processi di trasformazione che, nel progetto, devono intrecciarsi per diventare un *unicum*.

In quest'ottica la riqualificazione dei luoghi dell'organizzazione umana, la ricostruzione di reti ecologiche, la messa a norma del territorio, la valutazione e progettazione strategica e il governo dei conflitti non sono altro che un momento di ricomposizione delle istanze sociali in progetti coerenti di valorizzazione delle risorse locali nella garanzia delle identità, delle diversità, dei valori storico-ambientali.

La sostenibilità diventa il valore attraverso il quale si possono definire le trasformazioni come processo che organizza la cultura del divenire nella cultura del limite, come presupposto della progettazione sistemica, della partecipazione sociale alle decisioni, del governo dei processi.

Aggiungere al concetto di gestione democratica la difesa dei diritti delle generazioni future significa esplorare un terreno di indagine che, seppure agli albori, porta al principio per cui è solo con una nuova cultura sociale che potremo iniziare davvero processi decisionali partecipati e condivisi sulle trasformazioni sociali e sul governo dei conflitti.

Costruire sistemi di conoscenza e strutture sociali di valutazione sul principio della coscienza critica e del controllo sociale dell'informazione è diventato oggi un problema sul quale devono confrontarsi gli stessi principi della democrazia e della scienza.

Tutti i testi pubblicati nella collana sono sottoposti a un processo di blind peer review.



This volume is published in open access format, i.e. the file of the entire work can be freely downloaded from the FrancoAngeli Open Access platform (<http://bit.ly/francoangeli-oa>).

On the FrancoAngeli Open Access platform, it is possible to publish articles and monographs, according to ethical and quality standards while ensuring open access to the content itself. It guarantees the preservation in the major international OA archives and repositories. Through the integration with its entire catalog of publications and series, FrancoAngeli also maximizes visibility, user accessibility and impact for the author.

Read more:

[http://www.francoangeli.it/come\\_publicare/publicare\\_19.asp](http://www.francoangeli.it/come_publicare/publicare_19.asp)

Readers who wish to find out about the books and periodicals published by us can visit our website [www.francoangeli.it](http://www.francoangeli.it) and subscribe to our “Informatemi” (notify me) service to receive e-mail notifications.

**SAGGI**

Federica Isola, Sabrina Lai,  
Federica Leone, Corrado Zoppi

# **Green Infrastructure and Regional Planning**

An Operational Framework

territorio sostenibilità governance

**FrancoAngeli**

The book was implemented within the Research Program “Paesaggi rurali della Sardegna: pianificazione di infrastrutture verdi e blu e di reti territoriali complesse” [Rural landscapes of Sardinia: Planning policies for green and blue infrastructure and spatial complex networks], funded by the Autonomous Region of Sardinia for the period 2019-2021, under the provisions of the call for the presentation of “Projects related to fundamental or basic research” of the year 2017, implemented at the Department of Civil and Environmental Engineering and Architecture (DICAAR) of the University of Cagliari, Italy.

ISBN cartaceo: 9788835127017

ISBN e-book: 9788835141402

*Cover image:* View of Cala Goloritzè from Punta Salinas (Sardinia, Italy).  
Photo by Federica Isola

Copyright © 2022 by FrancoAngeli s.r.l., Milano, Italy.

This work, and each part thereof, is protected by copyright law and is published in this digital version under the license *Creative Commons Attribution-NoDerivatives 4.0 International* (CC-BY-ND 4.0)

*By downloading this work, the User accepts all the conditions of the license agreement for the work as stated and set out on the website*

<https://creativecommons.org/licenses/by-nd/4.0/>

Copyright © 2022 by FrancoAngeli s.r.l., Milano, Italy. ISBN 9788835141402

# Index

<b>Foreword</b>	pag.	9
<b>1. Introduction</b>	»	11
1.1. Bibliography	»	15
<b>2. Defining a spatial taxonomy for a regional infrastructure in Sardinia</b>	»	20
2.1. Conservation value ( <i>Consval</i> )	»	20
2.1.1. Assessing conservation value: a novel method based on Natura 2000 standard dataforms and Habitat Directive reporting	»	22
2.2. Natural value ( <i>Natval</i> )	»	25
2.2.1. Natural quality assessment through the InVEST model	»	28
2.3. Recreation value ( <i>Recrval</i> )	»	31
2.3.1. Recreational ES modeling through ESTIMAP	»	33
2.4. Landscape value ( <i>Landsval</i> )	»	52
2.4.1. Assessing landscape value based on the provisions of the Regional Landscape Plan	»	54
2.5. Agricultural and forestry value ( <i>Agrofor</i> )	»	56
2.5.1. Estimating agricultural and forestry value using land value as a proxy	»	57
2.6. Land surface temperature ( <i>LST</i> )	»	59
2.6.1. LST retrieval from Landsat imagery	»	60
2.7. Carbon storage and sequestration capacity ( <i>CO<sub>2</sub>Stor</i> )	»	63
2.7.1. Modeling carbon storage and sequestration through the InVEST suite	»	65
2.8. Mapping the components of a regional GI and identifying relevant areas for ES provision	»	67

2.8.1. Spatial distribution of the seven components of a regional GI	pag.	67
2.8.2. Identifying priority areas through an assessment of synergies and trade-offs between ecosystem services	»	69
2.9. Bibliography	»	73
<b>3. Mapping of ecological corridors as connections between protected areas: a study concerning Sardinia, Italy</b>	»	93
3.1. Introduction	»	94
3.2. Materials and methods	»	95
3.2.1. Spatial identification of the ecological corridors	»	95
3.2.2. Study area	»	99
3.2.3. Relation between EC and landscape components	»	101
3.3. Results	»	105
3.3.1. The spatial layout of ecological corridors	»	105
3.3.2. Discussion on the overlay of ecological corridors and landscape components	»	108
3.4. Bibliography	»	110
<b>4. Assessing the potential of green infrastructure to mitigate hydro-geological hazard: evidence-based policy suggestions from a Sardinian study area</b>	»	115
4.1. Introduction	»	115
4.2. Materials and methods	»	119
4.2.1 Study area	»	119
4.2.2. Methodological framework	»	122
4.3. Data	»	127
4.4. Findings	»	132
4.4.1. Flood and landslide hazards and their drivers	»	132
4.4.2. Estimates of the Logit models	»	133
4.5. Bibliography	»	136
<b>5. Conclusions</b>	»	143
5.1. The spatial taxonomy to identify the RGI	»	143
5.2. The EC of the regional network of protected areas	»	146
5.3. Natural hazards and GI	»	148
5.4. Bibliography	»	154
<b>6. Figures</b>	»	159

6.1. Figures Chapter 2	pag.	160
6.2. Figures Chapter 3	»	174
6.3. Figures Chapter 4	»	182





## Foreword

The authors have jointly contributed to the conception, design, execution, and interpretation of the research work reported in this volume.

Individual contributions are as follows.

Sabrina Lai, Federica Isola, Federica Leone and Corrado Zoppi have collaboratively designed the research structure of this volume and have jointly taken care of chapter 1.

Sabrina Lai has taken care of chapter 2, subsections 4.2.1., 4.2.3., 4.3.1. and section 5.1.

Federica Isola, Federica Leone and Corrado Zoppi have collaboratively studied the organization of chapter 3 and have jointly taken care of section 3.1 and subsection 3.2.1.

Federica Isola has taken care of subsection 3.2.2.

Federica Leone has taken care of subsection 3.3.1.

Federica Isola and Federica Leone have jointly taken care of sections 4.1., 5.2. and 5.3.

Corrado Zoppi has taken care of subsections 3.2.3, 3.3.2., 4.2.2. and 4.3.2.

Chapter 1, “Introduction”, is partly reproduced from: i) Lai S., Leone F. and Zoppi C. (2018), “Implementing green infrastructures beyond protected areas”, *Sustainability*, 10, 10 (3544): 1-16. DOI: 10.3390/su10103544, pp. 1-3, as for the definition of green infrastructure and methodological references; ii) Floris M. and Zoppi C. (2019), *Carbon Sequestration and Land-taking Processes. A Study concerning Sardinia (Italy)*, in: Gargiulo C. and Zoppi C., eds., *Planning, Nature and Ecosystem Services*, FedOAPress, Naples, Italy, pp. 66-79. DOI: 10.6093/978-88-6887-054-6, p. 67, as for carbon sequestration ecosystem service.

Chapter 2, “Defining a spatial taxonomy for a regional infrastructure in Sardinia”, partly draws upon: i) *Bridging Biodiversity Conservation Objectives with Landscape Planning through Green Infrastructures: A Case*

*Study from Sardinia, Italy*, in Gervasi O., Murgante B., Misra S., Borruso G., Torre C., Rocha A.M.A.C., Taniar D., Apduhan B.O., Stankova E. and Cuzzocrea, A., eds., *17<sup>th</sup> International Conference on Computational Science and Its Applications (ICCSA 2017), Lecture Notes in Computer Sciences Series, Vol. no. 10409*, Springer, Cham, Switzerland, pp. 456-472. DOI: 10.1007/978-3-319-62407-5\_39 (as for conservation value, natural value and landscape value) and from ii). Lai S., Leone F. and Zoppi C. (2020), “Spatial distribution of surface temperature and land cover: A study concerning Sardinia, Italy”, *Sustainability*, 12, 8 (3186): 1-20. DOI: 10.3390/su12083186 (as for land surface temperature retrieval).

Chapter 3, “Mapping of ecological corridors as connections between protected areas: A study concerning Sardinia, Italy”, is reproduced from Isola F., Leone F. and Zoppi C. (2022), “Mapping of ecological corridors as connections between protected areas: A study concerning Sardinia, Italy”, *Preprints 2022*, 2022050088: 1-24. DOI: 10.20944/ preprints202205.0088.v1, pp. 1-20. This article was submitted to *Sustainability* and is currently under review.

Chapter 4, “Green infrastructure and environmental risk: A case study concerning landslide and flood hazard mitigation in a coastal area of Sardinia”, is partly reproduced from: Lai S., Isola F., Leone F. and Zoppi C. (2021), “Assessing the potential of green infrastructure to mitigate hydro-geological hazard. Evidence-based policy suggestions from a Sardinian study area”, *TeMA. Journal of Land Use, Mobility and Environment*, Special Issue 1.2021 “The Emergency Plan for the use and management of the territory”: 109-133. DOI: 10.6092/1970-9870/7411.

Chapter 5, “Discussion and planning policy implications”, is partly reproduced from: i) Lai S., Leone F. and Zoppi C. (2020), “Land Surface Temperature and land cover dynamics. A study related to Sardinia, Italy”, *TeMA. Journal of Land Use, Mobility and Environment*, 13, 3: 329-351. DOI: 10.6092/1970-9870/7143, pp. 344-345, as for afforestation discussion, Section 5.2. “The EC of the regional network of protected areas”; ii) Isola F., Leone F. and Zoppi C. (2022), “Mapping of ecological corridors as connections between protected areas: A study concerning Sardinia, Italy”, *Preprints 2022*, 2022050088: 1-24. DOI: 10.20944/ preprints202205.0088.v1, pp. 20-21; this article was submitted to *Sustainability* and is currently under review; iii) Lai S., Isola F., Leone F. and Zoppi C. (2021), “Assessing the potential of green infrastructure to mitigate hydro-geological hazard. Evidence-based policy suggestions from a Sardinian study area”, *TeMA. Journal of Land Use, Mobility and Environment*, Special Issue 1.2021 “The Emergency Plan for the use and management of the territory”: 109-133. DOI: 10.6092/1970-9870/7411, pp. 125-128, as for Section 5.3 “Natural hazards and GI”.

# 1. Introduction

An important definition of green infrastructure (GI) is proposed by the European Commission in its Communication titled “Green infrastructure: enhancing Europe’s natural capital”, where GI is regarded as a network having the Natura 2000 sites at its core, capable of delivering numerous ecosystem services (ES), and is “strategically planned”, emphasizing the role of GI with regards to the integration of ecological connectivity, and protection of the environment and of ecosystems’ multiple functions, drawing on Benedict and McMahon (2006, p. 1), according to whom GI is «an interconnected network of natural areas and other open spaces that (...) provides a wide array of benefits for people and wildlife». As a consequence, identifying and managing GI is a core planning issue (Landscape Institute, 2009) especially under the provisions of the European Landscape Convention (Liquete *et al.*, 2015).

As for connectivity, Lennon (2015) highlights that, notwithstanding differences in defining GI, common conceptualizations of GI relate to networks, hence stressing that rather than protecting individual, isolated parcels of natural or seminatural areas, planning should take care of interconnected networks (Benedict and McMahon, 2002), comprising both core areas that support key ES and corridors that support species movements and dispersal, respectively, “hubs” and “links” in Laforteza *et al.* (2013).

With reference to multifunctionality, this is commonly understood as the combination of “ecological, social and economic, abiotic, biotic and cultural function of green spaces” (Hansen and Pauleit, 2014) or “the ability to provide several functions and benefits on the same spatial scale” (Millennium Ecosystem Assessment, 2003). As a consequence, GI multifunctionality has been analyzed in the light of the ES framework (Hansen and Pauleit, 2014), where ES are goods and services supplied by nature that sustain life and contribute, both directly and indirectly, to human wellbeing, variously defined, and classified in the literature according to many

different frameworks (prominently, the Millennium Ecosystem Assessment (2003); in Europe, the Common International Classification for Ecosystem Services (CICES) by the European Environment Agency<sup>1</sup>; and, in the United States, the Final Ecosystem Goods and Services Classification System (FECS-CS) by the United States Environmental Protection Agency (Landers and Nahlik, 2013)).

Beneficial functions provided by GI are broadly categorized by Pauleit *et al.* (as cited in Hansen and Pauleit, 2014) into ecological, social and economic categories, while Taylor-Lovell and Taylor (2013) explicitly group those ES and functions that, in their view, should be supplied by GI: production (including provisioning ecosystem services such as food or timber production), ecological (including supporting and regulatory ecosystem services, such as water purification or climate regulation), and cultural (including recreation, landscape quality, cultural heritage); the need to take into account communities' and users' needs and preferences is also underlined. This study emphasizes the second characteristic of GI, that is, the multifunctional use of natural capital that allows for multiple purposes, while connectivity can be easily integrated using the same methodology as in Cannas *et al.* (2018).

According to Hansen and DeFries (2007), protected areas are planned so as to implement virtuous ecological and socio-economic interactive relationships with surrounding areas, and, by doing so, build an integrated ecosystem. Furthermore, the assessment of protected area-related spatial policies could represent a reference point to enhance the efficiency and effectiveness of policy measures aimed at implementing environmental protection and related management measures (Gaston *et al.*, 2006; Ruiz Benito *et al.*, 2010).

Identifying and planning regional GI can be considered as an intentional way of spreading the positive impacts of environmental conservation policies across a spatial context much more complex and larger than the protected areas. Urban and rural settlements can be part of the spatial context of the regional GI as well (Wickham *et al.*, 2010; Spanò *et al.*, 2017).

This study builds upon a methodology applied in previous studies by Arcidiacono *et al.* (2016) and by Lai and Leone (2017), which both map a regional GI taking an Italian region as a case study. In the former, a GI for Lombardy was identified as a multifunctional GI taking into account three values: natural value, recreation value, and landscape value. In the latter, a

<sup>1</sup> CICES Version 5.1 available at the website <https://cices.eu/> [Accessed: 22 February 2022].

Sardinian GI was identified based upon four factors, i.e., adding to the three values used in Arcidiacono *et al.* (2016) a fourth layer accounting for conservation value.

Conservation value is based on the presence of areas whose natural characteristics are particularly important because hosting habitats rare, endangered, or representative of European biogeographical regions (i.e., habitats of community interest under the provisions of the Habitats Directive (no. 93/43/EEC)). Such habitats are meant to be maintained or restored in a favorable conservation status, and their presence calls for the designation of Natura 2000 sites, when criteria listed in Annex III of the Habitats Directive (concerning representativity, size, conservation status, and significance of the site) are met. According to a recent study (Salomaa *et al.*, 2017) carried out to explore Finnish experts' perceptions on GI implementation, the importance of GI in relation to biodiversity conservation has been emphasized by the majority of respondents. Moreover, GI can contribute to the reduction of habitat fragmentation which is one of the primary causes of species extinction (Weber *et al.*, 2006).

Natural value is related to biodiversity's capacity of providing ES; hence, it implies ecological integrity and current levels of ecosystem functions, key to supplying human-demanded ES. As such, under the Millennium Ecosystem Assessment (Millennium Ecosystem Assessment, 2003) classification, it would be categorized under the supporting services group. In the literature, trade-offs between ES are often analyzed and assessed through land use/land cover changes (Sharma *et al.*, 2018; Polasky *et al.*, 2011; Yang *et al.*, 2018). For example, Yang *et al.* (2018) studied the impacts of land use changes on ES trade-offs in the case of Yahne watershed in the Loess Plateau, China. In particular, their study investigates land use patterns that mitigate conflicts between food supply and conservation measures in order to be included within future restoration policies.

Recreation value concerns the landscape attractiveness for recreational activities. Landscapes and natural habitats are accounted for when choosing holiday locations or doing outdoor activities (prominently, active tourism), thus they positively affect both local communities' and tourists' quality of life and wellbeing, while also benefitting local economies. Therefore, recreation value accounts for cultural ES, as classified by the Millennium Ecosystem Assessment (2003). In the literature, recreation value is assessed through monetary analyses (Serkan and Rehber, 2008; Martín-López *et al.*, 2009; Lankia *et al.*, 2015; Mayer and Woltering, 2018) or through non-monetary analyses (Kenter, 2016; Kelemen *et al.*, 2014; Eagles *et al.*, 2000). In the last decades, non-monetary methods based on social media approaches have been used to assess recreation value (Wood *et al.*, 2013;

Sonter *et al.*, 2016; Hausmann *et al.*, 2018). For instance, Cunha *et al.* (2018) evaluated recreation services combining social media-based methods (using the InVEST recreation model) and official data sources in the Northwest coast of Portugal. In this study, we implement the ESTIMAP approach to map the spatial potential concerning the recreation ES supply in the regional GI (Zulian *et al.*, 2013).

Landscape value accounts for the interactions between natural and human factors that have shaped European cultures, as per the European Landscape Convention, and it is here assessed based on the endowment of natural and cultural resources, which are identified as landscape-related goods by the Italian Code on cultural goods and landscape (Law enacted by decree no. 2004/42). Various authors have highlighted the importance of landscape value within spatial planning (Zoppi and Lai, 2010; Orantes *et al.*, 2017) and also in relation to the definition of GI (Arcidiacono *et al.*, 2016).

In this study, three factors are added to the set previously used to identify the regional GI, which are related to agriculture and forestry, land surface temperature (LST) and carbon sequestration capacity. Agricultural output and forestry production are classed as provisioning ESs (see, among many: TEEB, 2010; Maes *et al.*, 2013, 2014; Science for Environment Policy, 2015). A close relationship can be identified between forestry, cropland and LST mitigation, as discussed in the following paragraphs. Afforestation is the most relevant reference for planning policies designed to decrease LST and to boost-up the spatial structure of ecological corridors as regards non-urbanized areas, such as rural zones<sup>2</sup>.

Finally, carbon sequestration, that is carbon capture and storage, is a phenomenon, based on photosynthesis, which characterizes peat swamps, forests and grasslands, and other similar ecological systems and consists in carbon dioxide removal from the air through its sequestration by soil and plants (Lal, 2008). The interaction involving air composition and soil has a strong influence on climate regulation (Jobbagy and Jackson, 2000) and is strictly correlated to changes in land cover. Moreover, land condition and green areas play an important role in regulating the carbon cycle since they provide carbon capture and storage as an ecosystem service (European Commission, 2012; Millennium Ecosystem Assessment, 2003).

In this volume, a methodological approach, based on the seven factors identified above, is implemented with reference to Sardinia, an Italian insu-

<sup>2</sup> This issue is analytically discussed in the second section of the Conclusions of this volume (Chapter 5).

lar region, both in terms of mapping a spatial taxonomy aimed at scoring the eligibility of patches to be included into the regional GI, and as regards the identification of ecological corridors, as linear connections between the nodes of the regional network of protected areas.

In the next chapter, the methodology to identify the regional GI is presented, the detail of the data-base definition is described, and the outcomes of the assessments are presented through maps that unveil the spatial distribution of areas that are more suitable for the inclusion in the regional GI. The third chapter shows the methodological approach used to detect ecological corridors, which are identified on the basis of the implementation of such methodology. The following chapter focuses on the relations between the regional GI and the spatial structure of landslide and flood hazards in Eastern Sardinia, as a relevant case study. The concluding chapter discusses the findings implications concerning the definition of spatial planning policies aimed at improving the living quality of the local communities on the basis of the implementation of the regional GI and the related ecological corridors.

## 1.1. Bibliography

- Arcidiacono A., Ronchi S. and Salata S. (2016), “Managing multiple ecosystem services for landscape conservation: A green infrastructure in Lombardy Region”, *Procedia Engineering*, 161: 2297-2303. DOI: 10.1016/j.proeng.2016.08.831.
- Benedict M. and McMahon E. (2002), “Green Infrastructure: Smart conservation for the 21<sup>st</sup> Century”, *Renewable Resources Journal*, 20, 3: 12-17.
- Benedict M. and McMahon E. (2006), *Green Infrastructure. Linking Landscapes and Communities*, Island Press, Washington, DC, United States.
- Cannas I., Lai S., Leone F. and Zoppi C. (2018), “Green infrastructure and ecological corridors: A regional study concerning Sardinia”, *Sustainability*, 10, 4 (1265): 1-21. DOI: 10.3390/su10041265.
- Cunha J., Elliott M. and Ramos S. (2018), “Linking modelling and empirical data to assess recreation services provided by coastal habitats: The case of NW Portugal”, *Ocean & Coastal Management*, 162: 60-70. DOI: 10.1016/j.ocecoaman.2017.12.022.
- Eagles P., McLean D. and Stabler M. (2000), “Estimating the tourism volume and value in protected areas in Canada and the USA”, *The George Wright Forum*, 17, 3: 62-76.
- European Commission (2012), *Guidelines on Best Practice to Limit, Mitigate or Compensate Soil Sealing*, Publications Office of the European Union, Luxembourg. DOI: 10.2779/75498.
- Gaston K.J., Charman K., Jackson S.F., Armsworth P.R., Bonn A., Briers R.A.,



- Callaghan C.S.Q., Catchpole R., Hopkins J., Kunin W.E., Latham J., Opdam P., Stoneman R., Stroud D.A. and Tratt R. (2006), “The ecological effectiveness of protected areas: The United Kingdom”, *Biological Conservation*, 132, 1: 76-87. DOI: 10.1016/j.biocon.2006.03.013.
- Hansen A.J. and DeFries R. (2007), “Ecological mechanisms linking protected areas to surrounding lands”, *Ecological Applications*, 17, 4: 974-988. DOI: 10.1890/05-1098.
- Hansen R. and Pauleit S. (2014), “From multifunctionality to multiple ecosystem services? A conceptual framework for multifunctionality in Green Infrastructure planning for urban areas”, *AMBIO*, 43, 4: 516-529. DOI: 10.1007/s13280-014-0510-2.
- Hausmann A., Toivonen T., Slotow R., Tenkanen H., Moilanen A., Heikinheimo V. and Di Minin E. (2018), “Social media data can be used to understand tourists’ preferences for nature-based experiences in protected areas”, *Conservation Letters*, 11, 1: 1-10. DOI: 10.1111/conl.12343.
- Jobbagy E.G. and Jackson R.B. (2000), “The vertical distribution of soil organic carbon and its relation to climate and vegetation”, *Ecological Applications*, 10, 2: 423-436. DOI: 10.1890/1051-0761(2000)010[0423:TVDOSO]2.0.CO;2.
- Kelemen E., García-Llorente M., Pataki G., Martín-López B. and Gómez-Baggethun E. (2014), *Non-monetary Techniques for the Valuation of Ecosystem Services*, in Potschin M. and Jax K., eds, *OpenNESS Reference Book EC FP7 Grant Agreement No. 308428*, text available at the website <http://www.openness-project.eu/sites/default/files/SP-Non-monetary-valuation.pdf> [Accessed: 22 February 2022].
- Kenter J.O. (2016), *Deliberative and Non-monetary Valuation: A Review of Methods*, in Potschin M., Haines-Young R., Fish R. and Turner R.K., eds, *Handbook of Ecosystem Services*, Routledge, London, United Kingdom, pp. 271-288.
- Lafortezza R., Davies C., Sanesi G. and Konijnendijk C.C. (2013), “Green Infrastructure as a tool to support spatial planning in European urban regions”, *iForest*, 6, June: 102-108. DOI: 10.3832/ifor0723-006.
- Lai S. and Leone F. (2017), “A methodological approach to identify a multifunctional green infrastructure at the regional scale. A case study from Sardinia, Italy”, *Urbanistica Informazioni*, 41, 272 s.i.: 836-840.
- Lal R. (2008), “Carbon sequestration”, *Philosophical Transactions of the Royal Society B*, 363: 815-830. DOI:10.1098/rstb.2007.2185.
- Landers D. and Nahlik A. (2013), *Final Ecosystem Goods and Services Classification System (FEGS-CS)*, U.S. Environmental Protection Agency, Washington, DC, United States, text available at the website <https://gispub4.epa.gov/FEGS/FEGS-CS%20FINAL%20V.2.8a.pdf> [Accessed: 22 February 2022].
- Landscape Institute (2009), *Green Infrastructure Connected and Multifunctional Landscapes: Position Statement*, Landscape Institute, London, United Kingdom.
- Lankia T., Kopperoinen L., Pouta E. and Neuvonen M. (2015), “Valuing recreational ecosystem service flow in Finland”, *Journal of Outdoor Recreation and Tourism*, 10: 14-28. DOI: 10.1016/j.jort.2015.04.006.

- Lennon M. (2015), “Green infrastructure and planning policy: A critical assessment”, *Local Environment*, 20, 8: 957-980. DOI: 10.1080/13549839.2014.880411.
- Liquete C., Kleeschulte S., Dige G., Maes J., Grizzetti B., Olah B. and Zulian G. (2015), “Mapping green infrastructure based on ecosystem services, and ecological networks: A pan-European case study”, *Environmental Science & Policy*, 54: 268-280. DOI: 10.1016/j.envsci.2015.07.009.
- Maes J., Teller A., Erhard M., Liquete C., Braat L., Berry P., Egoh B., Puydarrieux P., Fiorina C., Santos F., Paracchini M.L., Keune H., Wittmer H., Hauck J., Fiala I., Verburg P.H., Condé S., Schägner J.P., San Miguel J., Estreguil C., Ostermann O., Barredo J.I., Pereira H.M., Stott A., Laporte V., Meiner A., Olah B., Royo Gelabert E., Spyropoulou R., Petersen J.E., Maguire C., Zal N., Achilleos E., Rubin A., Ledoux L., Brown C., Raes C., Jacobs S., Vandewalle M., Connor D., Bidoglio G. (2013), *Mapping and Assessment of Ecosystems and their Services. An Analytical Framework for Ecosystem Assessments under Action 5 of the EU Biodiversity Strategy to 2020*, Publications Office of the European Union, Luxembourg. DOI: 10.2779/12398.
- Maes J., Teller A., Erhard M., Murphy P., Paracchini M.L., Barredo J.I., Grizzetti B., Cardoso A., Somma F., Petersen J.E., Meiner A., Gelabert E.R., Zal N., Kristensen P., Bastrup-Birk A., Biala K., Romao C., Piroddi C., Egoh B., Fiorina C., Santos F., Naruševičius V., Verboven J., Pereira H., Bengtsson J., Gocheva K., Marta-Pedroso C., Snäll T., Estreguil C., San Miguel J., Braat L., Grêt-Regamey A., Perez-Soba M., Degeorges P., Beaufaron G., Lillebø A., Malak D.A., Liquete C., Condé S., Moen J., Östergård H., Czúcz B., Drakou E.G., Zulian G., Lavalle C. (2014), *Mapping and Assessment of Ecosystems and their Services. Indicators for Ecosystem Assessments under Action 5 of the EU Biodiversity Strategy to 2020*, Publications Office of the European Union, Luxembourg. DOI: 10.2779/75203.
- Martín-López B., Gómez-Baggethun E., Lomas P.L. and Montes, C. (2009), “Effects of spatial and temporal scales on cultural services valuation”, *Journal of Environmental Management*, 90: 1050-1059. DOI: 10.1016/j.jenvman.2008.03.013.
- Mayer M. and Woltering M. (2018), “Assessing and valuing the recreational ecosystem services of Germany’s national parks using travel cost models”, *Ecosystem Services*, 31: 371-386. DOI: 10.1016/j.ecoser.2017.12.009.
- Millennium Ecosystem Assessment (2003), *Ecosystems and Human Well-Being: A Framework for Assessment*, Island Press, Washington, DC, United States.
- Orantes M.J.C., Kim J. and Kim J. (2017), “Socio-cultural asset integration for a green infrastructure network plan in Yesan County, Korea”, *Sustainability*, 9, 2 (192): 1-16. DOI: 10.3390/su9020192.
- Polasky S., Nelson E., Pennington D. and Johnson K.A. (2011), “The impact of land-use change on ecosystem services, biodiversity and returns to landowners: A case study in the state of Minnesota”, *Environmental and Resource Economics*, 48, 2: 219-242. DOI: 10.1007/s10640-010-9407-0.
- Ruiz Benito P., Cuevas J.A., Bravo de la Parra R., Prieto F., García del Barrio J.M. and Zavala M.A. (2010), “Land use change in a Mediterranean metropolitan

- region and its periphery: Assessment of conservation policies through CORINE Land Cover data and Markov models”, *Forest Systems*, 19, 3: 315-328. DOI: 10.5424/fs/2010193-8604.
- Salomaa A., Paloniemi R., Kotiaho J.S., Kettunen M., Apostolopoulou E. and Cent J. (2017), “Can green infrastructure help to conserve biodiversity?”, *Environment and Planning C*, 35, 2: 265-288. DOI: 10.1177/0263774X16649363.
- Science for Environment Policy (2015), *Ecosystem Services and the Environment*, In-depth Report 11 produced for the European Commission, DG Environment, by the Science Communication Unit, University of the West of England, Bristol, United Kingdom. DOI: 10.2779/57695.
- Serkan G. and Rehber E. (2008), “A travel cost study to estimate recreational value for a bird refuge at Lake Manyas, Turkey”, *Journal of Environmental Management*, 88: 1350-1360. DOI: 10.1016/j.jenvman.2007.07.017.
- Sharma R., Nehren U., Rahman S.A., Meyer M., Rimal B., Seta G.A. and Baral B. (2018), “Modeling land use and land cover changes and their effects on biodiversity in Central Kalimantan, Indonesia”, *Land*, 7, 2 (57): 1-14. DOI:10.3390/land7020057.
- Sonter L.J., Watson K.B., Wood, S.A. and Ricketts T.H. (2016), “Spatial and temporal dynamics and value of nature-based recreation, estimated via social media”, *PLoS ONE*, 11, 9 (e0162372): 1-16. DOI: 10.1371/journal.pone.0162372.
- Spanò M., Gentile F., Davies C. and Laforteza R (2017), “The DPSIR framework in support of green infrastructure planning: A case study in Southern Italy”, *Land Use Policy*, 61: 242-250. DOI: 10.1016/j.landusepol.2016.10.051.
- Taylor-Lovell S. and Taylor J.R. (2013), “Supplying urban ecosystem services through multifunctional green infrastructure in the United States”, *Landscape Ecology*, 28, 8: 1447-1463. DOI: 10.1007/s10980-013-9912-y.
- TEEB (2010), *The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations*, Earthscan, London, United Kingdom.
- Wang J. and Banzhaf E. (2018), “Towards a better understanding of green infrastructure: A critical review”, *Ecological Indicators*, 85: 758-772. DOI: 10.1016/j.ecolind.2017.09.018.
- Weber T., Sloan A. and Wolf J. (2006), “Maryland’s Green Infrastructure Assessment: Development of a comprehensive approach to land conservation”, *Landscape and Urban Planning*, 77: 94-110. DOI: 10.1016/j.landurbplan.2005.02.002.
- Wickham J.D., Riitters, K.H., Wade T.G. and Vogt, P. (2010), “A national assessment of green infrastructure and change for the conterminous United States using morphological image processing”, *Landscape and Urban Planning*, 94: 186-195. DOI: 10.1016/j.landurbplan.2009.10.003.
- Wood S.A., Guerry A.D., Silver J.M. and Lacayo M. (2013), “Using social media to quantify nature-based tourism and recreation”, *Science Reports*, 3 (2976): 1-7. DOI: 10.1038/srep02976.
- Yang S., Zhao W., Liu Y., Wang S., Wang J. and Zhai R. (2018), “Influence of land use change on the ecosystem service trade-offs in the ecological restoration area: Dynamics and scenarios in the Yanhe watershed, China”, *Science of the Total Environment*, 644: 556-566. DOI: 10.1016/j.scitotenv.2018.06.348.

- Zoppi C. and Lai S. (2010), “Assessment of the Regional Landscape Plan of Sardinia (Italy): A participatory-action-research case study type”, *Land Use Policy*, 27, 3: 690-705. DOI: 10.1016/j.landusepol.2009.09.004.
- Zulian G., Paracchini M.L., Maes J. and Liqueste C. (2013), *ESTIMAP: Ecosystem Services Mapping at European Scale*, JRC (European Commission - Joint Research Centre - Institute for Environment and Sustainability) Technical Report EUR 26474 ENG, Publications Office of the European Union, Luxembourg. DOI: 10.2788/6436.

## 2. *Defining a spatial taxonomy for a regional infrastructure in Sardinia*

This chapter focuses on the methodological aspects allowing for the spatial identification of a regional GI through an assessment of the seven factors listed in the introduction, which are as follows: conservation value, natural value, recreation value, landscape value, agricultural and forestry value, land surface temperature, and carbon storage and sequestration capacity. For each of the seven factors, the relevant subsection first provides background information on the chosen value, followed by a description of both the methodology and the input data needs and sources. The closing subsection accounts for the results, graphically accompanied by maps representing the spatial layout of each value; moreover, it provides an example of how such assessments can be used to identify interrelationships between those ES that are reflected within the values, with a view to supporting the definition of appropriate planning strategies aimed at preserving or enhancing current levels of ES provision.

### 2.1. **Conservation value (*Consval*)**

Conservation value (*Consval*) is here understood as a proxy for the intrinsic, non-use value of biodiversity, including both existence and bequest value, which are regarded as cultural ES (e.g., Raymond *et al.*, 2009). They account for the importance of preserving biodiversity for future generations (bequest value) and of maintaining biodiversity in present times, irrespective of whether it is “used” by humans (existence value) and are a product of social construction: as highlighted by the Millennium Ecosystem Assessment (2005a, p. 34, in Reyers *et al.*, 2012), they embed «deeply held historical, national, ethical, religious, and spiritual values people ascribe to ecosystems». Intrinsic, non-use values related to biodiversity conservation

for present and future generations have been consistently found out to be prioritized over other ecosystem services in studies assessing communities' perceptions (e.g., Raymond *et al.*, 2009; Larson *et al.*, 2013; Estruch-Guitart and Vallés-Planells, 2015).

As for evaluation methods, existence and bequest values are often assessed in monetary terms through stated preference models such as contingent valuation methods and willingness to pay exercises (for instance: Pearce, 2007; Yang *et al.*, 2008; Gan *et al.*, 2011; Huang and Wang, 2015), or through benefit transfer methods when site-specific information is not available (as in Pascal *et al.*, 2018). Non-monetary, socio-ecological methods include stakeholders surveys, community mapping (Raymond *et al.*, 2009), participatory geographic information (as in Vieira da Silva *et al.*, 2021). Other non-monetary methods use conservation proxies such as bird species indicators (Schröter *et al.*, 2020), or indicators related to protected areas, uniqueness/rarity of habitats and species, ecosystem integrity (Schirpke *et al.*, 2021), or vulnerability indices for forests and arable species (Dunford *et al.*, 2015).

In this study, an indicator for assessing conservation value is proposed based on the European Union (EU)'s key piece of legislation concerning biodiversity protection. Council Directive 92/43/EEC of 21 May 1992 “on the conservation of natural habitats and of wild fauna and flora” aims at ensuring habitats deemed of community interest, i.e., that are endangered or threatened with extinction in their natural range, or have a small natural range, or exhibit typical characteristics of one or more European biogeographical regions. The full list of natural habitats of community interest is provided in Annex I of the Habitats Directive, where a subset of the list is classed as “priority” habitats and marked with an asterisk, which signals a higher importance and calls for stricter conservation measures. Moreover, an interpretation manual of the habitats of community interest, regularly updated following the various EU enlargements, has been produced by the European Commission since 1999 (European Commission, 2013); subsequently, a number of Member States have made available their own interpretation handbooks so as to tailor the EU manual to their national and local specificities, and have produced national or regional maps of natural habitats of community interest.

### 2.1.1. *Assessing conservation value: a novel method based on Natura 2000 standard dataforms and Habitat Directive reporting*

Building on a regional report (CRITERIA and TEMI, 2014a, pp. 27-28) that ranks the importance of habitats of community interest in Sardinia with a view to defining a regional monitoring plan, this value was calculated as follows:

- for areas where no habitats of Community interest have been identified:

$$\text{Consval} = 0 \quad (1);$$

- for areas hosting habitats of Community interest:

$$\text{Consval} = P \cdot (R+T+K) \quad (2),$$

where:

- $P$  indicates whether a given habitat is enlisted as priority habitat ( $P=1.5$  in case of priority habitat,  $P=1$  in case of non-priority habitat).
- $R$  denotes rarity, which, for each habitat of Community interest, can be evaluated based on the number of Natura 2000 sites in which the presence of the habitat was recorded. Since information about sites belonging to Natura 2000 network is provided through standard data forms (European Commission, 2011), the number of sites in which each habitat is present can be easily retrieved in each region, or country, or biogeographical region. We used the 2017 version of the Natura 2000 database<sup>1</sup> as a source, which provides a manageable and handy compilation of all Natura 2000 standard data forms, and chose to categorize the number in the interval (1-5) by normalizing the number of occurrences (which ranges from 1 to 79) in that interval; the lower the number of occurrences, the higher the value of  $R$ .
- $T$  stands for threats, which are recorded in each Natura 2000 standard data form. Hence, the number of threats applies to Natura 2000 sites, which entails that a given habitat of Community interest can have different threat values, one for each site in which the habitat is recorded. We chose to categorize the number of threats recorded in the standard data forms in the (1-5) interval; moreover, the higher the number of threats, the higher the value of  $T$ .

<sup>1</sup> Available from <https://www.eea.europa.eu/data-and-maps/data/natura-8/> [Accessed: 22 February 2022].

- *K* stands for knowledge: since reliable and up-to-date information gathered through on-site surveys is not available for every habitat of community interest and for every Natura 2000 site, we deem the level of knowledge important from a conservationist’s standpoint. The level of knowledge in Sardinia was assessed by experts within a regional monitoring project, whose outcomes are available in an unpublished report (CRITERIA and TEMI, 2014b, pp. 42-44). For each habitat, the level of knowledge was therefore classed as “good”, “acceptable”, “insufficient”, “poor”. These judgments were converted into values in the 1-4 interval, where the lower the level of knowledge, the higher the value of *K* (hence, poor=4, insufficient=3, acceptable=2, good=1). Since *K* depends on subjective assessments, we chose to assign a maximum score (4) lower than in the case of both *R* and *T*.

With reference to the spatial dimension of this assessment, the following two spatial datasets were used: the first, the so-called “Carta della natura” (“Nature map”: Camarda *et al.*, 2015), has a scale of 1:50,000, and makes use of the CORINE<sup>2</sup> biotopes nomenclature, while the second, the so-called “Carta degli habitat” (“Habitat map”: CRITERIA and TEMI, 2014b), has a scale of 1:10,000 and maps habitats of community interest by using the Habitats Directive taxonomy within Natura 2000 sites only. The interoperability between the two taxonomies was handled through a conversion tool produced by the Italian Superior Institute for Environmental Protection and Research (ISPRA, 2013), which allowed us to map habitats of community interests also outside Natura 2000 sites by using the “Nature map” after appropriately reclassing the CORINE biotopes code into the Directive codes.

For each habitat listed in at least one standard data form in the Sardinian Natura 2000 network, and whose spatial distribution is retrievable by combining the “Habitat map” with the “Nature map”, tab. 1 provides the values of *P*, *K*, and *R*. *T* is not provided in the table because, for a single habitat, it takes different values depending on the Natura 2000 site in which it is contained.

As a result, where habitats of community interest are present, *Consval* can range from 1 (minimum conservation value) to 21 (max conservation value).

<sup>2</sup> CORINE stands for “COOrdination of INformation on the Environment” and it is a European program initiated in 1985 with the aim of supporting environmental policies through standardization of data collection and classification (<https://www.eea.europa.eu/help/glossary/eea-glossary/corine>). Although prominently known for the land cover taxonomy and datasets, it also offers a standard nomenclature for biodiversity accounts, as well as procedures for data collection and classification (see Moss *et al.*, 1995).



Tab. 1 - Types of habitats protected under the EU Directive 93/42/EEC in Sardinia (listed in 2017 standard data forms and mapped), and three components of *Consva*

Habitat code and denomination	P	K	R
1110 Sandbanks which are slightly covered by sea water all the time	1	4	2.90
1120 * Posidonia beds ( <i>Posidonia oceanica</i> )	1.5	2	1.62
1130 Estuaries	1	4	4.90
1150 * Coastal lagoons	1.5	3	2.59
1160 Large shallow inlets and bays	1	2	3.21
1170 Reefs	1	4	3.05
1210 Annual vegetation of drift lines	1	3	2.13
1240 Vegetated sea cliffs of the Mediterranean coasts with endemic <i>Limonium</i> spp.	1	1	2.33
1310 <i>Salicornia</i> and other annuals colonizing mud and sand	1	2	3.67
1410 Mediterranean salt meadows ( <i>Juncetalia maritimi</i> )	1	2	2.38
1420 Mediterranean and thermo-Atlantic halophilous scrubs ( <i>Sarcocornetea fruticosi</i> )	1	1	2.33
1430 Halo-nitrophilous scrubs ( <i>Pegano-Salsoletea</i> )	1	4	4.44
1510 * Mediterranean salt steppes ( <i>Limonietalia</i> )	1.5	3	3.05
2110 Embryonic shifting dunes	1	3	2.69
2120 Shifting dunes along the shoreline with <i>Ammophila arenaria</i> ('white dunes')	1	2	2.95
2210 Crucianellion maritimae fixed beach dunes	1	2	2.64
2230 <i>Malcolmietalia</i> dune grasslands	1	3	2.95
2240 <i>Brachypodietalia</i> dune grasslands with annuals	1	4	3.82
2250 * Coastal dunes with <i>Juniperus</i> spp.	1.5	2	2.95
2260 <i>Cisto-Lavenduleta</i> dune sclerophyllous scrubs	1	4	4.59
2270 * Wooded dunes with <i>Pinus pinea</i> and/or <i>Pinus pinaster</i>	1.5	2	3.82
3120 Oligotrophic waters containing very few minerals generally on sandy soils of the West Mediterranean, with <i>Isoetes</i> spp.	1	4	4.74
3130 Oligotrophic to mesotrophic standing waters with vegetation of the <i>Littorelletea uniflorae</i> and/or of the <i>Isoëto-Nanojuncetea</i>	1	3	4.23
3150 Natural eutrophic lakes with <i>Magnopotamion</i> or <i>Hydrocharition</i> -type vegetation	1	4	4.74
3170 * Mediterranean temporary ponds	1.5	4	4.13
3280 Constantly flowing Mediterranean rivers with <i>Paspalo-Agrostidion</i> species and hanging curtains of <i>Salix</i> and <i>Populus alba</i>	1	4	4.64
3290 Intermittently flowing Mediterranean rivers of the <i>Paspalo-Agrostidion</i>	1	4	4.79
4090 Endemic oro-Mediterranean heaths with gorse	1	2	4.90
5210 Arborescent matorral with <i>Juniperus</i> spp.	1	1	2.33
5230 * Arborescent matorral with <i>Laurus nobilis</i>	1.5	3	4.54
5320 Low formations of <i>Euphorbia</i> close to cliffs	1	3	3.77
5330 Thermo-Mediterranean and pre-desert scrub	1	3	1.00
5410 West Mediterranean cliff-top phryganas ( <i>Astragaloplantaginetum subulatae</i> )	1	4	4.64
5430 Endemic phryganas of the <i>Euphorbio-Verbascion</i>	1	3	3.15

<i>Habitat code and denomination</i>		<i>P</i>	<i>K</i>	<i>R</i>
6210	Semi-natural dry grasslands and scrubland facies on calcareous substrates ( <i>Festuco-Brometalia</i> ) (* important or orchid sites)	1.5	4	4.90
6220	* Pseudo-steppe with grasses and annuals of the <i>Thero-Brachypodietea</i>	1.5	3	1.56
6310	Dehesas with evergreen <i>Quercus</i> spp.	1	2	4.13
6420	Mediterranean tall humid grasslands of the <i>Molinio-Holoschoenion</i>	1	4	4.85
7220	* Petrifying springs with tufa formation ( <i>Cratoneurion</i> )	1.5	4	5.00
8130	Western Mediterranean and thermophilous scree	1	4	5.00
8210	Calcareous rocky slopes with chasmophytic vegetation	1	3	4.49
8220	Siliceous rocky slopes with chasmophytic vegetation	1	3	4.85
8310	Caves not open to the public	1	2	4.18
8330	Submerged or partially submerged sea caves	1	3	4.28
91E0	* Alluvial forests with <i>Alnus glutinosa</i> and <i>Fraxinus excelsior</i> (Alno-Padion, Alnion incanae, Salicion albae)	1.5	3	4.23
9260	<i>Castanea sativa</i> woods	1	3	5.00
92A0	<i>Salix alba</i> and <i>Populus alba</i> galleries	1	2	4.38
92D0	Southern riparian galleries and thickets ( <i>Nerio-Tamaricetea</i> and <i>Securinegion tinctoriae</i> )	1	3	2.44
9320	<i>Olea</i> and <i>Ceratonia</i> forests	1	2	2.95
9330	<i>Quercus suber</i> forests	1	2	3.92
9340	<i>Quercus ilex</i> and <i>Quercus rotundifolia</i> forests	1	3	2.38
9380	Forests of <i>Ilex aquifolium</i>	1	2	4.74
9540	Mediterranean pine forests with endemic Mesogean pines	1	4	4.64
9560	* Endemic forests with <i>Juniperus</i> spp.	1.5	4	5.00
9580	Mediterranean <i>Taxus baccata</i> woods	1.5	2	4.59

## 2.2. Natural value (*Natval*)

Natural value (*Natval*) accounts for biodiversity in a broad sense, beyond the intrinsic conservation value implicit in the definition of the Habitats Directive and it is related to ecosystems' capacity of providing home to animal and plant species, which in turn are indispensable for delivering a wide range of ES, since loss of habitats and species impact upon ecosystem functions and processes (Loreau *et al.*, 2001; Cardinale *et al.*, 2012; Maseyk *et al.*, 2017). Numerous studies have demonstrated how biodiversity, in its multiple meanings ranging from genetic variation within a species to differences between species and variety of ecosystems, plays a key role in regulating natural functions and processes (among many: Hooper *et al.*, 2005; Balvanera *et al.*, 2006; Hector and Bagchi, 2007; Cardinale, 2011; Isbell *et al.*, 2011).

For this reason, a long-standing debate on the very essence of this value can be traced in the academic literature, where different denominations ap-

pear, each entailing a specific nuance in the meaning and, consequently, a different way to assess the value. Among the most common ones, it is worth citing «ecological integrity» (Burkhard *et al.*, 2009), «degree of naturalness» (Paracchini and Capitani, 2011), and «habitat quality» (Nelson *et al.*, 2009; Polasky *et al.*, 2011).

The debate centers on whether ecosystems' capacity of supporting species should be regarded as an ecosystem service in itself. For the purpose of this research, it should be recalled that the expression “ecosystem services” refers to those goods and services provided by nature that sustain human life and well-being and that various categorizations of ecosystem services have been proposed so far. Among the most widely used, the Common International Classification of Ecosystem Services (CICES) only considers final goods and services, that is those for which a human demand exists (in accordance with Boyd and Banzhaf, 2007), and groups them into three main categories: provisioning, regulating and maintenance, and cultural services. In accordance with Müller (2005) and with Fisher and Turner (2008), other categorizations, such as the Millennium Ecosystem Assessment (2003) and The Economics of Ecosystems and Biodiversity (TEEB) (2011), also include a fourth group (labeled supporting services, or habitat services) that accounts for ecological functions and integrity, not directly “consumed” by people but necessary for ecosystems to produce final goods and services.

Depending on the taxonomy, ecosystems' capacity of hosting species and maintaining their life cycles is included either within the “regulating and maintenance” services or within the “supporting or habitat” services, depending on the taxonomy: the first holds for the CICES classification, and the second for the Millennium Ecosystem Assessment. The issue here is not merely a semantic one; rather, it stems from the conceptualization of ES, and, as pointed out by Liquete *et al.* (2016a), it is affected by scholars' perspectives and it bears consequences on assessments. For instance, economists warn against assessing natural value when evaluating a bundle of ES in monetary terms, because it would lead to double counting (Wallace, 2007; Turner *et al.*, 2010; Fu *et al.*, 2011), as the value of biodiversity would be counted both in the natural value and in the final ES that is demanded and consumed by humans.

Within this framework, and without addressing the issue of positioning ecosystems' capacity to support biodiversity and in turn other ES within either the supporting and habitat services or the regulating and maintenance ones, in this study natural value is assessed in non-monetary terms, and it is understood as ecosystems' capability to provide suitable conditions for species' persistence at both the individual and the populations levels (Hall *et al.*,

1997; Pilogallo and Scorza, 2021). To operationalize to concept, habitat quality is chosen as proxy, by assessing the extent to which terrestrial habitat types are close to their natural condition (Terrado *et al.*, 2016), i.e., unaffected by anthropogenic pressures. In other words, natural value in this study accounts for biodiversity's quality, which implies its ecological integrity, current levels of ecosystem functions, and ecosystems' capability to supply final, human-demanded ecosystem services notwithstanding pressures and threats to habitats.

The tool "Habitat quality", part of the InVEST<sup>3</sup> suite, produces habitat quality maps by combining information on land covers and threats to biodiversity, based on the assumption that areas having high values of habitat quality can better support biodiversity, while decreasing levels of quality imply lower biodiversity levels. The tool has been applied extensively for various purposes, as follows.

- To identify priority areas for conservation (Baral *et al.*, 2014; Duarte *et al.*, 2016; Lin *et al.*, 2017; Salata *et al.*, 2017) or to ground planning decisions for biodiversity conservation (Nolè *et al.*, 2020).
- To prioritize areas for intervention within already established natural protected areas (Sallustio *et al.*, 2007) or within polluted sites (Scorza *et al.*, 2020a).
- To investigate synergies and tradeoffs between habitat quality and other ES (Bai *et al.*, 2011; Yang W. *et al.*, 2018).
- To assess impacts on biodiversity generated by land-use changes in general (Polasky *et al.*, 2011; Leh *et al.*, 2013; Arunyawat and Shrestha, 2016; Yang S. *et al.*, 2018), by urban expansion (Sun *et al.*, 2018), or by large wind-farm projects (Saganeiti *et al.*, 2020; Scorza *et al.*, 2020b), by looking at either historical changes or at simulated scenarios.
- To support the spatial identification of ecological networks (Gao *et al.*, 2017) and corridors (Cannas *et al.*, 2018).

The tool requires the following input data:

- A current raster land cover map, where the classification of land covers is not predefined and can be chosen by the user; moreover, if scenarios are modeled, the user can optionally also add one baseline and one future land cover map. Land cover maps are used in lieu of habitats type

<sup>3</sup> InVEST, an acronym for "Integrated Valuation of Ecosystem Services and Tradeoffs", is a suite of tools developed by the Natural Capital Project and freely available from <https://naturalcapitalproject.stanford.edu/software/invest> [Accessed: 22 February 2022]. The suite tools allow for developing spatially explicit assessments of various ecosystem services in biophysical terms; some tools also allow for monetary evaluation.

maps because either they are readily available in many countries or they can be retrieved through remote sensing technique from satellite imagery, also readily available worldwide. Each land cover type is next assessed in terms of its suitability to support biodiversity, through the sensitivity matrix listed in item 5 below.

- A list of current threats to biodiversity, and for each threat a weight (which denotes the threat's relative importance), a decay distance and function.
- A raster map for each current threat source.
- A vector map representing accessibility to sources of degradation, in terms of relative protection to habitats provided by legal institutions.
- A sensitivity matrix, in which each land cover type is assessed in terms of its suitability to being regarded as a habitat type, where habitats represent resources and conditions present in an area that can support the life of given organisms and therefore are not restricted to those of community interest accounted for by *Consval*; moreover, each land cover type is also scored based on its sensitivity to each threat selected as per item 2 above.
- A so-called “half-saturation constant”, having default value 0.5.

### 2.2.1. *Natural quality assessment through the InVEST model*

In this study, the habitat quality in Sardinia was assessed using the InVEST model. For the raster land cover map, we started from the 2008 Land Cover Map produced by the Regional administration of Sardinia<sup>4</sup>; this is a vector dataset which classes land covers using the standard nomenclature of the European project CORINE, with a finer spatial resolution and a more detailed taxonomy, which is provided at the fifth level for woods and forests, than the one produced at the European level. Since the model requires a raster dataset, this map was first reclassified at the third level of the CORINE taxonomy, and next converted into a raster map having cellsize 25 x 25 meters.

As for the threats, the standard data forms concerning Sardinian Natura 2000 sites were examined; each standard data form lists threats and pressures that generate negative impacts on a given site. Next, from the whole

<sup>4</sup> Available from the regional geoportal: <http://www.sardegnaageoportale.it/index.php?xsl=2420&s=40&v=9&c=14480&es=6603&na=1&n=100&esp=1&tb=14401> [Accessed: 22 February 2022].

list, those threats and pressures that can be mapped and that impact on terrestrial areas (as opposed to marine areas, which are out of the scope of this study) were selected. As a result, a list of ten pressures and threats was obtained; for the weight and decay distance, a questionnaire was delivered to local experts in the field of biodiversity and environmental impact assessment. In the questionnaire, the weight was to be expressed using a “Likert” scale 1-5, hence grading the relative importance of a given threat, while the decay distance was to be provided in kilometers. For each threat, both the weights and the decay distances provided by the surveyed experts were next averaged; moreover, the weights were normalized in the (0-1) interval as per InVEST’s requirements. Tab. 2 provides a list of the ten selected threats, as well as their weights and decay distances, averaged and, as for weights only, also normalized. The decay function was always set as “linear”. The ten selected threats were mapped based on vector datasets freely available from the regional geoportal, subsequently converted into raster maps having cellsize 25 x 25 meters. Tab. 2 lists, in detail, the data sources used.

*Tab. 2 - Threats to biodiversity in the study area, parameters for the InVEST model (weight, decay distance and function), and spatial data sources*

<i>Code</i>	<i>Threat name</i>	<i>Weight</i>	<i>Decay distance [km]</i>	<i>Decay function</i>	<i>Data source (*)</i>
T01	Cultivation	0.58	1.63	linear	2008 Land Cover Map
T02	Grazing	0.68	0.58	linear	2008 Land Cover Map
T03	Removal of forest undergrowth	0.79	0.65	linear	2008 Land Cover Map
T04	Salt works	0.63	0.83	linear	2008 Land Cover Map
T05	Paths, tracks	0.53	0.55	linear	Regional multi-precision database
T06	Roads, motorways	0.95	3.00	linear	Regional multi-precision database
T07	Airports	0.95	4.75	linear	2008 Land Cover Map
T08	Urbanized areas	0.95	3.25	linear	2008 Land Cover Map
T09	Discharges	1.00	3.50	linear	2008 Land Cover Map
T10	Fire	0.95	2.05	linear	Burnt area maps

(\*) All of the spatial datasets can be freely downloaded from the regional geoportal: <http://www.sardegnageoportale.it>

With regards to accessibility to sources of biodiversity degradation, regional and national parks were considered, as well as areas protected and managed by the public regional forestry agency, as having the highest protection and hence lowest accessibility level (score 0.2); a second level was that of Natura 2000 sites (score 0.5); all the rest of the study area was con-

sidered as completely accessible (score 1). To map accessibility, vector maps of parks, areas protected and managed by the public regional forestry agency, and finally Natura 2000 sites, were used, all available from the regional geoportal.

The sensitivity of each habitat to each threat was developed using a two-step expert-based approach: first, each land cover code (at the third level of the CORINE taxonomy) was given a trichotomous value (1 if the land cover could be intrinsically regarded as habitat; 0.5 if it could be considered habitat contingent on external factors; else 0); second, for each land cover code that could be considered as habitat, a score representing that land cover's sensitivity to each threat was assigned. The full matrix is provided in tab. 3.

*Tab. 3 - The sensitivity matrix used as input for the InVEST habitat quality model*

<i>LC code</i>	<i>habitat score</i>	<i>T01</i>	<i>T02</i>	<i>T03</i>	<i>T04</i>	<i>T05</i>	<i>T06</i>	<i>T07</i>	<i>T08</i>	<i>T09</i>	<i>T10</i>
111	0	0	0	0	0	0	0	0	0	0	0
112	0	0	0	0	0	0	0	0	0	0	0
121	0	0	0	0	0	0	0	0	0	0	0
122	0	0	0	0	0	0	0	0	0	0	0
123	0	0	0	0	0	0	0	0	0	0	0
124	0	0	0	0	0	0	0	0	0	0	0
131	0	0	0	0	0	0	0	0	0	0	0
132	0	0	0	0	0	0	0	0	0	0	0
133	0	0	0	0	0	0	0	0	0	0	0
141	1	0	0	0	0	0	0.5	0.2	0.5	1	1
142	0	0	0	0	0	0	0	0	0	0	0
143	0	0	0	0	0	0	0	0	0	0	0
211	0.5	0	0.5	0	0	0	0.5	0	0.5	0.5	0.5
212	0.5	0	0.5	0	0	0	0.5	0	0.5	0.5	0.5
221	0.5	0	0.5	0	0	0	0.5	0	0.5	0.5	0.5
222	0.5	0	0.5	0	0	0	0.5	0	0.5	0.5	0.5
223	0.5	0	0.5	0	0	0	0.5	0	0.5	0.5	0.5
224	1	1	1	0.5	0	1	1	0.5	1	1	1
231	1	1	0.5	0	0	0.5	1	0.2	0.5	1	1
241	0.5	0	0.5	0	0	0	0.5	0	0.5	0.5	0.5
242	0.5	0	0.5	0	0	0	0.5	0	0.5	0.5	0.5
243	1	0.5	1	0.5	0	1	1	0.2	1	1	1
244	1	0.5	0.5	1	0	1	1	0.2	1	1	1
311	1	1	0.5	1	0	1	1	0.2	0.5	1	1
312	1	1	0.5	1	0	1	1	0.2	0.5	1	1
313	1	1	0.5	1	0	1	1	0.2	0.5	1	1
321	1	1	1	0	0	1	1	0.5	0.5	1	1
322	1	1	1	0	0	1	1	0.5	1	1	1
323	1	1	1	0.5	0	1	1	0.5	1	1	1
324	1	1	1	0.5	0	1	1	0.5	1	1	1
331	1	0	0	0	0	1	1	0.5	1	1	0

<i>LC code</i>	<i>habitat score</i>	<i>T01</i>	<i>T02</i>	<i>T03</i>	<i>T04</i>	<i>T05</i>	<i>T06</i>	<i>T07</i>	<i>T08</i>	<i>T09</i>	<i>T10</i>
332	1	0	0	0	0	1	1	0.2	1	1	0
333	1	1	1	0	0	1	1	0.5	1	1	1
411	1	1	0	0	1	0.5	1	0.5	1	1	0
421	1	0.5	0	0	1	0.5	1	0.5	1	1	0
422	1	0.5	0	0	0	0	1	0.2	1	1	0
423	1	0.5	0	0	0	0.5	1	0.2	1	1	0
511	1	0.5	0	0	0	0.5	1	0.2	1	1	0
512	1	0.5	0	0	0	0.5	1	0.2	1	1	0
521	1	0.5	0	0	1	0.5	1	0.2	1	1	0

### 2.3. Recreation value (*Recrval*)

Recreation value (*Recrval*) is a final ecosystem service part of the cultural ES group. In the MA taxonomy (Millennium Ecosystem Assessment, 2003, p. 58), this group includes different kinds of nonmaterial benefits derived from ecosystems such as “spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences”. Recreation, in particular, accounts for the fact that landscapes and natural habitats are among the factors that people take into account when deciding where they want to spend their holidays or just some leisure time, which not only positively affects residents’ and tourists’ quality of life and wellbeing, but also impacts directly and indirectly on local economies. In contrast to the other cultural ecosystem services, which are hardly ever assessed through quantitative or monetary approaches because of their subjective character, their immaterial and intangible nature (Milcu *et al.*, 2013; Ryfield *et al.*, 2019), as well as their inadequate definition leading to unclear operationalization (Blicharska *et al.*, 2017), recreational services are often measured through economic indicators. The TEEB, for instance, suggests that the recreational value related to biodiversity can be evaluated in monetary terms through travel cost methods (Kumar *et al.*, 2011), which have indeed been used by several scholars (among many, Fleming and Cook, 2008; Serkan and Rehber, 2008; Martín-López *et al.*, 2009; Lankia *et al.*, 2015; Mayer and Woltering, 2018), sometimes in combination with willingness to pay exercises, or with contingent valuation methods (Nielsen *et al.*, 2007; Rosenberger *et al.*, 2012; Jobstvogt *et al.*, 2014; van Berkel and Verburg, 2014).

A different approach is that of non-monetary evaluation, which, according to some scholars, would allow to capture in a broader and multidimensional way people’s understanding and valuing of non-tangible ecosystem services (Kenter, 2014) such as the recreational one. Several qualitative, socio-cultural approaches have therefore been proposed, including docu-



ment analysis, expert-based approaches, observation approaches, in-depth interviews, focus groups, questionnaires (Scholte *et al.*, 2015); such approaches are advocated as the ones that can provide a clearer picture of the relationship between cultural ecosystem services and their users (Milcu *et al.*, 2013). Other non-monetary approaches rely on quantitative methods, which, in principle, could easily be used to assess recreation values, as they imply collecting data on tourists and visitors from official statistics (as in Eagles *et al.*, 2000), or carrying out ad-hoc surveys (as in Jim and Chen, 2006; Voigt *et al.*, 2014; Kothencz *et al.*, 2017). However, because of the costs and time requirements, such data are often unavailable; as a consequence, social-media based approaches have been proposed that estimate visitor figures and preferences based on the number of pictures uploaded to social media such as Flickr (Wood *et al.*, 2013; Richards and Friess, 2015; Sonter *et al.*, 2016; Cunha *et al.*, 2018; Arkema *et al.*, 2021; Mouttaki *et al.*, 2021), Instagram (Hausmann *et al.*, 2017; Vieira *et al.*, 2018; Grzyb *et al.*, 2021) or Panoramio (Angradi *et al.*, 2018; Oteros-Rozas *et al.*, 2018), sometimes also combining data from two platforms. Limitations of such models are linked to the digital divide issue, as well as to their reliance on specific platforms, which is often constrained by privacy limitations in accessing and analyzing materials posted by users.

Finally, a different spatially explicit approach is that of ESTIMAP (“Ecosystem Service Mapping Tool”), a suite of conceptual tools developed by a group of researchers from the European Joint Research Centre to assess provision and demand of a set of ES at the EU level (Zulian *et al.*, 2014) and comprising a specific model to assess potential provision of nature-based outdoor recreation, as well as the spatial distribution of local populations’ met and unmet demand for recreational ES (Paracchini *et al.*, 2014). Originally developed to map terrestrial ES, the model was also applied to assess recreation potential in marine and coastal areas (Liquete *et al.*, 2016b). Moreover, although conceived for assessing the spatial distribution of ES supply and demand at the continental scale, the model has been and applied at various scales, from the national one in Bulgaria (Ih-timanski *et al.*, 2020), to the metropolitan one in Barcelona (Baró *et al.*, 2016) and in Oslo (Suarez *et al.*, 2020), to the municipal scale in Trento (Cortinovis *et al.*, 2018). An overview of adaptations of the original model to tailor it to the local level is provided in Zulian *et al.* (2018) with reference to four urban case studies. A similar conceptual approach, also including aspects that impact negatively on the landscape’s attractiveness for recreational users, such as wind turbines, power lines and solar plants, is proposed and applied taking German as a case study by Waltz and Stein (2018).

### 2.3.1. Recreational ES modeling through ESTIMAP

In this study, the original model as presented in Vallecillo *et al.* (2019) and Barton *et al.* (2019) was applied to Sardinia. This model, which is graphically summarized in fig. 1 and fig. 2, comprises three main steps, as follows:

- Mapping the potential provision of nature-based recreation (fig. 1).
- Identifying areas where the potential ES offer can actually be enjoyed and used (fig. 2).
- Mapping the spatial distribution of population whose demand of nature-based recreation is met or unmet (fig. 2).

The first step, concerning the potential provision of nature-based recreation, in turns comprises various sub-steps that basically serve the purpose of identifying areas that are, in principle, more attractive for recreational users. The original model identifies three groups of characteristics that are of interest to recreational users: i., suitability of land to support recreation; ii., presence of protected areas; iii., water-related elements. Although these characteristics have sometimes been tailored to local specificities and contexts, by either choosing only some (Ihtimanski *et al.*, 2020) or by adding other features (see for instance Cortinovia *et al.*, 2018), we regarded the ones proposed in the original model highly appropriate for analyzing recreational ES at the regional scale and in reference to an island, as Sardinia is.

As for the first characteristic, i.e., the suitability of land to support recreation, the key concept here is that the higher the degree of naturalness, the higher the suitability. The degree of naturalness is assessed based on its opposite, i.e., on an evaluation of the level of disturbance caused by human activities on ecosystems. To this end, the hemeroby index proposed by Paracchini and Capitani (2011) was used, where a score ranging from 1 (no disturbance) to 9 (maximum disturbance, implying that ecosystems are absent because replaced by artificial surfaces) is assigned to land cover classes, by using the third level of the CORINE land cover nomenclature. As shown in tab. 4, such correspondence between hemeroby index and land cover classes is mostly univocal, except for agricultural and forestry areas, where three values can be assigned depending on the intensity of management practices. For agricultural areas, intensity is estimated based on nutrient inputs and livestock density, while for forests it is assumed to depend upon differences between actual and potential vegetation.

To assign a specific value to each agricultural land parcel, data were re-

trieved from the National Census Institute<sup>5</sup>, which provides, among other nutrients, the amount of nitrogen contained in fertilizers distributed in 2019 for agricultural purposes at the province (NUTS3) level (tab. 5).

*Tab. 4 - Correspondence between hemeroby values and CORINE land cover (CLC) classes. Adapted after Paracchini and Capitani (2011)*

<i>CLC</i> <i>artificial</i> <i>surfaces</i>	<i>hemeroby</i> <i>index</i>	<i>CLC</i> <i>agricultural</i> <i>areas</i>	<i>hemeroby</i> <i>index</i>	<i>CLC</i> <i>forest and</i> <i>seminatural</i> <i>areas</i>	<i>hemeroby</i> <i>index</i>	<i>CLC</i> <i>wetlands</i>	<i>hemeroby</i> <i>index</i>
111	9	211	5-6-7	311	2-3-4	411	2
112	9	212	5-6-7	312	2-3-4	421	2
121	9	213	5-6-7	313	2-3-4	422	6
122	9	221	4-5-6	321	2-3-4		
123	9	222	4-5-6	322	2		
124	9	223	4-5-6	323	2		
131	8	231	3-4-5	324	2		
132	8	241	4-5-6	331	2		
133	8	242	4-5-6	332	1		
141	8	243	4-5-6	333	2		
142	8	244	3-4-5	334	6		

*Tab. 5 - Total nitrogen contained in fertilizers distributed for agricultural purposes at NUTS3 level in Sardinia, year 2019. Data retrieved from the National Census Institute*

<i>Provinces and Metropolitan Cities</i>	<i>Total nitrogen [kg]</i>
Cagliari - Città Metropolitana	4411000
Nuoro	678000
Oristano	2301000
Sassari	1569000
Sud Sardegna	8206000

Within each province, the total amount of nitrogen was averaged, by dividing it by the amount of agricultural area in that province, hence each land cover patch belonging to classes starting by “2” could be assigned its nitrogen input (in kilogram per hectare of agricultural area). Moreover, livestock intensity was assessed based on data retrieved from the National Zootechnical Register<sup>6</sup>, which provides the number of bovine animals, sheep, goats, equidae, pigs, and poultry that are reared within each munic-

<sup>5</sup> Available from <http://dati.istat.it/#>, under Section “Agriculture”, subsection “Production means/fertilizers”, indicator “nutrients contained, per province” [Accessed: 22 February 2022].

<sup>6</sup> Available from: [https://www.vetinfo.it/j6\\_statistiche/](https://www.vetinfo.it/j6_statistiche/). Data provided by the National Dataset of the Zootechnical Register established by the Ministry of Health at the “G. Caporale” Institute in Teramo. [Accessed: 22 February 2022].

ipality. The number of livestock from such different species was aggregated at the municipal level by making use of the livestock unit (LSU) coefficients available from Eurostat<sup>7</sup>, using the simplified categories in tab. 6 and next the total livestock density (Eurostat, 2019) was calculated by dividing, for each municipality, its total livestock unit by its total utilized agricultural area (tab. 7).

*Tab. 6 - Livestock unit coefficients (adapted from Eurostat)*

<i>Livestock types</i>	<i>Livestock unit coefficients</i>
Bovine animals	1
Sheep	0.1
Goats	0.1
Equidae	0.8
Pigs	0.3
Broilers	0.007
Laying hens	0.014
Other poultry	0.03

*Tab. 7 - Livestock intensity at the municipal level in Sardinia (LSU: livestock unit; AGRI: agricultural area; LS\_D: livestock density), calculated based on the number of livestock retrieved from the National Zootechnical Register*

<i>Municipality</i>	<i>LSU bovine</i>	<i>LSU equidae</i>	<i>LSU pigs</i>	<i>LSU sheep/goats</i>	<i>LSU poultry</i>	<i>LSU total</i>	<i>AGRI [ha]</i>	<i>LS_D [LSU/ha]</i>
Abbasanta	1503	43.2	48.0	803.2	0	2397.4	3289.32	0.73
Aggius	2825	23.2	91.2	61.3	0	3000.7	3422.30	0.88
Aglientu	1287	17.6	57.3	128.8	0	1490.7	5503.02	0.27
Aidomaggiore	561	17.6	94.5	793.2	0	1466.3	3272.64	0.45
Alà dei Sardi	1423	22.4	130.2	1022.7	0	2598.3	2676.58	0.97
Albagiara	0	3.2	4.5	128.4	161.3	297.4	802.12	0.37
Ales	49	8.0	43.2	345.4	0	445.6	1632.03	0.27
Alghero	665	100.8	353.1	1063.6	0	2182.5	13633.93	0.16
Allai	286	3.2	17.7	135.0	0	441.9	820.33	0.54
Anela	563	15.2	51.6	788.5	0	1418.3	1828.65	0.78
Arborea	32839	36.8	134.7	225.4	0	33235.9	7797.59	4.26
Arbus	657	29.6	300.3	2220.8	0	3207.7	5442.16	0.59
Ardara	740	15.2	86.4	1077.9	0	1919.5	3632.34	0.53
Ardauli	9	6.4	17.7	105.0	0	138.1	933.83	0.15
Aritzo	2297	8.8	48.0	448.3	0	2802.1	169.32	16.55
Armunzia	691	1.6	55.8	271.1	0	1019.5	611.15	1.67
Arzachena	2306	81.6	368.7	161.2	5.6	2923.1	8646.36	0.34

<sup>7</sup> Available from: [https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Livestock\\_unit\\_\(LSU\)](https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Livestock_unit_(LSU)) [Accessed: 22 February 2022].

<i>Municipality</i>	<i>LSU bovine</i>	<i>LSU equidae</i>	<i>LSU pigs</i>	<i>LSU sheep/ goats</i>	<i>LSU poultry</i>	<i>LSU total</i>	<i>AGRI [ha]</i>	<i>LS_D [LSU/ha]</i>
Arzana	5299	52.0	303.0	921.4	0	6575.4	1827.41	3.60
Assemini	261	51.2	215.7	1048.8	0	1576.7	4397.95	0.36
Assolo	133	10.4	41.7	231.9	0	417.0	1109.25	0.38
Asuni	189	5.6	33.9	432.9	0	661.4	1188.84	0.56
Atzara	881	11.2	91.5	296.0	0	1279.7	2368.75	0.54
Austis	392	15.2	85.5	711.8	0	1204.5	925.51	1.30
Badesi	365	12.0	24.0	16.3	0	417.3	1499.77	0.28
Ballao	431	3.2	54.3	381.3	0	869.8	965.51	0.90
Banari	211	11.2	5.7	194.1	0	422.0	1008.89	0.42
Baradili	0	0.8	3.3	17.6	0	21.7	545.06	0.04
Baratili San Pietro	0	4.0	20.4	166.0	0	190.4	555.83	0.34
Baressa	0	2.4	15.9	259.9	0	278.2	1041.72	0.27
Bari Sardo	19	52.8	165.6	740	0	977.4	2569.98	0.38
Barrali	32	15.2	36.6	264.1	0	347.9	675.58	0.51
Barumini	133	11.2	25.5	574.8	0	744.5	2521.28	0.30
Bauladu	357	14.4	56.7	331.9	0	760.0	675.24	1.13
Baunei	845	20.8	117.3	485.2	0	1468.3	334.66	4.39
Belvi	106	3.2	27.9	159.7	0	296.8	138.24	2.15
Benetutti	1684	45.6	198.0	2035.8	0	3963.4	6630.41	0.60
Berchidda	1615	33.6	112.2	2059.7	0	3820.5	7673.41	0.50
Bessude	378	17.6	80.7	553.8	0	1030.1	1651.13	0.62
Bidoni	8	0.8	2.4	216.3	0	227.5	412.69	0.55
Birori	778	8.0	32.1	449.2	0	1267.3	1396.17	0.91
Bitti	2005	52.0	129.9	6052.5	0	8239.4	11550.08	0.71
Bolotana	1590	45.6	63.6	2397.3	0	4096.5	7649.75	0.54
Bonarcado	653	36.0	91.8	1040.6	0	1821.4	1868.94	0.97
Bonnanaro	156	32.8	28.2	797.9	0	1014.9	2037.04	0.50
Bono	728	84.8	220.5	2430.3	0	3463.6	4116.07	0.84
Bonorva	2730	112.0	183.6	3720.9	0	6746.5	8427.35	0.80
Boroneddu	26	6.4	8.4	135.7	0	176.5	443.81	0.40
Borore	554	33.6	124.2	1839.3	0	2551.1	3463.79	0.74
Bortigali	4777	36.0	108.0	1598.8	0	6519.8	4995.22	1.31
Bortigiadas	1000	8.8	44.1	133.1	0	1186.0	2271.18	0.52
Borutta	93	3.2	3.3	113.7	0	213.2	401.57	0.53
Bosa	1975	26.4	48.6	1132.3	0	3182.3	2673.26	1.19
Bottidda	1739	17.6	322.5	1107.1	0	3186.2	2094.77	1.52
Buddusò	2450	66.4	204.0	1859.2	0	4579.6	5861.81	0.78
Budoni	887	37.6	196.2	231.4	0	1352.2	2769.69	0.49
Buggerru	46	2.4	12.9	150.9	0	212.2	361.51	0.59
Bultei	2012	34.4	165.9	1620.5	0	3832.8	3765.73	1.02

<i>Municipality</i>	<i>LSU bovine</i>	<i>LSU equidae</i>	<i>LSU pigs</i>	<i>LSU sheep/ goats</i>	<i>LSU poultry</i>	<i>LSU total</i>	<i>AGRI [ha]</i>	<i>LS_D [LSU/ha]</i>
Bulzi	130	12.0	27.3	536.7	0	706.0	2010.82	0.35
Burcei	1029	12.0	125.7	475.6	0	1642.3	925.27	1.77
Burgos	249	23.2	22.5	590.6	0	885.3	956.82	0.93
Busachi	220	35.2	204.3	1426.3	0	1885.8	2518.12	0.75
Cabras	29	16.0	39.0	671.4	0	755.4	6251.48	0.12
Cagliari	0	53.6	15.9	165.3	0	234.8	534.77	0.44
Calangianus	1188	11.2	43.5	115.8	0	1358.5	2367.61	0.57
Calasetta	42	33.6	9.9	234.5	0	320.0	1867.51	0.17
Capoterra	73	53.6	149.1	349.1	0	624.8	2202.03	0.28
Carbonia	129	68.0	111.6	2334.0	39.2	2681.8	6905.38	0.39
Cardedu	130	21.6	74.4	401.2	0	627.2	1551.27	0.40
Cargeghe	58	8.0	14.7	286.1	0	366.8	730.83	0.50
Carloforte	51	16.8	20.7	13.4	0	101.9	1682.57	0.06
Castelsardo	194	22.4	28.8	457.2	0	702.4	2824.92	0.25
Castiadas	127	32.0	129.6	899.6	0	1188.2	5227.46	0.23
Cheremule	188	11.2	31.8	493.3	0	724.3	1955.17	0.37
Chiamonti	1963	44.0	412.2	2288.1	0	4707.3	5041.36	0.93
Codrongianos	248	13.6	30.6	983.9	0	1276.1	2768.37	0.46
Collinas	0	5.6	12.6	145.4	0	163.6	1269.29	0.13
Cossoine	389	24.0	73.8	1262.7	0	1749.5	2555.36	0.68
Cuglieri	737	63.2	175.5	1323.9	0	2299.6	5125.80	0.45
Curcuris	3	1.6	9.9	230	0	244.5	517.63	0.47
Decimomannu	0	16.8	77.7	413.8	0	508.3	2113.08	0.24
Decimoputzu	75	35.2	60.3	1469.2	67.2	1706.9	3933.00	0.43
Desulo	1605	10.4	81.6	1283.9	0	2980.9	12.93	230.59
Dolianova	760	57.6	322.5	1163.9	614.3	2918.3	2501.53	1.17
Domus de Maria	181	12.8	71.4	274.7	0	539.9	1395.07	0.39
Domusnovas	163	18.4	93.9	852.4	0	1127.7	1468.79	0.77
Donori	67	12.8	255.9	484.9	0	820.6	2217.73	0.37
Dorgali	798	143.2	416.7	5338.1	112.0	6808.0	9101.89	0.75
Dualchi	214	23.2	55.8	759.7	0	1052.7	1710.83	0.62
Elini	0	4.0	13.5	27.2	0	44.7	337.31	0.13
Elmas	0	13.6	6.0	153.2	0	172.8	685.89	0.25
Erula	518	11.2	60	575.6	0	1164.8	2088.31	0.56
Escalaplano	909	5.6	424.5	1094.4	0	2433.5	2985.13	0.82
Escolca	0	5.6	44.7	221.0	0	271.3	1192.60	0.23
Esporlatu	317	16.0	19.5	839.2	0	1191.7	755.19	1.58
Esterzili	1061	13.6	67.8	425.2	0	1567.6	860.15	1.82
Florinas	37	20.8	43.5	694.5	0	795.8	2603.00	0.31
Fluminimaggiore	139	20	71.1	777.1	68.1	1075.3	1059.41	1.02
Flussio	24	4.8	5.7	255.0	0	289.5	483.06	0.60

<i>Municipality</i>	<i>LSU bovine</i>	<i>LSU equidae</i>	<i>LSU pigs</i>	<i>LSU sheep/goats</i>	<i>LSU poultry</i>	<i>LSU total</i>	<i>AGRI [ha]</i>	<i>LS_D [LSU/ha]</i>
Fonni	6575	67.2	289.5	2445.5	268.7	9645.9	4254.34	2.27
Fordongianus	371	8.8	61.5	546.8	0	988.1	1802.74	0.55
Furtei	42	10.4	45.6	177.1	0	275.1	2017.04	0.14
Gadoni	1121	10.4	40.8	266.9	63.0	1502.1	326.94	4.59
Gairo	736	14.4	100.2	362.1	0	1212.7	739.00	1.64
Galtelli	221	16.8	129.3	848.8	0	1215.9	2624.93	0.46
Gavoi	127	48.8	99.9	1166.6	0	1442.3	1717.69	0.84
Genoni	693	26.4	147.6	550.3	0	1417.3	2193.29	0.65
Genuri	0	2.4	5.4	41.4	0	49.2	668.92	0.07
Gergei	47	34.4	112.5	808.6	0	1002.5	3147.03	0.32
Gesico	124	16.0	102.3	780.5	0	1022.8	2490.67	0.41
Gesturi	6	32.8	136.5	722.4	0	897.7	2356.40	0.38
Ghilarza	826	40	124.2	968.8	0	1959.0	4029.36	0.49
Giave	231	32.8	57.9	1341.9	12.6	1676.2	3255.88	0.51
Giba	29	10.4	39.3	340.2	0	418.9	2387.92	0.18
Girasole	0	9.6	136.8	74.4	0	220.8	1055.02	0.21
Golfo Aranci	149	4.0	7.2	28.9	0	189.1	671.22	0.28
Goni	199	7.2	118.8	428.1	0	753.1	384.74	1.96
Gonnesa	14	21.6	33.6	562.6	0	631.8	1759.11	0.36
Gonnoscodina	0	4.8	49.5	5.7	0	60.0	746.92	0.08
Gonnosfanadiga	361	52.8	364.2	2088.6	1512	4378.5	5405.83	0.81
Gonnosnò	0	8.0	51.6	228.7	0	288.3	1227.64	0.23
Gonnostramatza	0	2.4	85.8	486.9	0	575.1	882.90	0.65
Guamaggiore	0	4.8	36.6	184.6	0	226.0	1541.13	0.15
Guasila	829	27.2	66.3	568.3	0	1490.8	4001.73	0.37
Guspini	1924	72.8	420.3	3587.2	75.4	6079.7	10240.26	0.59
Iglesias	594	79.2	402.3	2691.5	0	3767.0	4209.92	0.89
Ilbono	70	16.8	28.8	332.7	36.5	484.8	1889.91	0.26
Illorai	913	16.8	54.3	1338.6	0	2322.7	2992.07	0.78
Irgoli	1082	22.4	669.0	2333.8	0	4107.2	3031.32	1.35
Isili	246	32.8	960	1009.3	0	2248.1	3514.18	0.64
Ittireddu	578	19.2	145.8	1080.4	0	1823.4	1995.31	0.91
Ittiri	192	65.6	149.4	3556.6	0	3963.6	7457.38	0.53
Jerzu	194	19.2	70.8	433.4	0	717.4	2684.71	0.27
La Maddalena	0	4.8	3.3	5.7	0	13.8	0.00	0.00
Laconi	1501	45.6	205.5	933.2	0	2685.3	4699.88	0.57
Laerru	75	8.8	145.8	333.4	0	563.0	1653.85	0.34
Lanusei	18	31.2	504.0	557.0	0	1110.2	2537.26	0.44
Las Plassas	0	8.8	6.3	221.7	0	236.8	1061.40	0.22
Lei	353	10.4	48.3	578.0	0	989.7	981.92	1.01
Loceri	55	12.8	56.1	231.8	5.9	361.6	1279.26	0.28

<i>Municipality</i>	<i>LSU bovine</i>	<i>LSU equidae</i>	<i>LSU pigs</i>	<i>LSU sheep/ goats</i>	<i>LSU poultry</i>	<i>LSU total</i>	<i>AGRI [ha]</i>	<i>LS_D [LSU/ha]</i>
Loculi	406	8.0	588.9	985.9	0	1988.8	1386.83	1.43
Lodè	395	11.2	65.1	885.2	0	1356.5	3329.96	0.41
Lodine	20	1.6	30	262.0	0	313.6	507.26	0.62
Loiri Porto San Paolo	782	21.6	91.5	575.2	0	1470.3	5375.63	0.27
Lotzorai	175	8.0	143.4	230.7	0	557.1	1325.57	0.42
Lula	1205	29.6	352.5	1425.2	0	3012.3	4094.63	0.74
Lunamatrona	48	6.4	51.3	247.0	0	352.7	1924.03	0.18
Luogosanto	2161	36.0	51.9	165.5	0	2414.4	4725.18	0.51
Luras	1125	20.8	37.2	459.6	0	1642.6	4388.41	0.37
Macomer	3426	62.4	239.7	3162.1	0	6890.2	8700.99	0.79
Magomadas	0	2.4	2.7	62.6	0	67.7	794.86	0.09
Mamoiada	796	36.8	32.1	916.9	503.4	2285.2	3279.12	0.70
Mandas	153	32.0	172.2	671.0	0	1028.2	3419.39	0.30
Mara	214	11.2	31.8	367.6	0	624.6	1147.68	0.54
Maracalagonis	219	32.0	63.3	473.7	0	788.0	2916.58	0.27
Marrubiu	158	41.6	265.2	985.6	154.0	1604.4	4085.51	0.39
Martis	136	6.4	77.7	616.0	0	836.1	2088.10	0.40
Masainas	100	20.8	16.8	159.6	0	297.2	1765.34	0.17
Masullas	60	0.8	68.1	241.7	0	370.6	1140.34	0.32
Meana Sardo	1639	16.0	120.3	752.4	0	2527.7	2113.78	1.20
Milis	176	7.2	53.7	414.5	0	651.4	1454.51	0.45
Modolo	0	0	0.9	14.6	0	15.5	170.67	0.09
Mogorella	305	5.6	51.3	446.5	0	808.4	1342.98	0.60
Mogoro	28	45.6	329.1	785.0	0	1187.7	4194.50	0.28
Monastir	3	16.8	158.4	424.1	42.0	644.3	2481.47	0.26
Monserrato	8	13.6	9.0	42.5	0	73.1	302.94	0.24
Monteleone Rocca Doria	271	4.8	6.0	123.3	0	405.1	440.42	0.92
Monti	622	8.0	69.3	226.8	0	926.1	3867.69	0.24
Montresta	1039	3.2	39.0	340.4	0	1421.6	1009.64	1.41
Mores	3065	69.6	204.0	3121.5	0	6460.1	8653.35	0.75
Morgongiori	52	2.4	48.3	150.3	0	253.0	824.37	0.31
Muravera	167	28.8	134.4	476.0	0	806.2	3704.19	0.22
Muros	0	6.4	13.2	86.3	0	105.9	812.05	0.13
Musei	262	14.4	20.4	1294.1	0	1590.9	1946.06	0.82
Narbolia	433	17.6	59.4	772.4	1.4	1283.8	2350.58	0.55
Narcao	60	8.8	78.0	687.5	0	834.3	2366.44	0.35
Neoneli	60	8.8	75.9	429.3	0	574.0	726.91	0.79
Noragugume	333	15.2	80.1	1331.9	0.8	1761.0	2479.16	0.71
Norbello	491	50.4	72.0	864.8	0	1478.2	2406.26	0.61



<i>Municipality</i>	<i>LSU bovine</i>	<i>LSU equidae</i>	<i>LSU pigs</i>	<i>LSU sheep/ goats</i>	<i>LSU poultry</i>	<i>LSU total</i>	<i>AGRI [ha]</i>	<i>LS_D [LSU/ha]</i>
Nughedu San Nicolò	905	23.2	146.7	1204.2	3.3	2282.4	3477.09	0.66
Nughedu Santa Vittoria	6	12.8	11.4	238.4	0	268.6	756.10	0.36
Nule	782	34.4	204.6	2399.3	0	3420.3	3752.54	0.91
Nulvi	1100	50.4	229.5	1761.9	0	3141.8	5199.99	0.60
Nuoro	3081	161.6	187.8	2277.4	0	5707.8	9819.73	0.58
Nurachi	0	7.2	5.4	142.0	0	154.6	1505.17	0.10
Nuragus	240	16.8	66.9	800	0	1123.7	1787.65	0.63
Nurallao	195	20.8	69.9	437.5	0	723.2	1419.97	0.51
Nuraminis	0	7.2	24.9	624.7	0	656.8	4287.69	0.15
Nureci	44	3.2	20.4	208.4	0	276.0	852.63	0.32
Nurri	344	26.4	541.2	3132.4	0	4044.0	4829.63	0.84
Nuxis	23	8.8	39.6	179.6	0	251.0	1430.87	0.18
Olbia	3069	128.8	501.9	2591.4	0	6291.1	16529.14	0.38
Oliena	351	102.4	214.8	1882.3	0	2550.5	8294.78	0.31
Ollastra	85	18.4	70.8	742.5	0	916.7	1343.34	0.68
Ollolai	136	38.4	59.4	745.8	57.7	1037.3	835.79	1.24
Olmedo	69	16.8	15.3	311.0	0	412.1	2354.79	0.18
Olzai	770	24.0	65.4	1973.3	0	2832.7	3893.92	0.73
Onani	362	6.4	13.8	1251.6	0	1633.8	3213.03	0.51
Onifai	430	10.4	88.8	1033.9	0	1563.1	1612.56	0.97
Oniferi	1424	33.6	74.4	1091.8	0	2623.8	2305.06	1.14
Orani	3413	76.0	216.9	3544.7	0	7250.6	5897.01	1.23
Orgosolo	8176	160	632.4	2423.0	0	11391.4	4701.60	2.42
Oristano	426	129.6	120.9	938.3	0	1614.8	6659.70	0.24
Orosei	354	44.0	202.2	720.7	200.2	1521.1	4201.14	0.36
Orotelli	3086	56.0	101.4	2948.4	0	6191.8	2888.28	2.14
Orroli	865	26.4	432.3	1317.8	0	2641.5	3113.58	0.85
Ortacesus	31	10.4	121.8	958.7	0	1121.9	2125.63	0.53
Ortueri	263	26.4	123.3	662.1	0	1074.8	1917.99	0.56
Orune	2718	38.4	90.6	6759.6	0	9606.6	6541.97	1.47
Oschiri	1806	57.6	219.6	3273.6	0	5356.8	10982.28	0.49
Osidda	520	5.6	24.6	719.9	0	1270.1	1890.92	0.67
Osilo	544	115.2	206.7	2189.6	0	3055.5	6744.96	0.45
Osini	241	9.6	39.0	242.5	0	532.1	910.31	0.58
Ossi	49	49.6	29.7	303.7	0	432.0	2273.22	0.19
Ottana	490	48.8	62.7	1799.7	177.3	2578.5	3182.45	0.81
Ovodda	174	25.6	91.5	433.5	0	724.6	855.62	0.85
Ozieri	5164	127.2	784.2	7877.4	300.9	14253.7	22019.29	0.65
Pabillonis	92	12.8	56.1	1066.7	0	1227.6	3642.71	0.34

<i>Municipality</i>	<i>LSU bovine</i>	<i>LSU equidae</i>	<i>LSU pigs</i>	<i>LSU sheep/ goats</i>	<i>LSU poultry</i>	<i>LSU total</i>	<i>AGRI [ha]</i>	<i>LS_D [LSU/ha]</i>
Padria	513	20.8	54.3	1098.6	0	1686.7	3443.89	0.49
Padru	788	20	238.2	506.3	0	1552.5	4034.90	0.38
Palau	280	12.8	5.7	61.1	0	359.6	1671.46	0.22
Palmas Arborea	210	31.2	127.5	1031.3	0	1400.0	2452.43	0.57
Pattada	2378	97.6	175.2	2305.0	0	4955.8	6803.88	0.73
Pau	19	4.8	28.5	105.7	0	158.0	527.86	0.30
Pauli Arbarei	1	8.8	46.8	604.4	0	661.0	1448.52	0.46
Paulilatino	1289	63.2	145.8	1989.0	0	3487.0	6104.10	0.57
Perdasdefogu	813	12.0	52.5	214.5	0	1092.0	776.45	1.41
Perdaxius	126	8.0	63.0	633.1	0	830.1	1784.67	0.47
Perfugas	1043	28.8	90	1006.0	0	2167.8	4030.29	0.54
Pimentel	39	4.0	198.0	370.3	0	611.3	1323.36	0.46
Piscinas	13	7.2	51.6	295.0	0	366.8	958.19	0.38
Ploaghe	631	79.2	186.9	2441.7	0	3338.8	7600.54	0.44
Pompu	12	1.6	10.5	54.5	0	78.6	465.37	0.17
Porto Torres	53	31.2	43.8	573.9	0	701.9	3355.61	0.21
Portoscuso	31	3.2	2.4	71.7	0	108.3	1088.30	0.10
Posada	274	15.2	109.5	180.1	0	578.8	1940.20	0.30
Pozzomaggiore	1439	68.8	165.0	2249.0	0	3921.8	6917.93	0.57
Pula	15	70.4	75.0	362.0	0	522.4	3023.16	0.17
Putifigari	323	24.0	135.9	1001.0	0	1483.9	2504.97	0.59
Quartu Sant'Elena	40	112.8	65.7	382.7	0	601.2	2638.80	0.23
Quartucciu	3	36.0	3.9	128.0	247.2	418.1	1881.67	0.22
Riola Sardo	3	11.2	108.0	714.4	0	836.6	3855.95	0.22
Romana	39	12.0	39.6	489.9	0	580.5	1163.21	0.50
Ruinas	385	4.8	77.1	786.3	0	1253.2	1495.77	0.84
Sadali	142	32.0	88.5	323.2	346.5	932.2	1163.78	0.80
Sagama	252	6.4	25.5	400	0	683.9	1110.12	0.62
Samassi	14	16.0	29.7	297.0	0	356.7	4046.01	0.09
Samatzai	3	8.0	48.3	305.1	0	364.4	2813.08	0.13
Samugheo	1859	42.4	252.9	1396.8	0	3551.1	4853.09	0.73
San Basilio	96	41.6	551.1	1148.4	0	1837.1	2055.95	0.89
San Gavino Monreale	50	34.4	8481.6	2018.0	0	10584.0	7898.13	1.34
San Giovanni Suergiu	105	69.6	58.5	606.9	0	840.0	5027.90	0.17
San Nicolò d'Arcidano	67	8.8	101.4	793.0	0	970.2	2583.96	0.38
San Nicolò Gerrei	1921	5.6	182.1	755.2	0	2863.9	1088.76	2.63
San Sperate	14	30.4	46.8	201.3	0	292.5	2335.00	0.13

<i>Municipality</i>	<i>LSU bovine</i>	<i>LSU equidae</i>	<i>LSU pigs</i>	<i>LSU sheep/goats</i>	<i>LSU poultry</i>	<i>LSU total</i>	<i>AGRI [ha]</i>	<i>LS_D [LSU/ha]</i>
San Teodoro	561	35.2	93.9	160.1	0	850.2	2655.59	0.32
San Vero Milis	1136	27.2	64.8	666.1	0	1894.1	5367.84	0.35
San Vito	713	52.8	212.4	878.2	78.9	1935.3	3458.54	0.56
Sanluri	680	48.8	184.2	1356.0	3.5	2272.5	8036.82	0.28
Santa Giusta	41	31.2	25.2	1180.3	0	1277.7	4164.97	0.31
Santa Maria Coghinas	194	13.6	6.3	195.2	0	409.1	1413.42	0.29
Santa Teresa Gallura	1066	35.2	28.5	64.7	0	1194.4	3579.06	0.33
Santadi	181	16.8	123.3	1452.3	0	1773.4	3759.08	0.47
Sant'Andrea Frius	241	30.4	219.6	607.4	0	1098.4	1217.49	0.90
Sant'Anna Arresi	190	15.2	26.7	493.9	0	725.8	2167.96	0.33
Sant'Antioco	109	48.8	6.9	228.2	42.0	434.9	2677.33	0.16
Sant'Antonio di Gallura	1033	17.6	60.9	56.4	0	1167.9	2637.64	0.44
Santu Lussurgiu	2841	112.0	255.9	2183.4	0	5392.3	6146.66	0.88
Sardara	292	28.8	191.1	802.1	0	1314.0	4596.43	0.29
Sarroch	2	20.8	53.7	188.0	0	264.5	1893.28	0.14
Sarule	2734	42.4	139.2	1565.6	0	4481.2	2854.76	1.57
Sassari	2601	321.6	987.3	9321.2	0	13231.1	41760.73	0.32
Scano di Montiferro	888	32.8	61.2	764.7	140	1886.7	2237.13	0.84
Sedilo	856	116.8	125.7	3018.2	0	4116.7	5604.70	0.73
Sedini	851	24.0	78.9	716.1	0	1670.0	2914.35	0.57
Segariu	60	9.6	75.9	203.3	0	348.8	1330.66	0.26
Selargius	7	59.2	691.5	186.9	0	944.6	2151.19	0.44
Selegas	0	10.4	46.2	461.4	0	518.0	1975.41	0.26
Semestene	576	18.4	56.4	1065.9	0	1716.7	2006.28	0.86
Seneghe	1012	44.0	109.8	598.8	0	1764.6	3085.54	0.57
Senis	133	4.8	151.8	227.8	0	517.4	1412.17	0.37
Sennariolo	31	2.4	20.1	186.2	0	239.7	582.41	0.41
Sennori	11	36.0	15.0	198.6	0	260.6	2190.20	0.12
Senorbi	109	32.0	289.8	631.6	0	1062.4	3216.34	0.33
Serdiana	519	17.6	61.2	792.3	0	1390.1	3736.13	0.37
Serramanna	32	32.0	1042.2	1479.3	0	2585.5	7876.58	0.33
Serrenti	0	26.4	16.8	613.3	0	656.5	3960.87	0.17
Serri	83	13.6	146.1	541.6	0	784.3	1429.01	0.55
Sestu	8	56.8	333.3	672.5	56.4	1127.0	4110.65	0.27
Settimo San Pietro	6	18.4	30.6	99.0	0	154.0	1926.55	0.08
Setzu	0	0.8	1.8	154.3	0	156.9	492.64	0.32

<i>Municipality</i>	<i>LSU bovine</i>	<i>LSU equidae</i>	<i>LSU pigs</i>	<i>LSU sheep/ goats</i>	<i>LSU poultry</i>	<i>LSU total</i>	<i>AGRI [ha]</i>	<i>LS_D [LSU/ha]</i>
Seui	1753	16.0	32.7	702.4	0	2504.1	677.85	3.69
Seulo	828	26.4	285.0	498.8	0	1638.2	1002.50	1.63
Siamaggiore	96	7.2	49.2	455.8	0	608.2	1255.02	0.48
Siamanna	177	16.8	192.6	847.7	0	1234.1	1579.25	0.78
Siapiccia	37	10.4	62.4	586.9	0	696.7	1037.49	0.67
Siddi	49	3.2	12.0	213.9	0	278.1	726.24	0.38
Silanus	2330	61.6	180.3	2614.0	3.5	5189.4	3699.30	1.40
Siligo	938	22.4	75.0	890.1	0	1925.5	3423.11	0.56
Siliqua	832	46.4	177.3	5375.5	0	6431.2	9351.25	0.69
Silius	625	8.0	163.8	841.9	0	1638.7	810.78	2.02
Simala	87	2.4	23.7	9.0	0	122.1	1164.76	0.10
Simaxis	235	15.2	852.6	693.1	78.4	1874.3	2529.61	0.74
Sindia	2075	64.8	109.2	2512.2	0	4761.2	5129.64	0.93
Sini	32	2.4	24.9	61.1	0	120.4	694.30	0.17
Siniscola	956	59.2	208.5	3228.2	0	4451.9	7815.18	0.57
Sinnai	695	41.6	340.5	1281.1	0	2358.2	3227.88	0.73
Siris	0	0.8	15.3	38.0	0	54.1	426.95	0.13
Siurgus Donigala	935	38.4	1214.4	1459.7	0	3647.5	2906.87	1.25
Soddi	2	4.0	8.1	112.3	0	126.4	398.87	0.32
Solarussa	315	20	48.3	775.9	0	1159.2	2346.96	0.49
Soleminis	16	15.2	27.0	150.7	1459	1668.2	912.98	1.83
Sorgono	542	21.6	48.6	719.3	0	1331.5	2140.09	0.62
Sorradile	21	11.2	39.6	503.6	0	575.4	1190.25	0.48
Sorso	62	40	19.8	91.3	0	213.1	5317.83	0.04
Stintino	913	11.2	27.9	196.8	0	1148.9	3823.54	0.30
Suelli	28	8.0	56.1	429.9	0	522.0	1868.93	0.28
Suni	693	20.8	33.3	1001.4	0	1748.5	3777.22	0.46
Tadasuni	4	0.8	1.8	73.8	0	80.4	332.53	0.24
Talana	4425	7.2	330.3	954.2	0	5716.7	1002.70	5.70
Telti	1372	29.6	108.9	548.0	0	2058.5	5286.54	0.39
Tempio Pausania	3368	64.0	123.0	510.2	0	4065.2	8141.68	0.50
Tergu	455	9.6	36.9	485.0	0	986.5	2065.34	0.48
Terralba	1856	33.6	102.3	298.3	232.4	2522.6	3396.46	0.74
Tertenia	732	23.2	251.1	1622.4	0	2628.7	4060.72	0.65
Teti	225	8.8	62.4	565.9	0	862.1	1056.00	0.82
Teulada	1081	36.0	162.3	1388.3	0	2667.6	3564.24	0.75
Thiesi	2421	57.6	120.9	1388.6	0	3988.1	2949.19	1.35
Tiana	71	3.2	30.9	156.5	0	261.6	280.14	0.93
Tinnura	43	1.6	5.1	62.9	0	112.6	341.89	0.33
Tissi	20	12.0	2.1	28.8	0	62.9	637.41	0.10

<i>Municipality</i>	<i>LSU bovine</i>	<i>LSU equidae</i>	<i>LSU pigs</i>	<i>LSU sheep/ goats</i>	<i>LSU poultry</i>	<i>LSU total</i>	<i>AGRI [ha]</i>	<i>LS_D [LSU/ha]</i>
Tonara	176	8.8	15.0	135.3	351.4	686.5	72.05	9.53
Torpè	370	15.2	74.4	840.1	0	1299.7	2935.34	0.44
Torralba	390	28.8	60.9	1142.1	0	1621.8	3536.25	0.46
Tortoli	9	30.4	59.1	122.4	0	220.9	1942.81	0.11
Tramatza	27	7.2	39.6	827.8	0	901.6	1656.77	0.54
Tratalias	40	16.8	50.4	808.4	0	915.6	1503.52	0.61
Tresnuraghes	117	14.4	27.9	605.7	0	765.0	1898.02	0.40
Triei	31	11.2	298.8	329.3	0	670.3	1796.59	0.37
Trinità d'Agultu e Vignola	1841	23.2	94.5	218.2	0	2176.9	3539.29	0.62
Tuili	2	18.4	36.6	341.6	7.0	405.6	1838.14	0.22
Tula	1001	24.8	99.9	1115.5	0	2241.2	3416.47	0.66
Turri	366	4.0	4.5	105.6	0	480.1	937.04	0.51
Ula Tirso	0	4.0	44.4	312.5	0	360.9	733.36	0.49
Ulassai	1211	20.8	63.3	447.3	0	1742.4	859.54	2.03
Uras	52	15.2	66.6	1238.4	280.6	1652.8	3308.58	0.50
Uri	342	24.0	78.0	1023.4	0	1467.4	4347.24	0.34
Urzulei	1654	22.4	233.7	592.4	79.8	2582.3	647.60	3.99
Usellus	133	8.8	100.8	846.9	0	1089.5	2453.88	0.44
Usini	30	17.6	10.5	297.2	0	355.3	2629.26	0.14
Ussana	167	21.6	87.0	185.2	86.8	547.6	2947.74	0.19
Ussaramanna	35	7.2	12.9	111.4	0	166.5	906.09	0.18
Ussassai	55	1.6	36.0	108.0	0	200.6	408.52	0.49
Uta	801	84.0	426.6	1183.0	0	2494.6	6874.34	0.36
Valledoria	31	12.8	27.0	79.8	0	150.6	2084.06	0.07
Vallermosa	215	27.2	204.3	1466.7	226.5	2139.7	3557.81	0.60
Viddalba	938	6.4	54.9	121.9	0	1121.2	1114.21	1.01
Villa San Pietro	6	20	47.1	178.6	0	251.7	947.21	0.27
Villa Sant'Antonio	173	6.4	9.6	430	0	619.0	1627.62	0.38
Villa Verde	0	1.6	12.3	167.1	0	181.0	797.38	0.23
Villacidro	335	86.4	2259.6	2268.4	431.8	5381.2	8625.27	0.62
Vilagrande Strisaili	6583	52.8	624.6	1753.7	624.9	9639.0	2170.42	4.44
Villamar	25	40	136.5	691.3	0	892.8	3690.98	0.24
Villamassargia	1203	56.8	114.9	2083.8	0	3458.5	4209.11	0.82
Villanova Monteleone	3653	89.6	293.7	2535.3	0	6571.6	7657.26	0.86
Villanova Truschedu	284	4.8	69.9	163.4	0	522.1	603.82	0.86
Villanova Tulo	137	20	228.9	1001.6	0	1387.5	1264.80	1.10
Villanovaforru	28	8.0	13.8	165.2	0	215.0	997.01	0.22

<i>Municipality</i>	<i>LSU bovine</i>	<i>LSU equidae</i>	<i>LSU pigs</i>	<i>LSU sheep/goats</i>	<i>LSU poultry</i>	<i>LSU total</i>	<i>AGRI [ha]</i>	<i>LS_D [LSU/ha]</i>
Villanovafranca	1	14.4	37.8	581.0	0	634.2	2589.66	0.24
Villaperuccio	30	5.6	29.7	429.8	0	495.1	1471.63	0.34
Villaputzu	387	16.8	252.9	1002.7	0	1659.4	3709.97	0.45
Villasalto	2210	13.6	164.4	680.6	0	3068.6	1628.59	1.88
Villasimius	9	26.4	53.1	312.9	0	401.4	1563.34	0.26
Villasor	232	21.6	177.3	1299.3	46.5	1776.7	7907.41	0.22
Villaspeciosa	101	19.2	28.8	489.8	0	638.8	2127.05	0.30
Villaurbana	127	18.4	123.9	609.9	0	879.2	2620.55	0.34
Zeddiani	23	6.4	15.3	75.2	0	119.9	1123.95	0.11
Zerfaliu	47	8.8	36.3	335.4	0	427.5	1365.41	0.31

Finally, each land cover patch was assigned the lowest/medium/highest value of the three listed in tab. 8 depending on the levels of both the nitrogen input and the livestock intensity in the municipality to which it belongs. Following Paracchini and Capitani (2011), nutrient and livestock density values can be classed into three categories (“low”, “mid”, “high”), as per tab. 8, and for each patch the highest value of the two, implying the maximum disturbance, was chosen. Let us take, for instance, a patch whose land cover class is “231” (hence taking 3=lowest, 4=medium, or 5=highest as possible hemeroby index values, as per tab. 8) and that is included within a municipality where, on average, the nitrogen input is low and the livestock density is high; the disturbance in that patch is then regarded as high, which leads to assigning an hemeroby index value equaling 5 to that patch.

*Tab. 8 - Management intensity in agricultural areas (after Paracchini and Capitani, 2011)*

	<i>Low input</i>	<i>Mid input</i>	<i>High input</i>
Nitrogen input (kg/ha)	0-30	>30-150	>150
Livestock density (LSU/ha)	0-0.5	>0.5-1.2	>1.2

As for forestry areas, in the absence of detailed data on forestry management practices and presence of alien invasive species, the level of disturbance was only based on a qualitative assessment of the “distance” between actual and potential vegetation. The former is proxied by the land cover in forestry areas, and the latter is the type of vegetation that would be observed if humans had not had any influence, and which only depends on aspects such as climate, geology, geomorphology, and soil types. The potential distribution of vegetation series and geoseries in Sardinia was mapped by Bacchetta *et al.* (2009); after comparing (through a spatial intersection) the actual and potential forest vegetation, each patch classed as “311”, “312”, “313” or “321” was assigned the lowest, the middle or the

highest hemeroby index value in tab. 4 (respectively, 2, 3, or 4) depending on whether the current land cover is compatible, partly compatible, or incompatible with the potential vegetation in that patch.

The degree of naturalness was finally derived from the hemeroby index, by inverting the scale and normalizing it in the 0-1 interval.

The second characteristic in the first step concerns the presence and type of protected areas, which act as catalyzers for outdoor activities: Balmford *et al.* (2009), for instance, reported a global increase in nature-based recreation in natural protected areas, which needs to be appropriately managed so as not to compromise the parks' conservation objectives (Siikamäki *et al.*, 2015). Against the previously constantly growing trends, protected areas' attractiveness has recently been affected in opposite ways by the COVID-19 pandemic: on the one hand, globally renowned wildlife sanctuaries have witnessed collapsing numbers (Newsome, 2020) due to travel restrictions and decline in number of international tourists. On the other hand, as far as domestic national parks and other protected areas are concerned, after a dramatic decrease during the initial stay-at home order period (Ugolini *et al.*, 2021), also due to park closures enforced in many countries (for instance, Canada: Lesser and Nienhuis, 2020; United States: Landry *et al.*, 2020; the United Kingdom: Spencer *et al.*, 2020) to prevent people from travelling, visitation numbers have bounced back in the post-lockdown (Venter *et al.*, 2021) especially in destinations closer to urban areas (Rice *et al.*, 2020). Notwithstanding the challenges they presently face (see Templeton *et al.*, 2021), parks and other protected areas' attractiveness for recreational activities in the post-lockdown appears therefore to have been strengthened, as large open spaces allow for social distancing and are perceived as comparatively safe.

Within the ESTIMAP model, protected areas are mapped and scored relative to their potential capacity to attract recreation. Scores are expert-based and can be assigned by local experts either through ad-hoc questionnaires (as in Cortinovis *et al.*, 2018), or by having regard to management objectives pertaining to each type of protected area, by using the IUCN categories as a reference framework (as in Zulian *et al.*, 2013; La Notte *et al.*, 2017). Building on the latter approach, we identified five types of protected areas that are of relevance to Sardinia, which were then scored based on the corresponding IUCN category in terms of management objectives, as per tab. 9.

The third characteristic in the first step concerns water and, in the original ESTIMAP model, it comprises in turns three aspects as follows: distance from the coastline, geomorphology of the coast, and quality of bathing waters. Such focus on marine waters was here retained because it is

highly appropriate within an island, but it is worth mentioning that in other contexts, which are non-coastal or whose inland waters have prominent importance, the water component was either skipped (as in Cortinovis *et al.*, 2018) or revised to account for both the coastal and inland waters (as in Baró *et al.*, 2016, or in Suárez *et al.*, 2020).

Tab. 9 - Protected area types in Sardinia, together with their ruling legal framework, IUCN equivalent (having regard to each protected area's conservation objectives), and score

Type	Legal protection regime	IUCN equivalent	Score
National parks	National law on protected areas no. 1991/394	II	0.8
Regional parks	National law on protected areas no. 1991/394 Regional law on protected areas no. 1989/31	II	0.8
Ramsar sites	Decree of the President of the Italian Republic no. 1976/448, enforcing in Italy the International Convention on wetlands signed in Ramsar on February 2, 1971	Ib	1
Natura 2000 sites	Decree of the President of the Italian Republic no. 1997/357, transposing in Italy the EU Habitats Directive no. 1992/43	IV	0.8
Natural monuments	Regional law on protected areas no. 1989/31	III	1
Protected landscapes	Law enacted by decree no. 2004/42 Regional Landscape Plan of Sardinia	V	0.8

As for proximity to the coastline, the assumption here is that areas closer to the coastline are more appealing for daily recreation: therefore, the inverse logistic function in equation (3) was used:

$$f(d) = \frac{1+K}{K+e^{\alpha \cdot d}} \quad (3),$$

where:

- $d$  is the distance from the coastline [m].
- $\alpha$  and  $K$  are two parameters that define the shape of the function, set at  $3.5 \cdot 10^{-3}$  and 150, respectively, so that  $f(d)$  takes the maximum value (equaling 1) along the coastline and zeroes at about 3 km from the coastline, halving at approximately mid-distance (Paracchini *et al.*, 2014).

The second water-related aspect concerns coastal geomorphology, for which data from the European project “EUROSION” were used<sup>8</sup>. The spatial dataset available from the European Environment Agency describes

<sup>8</sup> Available from <https://www.eea.europa.eu/data-and-maps/data/geomorphology-geology-erosion-trends-and-coastal-defence-works> [Accessed: 22 February 2022].



each homogeneous trait of the coastline, among others, in terms of the coastal morpho-sedimentology. Since the dataset dates back to 2005, it was double-checked against more recent data from the regional geoportal, which led to some local corrections concerning almost exclusively traits classed as «Soft strands of heterogeneous category grain size», which were reclassified as «Coastlines made of soft non cohesive sediments, soft strands with beach-rock», plus few traits that are now artificial (e.g., enlargement of harbor areas). Following Liquete *et al.* (2016b), each morphological class was scored as per tab. 10, where the higher the score, the higher the attractiveness of a given trait of coastline.

Tab. 10 - Ranking (in terms of potential attractiveness for recreation) of coastal traits. After Liquete *et al.* (2016b)

<i>Coastal morpho-sedimentology</i>	<i>Score</i>
Developed beaches, small beaches, small beaches separated by rocky capes, artificial beaches	1
Coastlines made of soft non-cohesive sediments, soft strands with beach-rock	0.8
Rocks, hard cliffs, pond or lake shore type, soft strands with rocky intertidal flat	0.6
Conglomerates, eroded cliffs	0.5
Soft strands of heterogeneous category or of unknown category grain size	0.3
Strands made of muddy sediments, estuaries, harbor areas, coastal embankments for construction, polders, mine-waste sediments, artificial shoreline, dikes, unclassified	0

The third, and final, water-related aspect concerns the quality of bathing water, for which data from the European Environment Agency were retrieved. Under Directive 2006/7/EC of the European Parliament and of the Council of 15 February 2006, “concerning the management of bathing water quality” (which replaced an older version in force since the ‘70s), Member States in the bathing season must monitor indicators of microbiological pollution in fresh and coastal waters used as bathing places. The 2020 update<sup>9</sup>, containing data points corresponding to sites monitored in 2019, was used. As for Sardinia, the dataset contains 663 monitoring points, of which 653 were classed as “excellent”, 5 as “good”, 3 as “poor”, and 2 as “not classified” in summer 2019. A 1-km buffer was next drawn around each point, and scores were assigned as follows: 1 if the quality was either excellent or good, 0.5 if it was “sufficient” (but this value could not be found for Sardinian data points), 0 if it was poor; not classified points and their buffer zones were excluded.

<sup>9</sup> Available from <https://www.eea.europa.eu/data-and-maps/data/bathing-water-directive-status-of-bathing-water-12> [Accessed: 22 February 2022].

Finally, the total water-related value was obtained by summing the scores assigned to the three aspects; since each aspect could reach a maximum of 1, water-related value could range in the (0-3) interval and was next rescaled in the (0-1) interval to make it comparable with the first two components of the potential provision of nature-based recreation, i.e., suitability of land to support recreation and presence of protected areas, which both range in this interval. The potential provision of nature-based recreation was then obtained by summing the value of its three components.

Once completed ESTIMAP's first step, the recreational value (*Recrval*) is therefore assessed and mapped, as it accounts for the benefits that ecosystem can provide. Fig. 3 provides the spatial layout of the three components and of the total potential provision of nature-based recreation. The following two steps in the model can be implemented if, beside the potential supply, the demand and potential use of this ES are of interest.

In the second step, areas where the potential provision of the ES can actually be enjoyed and used by humans on a daily basis are identified. In this regard, a key assumption in the ESTIMAP model is that the recreational use of interest is limited to outdoor walks or cycling, without the use of any motorized means of transportation. Consequently, in the model the ES that can flow from ecosystem to humans is only a share of the total potential provision, and it is the share produced by high-quality ecosystems that are located close to human settlements and infrastructure. The Sardinian road layout was retrieved from the regional geoportal<sup>10</sup>, while for human settlements the 2018 CORINE land cover map (classes 1.1.1 «Continuous urban fabric», and 1.1.2, «Discontinuous urban fabric» only) was used in combination with 2011 data from the national census<sup>11</sup>, which has a finer resolution, although it is a bit older.

The distances from roads and residential areas are therefore cross-tabulated (after Vallecillo *et al.*, 2018) as per tab. 11.

<sup>10</sup> From the comprehensive 1:10,000 geodatabase available from

<sup>11</sup> From the so-called "Spatial baseline data" made available by the national census (<https://www.istat.it/it/archivio/104317>), the 2011 layer "Inhabited places of Italy" was used, from which the types 1 (cities, towns and villages), 2 (hamlets), as type 3 comprises industrial and commercial areas, while type 4 comprises the rest of the national territory not covered under the first three types, as explained in the metadata available from <https://www.istat.it/it/files//2013/11/Descrizione-dati-Pubblicazione-2016.03.09.pdf> [Accessed: 22 February 2022].

Tab. 11 - Cross tabulations used to produce the Human input map. Source: Vallecillo et al. (2018)

		Distance from roads [km]					Input map	
		<0.5	0.5-1	1-5	5-10	>10	classes: legend	
Distance from urban areas [km]	<0.5	1	1	2	3	4	1	1
	0.5-1	1	1	2	3	4	near	2
	1-5	2	2	2	4	5	proximal	3
	5-10	3	3	4	5	5	4	4
	>10	3	4	4	5	5	far	5

A second cross-tabulation is next performed between the potential ecosystem-based provision of the recreation ES (i.e., *Recrval*) and the Human input map. This preliminarily requires reclassing *Recrval*, which is a continuous variable in the (0-1) interval, into four classes, which, again after Vallecillo et al. (2018) are labelled as “very low”, “low”, “high”, and “very high”. For this reclassification, the quantile values were used in this study.

Tab. 12 provides the cross-tabulation matrix that allows classing each part of the study areas in terms of the combination of its levels of potential supply of the recreational ES and of proximity to urban settlements and infrastructures within the so-called “Recreation Opportunity Spectrum map”. Fig. 4 provides the maps of the distances from the roads and from the urban areas, as well as the maps of the Human input and of the Recreation Opportunity Spectrum. It is worth noticing that the distance from roads is always lower than ten kilometers, and therefore the seventh column in tab. 11 was not used in this analysis.

The third and final step of the ESTIMAP model allows to map the spatial distribution of met and unmet demand for daily based nature-based recreation in terms of number of trips per year to areas supplying high levels of *Recrval*; the trips are only those taken by resident population within a 4-km distance from where they live.

The model makes therefore a few assumptions, that can be summarized as follows:

- Only trips within walking distance or within light cycling trips (i.e., round trip shorter than 8 km) are considered.
- Only trips made by resident population in the study area are accounted for, hence leaving away tourists, who in certain areas can make up a large share of nature-goers.
- Only trips made without any motorized means of transportation are included, which means that activities in remote areas, which are often very attractive for hikers, climbers, bikers, are not taken into account.
- Only areas providing high levels of *Recrval* are considered; this assumption, coupled with the first item in this list, entails that only areas

scoring 9 in tab. 12 (High provision - near) as considered as effective suppliers of the recreational ES.

- The number of trips decreases when distance increase.  
Under these assumptions, the number of visits to high-provision areas can be calculated through equation 4 (after Vallecillo *et al.*, 2019a):

$$N = \sum_{i=1}^4 \frac{(1+k_i)}{(k_i + \exp(-\alpha_i \cdot \text{Pop}_i))} \quad (4),$$

where:

- $N$  is the total number of trips per week expected from population living within 4 km from high-provision areas.
- $i$  takes four values representing four buffer distances (1 km, ..., 4 km) from high-provision areas.
- $\alpha_i$  and  $k_i$  are two parameters that depend on the distance, and that have been estimated based on the outcomes of a survey in the UK (Vallecillo *et al.*, 2018).

Tab. 12 - Cross tabulations used to produce the Recreation Opportunity Spectrum (ROS) map. Source: Vallecillo *et al.* (2018)

		Recreval classes				ROS map classes: legend		
		Very low	Low	High	Very high			
		1	2	3	4			
Human input classes	5	1	1	4	7	Low provision	far	1
	4	1	4	4	7		proximal	2
	3	2	2	8	8		near	3
	2	3	5	5	9	Medium provision	far	4
	1	3	6	6	9		proximal	5
						High provision	near	6
							far	7
							proximal	8
							near	9

By using a raster dataset providing population data in the year 2015, having resolution of 250 m (Schiavina *et al.*, 2019), available from the repository of the Joint Research Centre of the European Commission and by using the function in equation (4), the spatial distribution of met and unmet demand for nature-based recreation can be mapped (fig. 5).

## 2.4. Landscape value (*Landsval*)

Similarly to recreation value discussed in Section 2.3, landscape value is a final ecosystem service comprised within the cultural ES group. As argued by the Millennium Ecosystem Assessment (2005b, p. 457), cultural ES are deeply interwoven and difficult to assess in isolation because they are often provided simultaneously. This is especially the case of a subset of intangible, and socially constructed, services provided by the landscape. In the Millennium Ecosystem Assessment taxonomy, this set comprises cultural identity, heritage value, and aesthetic appreciation of both natural and managed landscapes, and within the CICES nomenclature<sup>12</sup> their partially overlapping correspondents «things in nature that help people identify with the history or culture of where they live or come from», “using nature as a national or local emblem », and «the beauty of nature». Such ES are highly dependent on contexts and culture, because shaped through individual and collective (at the community level) system values, in turn related to individual and collective relationship with, and experience of, their environments. In Schaich *et al.*'s (2010) words, such ES «create strong ties between humans and their natural surroundings and play a crucial role in feeling at home in a landscape» (p. 270), place attachment, identification and memories being the most prominent ties (Lewica, 2008; Tengberg *et al.*, 2012). Further complexity is added when considering that this relationship is dual: humans' relationship with their natural environment both shapes and is shaped by culture, collective history, and memories (Fish *et al.*, 2016), which entails that the value that a person or a community attributes to a landscape is a complex combination of factors that characterize the environment and factors that characterize the person or the community (Gee and Burkhard, 2010). In addition, pristine and undisturbed natural environments are almost absent in European countries, where for millennia land uses have been managed, and consequently landscapes have been shaped, with the ultimate goal of sustaining human life by improving some services deemed more valuable than others (Schaich *et al.*, 2010; Tengberg *et al.*, 2012).

As a consequence, the value that people assign to a landscape is affected by their familiarity, experiences and traditions (Scholte *et al.*, 2015), which makes cultural ES in general difficult to assess: as noted in Section 2.3, ex-

<sup>12</sup> Common International Classification of Ecosystem Services (CICES) for Integrated Environmental and Economic Accounting, version 1.5, available from [https://cices.eu/content/uploads/sites/8/2018/03/Finalised-V5.1\\_18032018.xlsx](https://cices.eu/content/uploads/sites/8/2018/03/Finalised-V5.1_18032018.xlsx) [Accessed: 22 February 2022].

cept for nature-based recreation, all the other services pertaining to this group are seldom assessed through monetary approaches because, as with culture, they are intrinsically non-economic (Fish *et al.*, 2016) and non-marketable (Milcu *et al.* 2013), which makes it hard “to find meaningful ways of comparing the intangibles to the economic values generated from ecosystems” (Gee and Burkhard, 2010, p. 357).

Some monetary approaches, such as hedonic pricing (as in Sander and Haight, 2012), travel cost methods, and deliberative democratic monetary valuation to elicit social (as opposed to individual) willingness to pay (Orchard-Webb *et al.*, 2016) have been used to assess landscape quality (de Groot *et al.*, 2010) and cultural heritage (Daniel *et al.*, 2012). Monetary approaches to visual appreciation of landscapes can also be used in combination with mapping techniques to make the evaluation spatially explicit (as in van Berkel and Verbarg, 2014).

However, the most common approaches to assessing landscape values related to cultural heritage, identity, and quality are non-economic and rely on techniques proper to the realms of sociology and human geography, to engage stakeholders and elicit their perceptions, interpretations, and values. These include questionnaires (as in Gee and Burkhard, 2010), in-depth interviews (Plieninger *et al.*, 2013; Csurgó and Smith, 2021) or focus groups, meetings and workshops (as in Walter and Hamilton, 2014), sometimes complemented with visual aids and materials (as in Stewart *et al.*, 2004; Tengberg *et al.*, 2012; Frank *et al.*, 2013; Zoderer *et al.*, 2016) or with on-site surveys (as in Bieling and Plieninger, 2013), and participatory mapping (as in Brown *et al.*, 2012; Sherrouse *et al.*, 2011; Garcia-Martin *et al.*, 2017; for a comprehensive discussion on the use of participatory mapping to appraise place values see Brown *et al.*, 2020). The assessment of landscape-related values by using GIS-based desk analysis, in the absence of any stakeholder involvement, is usually limited to studies that only appraise visual aspects (as, for instance, in Swetnam *et al.*, 2017), which are referred to as landscape aesthetics, natural sceneries, scenic beauty depending on the study. Additionally, social media data in this kind of works can be used to elicit stakeholders’ values (as in Langemeyer *et al.*, 2018).

In this study, landscape value accounts for the interactions between natural and human factors as understood in the European Landscape Convention, which allows for integrating historic artifacts, archaeological sites and cultural heritage in general within managed ecosystems and makes it possible to incorporate their value within the ES framework (Hølleland *et al.*, 2017; Eliasson *et al.*, 2018). Within the European Landscape Convention, landscape is a complex system that includes not only its traditional factors

from the natural sciences (including, for instance, landforms, habitats composition and configuration), but also individual historic monuments and landmarks, minor spots of land (De Montis, 2016), and even everyday or degraded landscapes that have contributed to shaping the identity of European cultures. Landscape value, in this sense, is not restricted to areas of outstanding natural beauty, archaeological remains, historic monuments, or listed buildings, but it is grounded on people's perception of their territories, and on the recognition that different places show different characters. In compliance with the Convention, whose implementation varies across countries (De Montis, 2014), landscapes are to be protected, managed, and planned. Consequently, landscape plans are the tools whereby landscapes are interpreted, landscape quality and related values are identified, and protection devices taking various forms that span from strict regulations to soft guidelines to orient future scenarios are devised.

#### *2.4.1. Assessing landscape value based on the provisions of the Regional Landscape Plan*

Following Arcidiacono *et al.* (2016), in this study Landscape value (*Landsval*) is assessed based on the endowment of natural and cultural resources, which are identified as landscape-related goods by the Italian Code on cultural heritage and landscape (Law enacted by decree no. 2004/42), and it accounts for the landscape assets protected under the Regional Landscape Plan, in force in Sardinia since 2006.

The plan provides descriptive, prescriptive and indicative contents to which local land-use plans must conform (Zoppi and Lai, 2010), and moreover some prescriptive contents aimed at preserving current landscape quality values and setting restrictions on possible transformations of land uses are legally binding for the general public. The plan focuses especially on the coastal zone, but protection on certain categories of landscape features extends to the whole island, inland areas included. Landscape values to be preserved were identified within the plan-making process in the absence of adequate public participation, only limited to meetings with local authorities (Colavitti *et al.*, 2021), in stark contrast to common value-based approaches that rely on stakeholder consultation to elicit the importance attributed to cultural resources in general, and landscape features in particular (Tengberg *et al.*, 2012). We therefore identified protection levels defined in the plan, and a score was assigned to each protected landscape asset in the (0-1) interval depending on the level of restriction stemming from the plan implementation code, having also

regard to other restrictions originating from national and regional legislation, under the assumption that the level of restriction reflects the significance of the landscape value identified within the plan-making process. The full list of protection levels is provided in tab. 13, together with reference to the articles of the implementation code that provide rules and directions for each protection level, and finally the score we assigned, expressing the landscape value. As for the spatial layout, the full spatial dataset of the protection levels established by the Regional Landscape Plan was used, which is retrievable from the regional geoportal<sup>13</sup>. It is worth noting that parcels subject to multiple protection levels were assigned the score corresponding to the strictest protection level in force in that parcel.

*Tab. 13 - Landscape value: types of protected landscapes established in Sardinia by the Regional Landscape Plan, and value assigned on the basis of the restrictions in force*

	<i>Protected landscape type</i>	<i>Plan implementation code: ruling articles</i>	<i>Value</i>
Environmental assets	Coastal strip	8, 17, 18, 19, 20	1
	Coves, cliffs and small islands	8, 17, 18	0.8
	Sand dunes and beaches	8, 17, 18	0.8
	Coastal wetlands	8, 17, 18	0.8
	Areas above 900 m	8, 17, 18	0.8
	Lakes, reservoirs, wetlands and their 300-m buffers	8, 17, 18	1
	Rivers, creeks and their 150-m buffers	8, 17, 18	1
	Areas of significant importance for wild animals	17, 18, 38, 39, 40	0.2
	Areas of significant importance for plant species	17, 18, 38, 39, 40	0.2
	Grottos and caves	8, 17, 18	0.8
	Monumental trees	8, 17, 18	0.2
	Natural monuments (as per regional law 1989/31)	8, 17, 18	0.5
	National parks and marine protected areas	8, 17, 18	0.5
Volcanoes	8, 17, 18	0.5	
Historic and cultural assets	Listed buildings and areas (art.146 Decree 2004/42)	8	0.8
	Listed archaeological heritage	8, 47	1
	Archaeological areas subject to building restrictions	8, 47	0.5
	Areas with prehistoric, historic, cultural remnants	8, 47, 48, 49, 50	1
	Historic districts	8, 47, 51, 52, 53	0.8
	Traditional Sardinian farmer's building complexes	8, 47, 51, 52, 54	0.8

<sup>13</sup> The full spatial dataset can be retrieved from <https://www.sardegnaegeoportale.it/index.php?xsl=2420&s=40&v=9&c=14482&na=1&n=10&esp=1&tb=14401> [Accessed: 22 February 2022].



## 2.5. Agricultural and forestry value (*Agrofor*)

Agricultural crops and forestry production are a conspicuous part of the provisioning group of ES (among many: Millennium Ecosystem Assessment, 2003; Kumar *et al.*, 2011; Maes *et al.*, 2013). They are both influenced by the socio-economic context and heavily dependent on human management, including choice of crops, use of plant protection products, additional inputs (e.g., water, energy, and nutrients) to increase productivity (Zhang *et al.* 2007). All of these factors shape, either positively or negatively, interactions between agricultural and forestry production and other ES (Balbi *et al.*, 2015), which often results in trade-offs and/or clashes (Power, 2010; Raudsepp-Hearne *et al.*, 2010).

Provisioning ES have been assessed, so far, in a number of ways. A very common one is that of monetary evaluation based on market prices, which has been implemented, for instance, by Schirpke *et al.* (2015; 2017) for mushrooms, fodder production, and timber production in Natura 2000 sites in Italy, or by Adekola *et al.* (2012) at a very local scale, that of a wetland in South Africa. The absence of comprehensive and detailed spatial data on agricultural and forestry plots and yields, together with the volatility of market prices, which are extremely variable across time and space, makes monetary evaluations at the regional/national/supernational scales quite challenging. Thus, when the number of crops of interest is large or the scale goes beyond local, other methods are preferred.

Bio-physical assessments rely on quantitative models that estimate the amount of biomass that can be yielded by agricultural or forestry plots. Franzese *et al.* (2009) have compared two such methods (based on gross energy requirement and on emergy synthesis, respectively) to estimate annual corn production and willow production in Italy, while Vallecillo *et al.* (2019b) have spatially assessed the amount of 13 agricultural crop types produced in the EU by using a so-called “fast-track” approach that allows to disentangle the ecosystem contribution, which entails that human inputs in agricultural production are not accounted for. The latter approach was also applied to estimate biomass timber production from Italian forests (Comitato Capitale Naturale, 2021). Another bio-physical, spatially explicit, approach, links land covers with crops’ yields based on national statistics on observed yields; this model can be further enriched with data on fertilizers and has been applied, for instance, by Cao *et al.* (2017) and by Li *et al.* (2020).

Finally, another monetary approach posits that the economic value of agricultural and forestry ES is embedded into land prices (Ma and Swinton, 2011). Under this assumption, the monetary value of rural land can be tak-

en as a proxy for the potential provision of agricultural and forestry ES (Munafò *et al.*, 2014).

### 2.5.1. *Estimating agricultural and forestry value using land value as a proxy*

Building on the latter approach, in this study the agricultural and forestry value (*Agrofor*) was estimated based on two national datasets for agriculture and forestry areas, both providing monetary values of the land per unit of area; moreover, the 2018 CORINE land cover map<sup>14</sup> was used to make the assessment spatially explicit.

As for agricultural areas, a spreadsheet<sup>15</sup> produced by the National Research Council of Agriculture and Agricultural Economics (Italian acronym: CREA) was used, which provides the value of land plots in the year 2017 based on the type of crop, on elevation zone, and on location (by taking provinces<sup>16</sup>, i.e., Italian NUTS3 statistical regions, as the basic spatial units). Therefore, in order to map such values, two preliminary operations were required as summarized below.

First, a correspondence was established between CREA's taxonomy of crop types and CORINE land cover agricultural classes, as per tab. 14; as for land cover class "242 - Complex cultivation patterns", in the absence of any correspondence, for each province and elevation zone the land value was set as the mean agricultural land value in that province and elevation zone.

<sup>14</sup> Available from <https://land.copernicus.eu/pan-european/corine-land-cover/clc2018> [Accessed: 22 February 2022].

<sup>15</sup> Available from <https://crea-qa.cube.extrasys.it/-/banca-dati-valori-fondiari-bdvvf> [Accessed: 22 February 2022].

<sup>16</sup> A province in Italy is an intermediate tier of government between that of a region and that of a municipality and is composed of several adjacent municipalities. In Sardinia, provinces have varied several times as regards both number (ranging from a minimum of 3 to a maximum of 8) and boundaries (which depend on the set of included municipalities). Therefore, whenever provinces are involved for the assessment of agricultural and forestry values, the aggregations of the included municipalities at the relevant dates were considered, rather than the boundaries of the provinces, which are available only for some points in time.

Tab. 14 - Correspondence between agricultural areas in the CREA taxonomy and in the CORINE Land Cover one

CREA taxonomy: crop types		CORINE Land Cover classes: agricultural areas	
Code	Nomenclature	Code	Nomenclature
14	Arable land, vegetable gardens, garden center	211	Non-irrigated arable land
		212	Permanently irrigated land
		213	Rice fields
		241	Annual crops associated with permanent crops
15	Pastures	231	Pastures
16	Orchards and citrus groves	222	Fruit trees and berry plantations
17	Vineyards	221	Vineyards
18	Other utilized agricultural areas (UAA)	243	Land principally occupied by agriculture, with significant areas of natural vegetation
		244	Agro-forestry areas
8	Olive groves	223	Olive groves
---	---	242	Complex cultivation patterns

Second, because in the CREA's dataset the land value associated with a specific crop type varies depending on provinces and on the so-called "elevation zones" (original Italian: *zone altimetriche*), and because the spatial layout of elevation areas was not available off the shelf, an investigation on what these elevation zones are and how they can be mapped was carried out. Types of elevation zones are defined, for rural statistic purposes only, in a document produced by the National Census Institute (ISTAT, 1958, pp. 8-9), and in Sardinia they are as follows:

- Mountains: areas characterized by diffuse mountains above 700 m a.s.l., together with valleys or plateaus included between such mountains; the altitude can vary depending on the upper limit of olive orchards.
- Hills: areas characterized by diffuse hills below 700 m a.s.l.; as with mountains, the altitude can vary depending on the upper limit of olive orchards. A further differentiation is made, in Sardinia, between inner hills and coastal hills to account for the influence of the sea on climate and, in turns, on yielding potentials.
- Plains: low and flat areas characterized by the absence of diffuse elevated land.

Therefore, four "elevation zone" types are present in Sardinia. As far as their spatial layout is concerned, the above-mentioned document produced by the National Census Institute (ISTAT, 1958, pp. 84-86) provides a list of so-called "rural regions" (original Italian: *regioni agrarie*) included within each elevation zone type. Since agrarian regions are basically groups of contiguous municipalities (each listed in the document), this made it possi-

ble to derive the spatial layout of agrarian regions first and elevation zones next from that of Sardinian municipalities through a series of reclassification and dissolve operations.

As for forestry areas, data were retrieved from the National Revenue Agency<sup>17</sup> and the values are here differentiated according to type of production, provinces, and, again, rural regions as above defined. As with agricultural areas, a preliminary correspondence was established between the taxonomy of the National Revenue Agency (which includes, for instance, the following wood types of relevance to Sardinia: carob, chestnut, hazelnut, walnut, cork tree, as well as shrubby pastures, wood pastures, coppice) and that of the CORINE land cover sub-classes belonging to the 3.1 and part of the 3.2 second-level classes (“forests” and “shrubs”, respectively) of significance for forestry uses.

Moreover, since the land value dataset of the National Revenue Agency refers to 2007 (for the provinces of Cagliari, Oristano, and Sassari) and to 2011 (for the province of Nuoro only), all of the values were discounted<sup>18</sup> to 2017 to make them comparable with the values obtained for agricultural areas. The value ranges from zero (non-agricultural and non-forestry land) to a maximum of approximately 22,500 euros per hectare.

## 2.6. Land surface temperature (*LST*)

Land surface temperature (*LST*) is defined as «a fundamental aspect of climate and biology, affecting organisms and ecosystems from local to global scales» (Hulley *et al.*, 2019), as «the radiative skin temperature of the ground» (Hofierka *et al.*, 2020), which is affected by solar reflectance, thermal emissivity, and heat capacity. This entails that *LST* combines interactions between land surface and atmosphere with ground-atmosphere energy fluxes. *LST* represents therefore a key climate variable and its study allows researchers to analyze the behavior of the Earth’s environmental system (Neinavaz *et al.*, 2020)

Moreover, numerous studies have shown that *LST* is heavily affected by the presence, type, and abundance of vegetation and by the properties of

<sup>17</sup> Available from <https://www.agenziaentrate.gov.it/portale/web/guest/schede/fabbricatiterreni/omi/banche-dati/valori-agricoli-medi/valori-agricoli-medi-sardegna> [Accessed: 22 February 2022].

<sup>18</sup> Discount rates were retrieved from <http://rivaluta.istat.it:8080/Rivaluta/> [Accessed: 22 February 2022].

bare soil (Weng *et al.*, 2004), hence ultimately by land covers (Ayanlade, 2017; Lai *et al.*, 2020a; 2020b) and their changes (Feizizadeh *et al.*, 2013; Pal and Ziaul, 2017; Li *et al.*, 2020, Abir and Saha, 2021). Therefore, ecosystems affect local climate and exert a regulatory and mitigation function that can contribute to human wellbeing and quality of life, especially in urban areas, where the urban heat island effect is of concern and has become a significant field of research (Yuan and Bauer, 2007; Li *et al.*, 2016; Estoque *et al.*, 2017; Zhang *et al.*, 2017; Wang *et al.*, 2019) as regards urban ES.

*LST* is usually retrieved through remotely sensed thermal infrared data (Quattrocchi and Luvall, 1999; Weng, 2009; Lv and Zhou, 2011). A thorough theoretical background, also comprising an overview of the physics equations that allow to derive *LST* from the sensed spectral radiance, is provided by Li *et al.* (2013a; 2013b), who also discuss some algorithms and methods that have been implemented to handle radiometric calibration and cloud detection, as well as emissivity and atmospheric effects.

### 2.6.1. *LST* retrieval from Landsat imagery

A QGIS plugin implemented by Ndossi and Avdan (2016) implements a five-step procedure where various algorithms for *LST* retrieval are embedded. The plugin has been employed to extract *LST* from Landsat images in various studies, mainly at the city level, to assess the significance of urban trees in mitigating temperatures (Barbierato *et al.*, 2019), to investigate the urban heat island effect (Alves, 2016), or to estimate the impact of urban land-use change on *LST* (Dhar *et al.*, 2019; Sayão *et al.*, 2020; Ebrahimi *et al.*, 2022).

In the first step, the top-of-atmosphere spectral radiance is calculated for each pixel using thermal Landsat 8's band 10 pixel values as input, using equation (5) (USGS, 2021):

$$TOA = (M_L \cdot Q_{cal}) + AL \quad (5),$$

where:

- *TOA* is the top-of-atmosphere spectral radiance [ $W/(m^2 \cdot sr \cdot \mu m)$ ].
- $M_L$  is the band-specific multiplicative rescaling factor (retrievable from the image's metadata, provided by USGS as a plain text file together with the image, as "RADIANCE\_MULT\_BAND\_10").
- $Q_{cal}$  is the band 10 image pixel values (i.e., digital numbers), quantized and calibrated.

- $AL$  is the band-specific additive rescaling factor (retrievable from the image’s metadata, provided by USGS as plain text file together with the image, as “RADIANCE\_ADD\_BAND\_10”).

In the second step, the top-of-atmosphere spectral radiance is converted into the top-of-atmosphere brightness temperature as per equation (6) (USGS, 2021):

$$T = \frac{K_2}{\ln\left(\frac{K_1}{TOA} + 1\right)} \quad (6),$$

where:

- BT is the top-of-atmosphere brightness temperature [K].
- TOA is the top-of-atmosphere spectral radiance.
- $K_1$  and  $K_2$  are two specific thermal conversion constants (retrievable from the image’s metadata, provided by USGS as a plain text file together with the image, as “K1\_CONSTANT\_BAND\_10” and “K2\_CONSTANT\_BAND\_10”, respectively).

In the third step, the normalized difference vegetation index is calculated using Landsat 8’s bands 4 and 5 images as inputs, through equation (7) (Townshend *et al.*, 1985):

$$NDVI = \frac{NIR-RED}{NIR+RED} \quad (7),$$

where:

- NDVI is the normalized difference vegetation index.
- NIR is the near-infrared band. For Landsat 8 images, this is band 5.
- RED is the visible red band. For Landsat 8 images, this is band 4.

Once the NDVI is known, in the fourth step, the Land Surface Emissivity (LSE) can be calculated using various algorithms. Among those implemented in the plugin, the algorithm by Zhang *et al.* (2006) has been reported to yield the best results (Ndossi and Avdan, 2016) as per *LST* retrieval. This algorithm, which builds upon van de Griend and Owe’s (1993) findings concerning the correlation between LSE and NDVI, is summarized in tab. 15.

Tab. 15 - Relation between Land Surface Emissivity (LSE) and the normalized difference vegetation index (NDVI). Source: Ndossi and Avdan, 2016

NDVI	LSE
NDVI < -0.185	0.995
-0.185 ≤ NDVI < 0.157	0.985
0.157 ≤ NDVI ≤ 0.727	1.009 + 0.047 · ln(NDVI)
NDVI > 0.727	0.990

Finally, in the fifth step, *LST* can be calculated using four algorithms, of which the so-called “Planck function” is reported to be “easier to use in comparison to the other algorithms as it does not require atmospheric variables” (Ndossi and Avdan, 2016, p. 28), and makes use of equation (8) (Artis and Carnahan, 1982):

$$LST = \frac{BST}{1 + (\lambda \cdot \frac{BT}{\alpha}) \cdot \ln(LSE)} \quad (8),$$

where:

- *LST* is land surface temperature [K].
- *BT* is top-of-atmosphere brightness temperature [K].
- *LSE* is land surface emissivity.
- $\lambda$  is wavelength of the emitted radiance [m] =  $1.0895 \cdot 10^{-5}$  m for Landsat 8 TIRS (Zhao *et al.*, 2018).
- $\alpha = h \cdot c / \sigma$  (where  $h$  is Planck’s constant,  $c$  is the velocity of light, and  $\sigma$  is Boltzmann’s constant) =  $1.438 \cdot 10^{-2}$  mK (Avdan and Jovanovska, 2016).

The above-listed five steps were implemented by using two sets of Landsat 8 satellite images concerning Sardinia, acquired in Spring and Summer 2019. Landsat 8 OLI (Operational Land Imager) and TIRS (Thermal Infrared Sensor) images are freely available from the US Geological Survey Earth Resources Observation and Science website<sup>19</sup>, where data can be searched and retrieved based on spatial and temporal criteria. Two searches were performed; the first concerns the mid-summer season (15 July - 30 August 2019), in which temperature peak in Sardinia, while the second concerns the mid-spring season (15 April - 31 May 2019), in which vegetation growth is at its highest, before the dry season and the annual crop harvesting. For each time period, five images were retrieved, two belonging to Landsat scene 192 (on May 16 for the spring search and August 20 for the summer search) and three to Landsat scene 193 (on May 23 for

<sup>19</sup> Available from: <https://earthexplorer.usgs.gov/> [Accessed: 22 February 2022].

the spring search and August 11 for the summer search). No single-date images covering the whole island can be retrieved because of the configuration of the satellite acquisition paths.

Details for each image are provided in tab. 16, while fig. 6 provides the spatial layout of scenes 192 and 193, shown as dotted rectangles, and the images' footprints, shown as colorful squares inside the scenes.

*Tab. 16 - Selected Landsat 8 images*

<i>Image code</i>	<i>Scene</i>	<i>Cell size</i>	<i>Date</i>	<i>Season</i>
LC08_L1TP_192032_20190516_20190521_01_T2	192	30 m	May 16, 2019	Spring
LC08_L1TP_192033_20190516_20190521_01_T1	192	30 m	May 16, 2019	
LC08_L1TP_193031_20190523_20190604_01_T2	193	30 m	May 23, 2019	
LC08_L1TP_193032_20190523_20190604_01_T1	193	30 m	May 23, 2019	
LC08_L1TP_193033_20190523_20190604_01_T1	193	30 m	May 23, 2019	
LC08_L1TP_193031_20190811_20190820_01_T1	193	30 m	August 11, 2019	Summer
LC08_L1TP_193032_20190811_20190820_01_T1	193	30 m	August 11, 2019	
LC08_L1TP_193033_20190811_20190820_01_T1	193	30 m	August 11, 2019	
LC08_L1TP_192032_20190820_20190903_01_T1	192	30 m	August 20, 2019	
LC08_L1TP_192033_20190820_20190903_01_T1	192	30 m	August 20, 2019	

By implementing the steps in Ndossi and Avdan's plugin, ten *LST* raster maps (one for each satellite image in tab. 16) were retrieved, each having cell size 30 meters. The five spring images were next merged, as well as the five summer images; a full overview of the process is provided in fig. 7. In this way, two *LST* regional maps were obtained, one for the time period 16-23 May, 2019 and one for the time period 11-20 August, 2019 (fig. 8).

Since in both cases images from scene 192 overlap those from scene 193 (as shown in fig. 6), and since in both cases the maximum values always correspond to pixels belonging to scene 193, for overlapping pixels the value associated to images in scene 193 was consistently retained. Moreover, it is worth mentioning that that some parts of the island were covered by clouds when the spring images were produced; as this locally affected both NDVI and *LST* values, such parts were filtered and excluded from the process.

## **2.7. Carbon storage and sequestration capacity (*CO<sub>2</sub>Stor*)**

Carbon sequestration is the process whereby carbon dioxide (CO<sub>2</sub>), the most important greenhouse gas generated by human activities (EPA, 2021),



is removed from the atmosphere and transferred to either water or terrestrial carbon pools. By doing so, carbon sequestration and storage prevents or mitigates the impacts that would be caused by increased carbon concentrations in the atmosphere, such as higher global temperatures, sea-level rise, wildfires, and other phenomena associated with climate change (Lal, 2008).

Carbon (C) can be removed from the atmosphere through two broad processes, i.e., abiotic and biotic. Abiotic processes comprise various engineered trapping mechanisms through which carbon dioxide is stored in geological sinks (Kambale and Tripathi, 2010); although carbon sequestration can be driven by humans and various technologies to capture, transport, and store carbon within appropriate reservoirs have been available for decades now (Lackner, 2003), anthropogenic sequestration is only a modest fraction of the total carbon uptake compared to the natural one (Ghommem *et al.*, 2012). The biotic process occurs naturally through photosynthesis, that is, the process through which vegetation captures carbon dioxide and converts it into oxygen, which is next released again into the atmosphere, and carbon, which is stocked either into the ocean and other minor water basins, or into one of the available terrestrial pools. While the ocean is by far the most important carbon pool on Earth (Lal, 2008), on land the greatest storage capacity is that of soil, followed by vegetation (Smith, 2012); however, the pools are interconnected with each other and to the atmosphere via flux exchanges (Dixon *et al.*, 1994), which entails variability in the amount of carbon stored in each sink. Indeed, there is more than just one type of terrestrial sink because, once removed from the atmosphere by vegetation, carbon is first stocked into living plant matter (both above-ground biomass, such as leaves, branches, trunks, and below-ground biomass, i.e., living roots); next, as vegetation dies, carbon is stored into dead organic matter (such as dead leaves and deadwood) which finally decomposes, hence stabilizing carbon in the soil through mineralization or through leaching processes (Błońska *et al.*, 2019).

Therefore, on land, the beneficial process of removing carbon dioxide is undertaken by ecosystems, and it is deeply affected by land cover change (Jobbagy and Jackson, 2000), to the extent that, according to IPCC (2013), land cover change is the second most important driver of CO<sub>2</sub> emissions after fossil fuel burning. The relationship between land cover changes and CO<sub>2</sub> emissions is actually ambivalent, since land conversion can result either in increased or in decreased atmospheric carbon (Gries *et al.*, 2019) depending on the type of change, as well as on agricultural management practices, some of which can in principle increase the amount of organic carbon in soils (Smith, 2012). Moreover, other factors add further layers of complexity to the relationship between land cover changes and global tem-

perature, making it not straightforward and even counterintuitive. Bala *et al.* (2007), for instance, argued that while large-scale deforestation produces a warming effect due to increased quantities of atmospheric carbon, nonetheless it results in an overall cooling effect because of increased land surface albedo and decreased evapotranspiration, which in turns, depending on the latitude (Bonan, 2008), triggers changes in rainfall patterns and wind speed (Malhi *et al.*, 2008).

Soil organic carbon can be easily quantified through appropriate sampling and direct measurement; however, the costs to carry out large-scale measurements can make direct assessment cost-ineffective (Smith *et al.*, 2020), which favors modeling simulations and remote sensing techniques. As for carbon stored in both below- and above-ground biomass, it is often estimated by multiplying the total biomass by a conversion factor (Ponce-Hernandez, 2004); prior estimation of the amount of biomass is therefore required, which can be based on field surveys, on inventories, or on spectral analysis of satellite imagery. For a thorough list of methods, the reader can refer to Petrokofsky *et al.* (2012, Appendix B).

### 2.7.1. Modeling carbon storage and sequestration through the InVEST suite

The InVEST “Carbon Storage and Sequestration” model, part of the InVEST suite,<sup>20</sup> only considers terrestrial carbon sinks<sup>21</sup> and assumes that carbon can be stored in four pools as follows: above-ground biomass, below-ground biomass, dead organic matter, and soil (by considering the top 30-cm deep layer). The total amount of carbon currently stored in the area of interest is estimated in biophysical terms based on a land cover map coupled with a table that provides, for each land cover type, the carbon density (i.e., the amount of carbon per unit of land) that each land cover stores in each carbon pool that the user wants to consider, or for which data are available. The output is a carbon density map, whose unit of measurement is Mg of carbon per pixel, where the amounts of carbon stored in each pool are aggregated as per equation 9:

<sup>20</sup> InVEST is freely available from <https://naturalcapitalproject.stanford.edu/software/invest> [Accessed: 22 February 2022].

<sup>21</sup> Another tool in the suite, named “Marine Blue Carbon”, models carbon removed by, and stored in, vegetal biomass such as mangroves and seagrasses; it can therefore be regarded as an adaptation of the Carbon Storage and Sequestration” model developed for coastal and marine areas (Guerry *et al.*, 2012).

$$CT_{Lck,ij} = CA_{Lck,ij} + CB_{Lck,ij} + CD_{Lck,ij} + CS_{Lck,ij} \quad (9),$$

Where  $ij$  denotes a cell in the raster map whose land cover type is LCK, CA, CB, CD, CS are the carbon densities in above-ground biomass, below-ground biomass, dead organic matter, and soil respectively, while CT is the total carbon density.

The model was used in several studies at various scales and with different purposes as follows.

- To quantify the amount of carbon stored in terrestrial pools at various scales (Grafius *et al.*, 2016 for three English towns; Chacko *et al.*, 2019 for a natural protected area in India; Piyathilake *et al.*, 2021 for a province in Sri Lanka).
- To assess impacts on the amount of stored carbon generated by historical land-use changes at the district level in Seoul (Han *et al.*, 2018), or at the state level in Minnesota, US (Polasky *et al.*, 2011) and in Ghana and Cote d'Ivoire (Leh *et al.*, 2013).
- To estimate the potential loss of carbon stored in the above-ground pool as a consequence of a natural disaster, by looking at hurricanes in Florida (Delphin *et al.*, 2013)
- To predict changes in carbon storage resulting from urban expansion (He *et al.*, 2016; Lahiji *et al.*, 2020), from agricultural expansion (Chaplin-Kramer *et al.*, 2015) or, in more general terms, from land-use changes associated with alternative future scenarios at the local scale (Nelson *et al.*, 2009; Kovacs *et al.*, 2013; Babbar *et al.*, 2021) or at the global scale (Nelson *et al.*, 2010), in the latter case by looking only at carbon stored in biomass.

A challenging task is that of assigning to each land cover its appropriate carbon density value, which can be done based on sample collection (as in Rajbanshi and Das, 2021), on available literature (as in Leh *et al.*, 2013; Grafius *et al.*, 2016; Han *et al.*, 2018; Babbar *et al.*, 2021; Piyathilake *et al.*, 2021) or datasets (as in Nelson *et al.*, 2010 and in Chaplin-Kramer *et al.*, 2015), on national inventories (as in He *et al.*, 2016; Pilogallo *et al.*, 2019; Scorza *et al.*, 2020b), on plot-level inventories (as in Delphin *et al.*, 2013). Due to the lack of data on below-ground biomass, in the InVEST model only the remaining three carbon pools (i. above-ground biomass, ii. soil organic content, iii. dead organic matter) were considered; for each pool the corresponding carbon density values were assigned based on the

2005 National Inventory of Italian Forests<sup>22</sup> and on a regional pilot project concerning land units and soil capacity in Sardinia<sup>23</sup>. The model was run by Maddalena Floris as part of her doctoral thesis (Floris, 2020), to which the reader can refer for further details.

## 2.8. Mapping the components of a regional GI and identifying relevant areas for ES provision

This section is organized as follows. In the first subsection, the spatial distribution of each single value presented in the previous sections is mapped and the values are discussed individually; in the second subsection, building on the assessment of the seven values, their interaction is assessed in terms of synergies and trade-offs, and a method for identifying areas that provide similar bundles of ecosystem services is presented.

### 2.8.1. Spatial distribution of the seven components of a regional GI

Fig. 9 provides the spatial layout of the seven ecosystem services assessed as per the previous sections in this chapter. All of the values are normalized in the [0-1] interval; as for *LST*, the summer map in fig. 8 was chosen over the spring one due to the absence of clouds, and the values were inversely normalized, so lower scores correspond to higher temperatures and vice versa.

Firstly, as for Conservation value (*Consval*), areas taking non-null values are mostly, but not exclusively, located within Natura 2000 sites and highly spatially clustered in their immediate surroundings. A large part of the island (approximately 66%) takes null conservation values, which means that it does not host any habitats of community interest.

Out of the rest of the island (34%), in which such habitats can be found (*Consval* ≠ 0), the most part takes low values: only 0.90% of the island's surface takes values higher than 0.75; 4.95% takes values between 0.50 and 0.75, and finally 27.80% shows values below 0.50.

Secondly, concerning Natural value (*Natval*), only a small part of the is-

<sup>22</sup> Available from: <https://www.sian.it/inventarioforestale/> [Accessed: 22 February 2022].

<sup>23</sup> Available from: <http://www.sardegnaegeoportale.it/index.php?xsl=2420&s=40&v=9&c=14481&es=6603&na=1&n=100&esp=1&tb=14401> [Accessed: 22 February 2022].

land (3.44%) takes null values ( $Natval = 0$ ); 35.51% of the region hosts low-quality habitats taking ( $Natval \leq 0.33$ ), while 62.45% of the region hosts middle-quality habitats ( $0.33 < Natval \leq 0.66$ ), and, finally, the remaining 13.8% hosts high-quality habitats ( $0.66 < Natval \leq 1$ ). The mean value across the region equals 0.43. High values mostly concern the island's largest forests (to the south-west, Gutturu Mannu and Linas; to the south-east, Sette Fratelli, to the mid-east the Gennargentu and Supramonte chains) and, especially, the regional and national protected areas: although very small in size, the Asinara and La Maddalena National Parks as well as the Capo Caccia and Tepilora Regional Parks are clearly identifiable to the north, as well as the Gutturu Mannu and Molentargius Regional Parks to the south.

Thirdly, Recreation value ( $Recrval$ ) equals 0 in a negligible part of the island. Approximately 49.5% of the island takes low values ( $Recrval \leq 0.33$ ), and around 44.75% takes mid values ( $0.33 < Recrval \leq 0.66$ ), while only the remaining 5.75% takes very high values ( $0.66 < Recrval \leq 1$ ). The spatial patterns of  $Recrval$  are somewhat similar to those of  $Natval$ , meaning that areas having high and low values correspond, to some extent, although  $Recrval$  is less fragmented than  $Recrval$ ; moreover, they tend to differ along the coastline, where  $Recrval$  always takes high values, contrary to  $Recrval$ , which ranges freely in the [0-1] interval.

Fourthly, Landscape value ( $Landsval$ ) equals 0 in 61.18% of the region. Furthermore, this variable is categorical and only takes the following values: 0.20 (0.26% of the regional land mass); 0.5 (4.21%); 0.8 (4.17%) and 1 (30.18%). Therefore, among non-null values, the maximum value spatially dominates, mainly because of three main environmental assets: "Coastal strip", "Lakes, reservoirs, wetlands and their 300-m buffers" and "(listed) Rivers, creeks and their 150-m buffers"; the first is protected under the Regional Landscape Plan (article 20 of the plan implementation code), which forbids any kind of new development while allowing restoration or renewal of existent buildings, while the second and the third are protected under the national law on cultural goods and landscape, whereas the Regional Landscape Plan only maps areas that are preserved and protected as belonging to this type. A fourth type of landscape asset, belonging to the cultural group, and comprising both "Listed archaeological heritage" and "Areas with pre-historic, historic, cultural remnants", also brings about the maximum value, but is less significant in terms of size.

Fifthly, Agricultural and forestry value ( $Agrofor$ ) is null in around 34.1% of the island; around 47.3% takes low values ( $Agrofor \leq 0.33$ ), while only 14.1% takes mid values ( $0.33 < Agrofor \leq 0.66$ ), and a mere 4.5 takes high values ( $0.11 < Agrofor \leq 1$ ). The latter are remarkably clustered along

the two main plains: Nurra to the north, and, especially, Campidano, stretching from the mid-west to the south.

Sixthly, Land surface temperature ( $LST$ ) in summer mostly (59.9%) takes mid normalized values ( $0.33 < LST \leq 0.66$ ), whereas 38.7% of the island is characterized by low normalized values ( $0 < LST \leq 0.33$ ), meaning that the surface temperature is hot, and a mere 1.4% takes high normalized values ( $0.66 < LST \leq 1$ ), hence it is cooler than the rest of the island. No real clusters emerge, here: the small, darker spots in the map generally correspond to lakes and wetlands, while the medium-to-dark shades of green in general correspond to mountain chains and peaks. The medium-to-dark shade to the south-east of the island is to be attributed to the fact that satellite images in this part of the island were retrieved in a different date than the rest of the region.

Finally, Carbon storage and sequestration capacity ( $CO2Stor$ ) is null ( $CO2Stor = 0$ ) in around 2.2% of the island, and only 4.8% takes low values ( $0 < CO2Stor \leq 0.33$ ), while the large majority, corresponding to approximately 74.4%, takes mid values ( $0.33 < CO2Stor \leq 0.66$ ), and around 18.6% takes high values ( $0.66 < CO2Stor \leq 1$ ). As with  $LST$ , and even more so, no clear spatial pattern emerges, except for low and very low values, which generally correspond to urban areas, artificial areas, and inland waters.

### *2.8.2. Identifying priority areas through an assessment of synergies and trade-offs between ecosystem services*

The availability of spatially explicit assessment of multiple ES makes it possible to identify priority areas for the inclusion in a regional that can be used to ground planning policies aiming at preserving or enhancing current levels of ES supply. Such identification can be done, basically, in two ways. One simply relies on assessing which areas have the highest potential to deliver several ES by calculating the sum of the bio-physical values, normalized for the sake of comparability. The second relies on spatial statistics methods, which allow for more nuanced results because the mere total value does not let the analyst, and the decision maker, understand which values contribute to the total and which do not, hence it does not make it possible to understand the strengths and weaknesses, in delivering ES, of a given area. Methods based on spatial statistics that assess interrelationships between ES, in terms of both synergies and trade-offs, do not lead to oversimplifying the assessment through a single value, and therefore the results need to be carefully interpreted and communicated; rather, they provide a multifaceted representation of the combinations of ES supplied.

For such analyses, the municipal level is the optimal territorial unit, in Italy, because municipalities represent the lowest administrative tier of government in charge of land-use planning, whose provisions can greatly affect the provision of ES. Therefore, ES data presented in the previous subsection need to be preliminarily preprocessed so as to retrieve the mean normalized value for each municipality. In the Sardinian case, the number of municipalities is 377, which entails building a matrix having 377 rows and seven columns, each representing a single ES, where cells contain the average municipal value of an ES in a municipality. Fig. 10 provides an overview of the average normalized values of each ES at the municipal level.

Following Raudsepp-Hearne *et al.* (2010), Turner *et al.* (2014), Queiroz *et al.* (2015), the analysis comprises three steps, as follows.

- For each ES, spatial patterns are analyzed by assessing spatial autocorrelation through Moran's  $I$  index; hot spots and cold spots of municipalities having statistically significant higher or lower values than their surrounding municipalities are identified through the Getis-Ord  $G_i^*$  statistics.
- Statistically significant (linear) correlations between each pair of ES are assessed through Pearson's correlation coefficient.
- Clusters comprising municipalities having a level of in-group similarity higher than their dissimilarities with respect to municipality not belonging to the group are spatially identified by applying first a principal component analysis (PCA), aimed at reducing redundancies due to the presence of correlations, and next a cluster analysis through the k-means algorithm.

The analysis of spatial autocorrelation carried out using the queen contiguity conceptualization<sup>24</sup>, shows evidence of spatial agglomeration ( $I > 0$ ) statistically significant and decreasing up to the fifth level of (cumulative) contiguity for all the ES, as shown in fig. 11, but for *Natval*, for which  $I$  is significant only at the first two levels.

The results of the hot spot and cold spot analysis are shown in fig. 12, which puts in evidence that some parts of the island can be either hot spots or cold spots, depending on the ES at stake.

The Campidano plain, for instance, which spans from the eastern coast to the southern one, is a hot spot for *Agrofor*, and a cold spot for *Consva*,

<sup>24</sup> This means that two polygons, i.e., two municipalities, are regarded as contiguous if their boundaries share at least a point, as opposed to rook contiguity, whereby two polygons are regarded as contiguous if a trait of their boundaries is shared.

*Recrval*, and partially also for *Landsval*, while large part of the inner island is a hot spot for *Consval* and a cold spot for *Agrofor*; southern Ogliastro, a subregion laying to the west of the island, is a hot spot for *CO2Stor*, *Recrval* and *LST* and a cold spot for *Agrofor*. From this assessment, spatial patterns of agglomerations concerning single ES emerge.

The Pearson coefficients (tab. 17) show that 16 out of the 21 pairs of ES are significantly and linearly correlated; negative correlations always concern *Agrofor* and *CO2Stor*, which therefore compete with other ES and, furthermore, with each other. Positive significant correlations (synergies) characterize *Recrval* and *LST*; the correlations between *Recrval* and *Landsval* and between *Recrval* and *LST* are strong ( $\rho=0.725$  and  $\rho=0.542$ , respectively), while the others are generally moderate.

Tab. 17 - Analysis of the mutual correlations between the seven ES. Above the diagonal: Pearson coefficients ( $\rho$ ); the shades of grey signal the strength of the correlation. Below the diagonal: significance of the correlations (\*\*\*:  $p < 0.001$ ; \*\*:  $p < 0.01$ ; \*:  $p < 0.05$ )

Consval	0.158	0.359	0.138	-0.541	0.147	0.407
**	Natval	0.320	0.173	0.080	-0.036	0.033
***	***	Recrval	0.725	-0.407	-0.011	0.542
**	***	***	Landsval	-0.095	-0.314	0.486
***	***	***	Agrofor	***	-0.308	-0.372
**			***	***	CO2Stor	0.155
***		***	***	***	**	LST

Due to the presence of mutual correlation, the territory can be conceived of as a provider of bundles of ES, rather than of single, independent, ES, hence the PCA is helpful to reduce redundancies. When applying the PCA, several methods exist to identify the new principal components, which are linear combinations of the original components, which, in this case, are the seven ES. Such methods, however, lead to different results<sup>25</sup>; therefore, the choice of the method is to a certain extent, a matter of subjectivity. As the last column in tab. 18 shows, approximately 93% of the variance can be explained through four new axes, or around 97% through five axes, which represent as many combinations of the seven ES. When applying Cattell's scree test (Cattell, 1966), this would be not the first, but the second elbow in the graph shown in fig. 13.

The number of new principal components can be used to run the k-means algorithm to perform the cluster analysis, hence retrieving five

<sup>25</sup> Reviews and comparisons of methods for reducing dimensionality, the so-called "stopping rules", are provided, for instance, by Jackson (1993), Peres-Neto *et al.* (2005), Cangelosi and Gorieli (2007), Abdi and Williams (2010).



groups, whose spatial layout is shown in fig. 14, together with the spider diagrams that provide the mean value of each ES in each group.

Tab. 18 - PCA results: percent and accumulative eigenvalues

Principal component	Eigenvalue	Percent of eigenvalues	Accumulative of eigenvalues
1	0.03999	51.6942	51.6942
2	0.01822	23.5484	75.2426
3	0.00749	9.6777	84.9203
4	0.00687	8.8793	93.7996
5	0.00241	3.1201	96.9198
6	0.00163	2.1055	99.0252
7	0.00075	0.9748	100.0000

The outcomes of the cluster analysis, run through the k-means algorithm in ArcGIS®ESRI, version 10.7, are shown in fig. 14, which provides the spatial layout of the five municipal clusters here identified; municipalities in each cluster share common features in terms of bundles of ES provided, and they also share some distinctive environmental and socio-economic characteristics. Group 3, where *Landsval* and *Recrval* dominate, comprises almost exclusively coastal municipalities, whose economies rely on tourism, and whose urbanization levels are generally higher than those within the rest of the island, while *Agrofor* and, especially, *Consval* levels are quite low.

Group 2, having high values of both *Agrofor* and *CO2Stor*, corresponds to the island's main plains, hosting intensive agriculture and farming that yield comparatively high incomes with respect to Sardinian standards; *Natval* takes intermediate values, in this group, owing to the fact that non-intensive agricultural areas can act as habitats especially for birds, as well as forestry areas, which can host numerous types of both animal and plant species; *Recrval* takes, on average, mid-to-low values, while *Landsval* and, especially, *Consval* are very low.

Groups 1 and 4, both showing high values of *CO2Stor*, mainly differ as regards *LST* (high in 1 and in low 4); *Natval* in both groups takes intermediate values, as well as *Recrval*, while *Landsval* and, especially, *Consval* are very low; both groups comprise inner and sparsely populated municipalities, and they differ as for the morphology, which is gentler in group 4, and the vegetation, which in group 4 is richer in steppe and other herbaceous vegetation and pastures. Finally, group 5 comprises municipalities having high values of all ES except *Agrofor*; it includes the island's main mountain areas, whose landscapes are marked by maquis and forests, the greatest providers of ES in Sardinia.

## 2.9. Bibliography

- Abdi H. and Williams L.J. (2010), “Principal component analysis”, *WIREs Computational Statistics*, 2: 433-459. DOI: 10.1002/wics.101.
- Abir F.A. and Saha R. (2021), “Assessment of land surface temperature and land cover variability during winter: A spatio-temporal analysis of Pabna municipality in Bangladesh”, *Environmental Challenges*, 4 (100167): 1-12. DOI: 10.1016/j.envc.2021.100167.
- Adekola O., Morardet S., de Groot S. and Grelot F. (2012), “Contribution of provisioning services of the Ga-Mampa wetland, South Africa, to local livelihoods”, *International Journal of Biodiversity Science, Ecosystem Services & Management*, 8:3, 248-264. DOI: 10.1080/21513732.2012.671191.
- Alves E.D.L. (2016), “Seasonal and spatial variation of surface urban heat island intensity in a small urban agglomerate in Brazil”, *Climate*, 4 (61): 1-11. DOI:10.3390/cli4040061.
- Angradi T.R., Launspach J.J. and Debbout R. (2018), “Determining preferences for ecosystem benefits in Great Lakes Areas of Concern from photographs posted to social media”, *Journal of Great Lakes Research*, 44(2): 340-351. DOI: 10.1016/j.jglr.2017.12.007.
- Arcidiacono A., Ronchi S. and Salata S. (2016), “Managing multiple ecosystem services for landscape conservation: A green infrastructure in Lombardy Region”, *Procedia Engineering*, 161: 2297-2303. DOI: 10.1016/j.proeng.2016.08.831.
- Arkema K.K., Fisher D.M., Wyatt K., Wood S.A. and Payne H.J. (2021), “Advancing sustainable development and protected area management with social media-based tourism data”, *Sustainability*, 13, 5 (2427): 1-18. DOI: 10.3390/su13052427.
- Artis D.A. and Carnahan W.H. (1982), “Survey of emissivity variability in thermography of urban areas”, *Remote Sensing of Environment*, 12 (4): 313-329. DOI: 10.1016/0034-4257(82)90043-8.
- Arunyawat S. and Shrestha R.P. (2016), “Assessing land use change and its impact on ecosystem services in Northern Thailand”, *Sustainability*, 8, 8 (768): 1-22. DOI: 10.3390/su8080768.
- Avdan U. and Jovanovska G. (2016), “Algorithm for automated mapping of land surface temperature using LANDSAT 8 satellite data”, *Journal of Sensors*, (1480307), pp. 1-8. DOI: 10.1155/2016/1480307.
- Ayanlade A. (2017), “Remote sensing approaches for land use and land surface temperature assessment: a review of methods”, *International Journal of Image and Data Fusion*, 8 (3): 188-210. DOI: 10.1080/19479832.2017.1299802.
- Babbar D., Arendran G., Sahana M., Sarma K., Raj K. and Sivasdas A. (2021), “Assessment and prediction of carbon sequestration using Markov chain and InVEST model in Sariska Tiger Reserve, India”, *Journal of Cleaner Production*, 278 (123333): 1-17. DOI: 10.1016/j.jclepro.2020.123333.
- Bacchetta G., Bagella S., Biondi E., Farris E., Filigheddu R. and Mossa L. (2009), “Vegetazione forestale e serie di vegetazione della Sardegna (con rappresentazione cartografica alla scala 1: 350.000)” [“Forest vegetation and

- serial vegetation of Sardinia (with map at the scale 1:350,000”], *Fitosociologia*, 46 (1): 3-82.
- Bai Y., Zhuang C., Ouyang Z., Zheng H. and Jiang B. (2011), “Spatial characteristics between biodiversity and ecosystem services in a human-dominated watershed”, *Ecological Complexity*, 8 (2): 177-183. DOI: 10.1016/j.ecocom.2011.01.007.
- Bala G., Caldeira K., Wickett M., Phillips T.J., Lobell D.B., Delire C. and Mirin A. (2007), “Combined climate and carbon-cycle effects of large-scale deforestation”, *Proceedings of the National Academy of Sciences*, 104 (16): 6550-6555. DOI: 10.1073/pnas.0608998104.
- Balbi S., del Prado, A., Gallejones P., Geevan C.P., Pardo G., Pérez-Miñana E., Manrique E., Hernandez-Santiago C. and Villa F. (2015), “Modeling trade-offs among ecosystem services in agricultural production systems”, *Environmental Modelling & Software*, 72: 314-326. DOI: 10.1016/j.envsoft.2014.12.017.
- Balmford A., Beresford J., Green J., Naidoo R., Walpole M. and Manica A. (2009), “A global perspective on trends in nature-based tourism”, *Plos Biology*, 7, 6 (e1000144): 1-6. DOI: 10.1371/journal.pbio.1000144.
- Balvanera P., Pfisterer A.B., Buchmann N., He J.-S., Nakashizuka T., Raffaelli D. and Schmid B. (2006), *Ecology Letters*, 9: 1146-1156. DOI: 10.1111/j.1461-0248.2006.00963.x.
- Baral H., Keenan R.J., Sharma S.K., Stork N.E. and Kasel S. (2014), “Spatial assessment and mapping of biodiversity and conservation priorities in a heavily modified and fragmented production landscape in north-central Victoria, Australia”, *Ecological Indicators*, 36: 552-562. DOI: 10.1016/j.ecolind.2013.09.022.
- Barbierato E., Bernetti I., Capecchi I. and Saragosa C. (2019), “Quantifying the impact of trees on land surface temperature: A downscaling algorithm at city-scale”, *European Journal of Remote Sensing*, 52: 74-83. DOI: 10.1080/22797254.2019.1646104.
- Baró F., Palomo I., Zulian G., Vizcaino P., Haase D. and Gómez-Baggethun E. (2016), “Mapping ecosystem service capacity, flow and demand for landscape and urban planning: A case study in the Barcelona metropolitan region”, *Land Use Policy*, 57, 405-417. DOI: 10.1016/j.landusepol.2016.06.006.
- Barton D.N., Obst C., Day B., Caparrós A., Dadvand P., Fenichel E., Havinga I., Hein L., McPhearson T., Randrup T. and Zulian G. (2019), *Recreation services from ecosystems*, text available at the website [https://seea.un.org/sites/seea.un.org/files/discussion\\_paper\\_10\\_-\\_recreation\\_services\\_final\\_0.pdf](https://seea.un.org/sites/seea.un.org/files/discussion_paper_10_-_recreation_services_final_0.pdf) [Accessed: 22 February 2022].
- Bieling C. and Plieninger T. (2013), “Recording manifestations of cultural ecosystem services in the landscape”, *Landscape Research*, 38 (5): 649-667. DOI: 10.1080/01426397.2012.691469.
- Blicharska M., Smithers R.J., Hedblom M., Hedenås H., Mikusiński G., Pedersen E., Sandström P., and Svensson J. (2017), “Shades of grey challenge practical application of the cultural ecosystem services concept”, *Ecosystem Services*, 23: 55-70. DOI: 10.1016/j.ecoser.2016.11.014.
- Błońska E., Lasota J. and Piaszczyk W. (2019), “Dissolved carbon and nitrogen

- release from deadwood of different tree species in various stages of decomposition”, *Soil Science and Plant Nutrition*, 65 (1): 100-107. DOI: 10.1080/00380768.2018.1545517.
- Bonan G.B. (2008), “Forests and climate change: Forcings, feedbacks, and the climate benefits of forests”, *Science*, 320 (5882): 1444-1449. DOI: 10.1126/science.1155121.
- Boyd J. and Banzhaf S. (2007), “What are ecosystem services?”, *Ecological Economics*, 63: 616-626. DOI: 10.1016/j.ecolecon.2007.01.002.
- Brown G., Montag J.M. and Lyon K. (2012), “Public participation GIS: A method for identifying ecosystem services”, *Society & Natural Resources*, 25 (7): 633-651. DOI: 10.1080/08941920.2011.621511.
- Brown G., Reed P. and Raymond C.M. (2020), “Mapping place values: 10 lessons from two decades of public participation GIS empirical research”, *Applied Geography*, 116 (102156): 1-8. DOI: 10.1016/j.apgeog.2020.102156.
- Burkhard B., Kroll F., Müller F. and Windhorst W. (2009), “Landscapes’ capacities to provide ecosystem services. A concept for land-cover based assessments”, *Landscape Online*, 15: 1-22. DOI:10.3097/LO.200915.
- Camarda I., Laureti L., Angelini P., Capogrossi R., Carta L. and Brunu A. (2015), *Il Sistema Carta della Natura della Sardegna*. ISPRA, Serie Rapporti, 222/2015 [*The Nature map of Sardinia*. ISPRA, Report series, no. 225/2015], text available at the website: [https://www.isprambiente.gov.it/files/publicazioni/rapporti/R\\_222\\_15.pdf](https://www.isprambiente.gov.it/files/publicazioni/rapporti/R_222_15.pdf) [Accessed: 22 February 2022].
- Cangelosi R. and Goriely A. (2007), “Component retention in principal component analysis with application to cDNA microarray data”, *Biology Direct*, 2 (2): 1-21. DOI:10.1186/1745-6150-2-2.
- Cannas I., Lai S., Leone F. and Zoppi C. (2018), “Green infrastructure and ecological corridors: A regional study concerning Sardinia”, *Sustainability*, 10, 4 (1265): 1-21. DOI: 10.3390/su10041265.
- Cao W., Li R., Chi X., Chen N., Chen J., Zhang H. and Zhang F. (2017), “Island urbanization and its ecological consequences: A case study in the Zhoushan Island, East China”, *Ecological Indicators*, 76: 1-14. DOI: 10.1016/j.ecolind.2017.01.001.
- Cardinale B.J. (2011), “Biodiversity improves water quality through niche partitioning”, *Nature*, 472: 86-89. DOI: 10.1038/nature09904.
- Cardinale B.J., Duffy J.E., Gonzalez A., Hooper D.U., Perrings C., Venail P., Narwani A., Mace G.M., Tilman D., Wardle D.A., Kinzig A.P., Daily G.C., Loreau M., Grace J.B., Larigauderie A., Srivastava D.S. and Naeem S. (2012), “Biodiversity loss and its impact on humanity”, *Nature*, 486: 59-67. DOI: 10.1038/nature11148.
- Cattell R.B. (1966), “The scree test for the number of factors”, *Multivariate Behavioral Research*, 1(2): 245-276. DOI: 10.1207/s15327906mbr0102\_10.
- Chacko S., Ravichandran C., Vairavel S.M. and Mathew J. (2019), “Employing measurers of spatial distribution of carbon storage in Periyar Tiger Reserve, Southern Western Ghats, India”, *Journal of Geovisualization and Spatial Analysis*, 3, 1: 1-7. DOI: 10.1007/s41651-018-0024-8.

- Chaplin-Kramer R., Sharp R.P., Mandle L., Sim S., Johnson J., Butnar I., Milà i Canals L., Eichelberger B.A., Ramler I., Mueller C., McLachlan N., Yousefi A., King H. and Kareiva P.M. (2015), “Spatial impacts of agricultural expansion”, *Proceedings of the National Academy of Sciences*, 112 (24): 7402-7407. DOI: 10.1073/pnas.1406485112.
- Colavitti A.M., Floris A., Serra S. (2021), “Mind the gap: Why the landscape planning system in Sardinia does not work”, *Sustainability*, 13 (7300): 1-21. DOI: 10.3390/su13137300.
- Comitato Capitale Naturale (2021), *Quarto rapporto sullo stato del capitale naturale in Italia [Fourth Report on the State of the Natural Capital in Italy]*, text available at the website [https://www.minambiente.it/sites/default/files/archivio/allegati/CapitaleNaturale/IV\\_Rapporto\\_CN.pdf](https://www.minambiente.it/sites/default/files/archivio/allegati/CapitaleNaturale/IV_Rapporto_CN.pdf) [Accessed: 22 February 2022].
- Cortinovis C., Zulian G. and Geneletti D. (2018), “Assessing nature-based recreation to support urban green infrastructure planning in Trento (Italy)”, *Land*, 7, 4 (112): 1-20. DOI: 10.3390/land7040112.
- CRITERIA and TEMI (2014a), *Monitoraggio dello stato di conservazione degli habitat e delle specie di importanza comunitaria presenti nei siti della Rete Natura 2000 in Sardegna. Definizione della rete di monitoraggio. Volume 2: Piano di monitoraggio degli habitat e delle specie vegetali [Monitoring the conservation status of habitats and species of community interest within Natura 2000 sites in Sardinia. Defining a monitoring system. Volume 2: Monitoring plan for habitats and plant species]*. MIMEO.
- CRITERIA and TEMI (2014b), *Monitoraggio dello stato di conservazione degli habitat e delle specie di importanza comunitaria presenti nei siti della Rete Natura 2000 in Sardegna. Elaborazione rapporto di sintesi sullo stato di conservazione di habitat e specie (Linea 4, 4.c.1) [Monitoring the conservation status of habitats and species of community interest within Natura 2000 sites in Sardinia. Synthesis report on conservation status of habitats and species (Deliverable 4.c.1)]*. MIMEO.
- Csurgó B. and Smith M.K. (2021), “The value of cultural ecosystem services in a rural landscape context”, *Journal of Rural Studies*, 86: 76-89. DOI: 10.1016/j.jrurstud.2021.05.030.
- Cunha J., Elliott M. and Ramos S. (2018), “Linking modelling and empirical data to assess recreation services provided by coastal habitats: The case of NW Portugal”, *Ocean & Coastal Management*, 162: 60-70. DOI: 10.1016/j.ocecoaman.2017.12.022.
- Daniel T. C., Muhar A., Arnberger A., Aznar O., Boyd J.W., Chan K.M.A., Costanza R., Elmqvist T., Flint C.G., Gobster P.H., Grêt-Regamey A., Lave R., Muhar S., Penker M., Ribe R.G., Schauppenlehner T., Sikor T., Soloviy I., Spierenburg M., Taczanowska K., Tam J. and von der Dunk A. (2012), “Contributions of cultural services to the ecosystem services agenda”, *Proceedings of the National Academy of Sciences*, 109 (23): 8812-8819. DOI: 10.1073/pnas.1114773109.
- de Groot R.S., Alkemade R., Braat L., Hein L. and Willemen L. (2010), “Chal-

- lenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making”, *Ecological Complexity*, 7 (3): 260-272. DOI: 10.1016/j.ecocom.2009.10.006.
- 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. DOI: 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. DOI: 10.1080/09654313.2016.1178215.
- Delphin S., Escobedo F.J., Abd-Elrahman A. and Cropper W. (2013), “Mapping potential carbon and timber losses from hurricanes using a decision tree and ecosystem services driver model”, *Journal of Environmental Management*, 129: 599-607. DOI: 10.1016/j.jenvman.2013.08.029.
- Dhar R.B., Chakraborty S., Chattopadhyay R. and Sikdar P.K. (2019), “Impact of land-use/land-cover change on land surface temperature using satellite data: A case study of Rajarhat Block, North 24-Parganas District, West Bengal”, *Journal of the Indian Society of Remote Sensing*, 47: 331-348. DOI:10.1007/s12524-019-00939-1.
- Dixon R.K., Brown S., Houghton R.A., Solomon A.M., Trexler M.C. and Wisniewski J. (1994), “Carbon pools and flux of global forest ecosystems”, *Science*, 263 (5144): 185-190.
- Duarte G.T., Ribeiro M.C. and Paglia A.P. (2016), “Ecosystem services modeling as a tool for defining priority areas for conservation”, *PLoS ONE*, 11 (e0154573): 1-19. DOI: 10.1371/journal.pone.0154573.
- Dunford R.W., Smith A.C., Harrison P.A. and Hanganu D. (2015), “Ecosystem service provision in a changing Europe: adapting to the impacts of combined climate and socio-economic change”, *Landscape Ecology*, 30: 443-461. DOI: 10.1007/s10980-014-0148-2.
- Eagles P., McLean D. and Stabler M. (2000), “Estimating the tourism volume and value in protected areas in Canada and the USA”, *George Wright Forum*, 17: 62-76.
- Ebrahim A., Motamedvaziri B., Nazemosadat S.M.J. and Ahmadi H. (2022), “Investigating the land surface temperature reaction to the land cover patterns during three decades using Landsat data”, *International Journal of Environmental Science and Technology*, 19: 159-172. DOI: 10.1007/s13762-021-03294-2.
- Eliasson I., Knez I. and Fredholm S. (2018), “Heritage planning in practice and the role of cultural ecosystem services”, *Heritage & Society*, 11(1): 44-69. DOI: 10.1080/2159032X.2019.1576428.
- EPA (2021), *Overview of Greenhouse Gases*, text available at the website <https://www.epa.gov/ghgemissions/overview-greenhouse-gases> [Accessed: 22 February 2022].
- Estoque R.C., Murayama Y. and Myint S.W. (2017), “Effects of landscape composition and pattern on land surface temperature: An urban heat island study in the megacities of Southeast Asia”, *Science of the Total Environment*, 577: 349-359. DOI: 10.1016/j.scitotenv.2016.10.195.

- Estruch-Guitart V. and Vallés-Planells M. (2015), “The role of landscape aesthetics in the total economic value of landscape: a case study of Albufera Natural Park”, *WIT Transactions on Ecology and the Environment*, 192: 219-230. DOI:10.2495/ECO150201.
- European Commission (2011), *Commission Implementing Decision of 11 July 2011 concerning a site information format for Natura 2000 sites*, text available at the website <http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32011D0484> [Accessed: 22 February 2022].
- European Commission (2013), *Interpretation Manual of European Union Habitats - EUR28*, text available at the website [http://ec.europa.eu/environment/nature/legislation/habitatsdirective/docs/Int\\_Manual\\_EU28.pdf](http://ec.europa.eu/environment/nature/legislation/habitatsdirective/docs/Int_Manual_EU28.pdf) [Accessed: 22 February 2022].
- Eurostat (2019), *Agri-Environmental Indicator - Livestock Patterns*, text available at the website [https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agri-environmental\\_indicator\\_-\\_livestock\\_patterns](https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agri-environmental_indicator_-_livestock_patterns) [Accessed: 08 July 2021].
- Feizizadeh B., Blaschke T., Nazmfar H., Akbari E. and Kohbanani H.R. (2013), “Monitoring land surface temperature relationship to land use/land cover from satellite imagery in Maraqeh County”, *Journal of Environmental Planning and Management*, 56 (9): 1290-1315. DOI:10.1080/09640568.2012.717888.
- Fish R., Church A. and Winter M. (2016), “Conceptualising cultural ecosystem services: A novel framework for research and critical engagement”, *Ecosystem Services*, 21: 208-217. DOI: 10.1016/j.ecoser.2016.09.002.
- Fisher B. and Turner R.K. (2008), “Ecosystem services: classification for valuation”, *Biological Conservation*, 141: 1167-1169. DOI: 10.1016/j.biocon.2008.02.019.
- Fleming C.M. and Cook A. (2008), “The recreational value of Lake McKenzie, Fraser Island: An application of the travel cost method”, *Tourism Management*, 29 (6): 1197-1205. DOI: 10.1016/j.tourman.2008.02.022.
- Floris M. (2020), *I Servizi Ecosistemici nella Pianificazione Spaziale come Strumenti Interpretativi per la Definizione di Tassonomie Territoriali Innovative [Ecosystem Services within Spatial Planning as Knowledge-Interpreting Tools for the Definition of Innovative Spatial Taxonomies]*, unpublished doctoral thesis discussed at the University of Cagliari on 6 March 2020.
- Frank S., Fürst C., Koschke L., Witt A. and Makeschin F. (2013), “Assessment of landscape aesthetics. Validation of a landscape metrics-based assessment by visual estimation of the scenic beauty”, *Ecological Indicators*, 32: 222-231. DOI: 10.1016/j.ecolind.2013.03.026.
- Franzese P.P., Rydberg T., Russo G.F. and Ulgiati S. (2009), “Sustainable biomass production: A comparison between Gross Energy Requirement and Emery Synthesis methods”, *Ecological Indicators*, 9(5): 959-970. DOI: 10.1016/j.ecolind.2008.11.004.
- Fu B.-J., Su C.-H., Wei Y.-P., Willett I.R., Lü Y.-H. and Liu G.-H. (2011), “Double counting in ecosystem services valuation: causes and countermeasures”, *Ecological Research*, 26: 1-14. DOI: 10.1007/s11284-010-0766-3.

- Gan F., Du H., Wei Q. and Fan E. (2011), "Evaluation of the ecosystem values of aquatic wildlife reserves: A case of Chinese Sturgeon Natural Reserve in Yi-chang reaches of the Yangtze river", *Journal of Applied Ichthyology*, 27: 376-382. DOI: 10.1111/j.1439-0426.2010.01659.x.
- Gao Y., Ma L., Liu J., Zhuang Z., Huang Q. and Li M. (2017), "Constructing ecological networks based on habitat quality assessment: A case study of Changzhou, China", *Scientific Reports*, 7 (46073): 1-11. DOI: 10.1038/srep46073.
- Garcia-Martin M., Fagerholm N., Bieling C., Gounaridis D., Kizos T., Printsmann A., Müller M., Lieskovský J. and Plieninger, T. (2017), "Participatory mapping of landscape values in a pan-European perspective", *Landscape Ecology*, 32: 2133-2150. DOI: 10.1007/s10980-017-0531-x.
- Gee K. and Burkhard B. (2010), "Cultural ecosystem services in the context of offshore wind farming: A case study from the west coast of Schleswig-Holstein", *Ecological Complexity*, 7 (3): 349-358. DOI: 10.1016/j.ecocom.2010.02.008.
- Ghommeh M., Hajj M.R. and Puri I.K. (2012), "Influence of natural and anthropogenic carbon dioxide sequestration on global warming", *Ecological Modelling*, 235-236: 1-7. DOI: 10.1016/j.ecolmodel.2012.04.005.
- Grafius D.R., Corstanje R., Warren P.H., Evans K.L., Hancock S. and Harris J.A. (2016), "The impact of land use/land cover scale on modelling urban ecosystem services", *Landscape Ecology*, 31: 1509-1522. DOI: 10.1007/s10980-015-0337-7.
- Gries T., Redlin M. and Ugarte J.E. (2019), "Human-induced climate change: the impact of land-use change", *Theoretical and Applied Climatology*, 135: 1031-1044. DOI: 10.1007/s00704-018-2422-8.
- Grzyb T., Kulczyk S., Derek M. and Woźniak E. (2021), "Using social media to assess recreation across urban green spaces in times of abrupt change", *Ecosystem Services*, 49 (101297): 1-13. DOI: 10.1016/j.ecoser.2021.101297.
- Guerry A.D., Ruckelshaus M.H., Arkema K.K., Bernhardt J.R., Guannel G., Kim C.-K., Marsik M., Papenfus M., Toft J.E., Verutes G., Wood S.A., Beck M., Chan F., Chan K.M.A., Gelfenbaum G., Gold B.D., Halpern B.S., Labiosa W.B., Lester S.E., Levin P.S., McField M., Pinsky M.L., Plummer M., Polasky S., Ruggiero P., Sutherland D.A., Tallis H., Day A. and Spencer J. (2012), "Modeling benefits from nature: using ecosystem services to inform coastal and marine spatial planning," *International Journal of Biodiversity Science, Ecosystem Services & Management*, 8 (1-2): 107-121. DOI: 10.1080/21513732.2011.647835.
- Hall L.S., Krausman P.R. and Morrison M.L. (1997), "The habitat concept and a plea for standard terminology", *Wildlife Society Bulletin*, 25 (1): 173-182.
- Han Y., Kang W. and Song Y. (2018), "Mapping and quantifying variations in ecosystem services of urban green spaces: A test case of carbon sequestration at the district scale for Seoul, Korea (1975-2015)", *International Review for Spatial Planning and Sustainable Development*, 6 (3): 110-120. DOI: 10.14246/irspsd.6.3\_110.
- Hausmann A., Toivonen T., Slotow R., Tenkanen H., Moilanen A., Heikinheimo V. and Di Minin E. (2017), "Social media data can be used to understand tour-



- ists' preferences for nature-based experiences in protected areas", *Conservation Letters*, 10, 1 (e12343): 1-10. DOI: 10.1111/conl.12343.
- He C., Zhang D., Huang Q. and Zhao Y. (2016), "Assessing the potential impacts of urban expansion on regional carbon storage by linking the LUSD-urban and InVEST models", *Environmental Modelling & Software*, 75: 44-58. DOI: 10.1016/j.envsoft.2015.09.015.
- Hector A. and Bagchi R. (2007), "Biodiversity and ecosystem multifunctionality", *Nature*, 448: 188-190. DOI: 10.1038/nature05947.
- Hofierka J., Gallay M., Onačillová and K., Hofierka J.Jr. (2020), "Physically-based land surface temperature modeling in urban areas using a 3-D city model and multispectral satellite data", *Urban Climate*, 31 (100566): 1-16. DOI: 10.1016/j.uclim.2019.100566.
- Hølleland H., Skrede J. and Holmgaard S.B. (2017), "Cultural heritage and ecosystem services: A literature review", *Conservation and Management of Archaeological Sites*, 19 (3): 210-237. DOI: 10.1080/13505033.2017.1342069.
- Hooper D.U., Chapin F.S. III, Ewel J.J., Hector A., Inchausti P., Lavorel S., Lawton J.H., Lodge D.M., Loreau M., Naeem S., Schmid B., Setälä H., Symstad A.J., Vandermeer J. and Wardle D.A. (2005), "Effects of biodiversity on ecosystem functioning: a consensus of current knowledge", *Ecological Monographs*, 75: 3-35. DOI:10.1890/04-0922.
- Huang C.-H. and Wang C.-H. (2015), "Estimating the total economic value of cultivated flower land in Taiwan", *Sustainability*, 7 (4): 4764-4782. DOI: 10.3390/su7044764.
- Hulley G.C., Ghent D., Götttsche F.M., Guillevic P.C., Mildrexler D.J., Coll and Land C. (2019), *Land surface temperature*, in Hulley G.C. and Ghent D., eds., *Taking the Temperature of the Earth Steps Towards Integrated Understanding of Variability and Change*, Elsevier, Amsterdam, The Netherlands, pp. 57-127.
- Ihtimanski I., Nedkov S. and Semerdzhieva L. (2020), "Mapping the natural heritage as a source of recreation services at national scale in Bulgaria", *One Ecosystem*, 5 (e54621): 1-23. DOI: 10.3897/oneeco.5.e54621.
- IPCC (2013), *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, United Kingdom and New York, NY, United States.
- Isbell F., Calcagno V., Hector A., Connolly J., Harpole W.S., Reich P.B., Scherer-Lorenzen M., Schmid B., Tilman D., van Ruijven J., Weigelt A., Wilsey B.J., Zavaleta E.S. and Loreau M. (2011), "High plant diversity is needed to maintain ecosystem services", *Nature*, 477: 199-202. DOI: 10.1038/nature10282.
- ISPRA (2013), *Tabella delle corrispondenze in uso nel Sistema Carta della Natura [Correspondence table for codes used within the Nature map system]*, text available at the website: [http://www.isprambiente.gov.it/files/biodiversita/Tabella\\_Corrispondenze\\_181213.xls](http://www.isprambiente.gov.it/files/biodiversita/Tabella_Corrispondenze_181213.xls) [Accessed: 22 February 2022].
- ISTAT (1958), *Circoscrizioni statistiche. Metodi e norme [Statistical Districts. Methods and Rules]*, text available at the website

- [https://ebiblio.istat.it/digibib/Metodi%20e%20norme/SBL0493189MeN\\_Serie\\_C1\\_Circoscrizioni\\_statistiche.pdf](https://ebiblio.istat.it/digibib/Metodi%20e%20norme/SBL0493189MeN_Serie_C1_Circoscrizioni_statistiche.pdf) [Accessed: 22 February 2022].
- Jackson D.A. (1993), "Stopping rules in principal components analysis: A comparison of heuristical and statistical approaches", *Ecology*, 74: 2204-2214. DOI: 10.2307/1939574.
- Jim C.Y. and Chen W.Y. (2006), "Perception and attitude of residents toward urban green spaces in Guangzhou (China)", *Environmental Management*, 38: 338-349. DOI: 10.1007/s00267-005-0166-6.
- Jobbagy E.G. and Jackson R.B. (2000), "The vertical distribution of soil organic carbon and its relation to climate and vegetation", *Ecological Applications*, 10: 423-436. DOI: 10.1890/1051-0761(2000)010[0423:TVDOS0]2.0.CO;2.
- Jobstvogt N., Watson V. and Kenter J.O. (2014), "Looking below the surface: The cultural ecosystem service values of UK marine protected areas (MPAs)", *Ecosystem Services*, 10: 97-110. DOI: 10.1016/j.ecoser.2014.09.006.
- Kambale J.B. and Tripathi V.K. (2010), "Biotic and abiotic processes as a carbon sequestration strategy", *Journal of Environmental Research and Development*, 5 (1): 240-251.
- Kenter J.O. (2014), *Deliberative and non-monetary valuation: A review of methods*. Laurence Mee Centre for People and the Sea, Working Papers 2014-02.
- Kothencz G., Kolcsár R., Cabrera-Barona P. and Szilassi P. (2017), "Urban green space perception and its contribution to well-being", *International Journal of Environmental Research and Public Health*, 14, 7 (766): 1-14. DOI:10.3390/ijerph14070766.
- Kovacs K., Polasky S., Nelson E., Keeler B.L., Pennington D., Plantinga A. and Taff S.J. (2013), "Evaluating the return in ecosystem services from investment in public land acquisitions", *PLoS ONE*, 8, 6 (e62202): 1-17. DOI: 10.1371/journal.pone.0062202.
- Kumar P., ed. (2011), *The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations*, Routledge, New York, NY, United States.
- La Notte A., Vallecillo S., Polce C., Zulian G. and Maes J. (2017), *Implementing an EU system of accounting for ecosystems and their services. Initial proposals for the implementation of ecosystem services accounts*, JRC Technical Report EUR 28681 EN. Publications Office of the European Union, Luxembourg. DOI: 10.2760/214137.
- Lackner K.S. (2003), "A guide to CO<sub>2</sub> sequestration", *Science*, 300 (5626): 1677-1678. DOI: 10.1126/science.1079033.
- Lahiji R.N., Dinan N.M., Liaghati H., Ghaffarzadeh H. and Vafaeinejad A. (2020), "Scenario-based estimation of catchment carbon storage: linking multi-objective land allocation with InVEST model in a mixed agriculture-forest landscape", *Frontiers of Earth Science*, 14: 637-646. DOI: 10.1007/s11707-020-0825-1.
- Lai S., Leone F. and Zoppi C. (2020a), "Spatial distribution of surface temperature and land cover: A study concerning Sardinia, Italy", *Sustainability*, 12, 8 (3186): 1-20. DOI: 10.3390/su12083186.
- Lai S., Leone F. and Zoppi C. (2020b), "Land Surface Temperature and land cover

- dynamics. A study related to Sardinia, Italy”, *TeMA. Journal of Land Use, Mobility and Environment*, 13 (3): 329-351. DOI: 10.6092/1970-9870/7143.
- Lal R. (2008), “Carbon sequestration”, *Philosophical Transactions of the Royal Society B*, 363: 815-830. DOI:10.1098/rstb.2007.2185.
- Landry C.E., Bergstrom J., Salazar J. and Turner D. (2021), “How has the COVID-19 pandemic affected outdoor recreation in the U.S.? A revealed preference approach”, *Applied Economics Perspectives and Policy*, 43: 443-457. DOI: 10.1002/aapp.13119.
- Langemeyer J., Calcagni F. and Baró F. (2018), “Mapping the intangible: Using geolocated social media data to examine landscape aesthetics”, *Land Use Policy*, 77: 542-552. DOI: 10.1016/j.landusepol.2018.05.049
- Lankia T., Kopperoinen L., Pouta E. and Neuvonen M. (2015), “Valuing recreational ecosystem service flow in Finland”, *Journal of Outdoor Recreation and Tourism*, 10: 14-28. DOI: 10.1016/j.jort.2015.04.006.
- Larson S., Stoeckl N., Neil B. and Welters R. (2013), “Using resident perceptions of values associated with the Australian Tropical Rivers to identify policy and management priorities”, *Ecological Economics*, 94: 9-18. DOI: 10.1016/j.ecolecon.2013.07.005.
- Leh M.D.K., Matlock M.D., Cummings E.C. and Nalley L.L. (2013), “Quantifying and mapping multiple ecosystem services change in West Africa”, *Agriculture, Ecosystems & Environment*, 165: 6-18. DOI: 10.1016/j.agee.2012.12.001.
- Lesser I.A. and Nienhuis C.P. (2020), “The Impact of COVID-19 on physical activity behavior and well-being of Canadians”, *International Journal of Environmental Research and Public Health*, 17, 11 (3899): 1-12. DOI: 10.3390/ijerph17113899.
- Lewica M. (2008), “Place attachment, place identity, and place memory: Restoring the forgotten city past”, *Journal of Environmental Psychology*, 28 (3): 209-231. DOI: 10.1016/j.jenvp.2008.02.001.
- Li X.X., Koh T.Y., Panda J. and Norford L.K. (2016), “Impact of urbanization patterns on the local climate of a tropical city, Singapore: An ensemble study”, *Journal of Geophysical Research: Atmospheres*, 121: 4386-4440. DOI:10.1002/2015JD024452.
- Li Z., Cheng X. and Han H. (2020), “Analyzing land-use change scenarios for ecosystem services and their trade-offs in the ecological conservation area in Beijing, China”, *International Journal of Environmental Research and Public Health*, 17, 22 (8632): 1-20. DOI: 10.3390/ijerph17228632.
- Li Z.-L., Tang B.-H., Wu H., Ren H., Yan G., Wan Z., Trigo I.F. and Sobrino J.A. (2013a), “Satellite-derived land surface temperature: Current status and perspectives”, *Remote Sensing of Environment*, 131:14-37. DOI: 10.1016/j.rse.2012.12.008.
- Li Z.-L., Wu H., Wang N., Qiu S., Sobrino J.A., Wan Z., Tang B.-H. and Yan G. (2013b), “Land surface emissivity retrieval from satellite data”, *International Journal of Remote Sensing*, 34 (9-10): 3084-3127. DOI: 10.1080/01431161.2012.716540.
- Lin Y.-P., Lin W.-C., Wang Y.-C., Lien W.-Y., Huang T., Hsu C.-C., Schmeller

- D.S. and Crossman N.D. (2017), “Systematically designating conservation areas for protecting habitat quality and multiple ecosystem services”, *Environmental Modelling & Software*, 90: 126-146. DOI: 10.1016/j.envsoft.2017.01.003.
- Liquete C., Cid N., Lanzasova D., Grizzetti B. and Reynaud A. (2016a), “Perspectives on the link between ecosystem services and biodiversity: The assessment of the nursery function”, *Ecological Indicators*, 63: 249-257. DOI: 10.1016/j.ecolind.2015.11.058.
- Liquete C., Piroddi C., Macías D., Druon J.-N. and Zulian G. (2016b), “Ecosystem services sustainability in the Mediterranean Sea: assessment of status and trends using multiple modelling approaches”, *Scientific Reports*, 6 (34162): 1-14. DOI: 10.1038/srep34162.
- Loreau M., Naeem S., Inchausti P., Bengtsson J., Grime J.P., Hector A., Hooper D.U., Huston M.A., Raffaelli D., Schmid B., Tilman D. and Wardle D.A. (2001), “Biodiversity and ecosystem functioning: Current knowledge and future challenges”, *Science*, 294 (5543): 804-808. DOI: 10.1126/science.1064088.
- Lv Z. and Zhou Q. (2011), “Utility of Landsat image in the study of land cover and land surface temperature change”, *Procedia Environmental Sciences*, 10: 1287-1292. DOI: 10.1016/j.proenv.2011.09.206.
- Ma S. and Swinton S.M. (2011), “Valuation of ecosystem services from rural landscapes using agricultural land prices”, *Ecological Economics*, 70(9): 1649-1659. DOI: 10.1016/j.ecolecon.2011.04.004.
- Maes J., Teller A., Erhard M., Liquete C., Braat L., Berry P., Egoh B., Puydarrieux P., Fiorina C., Santos F., Paracchini M.L., Keune H., Wittmer H., Hauck J., Fiala I., Verburg P.H., Condé S., Schägner J.P., San Miguel J., Estreguil C., Ostermann O., Barredo J.I., Pereira H.M., Stott A., Laporte V., Meiner A., Olah B., Royo Gelabert E., Spyropoulou R., Petersen J.E., Maguire C., Zal N., Achilleos E., Rubin A., Ledoux L., Brown C., Raes C., Jacobs S., Vandewalle M., Connor D., Bidoglio G. (2013), *Mapping and Assessment of Ecosystems and Their Services. An Analytical Framework for Ecosystem Assessments under Action 5 of the EU Biodiversity Strategy to 2020*. Publications Office of the European Union, Luxembourg. DOI: 10.2779/12398.
- Malhi Y., Roberts J.T., Betts R.A., Killeen T.J., Li W. and Nobre C.A. (2008), “Climate change, deforestation, and the fate of the Amazon”, *Science*, 319 (5860): 169-172. DOI: 10.1126/science.1146961.
- Martín-López B., Gómez-Baggethun E., Lomas P.L. and Montes C. (2009), “Effects of spatial and temporal scales on cultural services valuation”, *Journal of Environmental Management*, 90: 1050-1059. DOI: 10.1016/j.jenvman.2008.03.013.
- Maseyk F.J., Mackay A.D., Possingham H.P., Dominati E.J. and Buckley Y.M. (2017), “Managing natural capital stocks for the provision of ecosystem services”, *Conservation Letters*, 10: 211-220. DOI: 10.1111/conl.12242.
- Mayer M. and Woltering M. (2018), “Assessing and valuing the recreational ecosystem services of Germany’s national parks using travel cost models”, *Ecosystem Services*, 31: 371-386. DOI: 10.1016/j.ecoser.2017.12.009.

- Milcu A.I., Hanspach J., Abson D. and Fischer J. (2013), “Cultural ecosystem services: a literature review and prospects for future research”, *Ecology and Society*, 18, 3 (44): 1-34. DOI: 10.5751/ES-05790-180344.
- Millennium Ecosystem Assessment (2003), *Ecosystems and Human Well-Being: A Framework for Assessment*, Island Press, Washington DC, United States.
- Millennium Ecosystem Assessment (2005a), *Ecosystems and Human Well-Being: Our Human Planet*, Island Press, Washington DC, United States.
- Millennium Ecosystem Assessment (2005b), *Ecosystems and Human Well-being: Current State and Trends*, Island Press, Washington DC, United States.
- Moss D., Davies C. and Roy D. (1995), *CORINE Biotopes Sites - Database Status and Perspectives*, European Environment Agency, Copenhagen, Denmark.
- Mouttaki I., Khomalli Y., Maanan M., Bagdanavičiūtė I., Rhinane H., Kuriqi A., Pham Q.B. and Maanan M. (2021), “A new approach to mapping cultural ecosystem services”, *Environments*, 8, 6 (56): 1-14. DOI:10.3390/environments8060056.
- Müller F. (2005), “Indicating ecosystem and landscape organization”, *Ecological Indicators*, 5: 280-294. DOI: 10.1016/j.ecolind.2005.03.017.
- Munafò M., Assennato F., Bottinelli F., Di Legginio M., Finocchiaro G., Fumanti F., Galosi A., Marinosci I., Pranzo S., Soraci M., Strollo A., De Toni A., Sallustio L. and Marchetti M. (2014), *Valutazione e quantificazione dei benefici ecosistemici resi dal suolo [Assessment and Quantification of the Ecosystem Benefits Provided by Soil]*. Technical report of the project SAM4CP (LIFE ENV/IT/001218), Action B1, text available at the website [http://www.sam4cp.eu/wp-content/uploads/2014/11/report\\_sintesi\\_B1.pdf](http://www.sam4cp.eu/wp-content/uploads/2014/11/report_sintesi_B1.pdf) [Accessed: 22 February 2022].
- Ndossi M.I. and Avdan U. (2016), “Application of open source coding technologies in the production of Land Surface Temperature (LST) maps from Landsat: A PyQGIS Plugin”, *Remote Sensing*, 8 (413): 1-31. DOI: 10.3390/rs8050413.
- Neinavaz E., Skidmore A.K. and Darvishzadeh R. (2020), “Effects of prediction accuracy of the proportion of vegetation cover on land surface emissivity and temperature using the NDVI threshold method”, *International Journal of Applied Earth Observation and Geoinformation*, 85 (101984): 1-13. DOI: 10.1016/j.jag.2019.101984.
- Nelson E., Mendoza G., Regetz J., Polasky S., Tallis H., Cameron D., Chan K.M., Daily G.C., Goldstein J., Kareiva P.M., Lonsdorf E., Naidoo R., Ricketts T.H. and Shaw M. (2009), “Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales”, *Frontiers in Ecology and the Environment*, 7: 4-11. DOI: 10.1890/080023.
- Nelson E., Sander H., Hawthorne P., Conte M., Ennaanay D., Wolny S., Manson S. and Polasky S. (2010), “Projecting global land-use change and its effect on ecosystem service provision and biodiversity with simple models”, *PLoS ONE*, 5, 12 (e14327): 1-12. DOI: 10.1371/journal.pone.0014327.
- Newsome D. (2020), “The collapse of tourism and its impact on wildlife tourism destinations”, *Journal of Tourism Futures*, 7 (3): 295-302. DOI: 10.1108/JTF-04-2020-0053.

- Nielsen A.B., Olsen S.B. and Lundhede T. (2007), “An economic valuation of the recreational benefits associated with nature-based forest management practices”, *Landscape and Urban Planning*, 80 (1-2): 63-71. DOI: 10.1016/j.landurbplan.2006.06.003.
- Nolè L., Pilogallo A., Saganeiti L., Scorza F., Santos L. and Murgante B. (2020), *Habitat Degradation: A Comparative Study between Tomar (PT) and Potenza (IT)*, in Gervasi O., Murgante B., Misra S., Garau C., Blečić I., Taniar D., Apduhan B.O., Rocha A.M.A.C., Tarantino E., Torre C.M. and Karaca Y., eds., *21<sup>st</sup> International Conference on Computational Science and Its Applications (ICCSA 2021)*, Lecture Notes in Computer Science, Vol. no. 12253. Springer, Cham, Switzerland, pp. 645-654. DOI: 10.1007/978-3-030-58814-4\_51.
- Orchard-Webb J., Kenter J.O., Bryce R. and Church A. (2016), “Deliberative democratic monetary valuation to implement the ecosystem approach”, *Ecosystem Services*, 21: 308-318. DOI: 10.1016/j.ecoser.2016.09.005.
- Oteros-Rozas E., Martín-López B., Fagerholm N., Bieling C. and Plieninger T. (2018), “Using social media photos to explore the relation between cultural ecosystem services and landscape features across five European sites”, *Ecological Indicators*, 94 (2): 74-86. DOI: 10.1016/j.ecolind.2017.02.009.
- Pal S. and Ziaul S. (2017), “Detection of land use and land cover change and land surface temperature in English Bazar urban centre”, *Egyptian Journal of Remote Sensing and Space Science*, 20 (1): 125-145. DOI: 10.1016/j.ejrs.2016.11.003.
- Paracchini M.L. and Capitani C. (2011), *Implementation of a EU Wide Indicator for the Rural-Agrarian Landscape*. Publications Office of the European Union, Luxembourg.
- Paracchini M.L., Zulian G., Kopperoinen L., Maes J., Schägner J.P., Termansen M., Zandersen M., Perez-Soba M., Scholefield P.A. and Bidoglio G. (2014), “Mapping cultural ecosystem services: A framework to assess the potential for outdoor recreation across the EU”, *Ecological Indicators*, 45: 371-385. DOI: 10.1016/j.ecolind.2014.04.018.
- Pascal N., Brathwaite A., Brander L., Seidl A., Philip M. and Clua E. (2018), “Evidence of economic benefits for public investment in MPAs”, *Ecosystem Services*, 30: 3-13. DOI: 10.1016/j.ecoser.2017.10.017.
- Pearce D. (2007), “Do we really care about biodiversity?”, *Environmental and Resource Economics*, 37: 313-333. DOI:10.1007/s10640-007-9118-3.
- Peres-Neto P.R., Jackson D.A. and Somers K.M. (2005), “How many principal components? Stopping rules for determining the number of non-trivial axes revisited”, *Computational Statistics & Data Analysis*, 49(4): 974-997. DOI: 10.1016/j.csda.2004.06.015.
- Petrokofsky G., Kanamaru H., Achard F., Goetz S.J., Joosten H., Holmgren P., Lehtonen A., Menton M.C.S., Pullin A.S. and Wattenbach M. (2012), “Comparison of methods for measuring and assessing carbon stocks and carbon stock changes in terrestrial carbon pools. How do the accuracy and precision of current methods compare? A systematic review protocol”, *Environmental Evidence*, 1 (6): 1-21. DOI:10.1186/2047-2382-1-6.

- Pilogallo A., Saganeiti L., Scorza F. and Murgante B. (2019), “Ecosystem services’ based impact assessment for low carbon transition processes”, *TeMA. Journal of Land Use, Mobility and Environment*, 12: 127-138. DOI: 10.6092/1970-9870/6117.
- Pilogallo A., Scorza F. (2021), *Regulation and Maintenance Ecosystem Services (ReMES): A Spatial Assessment in the Basilicata Region (Southern Italy)*, in Gervasi O., Murgante B., Misra S., Garau C., Blečić I., Taniar D., Apduhan B.O., Rocha A.M.A.C., Tarantino E. and Torre C.M., eds., *21<sup>st</sup> International Conference on Computational Science and Its Applications (ICCSA 2021)*, Lecture Notes in Computer Science, Vol. no. 12955, Springer, Cham, Switzerland, pp. 703-716. DOI: 10.1007/978-3-030-87007-2\_50.
- Piyathilake I.D.U.H., Udayakumara E.P.N., Ranaweera L.V. and Gunatilake K. (2021), “Modeling predictive assessment of carbon storage using InVEST model in Uva province, Sri Lanka”, *Modeling Earth Systems and Environment*, ahead-of-print. DOI: 10.1007/s40808-021-01207-3.
- Plieninger T., Dijks S., Oteros-Rozas E. and Bieling, C. (2013), “Assessing, mapping, and quantifying cultural ecosystem services at community level”, *Land Use Policy*, 33: 118-129. DOI: 10.1016/j.landusepol.2012.12.013.
- Polasky S., Nelson E., Pennington D. and Johnson K.A. (2011), “The impact of land-use change on ecosystem services, biodiversity and returns to landowners: A case study in the state of Minnesota”, *Environmental and Resource Economics*, 48, 2: 219-242. DOI: 10.1007/s10640-010-9407-0.
- Ponce-Hernandez R. (2004), *Assessing Carbon Stocks and Modelling Win-Win Scenarios of Carbon Sequestration through Land-Use Changes*, Food and Agriculture Organization of the United Nations, Rome, Italy.
- Power A.G. (2010), “Ecosystem services and agriculture: tradeoffs and synergies”, *Philosophical Transactions of the Royal Society B - Biological Sciences*, 365: 2959-2971. DOI: 10.1098/rstb.2010.0143.
- Quattrochi D.A. and Luvall, J.C. (1999), “Thermal infrared remote sensing for analysis of landscape ecological processes: methods and applications”, *Landscape Ecology*, 14: 577-598. DOI: 10.1023/A:1008168910634.
- Queiroz C., Meacham M., Richter K., Norström A.V., Andersson E., Norberg J. and Peterson G. (2015), “Mapping bundles of ecosystem services reveals distinct types of multifunctionality within a Swedish landscape”, *AMBIO*, 44: 89-101. DOI: 10.1007/s13280-014-0601-0.
- Rajbanshi J. and Das S. (2021), “Changes in carbon stocks and its economic valuation under a changing land use pattern. A multitemporal study in Konar catchment, India”, *Land Degradation & Development*, 32 (13): 3573-3587. DOI: 10.1002/ldr.3959.
- Raudsepp-Hearne C., Peterson G.D. and Bennett E.M. (2010), “Ecosystem service bundles for analyzing tradeoffs in diverse landscapes”, *Proceedings of the National Academy of Sciences*, 107 (11): 5242-5247. DOI: 10.1073/pnas.0907284107.
- Raymond C.M., Bryan B.A., MacDonald D.D., Cast A., Strathearn S., Grandgirard A. and Kalivas T. (2009), “Mapping community values for natural capital and

- ecosystem services”, *Ecological Economics*, 68 (5): 1301-1315. DOI: 10.1016/j.ecolecon.2008.12.006.
- Reyers B., Polasky S., Tallis H., Mooney H.A. and Larigauderie A. (2012), “Finding common ground for biodiversity and ecosystem services”, *BioScience*, 62 (5): 503-507. DOI: 10.1525/bio.2012.62.5.12.
- Rice W.L., Mateer T.J., Reigner N., Newman P., Lawhon B. and Taff B.D. (2020), “Changes in recreational behaviors of outdoor enthusiasts during the COVID-19 pandemic: analysis across urban and rural communities”, *Journal of Urban Ecology*, 6, 1 (juaa020): 1-7. DOI: 10.1093/jue/juaa020.
- Richards D.R. and Friess D.A. (2015), “A rapid indicator of cultural ecosystem service usage at a fine spatial scale: Content analysis of social media photographs”, *Ecological Indicators*, 53: 187-195. DOI: 10.1016/j.ecolind.2015.01.034.
- Rosenberger R.S., Needham M.D., Morzillo A.T. and Moehrke C. (2012), “Attitudes, willingness to pay, and stated values for recreation use fees at an urban proximate forest”, *Journal of Forest Economics*, 18 (4): 271-281. DOI: 10.1016/j.jfe.2012.06.003.
- Ryfield F., Cabana D., Brannigan J. and Crowe T. (2019), “Conceptualizing ‘sense of place’ in cultural ecosystem services: A framework for interdisciplinary research”, *Ecosystem Services*, 36 (100907): 1-13. DOI: 10.1016/j.ecoser.2019.100907.
- Saganeiti L., Pilogallo A., Faruolo G., Scorza F. and Murgante B. (2020), “Territorial fragmentation and renewable energy source plants: Which relationship?”, *Sustainability*, 12, 5 (1828): 1-14. DOI: 10.3390/su12051828.
- Salata S., Ronchi S., Arcidiacono A., Ghirardelli F. (2017), “Mapping habitat quality in the Lombardy Region, Italy”, *One Ecosystem*, 2 (e11402): 1-9. DOI: 10.3897/oneeco.2.e11402.
- Sallustio L., De Toni A., Strollo A., Di Febraro M., Gissi E., Casella L., Geneletti D., Munafò M., Vizzarri M. and Marchetti M. (2017), “Assessing habitat quality in relation to the spatial distribution of protected areas in Italy”, *Journal of Environmental Management*, 201: 129-137. DOI: 10.1016/j.jenvman.2017.06.031.
- Sander H.A. and Haight R.G. (2012), “Estimating the economic value of cultural ecosystem services in an urbanizing area using hedonic pricing”, *Journal of Environmental Management*, 113: 194-205. DOI: 10.1016/j.jenvman.2012.08.031.
- Sayão V.M., dos Santos N.V., de Sousa Mendes W., Marques K.P.P., Safanelli J.L., Poppiel R.R. and Demattê J. A.M. (2020), “Land use/land cover changes and bare soil surface temperature monitoring in southeast Brazil”, *Geoderma Regional*, 22 (e00313): 1-13. DOI: 10.1016/j.geodrs.2020.e00313.
- Schaich H., Bieling C. and Plieninger T. (2010), “Linking ecosystem services with cultural landscape research”, *GAIA - Ecological Perspectives for Science and Society*, 19 (4): 269-277. DOI: 10.14512/gaia.19.4.9.
- Schiavina M., Freire S. and MacManus K. (2019), *GHS population grid multitemporal (1975-1990-2000-2015)*, R2019A. European Commission, Joint Research Centre (JRC). DOI: 10.2905/0C6B9751-A71F-4062-830B-43C9F432370F.



- Schirpke U., Scolozzi R. and De Marco C. (2015), *Applicazione del modello dimostrativo di valutazione qualitativa e quantitativa dei servizi ecosistemici nei siti pilota. Parte I: Quantificazione dei servizi ecosistemici [Implementation of the Demonstrative Model for Qualitative and Quantitative Assessment of Ecosystem Services in Pilot Areas]*. Report of the project Making Good Natura (LIFE+11 ENV/IT/000168)], text available at the website [http://www.lifemgn-serviziecosistemici.eu/IT/Documents/doc\\_mgn/LIFE+MGN\\_Report\\_B4-9.pdf](http://www.lifemgn-serviziecosistemici.eu/IT/Documents/doc_mgn/LIFE+MGN_Report_B4-9.pdf) [Accessed: 22 February 2022].
- Schirpke U., Marino D., Marucci A., Palmieri P. and Scolozzi R. (2017), “Operationalising ecosystem services for effective management of protected areas: Experiences and challenges”, *Ecosystem Services*, 28: 105-114. DOI: 10.1016/j.ecoser.2017.10.009.
- Schirpke U., Ebner M., Pritsch H., Fontana V. and Kurmayer R. (2021), “Quantifying ecosystem services of high mountain lakes across different socio-ecological contexts”, *Sustainability*, 13, 11 (6051): 1-22. DOI: 10.3390/su13116051.
- Scholte S.S.K., van Teeffelen A.J.A. and Verburg P.H. (2015), “Integrating socio-cultural perspectives into ecosystem service valuation: A review of concepts and methods”, *Ecological Economics*, 114: 67-78. DOI: 10.1016/j.ecolecon.2015.03.007.
- Schröter M., Kraemer R., Remme R.P. and van Oudenhoven A.P.E. (2020), “Distant regions underpin interregional flows of cultural ecosystem services provided by birds and mammals”, *Ambio*, 49: 1100-1113. DOI: 10.1007/s13280-019-01261-3.
- Scorza F., Pilogallo A., Saganeiti L. and Murgante B. (2020a), “Natura 2000 areas and Sites of National Interest (SNI): Measuring (un)integration between naturalness preservation and environmental remediation policies”, *Sustainability*, 12, 7 (2928): 1-16. DOI: 10.3390/su12072928.
- Scorza F., Pilogallo A., Saganeiti L., Murgante B. and Pontrandolfi P. (2020b), “Comparing the territorial performances of renewable energy sources' plants with an integrated ecosystem services loss assessment: A case study from the Basilicata region (Italy)”, *Sustainable Cities and Society*, 56 (102082): 1-17. DOI: 10.1016/j.scs.2020.102082.
- Serkan G. and Rehber E. (2008), “A travel cost study to estimate recreational value for a bird refuge at Lake Manyas, Turkey”, *Journal of Environmental Management*, 88: 1350-1360. DOI: 10.1016/j.jenvman.2007.07.017.
- Sherrouse B.C., Clement J.M. and Semmens D.J. (2011), “A GIS application for assessing, mapping, and quantifying the social values of ecosystem services”, *Applied Geography*, 31(2): 748-760. DOI: 10.1016/j.apgeog.2010.08.002.
- Siikamäki P., Kangas K., Paasivaara A. and Schroderus S. (2015), “Biodiversity attracts visitors to national parks”, *Biodiversity and Conservation*, 24: 2521-2534. DOI: 10.1007/s10531-015-0941-5.
- Smith P. (2012), “Soils and climate change”, *Current Opinion in Environmental Sustainability*, 4 (5): 539-544. DOI: 10.1016/j.cosust.2012.06.005.
- Smith P., Soussana J.-F., Angers D., Schipper L., Chenu C., Rasse D.P., Batjes N.H., van Egmond F., McNeill S., Kuhnert M., Arias-Navarro C., Olesen J.E.,

- Chirinda N., Fornara D., Wollenberg E., Álvaro-Fuentes J., Sanz-Cobena A. and Klumpp K. (2020), “How to measure, report and verify soil carbon change to realize the potential of soil carbon sequestration for atmospheric greenhouse gas removal”, *Global Change Biology*, 26: 219-241. DOI: 10.1111/gcb.14815.
- Sonter L.J., Watson K.B., Wood, S.A. and Ricketts T.H. (2016), “Spatial and temporal dynamics and value of nature-based recreation, estimated via social media”, *PLoS ONE*, 11, 9 (e0162372): 1-16. DOI: 10.1371/journal.pone.0162372.
- Spencer L.H., Lynch M., Lawrence C.L. and Edwards R.T. (2020), “A scoping review of how income affects accessing local green space to engage in outdoor physical activity to improve well-being: Implications for Post-COVID-19”, *International Journal of Environmental Research and Public Health*, 17, 24 (9313): 1-15. DOI: 10.3390/ijerph17249313.
- Stewart W.P., Liebert D. and Larkin K.W. (2004), “Community identities as visions for landscape change”, *Landscape and Urban Planning*, 69 (2-3): 315-334. DOI: 10.1016/j.landurbplan.2003.07.005.
- Suárez M., Barton D.N., Cimbuova Z., Rusch G.M., Gómez-Baggethun E. and Onaindia M. (2020), “Environmental justice and outdoor recreation opportunities: A spatially explicit assessment in Oslo metropolitan area, Norway”, *Environmental Science & Policy*, 108: 133-143. DOI: 10.1016/j.envsci.2020.03.014.
- Sun X., Crittenden J.C., Li F., Lu Z. and Dou X., “Urban expansion simulation and the spatio-temporal changes of ecosystem services, a case study in Atlanta Metropolitan area, USA”, *Science of the Total Environment*, 622-623: 974-987. DOI: 10.1016/j.scitotenv.2017.12.062.
- Swetnam R.D., Harrison-Curran S.K. and Smith G.R. (2017), “Quantifying visual landscape quality in rural Wales: A GIS-enabled method for extensive monitoring of a valued cultural ecosystem service”, *Ecosystem Services*, 26, 451-464. DOI: 10.1016/j.ecoser.2016.11.004.
- Templeton A.J., Goonan K. and Fyall A. (2021), “COVID-19 and its impact on visitation and management at US national parks”, *International Hospitality Review*, 35(2): 240-259. DOI: 10.1108/IHR-08-2020-0039.
- Tengberg A., Fredholm S., Eliasson I., Knez I., Saltzman K. and Wetterberg O. (2012), “Cultural ecosystem services provided by landscapes: Assessment of heritage values and identity”, *Ecosystem Services*, 2: 14-26. DOI: 10.1016/j.ecoser.2012.07.006.
- Terrado M., Sabater S., Chaplin-Kramer B., Mandle L., Ziv G. and Acuña V. (2016), “Model development for the assessment of terrestrial and aquatic habitat quality in conservation planning”, *Science of the Total Environment*, 540: 63-70. DOI: 10.1016/j.scitotenv.2015.03.064.
- Townshend J.R.G., Goff T.E. and Tucker C.J. (1985), “Multitemporal dimensionality of images of normalized difference vegetation index at continental scales”, *IEEE Transactions on Geoscience and Remote Sensing*, GE-23 (6): 888-895. DOI:10.1109/TGRS.1985.289474.
- Turner K.G., Odgaard M.V., Bøcher P.K., Dalgaard T. and Svenning J.-C. (2014), “Bundling ecosystem services in Denmark: Trade-offs and synergies in a cul-

- tural landscape”, *Landscape and Urban Planning*, 125: 89-104. DOI: 10.1016/j.landurbplan.2014.02.007.
- Turner R.K., Morse-Jones S. and Fisher B. (2010), “Ecosystem valuation”, *Annals of the New York Academy of Sciences*, 1185: 79-101. DOI: 10.1111/j.1749-6632.2009.05280.x.
- Ugolini F., Massetti L., Pearlmutter D. and Sanesi G. (2021), “Usage of urban green space and related feelings of deprivation during the COVID-19 lockdown: Lessons learned from an Italian case study”, *Land Use Policy*, 105 (105437): 1-11. DOI: 10.1016/j.landusepol.2021.105437.
- USGS (2021), *Using the USGS Landsat Level-1 Data Product*, text available at the website <https://www.usgs.gov/land-resources/nli/landsat/using-usgs-landsat-level-1-data-product> [Accessed: 08 July 2021].
- Vallecillo S., La Notte A., Polce C., Zulian G., Alexandris N., Ferrini S. and Maes J. (2018), *Ecosystem services accounting: Part I - Outdoor recreation and crop pollination*, EUR 29024 EN. Publications Office of the European Union, Luxembourg. DOI:10.2760/619793.
- Vallecillo S., La Notte A., Zulian G., Ferrini S. and Maes J. (2019a), “Ecosystem services accounts: Valuing the actual flow of nature-based recreation from ecosystems to people”, *Ecological Modelling*, 392: 196-211. DOI: 10.1016/j.ecolmodel.2018.09.023.
- Vallecillo S., La Notte A., Kakoulaki G., Kamberaj J., Robert N., Dottori F., Feyer L., Rega C. and Maes J. (2019b), *Ecosystem Services Accounting. Part II-Pilot Accounts for Crop and Timber Provision, Global Climate Regulation and Flood Control*. EUR 29731 EN. Publications Office of the European Union, Luxembourg.
- van Berkel D.B. and Verburg P.H. (2014), “Spatial quantification and valuation of cultural ecosystem services in an agricultural landscape”, *Ecological Indicators*, 37: 163-174. DOI: 10.1016/j.ecolind.2012.06.025.
- van de Griend A.A. and Owe M. (1993), “On the relationship between thermal emissivity and the normalized different vegetation index for natural surfaces”, *International Journal of Remote Sensing*, 14 (6): 1119-1131. DOI: 10.1080/01431169308904400.
- Venter Z.S., Barton D.N., Gundersen V., Figari H. and Nowell M.S. (2021), “Back to nature: Norwegians sustain increased recreational use of urban green space months after the COVID-19 outbreak”, *Landscape and Urban Planning*, 214 (104175): 1-10. DOI: 10.1016/j.landurbplan.2021.104175.
- Vieira F.A.S., Bragagnolo C., Correia R.A., Malhado A.C.M. and Ladle R.J. (2018), “A salience index for integrating multiple user perspectives in cultural ecosystem service assessments”, *Ecosystem Services*, 32: 182-192. DOI: 10.1016/j.ecoser.2018.07.009.
- Vieira da Silva C., Ortigão M., Willaert Y., Rosa R., Catela Nunes L. and Cunha-e-Sá M.A. (2021), “Participatory Geographic Information Systems (PGIS): Alternative approaches to identify potential conflicts and positional accuracy in marine and coastal ecosystem services”, *Marine Policy*, 131 (104650): 1-13. DOI: 10.1016/j.marpol.2021.104650.

- Voigt A., Kabisch N., Wurster D., Haase D. and Breuste J. (2014), “Structural diversity: A multi-dimensional approach to assess recreational services in urban parks”, *AMBIO*, 43: 480-491. DOI: 10.1007/s13280-014-0508-9.
- Wallace K.J. (2007), “Classification of ecosystem services: problems and solutions”, *Biological Conservation*, 139 (3-4): 235-246. DOI: 10.1016/j.biocon.2007.07.015.
- Walter R.K. and Hamilton R.J. (2014), “A cultural landscape approach to community-based conservation in Solomon Islands”, *Ecology and Society*, 19, 4 (41): 1-10. DOI: 10.5751/ES-06646-190441.
- Walz U. and Stein C. (2018), “Indicator for a monitoring of Germany’s landscape attractiveness”, *Ecological Indicators*, 94 (2): 64-73. DOI: 10.1016/j.ecolind.2017.06.052.
- Wang C., Li Y., Myint S.W., Zhao Q. and Wentz E.A. (2019), “Impacts of spatial clustering of urban land cover on land surface temperature across Köppen climate zones in the contiguous United States”. *Landscape and Urban Planning*, 192 (103668): 1-11. DOI: 10.1016/j.landurbplan.2019.103668.
- Weng Q. (2009), “Thermal infrared remote sensing for urban climate and environmental studies: Methods, applications, and trends”, *ISPRS Journal of Photogrammetry and Remote Sensing*, 64 (4): 335-344. DOI: 10.1016/j.isprsjprs.2009.03.007.
- Weng Q., Lu D. and Schubring J. (2004), “Estimation of land surface temperature-vegetation abundance relationship for urban heat island studies”, *Remote Sensing of Environment*, 89 (4): 467-483. DOI: 10.1016/j.rse.2003.11.005.
- Wood S.A., Guerry A.D., Silver J.M. and Lacayo M. (2013), “Using social media to quantify nature-based tourism and recreation”, *Scientific Reports*, 3 (2976): 1-7. DOI: 10.1038/srep02976.
- Yang S., Zhao W., Liu Y., Wang S., Wang J. and Zhai R. (2018), “Influence of land use change on the ecosystem service trade-offs in the ecological restoration area: Dynamics and scenarios in the Yanhe watershed, China”, *Science of the Total Environment*, 644: 556-566. DOI: 10.1016/j.scitotenv.2018.06.348.
- Yang W., Chang J., Xu B., Peng C. and Ge Y. (2018), “Ecosystem service value assessment for constructed wetlands: A case study in Hangzhou, China”, *Ecological Economics*, 68 (1-2): 116-125. DOI: 10.1016/j.ecolecon.2008.02.008.
- Yuan F. and Bauer M.E. (2007), “Comparison of impervious surface area and normalized difference vegetation index as indicators of surface urban heat island effects in Landsat imagery”, *Remote Sensing of Environment*, 106 (3): 375-386. DOI: 10.1016/j.rse.2006.09.003.
- Zhang J., Wang Y. and Li Y. (2006), “A C++ Program for retrieving land surface temperature from the data of Landsat TM/ETM+ band6”, *Computers & Geosciences*, 32 (10): 1796-1805. DOI: 10.1016/j.cageo.2006.05.001.
- Zhang W., Ricketts T.H., Kremen C., Carney C. and Swinton S.M. (2007), “Ecosystem services and dis-services to agriculture”, *Ecological Economics*, 64(2): 253-260. DOI: 10.1016/j.ecolecon.2007.02.024.
- Zhang X., Estoque R.C., Murayama Y. (2017), “An urban heat island study in

- Nanchang City, China based on land surface temperature and social-ecological variables”, *Sustainable Cities and Society*, 32: 557-568. DOI: 10.1016/j.scs.2017.05.005.
- Zhao C., Jensen J., Weng Q. and Weaver R. (2018), “A geographically weighted regression analysis of the underlying factors related to the surface urban heat island phenomenon”, *Remote Sensing*, 10, 9 (1428): 1-18. DOI:10.3390/rs10091428.
- Zoderer B.M., Tasser E., Erb K.-H., Lupo Stanghellini P.S. and Tappeiner U. (2016), “Identifying and mapping the tourists’ perception of cultural ecosystem services: A case study from an Alpine region”, *Land Use Policy*, 56: 251-261. DOI: 10.1016/j.landusepol.2016.05.004.
- Zoppi C. and Lai S. (2010), “Assessment of the Regional Landscape Plan of Sardinia (Italy): A participatory-action-research case study type”, *Land Use Policy*, 27 (3): 690-705. DOI: 10.1016/j.landusepol.2009.09.004.
- Zulian G., Paracchini M.L., Maes J. and Lique C. (2013), *ESTIMAP: Ecosystem services mapping at European scale*. JRC (European Commission - Joint Research Centre - Institute for Environment and Sustainability) Technical Report EUR 26474 ENG. Publications Office of the European Union, Luxembourg. DOI: 10.2788/6436.
- Zulian G., Polce C. and Maes J. (2014), “ESTIMAP: A GIS-based model to map ecosystem services in the European Union”, *Annali di Botanica*, 4: 1-7. DOI: 10.4462/annbotm-11807.
- Zulian G., Stange E., Woods H., Carvalho L., Dick J., Andrews C., Baró F., Vizcaino P., Barton D.N., Nowel M., Rusch G.M., Autunes P., Fernandes J., Ferraz D., dos Santos R.F., Aszalós R., Arany I., Czúcz B., Priess J.A., Hoyer C., Bürger-Patricio G., Lapola D., Mederly P., Halabuk A., Bezak P., Kopperoinen L. and Viinikka A. (2018), “Practical application of spatial ecosystem service models to aid decision support”, *Ecosystem Services*, 29: 465-480. DOI: 10.1016/j.ecoser.2017.11.005.

### *3. Mapping of ecological corridors as connections between protected areas: a study concerning Sardinia, Italy*

An important set of ES provided by GI consists of habitats and species protection and improvement, which coincides with biodiversity conservation and enhancement. The EU Biodiversity Strategy for 2030 recommends that Member States «[E]nsure no deterioration in conservation trends and status of all protected habitats and species by 2030. In addition, Member States will have to ensure that at least 30% of species and habitats not currently in favourable status are in that category or show a strong positive trend» (European Commission, 2020, pp. 6-7). From this perspective, one of the most outstanding features of GI is its attitude towards addressing the negative impacts of habitat fragmentation on the supply of ES related to biodiversity by strengthening the effectiveness of connections between protected areas.

Building on a methodological approach defined in previous studies by Cannas, published in a set of articles between 2017 and 2018 (Cannas and Zoppi, 2017a; 2017b; Cannas *et al.*, 2018a; 2018b), this chapter identifies ecological corridors (EC) with reference to the spatial layout of a set of protected areas. Moreover, such methodological approach is implemented into the context of the Sardinian region to map EC, which form, together with protected areas, a network representing the spatial framework of a regional GI. Finally, the relation between the EC and the spatial taxonomy of the landscape components featured by environmental relevance (LCFER), identified by the Regional Landscape Plan (RLP) is analyzed, in order to assess if, and to what extent, the present regional spatial zoning code can be used as a basis to implement regulations aimed at protecting EC.

### 3.1. Introduction

The EC are important spatial structures aimed at improving the effectiveness of ecological networks by supporting their connection capacity as for migration of wild species, their spatial layout and their potential in terms of genetic exchange. EC connection capacity can manifest through minimizing impacts on wild species and genetic flows coming from pressures generated by human activities, such as agriculture and forestry, air and water pollution, gray infrastructure and urban expansion. These threats could cause negative environmental effects as a consequence of the break-up of ecosystem matrices (D'Ambrogi *et al.*, 2015).

The conceptual category of connectivity expresses more precisely than that of connection the capacity of connecting ES, since it includes environmental and landscape aspects, such as the spatial position, the physical continuity, and the presence, type and dimension of natural and anthropic structures, and functional and ecological features, such as the functional perception of species, their ecological and behavioral needs, and their specialization characteristics as well (Battisti, 2004; D'Ambrogi *et al.*, 2013; 2015). This is in line with Baudry and Merriam (1988) who claim that flows of species across ecological networks are often correlated to the connectivity of spatial, mostly linear, elements, which can be defined as EC.

As per the operational definition of GI given by the European Commission, spatial connectivity concerning the provision of ES is strictly related to the conceptual category of ecological network, since a GI can be considered as «[A] strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ESs. It incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas. On land, GI is present in rural and urban settings» (European Commission, 2013, p. 3), and, «The work done over the last 25 years to establish and consolidate the network means that the backbone of the EU's GI is already in place. It is a reservoir of biodiversity that can be drawn upon to repopulate and revitalize degraded environments and catalyze the development of GI. This will also help reduce the fragmentation of the ecosystems, improving the connectivity between sites in the Natura 2000 network and thus achieving the objectives of Article 10 of the Habitats Directive» (European Commission, 2013, p. 7). This implies that GI and ES are strictly related to each other, and that public policies should prioritize ecological networks in terms of environmental protection and enhancement (Liquete *et al.*, 2015). As a consequence, regional and urban planning processes should adequately man-

age, improve and monitor the effectiveness of GI as ecological network which provides ES and the spatial connectivity of such systems.

This also entails that GI are particularly important as regards restoration of biodiversity, decrease of ecosystem fragmentation and increase of their capacity of providing ES (Directorate-General Environment, European Commission, 2012). That being so, an operational management goal concerning GI can be identified as its role in promoting and improving ES provision and habitat restoration (EEA, 2014; Liqueste *et al.*, 2015).

In the second section, the study area is described with reference to the protected areas which are assumed as the nodes of the spatial layout of the Sardinian ecological network, and the methodology adopted to identify EC is presented. Moreover, the methodological approach used to analyze the spatial relationship between EC and the LCFER, identified by the RLP, is described as well.

Section 3 shows the results concerning the identification of Sardinian EC and the assessment of the relation between EC and the LCFER. whereas the implications of the chapter in terms of planning policy recommendations, its limitations and future research perspectives are presented in the fifth chapter of this volume.

## **3.2. Materials and methods**

This section is organized as follows. The first subsection describes the study area and the set of protected areas which are identified as the nodes of the Sardinian regional ecological network. This subsection was written by Lai and reproduced from a previous article by Lai *et al.* (2017). The following subsection presents the methodological approach implemented to identify the EC, which is based on studies by Cannas published in a set of articles between 2017 and 2018 (Cannas and Zoppi, 2017a; 2017b; Cannas *et al.*, 2018a; 2018b). Finally, the third subsection discusses the regression model used to assess the relation between EC and the LCFER, identified by the RLP.

### *3.2.1. Spatial identification of the ecological corridors*

The concept of landscape connectivity was introduced by Taylor *et al.* (1993) as a relevant measure of the landscape structure in line with the theory developed by Dunning *et al.* (1992). According to Taylor *et al.* (1993), landscape connectivity is defined as the «degree to which the landscape fa-



cilitates or impedes movement among resource patches» (p. 571). According to With *et al.* (1997), landscape connectivity concerns «the functional relationship among habitat patches, owing to the spatial contagion of habitat and the movement responses of organisms to landscape structure» (p. 151).

In particular, the second definition reflects the dual nature of connectivity, which entails a structural and a functional dimension (structural connectivity, functional connectivity). Structural connectivity is environmentally oriented, while functional connectivity is species-oriented (Issii *et al.*, 2020). In this chapter, the second dimension of connectivity is considered and used. In a nutshell, functional connectivity concerns the movement capacity of species as a function of their intrinsic mobility and of spatial patches suitability to facilitate species movement (Tischendorf and Fahrig, 2000; Taylor *et al.*, 1993).

The concept of landscape connectivity as a means to counter landscape fragmentation has been increasingly embedded into environmental policies, e.g., through technical categories such as greenways, GI and EC, in order to address the problem of biodiversity loss (Balbi *et al.*, 2019; Simberloff *et al.*, 1992). The concept of EC is treated in the literature with reference to different scientific and technical profiles (among many, Saunders and Hobbs, 1991; Rosenberg *et al.*, 1995; Hess and Fischer, 2001). According to Hess and Fisher (2001), the use of the term “corridor” is associated to two important theories of conservation biology, i.e., island biogeography (MacArthur and Wilson, 1967) and metapopulations (Levins, 1969), which focus on functional connectivity.

Functional connectivity is often analyzed through resistance-based models, where resistance «represents the willingness of an organism to cross a particular environment, the physiological cost of moving through a particular environment, the reduction in survival for the organism moving through a particular environment, or an integration of all these factors» (Zeller *et al.*, 2012, p. 778). Resistance-based models are widely described and discussed in the literature. The most complex models, such as the circuit theory-based (McRae *et al.*, 2008) and the individual-based models (Palmer *et al.*, 2011), are difficult to implement due to the overwhelming quantity of input data, and to the needed accuracy in data collection and computational power (Balbi *et al.*, 2019). On the other hand, least-cost path (LCP) models are increasingly used to identify EC (Wu *et al.*, 2021; Guo *et al.*, 2020).

LCP models detect spatially identified pathways, which connect habitat patches, characterized by the minimum resistance to species movement, or by the highest probability of movement to take place. LCP models postu-

late that organisms have an in-depth knowledge of the landscape that leads them to follow the optimal route (Balbi *et al.*, 2019).

According to Sawyer *et al.* (2011), the attractiveness of this typology of models reflects three important points. First, LCP models make it possible to quantitatively compare potential movement paths within large areas. Secondly, complex effects of habitats on species movement can be integrated into these models. Finally, LCP models go beyond the limits of analyses based exclusively on structural connectivity by incorporating the species' perception of the surrounding environment. LCP models are particularly effective as regards computational efficiency, model implementation ease, and flexibility related to the inclusion of different environmental profiles and aspects in the model structure (Adriaensen *et al.*, 2003; Coulon *et al.*, 2015; Wu *et al.*, 2021). LCP models often integrate experts' judgments into spatial datasets in order to identify resistance values of areal units (Sawyer *et al.*, 2011; Osborn and Parker, 2003; Kong *et al.*, 2010; Larkin *et al.*, 2004).

Building on a methodology developed by Cannas (Cannas and Zoppi, 2017a; 2017b; Cannas *et al.*, 2018a; 2018b), the spatial taxonomy of connectivity is identified on the basis of an LCP model, through four phases, as follows:

- definition of a habitat-suitability map;
- definition of an ecological-integrity map;
- definition of a resistance map;
- spatial identification of EC.

The first phase aims at defining a habitat-suitability map, where habitat suitability is defined as the probability of habitat use by species. The elaboration of this map is based on the Sardinian land cover vector map and on a study concerning species-specific values of habitat suitability. Land covers are classed according to the Sardinian land cover vector map produced by the Regional Administration of Sardinia in 2008, at the third level of the CORINE<sup>1</sup> Land Cover (CLC) nomenclature<sup>2</sup>. Moreover, species-specific values of habitat suitability are identified on the basis of a study by AGRISTUDIO *et al.* (2011), commissioned by the Regional Administration of Sardinia, concerning the conservation status of species and habitats of community interest within the Sardinian N2S. The study provides habi-

<sup>1</sup> CORINE is the acronym of COoRdination de l'INformation sur l'Environnement [Coordination of the information concerning the environment].

<sup>2</sup> A complete description of the CORINE Programme is available at the website <https://www.eea.europa.eu/publications/COR0-landcover> [Accessed: 22 February 2022].

tat-suitability species-specific values, on an ordinal scale between 0 and 3 (0: non-suitable; 3: extremely suitable), for each CLC class of the Sardinian land cover map in relation to each Sardinian N2S. The evaluation is based on experts' judgments. A habitat-suitability map is elaborated on the basis of two assumptions. First, the habitat suitability species-specific values, associated to land cover classes located in the N2S by the AGRISTUDIO *et al.*'s (2011) study, are associated to the same land cover classes of areas outside the N2S as well. Secondly, the total value of the species-specific habitat suitability associated to each land cover class is equal to the average value of the single species-specific values associated to the land cover class. Finally, a habitat-suitability vector map is defined, which identifies a taxonomy concerning the entire regional area.

The second phase aims at defining an ecological-integrity map, which builds on studies developed by Burkhard *et al.* (2009; 2012), where an assessment of land cover classes' capacities to provide ES is implemented through experts' judgments, on the basis of the founding concept that the higher the ecological integrity, the higher the suitability to species' transition and movement. Ecological integrity concerns supporting ES defined as ES which help to maintain and enhance the supply of the other types of ES, namely provisioning, regulating and cultural ES. The ecological-integrity index is equal to the sum of the scores associated to seven ES supply indicators (abiotic heterogeneity, biodiversity, biotic waterflows, metabolic efficiency, exergy capture, reduction of nutrient loss and storage capacity) that represent supporting ES in relation to each of the 44 third-level land cover classes of the CLC taxonomy. As a result, by mapping the values of the ecological-integrity index, an ecological-integrity vector map is obtained for the entire regional area.

The third phase aims at defining the resistance map by means of the habitat-suitability and ecological-integrity maps, building on a study by LaRue and Nielsen (2008). First, the two vector maps are converted into raster maps; secondly, two maps are defined by mapping the inverse of the sum of the habitat suitability and of the ecological-integrity index; thirdly the new raster maps are scaled, on an ordinal scale between 1 and 100 (1: the lowest resistance; 100: the highest resistance), according to a study by the European Environment Agency (2014). Finally, the values of the two re-scaled raster maps are summed-up and mapped on a patch-by-patch basis. The resulting spatial taxonomy is the resistance map.

The fourth phase aims at spatially identifying EC that connect the Sardinian NPA through the use of the Linkage Pathways Tool (LPT) of the GIS Linkage Mapper (LM) Toolbox. LPT implements the LCP approach by identifying the Cost-Weighted Distance (CWD) (McRae and Kavanagh,

2017). The LCP laying between two core areas is identified by the path which shows the minimum CWD. Input data required by the LPT are a vector map of core areas and a raster resistance map. In this study, each core area is identified either by a single NPA, in case the overlapping of multiple NPA does not occur, or by the spatial envelope of overlapping NPA, whereas phases 1 thru 3 identify the resistance map.

The CWD of a path between two core areas is obtained by: i. averaging the resistance values of pairs of adjacent patches; ii. multiplying such average values times the geometric distance of the patches' centers (Shirabe, 2018); and, iii. summing-up the results of item ii. along the path.

The relevant outputs offered by LPT are the linear developments of the EC and the raster map of the CWD values. Fig. 2 shows the implementation of the LPT processing process.

LPT proceeds as follows, in order to identify the LCP between two core areas A and B.

First, the normalized distance related to each patch  $i$  connecting A and B,  $ND_{iAB}$ , is calculated, as follows:

$$ND_{iAB} = CWD_{iA} + CWD_{iB} - LCWD_{AB} \quad (1),$$

where:  $ND_{iAB}$  is the normalized distance between A and B measured along a path which includes patch  $i$ ;  $CWD_{iA}$  and  $CWD_{iB}$  are the cost-weighted distances from patch  $i$  to core areas A and B; and,  $LCWD_{AB}$  is the least CWD, i.e. the CWD measured along the LCP connecting A and B (McRae and Kavanagh, 2017).

Secondly, the LCP, i.e., the EC, connecting A and B, is identified by the spatial sequence of patches  $j$ 's which show  $ND_{jAB} = 0$ .

### 3.2.2. *Study area*<sup>3</sup>

Our case study is related to the Sardinian regional context. Sardinia is the second largest Italian island, located in Western Mediterranean, with an area of around 24,000 km<sup>2</sup>. Sardinia is part of the European Mediterra-

<sup>3</sup> This subsection builds on Lai S., Leone F. and Zoppi C. (2017), "Anthropization processes and protection of the environment: An assessment of land cover changes in Sardinia, Italy", *Sustainability*, 9, 12 (2174): 1-19. DOI: 10.3390/su9122174, Subsection 3.1. Study Area and Protection Levels, pp. 3-4 (written by Sabrina Lai).

nean biogeographical region (European Commission, 2016; Council of Europe - Directorate of Culture and Cultural and Natural Heritage, 2010).

Two regimes of environmental protection are identified by the Italian legislation, that is, natural protected areas (NPAs) and Natura 2000 Sites (N2Ss). Sardinian NPAs and N2Ss are shown in Figure 1.

N2Ss are managed by the national government, whereas the regional governments rule over the regional NPAs.

Four regional natural parks are established under the provisions of Regional Laws nos. 1999/4, 1999/5, 2014/20 and 2014/21 respectively, that is, Porto Conte, Molentargius-Saline, Gutturu Mannu and Tepilora.

Moreover, our study includes, among the regional NPAs, public woods, permanent oases of faunal protection and Ramsar sites. Public woods, managed by the Regional Agency of Forests, are characterized by significant environmental and landscape values, whose conservation and enhancement is important in order to address and mitigate negative impacts caused by natural disasters, such as fires, floods and landslides. Regional Law no. 1998/23 identifies the permanent oases of faunal protection. Nine Sardinian sites are protected under the provisions of the Ramsar Convention, signed in 1971.

As regards the N2Ss, the Natura 2000 Network includes areas designated under the provisions of Directive no. 92/43/EEC (the Habitats Directive) and of Directive no. 2009/147/EC (the Birds Directive), and encompasses more than 27,000 sites, representing the backbone of the European Union's policies on protection of nature and biodiversity (Directorate-General Environment, European Commission, 2016). N2Ss include the following: sites of community interest (SCIs) and special areas of conservation (SACs), established under the Habitats Directive, and special protection areas (SPAs), established under the Birds Directive. SPAs are designated by the European Union member states in relation to a number of scientific criteria, in order to provide bird protection. As regards SCIs and SACs, the designation process develops from Member States' proposals addressed to the European Commission who is responsible for their establishment. SCIs can become SACs within six years since their establishment, provided that conservation measures are identified. Sardinian N2Ss are classified as follows: 31 SPAs, 87 SACs and 10 SCIs<sup>4</sup>.

<sup>4</sup> Data available at the website <https://www.eea.europa.eu/data-and-maps/data/natura-13/natura-2000-spatial-data/natura-2000-shapefile-1> [Accessed: 22 February 2022].

### 3.2.3. Relation between EC and landscape components

The LCFER represent a spatial taxonomy of the regional land aimed at defining differentiated levels of protection depending on the value of nature and natural resources. This taxonomy was defined in the RLP approved by the Deliberation of the Sardinian Regional Government no. 36/7 of September 5, 2006, and implemented a protection regime which did not take account of ecological corridors, whereas their importance was recognized by art. 10 of the Habitats and Birds Directives, according to which EC make the Natura 2000 Network internally connected from the functional and ecological points of view. As a consequence, EC can be considered areal structures connecting habitats to enhance and support biodiversity, and, in so doing, increasing the ES provision (Cannas *et al.*, 2018a; 2018b).

Thus, the implementation of EC protection into the Sardinian spatial planning framework, established under the provisions of the RLP code, has to be developed by identifying EC as areas with the highest protection level among the LCFER.

The spatial layout of EC connecting core areas is defined by the raster map of CWD values clustered into ten deciles, whose second's upper limit is assumed as the threshold for the inclusion of a patch in an EC (Cannas and Zoppi, 2017a). The CWD of a patch  $j$ , included in an EC connecting the core areas A and B, is calculated as follows:

$$CWD_j = CWD_{jA} + CWD_{jB} \quad (2),$$

where  $CWD_{jA}$  and  $CWD_{jB}$  are the cost-weighted distances from patch  $j$  to core areas A and B.

The assessment of the relations between EC and LCFER is implemented through a linear regression model which relates the eligibility of a patch to be included in an EC and the areas of the LCFER overlaid by the corridors.

The LCFER classed by the RLP implementation code (IC)<sup>5</sup> are the following<sup>6</sup>:

- natural and subnatural areas, which include: scrub vegetation in dry areas and wetlands (areas covered with sparse vegetation, between 5% and 40%; riparian areas covered with non-arboreal vegetation; Mediterranean

<sup>5</sup> The text of the RLP IC is available at the website [http://www.regione.sardegna.it/documenti/1\\_22\\_20060911101100.pdf](http://www.regione.sardegna.it/documenti/1_22_20060911101100.pdf) [Accessed: 22 February 2022].

<sup>6</sup> Information drawn from the “Legenda Piano Paesaggistico Regionale” [Caption Regional Landscape Plan], available at the website [http://www.sardegna.territorio.it/documenti/6\\_83\\_20061006113400.pdf](http://www.sardegna.territorio.it/documenti/6_83_20061006113400.pdf) [Accessed: 22 February 2022].

an scrub; river beds larger than 25 meters; inland marshes; salt marshes; rock faces); and, woodlands (mixed coniferous and broadleaf woods; broadleaf woods);

- seminatural areas, which include: grasslands (steady meadows; natural pastures; thickets and shrublands; garrigues; natural recolonization areas); and, cork and chestnut woods;
- areas dedicated to agriculture and forestry, which include: specialized and tree crops (vineyards; orchards; temporary olive- and vineyard-related crops; temporary crops related to other permanent crops); artificial woods (coniferous woods; poplar, willow and eucalypt woods; other trees for timber; arboriculture with coniferous forest trees; artificial recolonization areas); and, specialized herbaceous crops, agricultural and forest areas, and uncultivated areas (non-irrigated arable land; artificial meadows; simple arable land and full-field horticultural crops; paddies; breeding grounds; greenhouse crops; complex parcel cropping systems; areas characterized by prevailing agricultural crops and residual important natural land; uncultivated areas).

According to the RLP IC, the protection regime concerning natural and subnatural areas forbids whichever spatial transformation, including new buildings or land use modifications, which is likely to undermine the ecosystem structure, steadiness and functionality, or the landscape enjoyment potential. As for dunal and retrodunal habitats featured by non-arboreal vegetation or Mediterranean scrub, vehicle and pedestrian access and temporary installations are not allowed if they may put at risk natural resources conservation. Moreover, the RLP IC forbids the implementation of spatial transformations which may cause water pollution or landfill as regards wetlands. Finally, afforestation is not allowed if potentially harmful to priority habitats designed by the Habitats and Birds Directives, with the exception of conservation operations.

As for seminatural areas, the RLP IC states that whichever spatial transformation, including new buildings or land use modifications, which is likely to undermine the ecosystem structure, steadiness and functionality, or the landscape enjoyment potential, is not allowed, with the exception of operations aimed at improving the ecosystems structure and functioning, the conservation status of biotic and abiotic natural resources, and at mitigating environmental hazard and degradation of natural resources. In woodlands, land use modifications are forbidden except land use changes related to the development of new faunistic or floristic populations and to the enhancement of the habitats of protected wildlife. Moreover, new facilities are not permitted, whereas restoration of existing buildings is allowed provided that they will be used to improve the conditions of nature and natural

resources, and that the operations do not entail an increase in building volume, floor area and covered surface.

New infrastructure, such as roads, power lines, hydraulic pipelines, etc., which may alter the forest land cover or increase fire or pollution hazards are not allowed in seminatural areas, with the exception of operations aimed at forest management and soil protection. Furthermore, the RLP IC forbids new roads, power lines and wind turbines close to wetlands and to areas characterized by the presence of species of community interest, especially with reference to birdlife, or which may generate negative impacts on the landscape perception. River systems and riparian areas have to be protected from soil-sealing operations, afforestation implemented by using alien species and removal of sand and sediments from the river beds.

As for dunal systems and sandy seashores, vehicle traffic is strictly forbidden, and sand and sediment removal is not allowed as well. Finally, a general rule concerning seminatural areas concerns a ban on the use of alien species for afforestation, reforestation, and renaturation.

With reference to areas dedicated to agriculture and forestry, and uncultivated areas, the RLP IC forbids transitions from agriculture and forestry to other land uses, with the exception of changes motivated by reasons related to the implementation of relevant public utilities for which it is demonstrated that no other location is presently available. Limited land use transitions are allowed to make more effective infrastructure, facilities and machinery exclusively devoted to agriculture or forestry. Moreover, the biodiversity improvement as regards native species of agrarian interest, the conservation of local traditional agricultural systems and the protection of typical rural scenery are indicated as important addresses, stated as planning rules as per art. 29 of the RLP IC, in particular with reference to peri-urban zones and historic terrace farming areas.

All in all, the RLP IC identifies rules concerning natural, subnatural and seminatural areas which are almost entirely consistent with a nature protection regime aimed at strengthening the effectiveness of EC. The main regulatory feature of the RLP IC with respect to these areas is the general objective of protecting the structure and functionality of ecosystems, biodiversity, nature and natural resources, with particular attention to habitats and species identified by the Habitats and the Birds Directives, dunal and coastal environments, and wetlands as main sources of biodiversity, especially as regards birdlife. In woodlands, modifications of land use are not allowed, except for improvement of wildlife habitats and increase in faunistic and floristic populations. Rules concerning agriculture and forestry are less restrictive, since land use transitions are allowed if they aim at improving farm and forest productivity, even though protection of traditional prac-



tices, scenery and biodiversity protection with reference to rural landscapes and environments are targeted as important planning policy goals.

The relation between EC and the LCFER described so far is analyzed through a multiple linear regression model which assesses the correlations between CWD and the areas of the LCFER which overlay EC. The model takes the following form:

$$ECWD = \beta_0 + \beta_1SCRB + \beta_2WOOD + \beta_3GRAS + \beta_4CCHW + \beta_5SPTC + \beta_6ARWO + \beta_7HAFU + \beta_8ALTD, \quad (3)$$

where dependent and explanatory variables identify the areal dimensions of EC and of the overlays of EC and the LCFER:

- ECWD is the CWD of a patch included in an EC;
- SCRB is for scrub vegetation in dry areas and wetlands;
- WOOD is for woodlands;
- GRAS is for grasslands;
- CCHW is for cork and chestnut woods;
- SPTC is for specialized and tree crops;
- ARWO is for artificial woods;
- HAFU is for specialized herbaceous crops, agricultural and forest areas, and uncultivated areas;
- ALTD is a control variable which represents the average altitude in an EC.

The outcomes of the regression model identify the quantitative correlations between the linear dimension of EC, ECWD, and the presence of LCFER.

As per many studies related to correlations between spatial variables, a regression model is used since no prior hypothesis seems to be plausible as regards the effect of covariates on the dependent variable (among many: Cheshire and Sheppard, 1995; Stewart and Libby, 1998; Sklenicka *et al.*, 2013; Zoppi *et al.*, 2015).

Thus, a surface, characterized by an unknown equation, representing a spatial phenomenon featured by  $n$  factors, is approximated, in an infinitesimal neighborhood of one of its points, by its tangential hyperplane. The infinitesimal area shared by the hyperplane and the surface, is identified by the known equation of the tangential hyperplane, that is, by the linear relation between the covariates. Such linear relation locally approximates the unknown surface. That being so, multiple regression model (3) estimates the trace of an eight-dimensional hyperplane on an eight-dimensional surface whose equation is unknown (Bera and Byron, 1983; Wolman and

Couper, 2003), which shows the linear correlations between ECWD and the eight dependent variables defined above.

The variable ALTD is utilized as a control variable to check the effect of the altitude of an EC on its areal dimension; so, if the estimate of the coefficient  $\beta_8$  were significant, this would imply that the altitude is likely to cause a relevant impact on ECWD. The sign of the estimated coefficient indicates if the impact is positive or negative, i.e., if the greater the altitude, the lower ECWD, or the other way around.

Finally, a 5% p-value significance test is used with reference to the estimated coefficients of model (3) to see if their estimates are significantly different than zero.

### 3.3. Results

This section is organized as follows. The first subsection presents the spatial layout of the EC identified through the implementation of the methodology described in subsection 3.2.2. The following subsection operationalizes the regression model defined in subsection 3.2.3.

#### 3.3.1. *The spatial layout of ecological corridors*

The implementation of the methodological approach developed by Cannas (Cannas and Zoppi, 2017a; 2017b; Cannas *et al.*, 2018a; 2018b), and described in section 3.2.2., generates two outputs: i. the raster map of the CWD values; ii. the spatial identification of the EC that connect the NPA of the Sardinian protected area network. Fig. 2 shows the EC identified in the study area and fig. 3 reports the CWD values, included in a range between 0 to 225,201 km. As described in section 3.2.3., the CWD values are clustered into ten deciles, whose second's upper limit is assumed as the threshold for the inclusion of a patch in an EC. The CWD values included in the first two deciles range from 0 to 9,741 km. In fig. 2 and 3, the EC are shown as linear elements.

Through LPT, 240 EC are identified, with length values ranging between 0.07 km and 27.34 km. Moreover, two important qualitative attributes of the EC connecting two core areas have to be emphasized: the ratio of the CWD to the Euclidean distance (CWD/ED) and the ratio of CWD to the length of the EC (CWD/LCP) (Feng *et al.*, 2021; Dutta *et al.*, 2016). The former measures the resistance to species movement between two core areas in relation to their proximity, i.e., the connectivity quality of the con-

necting EC, as long as the latter identifies the average resistance to species movement along the EC which connects two core areas.

*Tab. 1 - Name and typology of NPA included within core areas connected by EC which shows the highest and lowest values of CWD/ED index and CWD/LCP index*

<i>EC code</i>	<i>Core area code</i>	<i>Name of connected NPA</i>	<i>Typology of NPA</i>
		Monte dei Sette Fratelli	SPA
		Monte dei Sette Fratelli e Sarrabus	SAC
		Monte Genis	Permanent oases of faunal protection
		Castiadas-Sette Fratelli	Permanent oases of faunal protection
22	7	Campidano	Permanent oases of faunal protection
		Campidano	Public woods
		Campidano Santo Barzolu	Public woods
		Castiadas	Public woods
		San Vito	Public woods
		Sa Scova	Public woods
		Sette Fratelli	Public woods
		Villasalto	Public woods
	24	Baccu Arroddas - Rio Molas	Public woods
122	47	Olzai	Public woods
	148	Monte Gonare	SAC
			Permanent oases of faunal protection
112	49	Ussai	Permanent oases of faunal protection
		Barigadu	Public woods
	40	Foresta di Uatzo	Public woods
		Parco Naturale Regionale di Molentargius saline	Natural regional park
		Monte Sant'Elia, Cala Mosca e Cala Fighera	SAC
		Stagno di Cagliari, Saline di Macchiareddu, Laguna di Santa Gilla	SAC
		Stagno di Molentargius e territori limitrofi	SAC
	4	Torre del Poetto	SAC
		Stagno di Cagliari	SPA
12		Saline di Molentargius	SPA
		Santa Gilla	Permanent oases of faunal protection
		Stagni di Quartu Molentargius	Permanent oases of faunal protection
		Stagno di Molentargius	Ramsar Site
		Stagno di Cagliari	Ramsar Site
		Brunco de Su Monte Moru - Geremean	SAC
	10	(Mari Pintau)	SAC
		Costa di Cagliari	SAC

<i>EC code</i>	<i>Core area code</i>	<i>Name of connected NPA</i>	<i>Typology of NPA</i>
		Capo Carbonara e stagno di Notteri – Punta Molentis	SPA
		Fascia litoranea sud orientale	Permanent oases of faunal protection
	140	Stagno di Santa Caterina	SAC
		Stagno di Porto Botte	SAC
228	152	Isola Rossa e Capo Teulada	SCI
		Promontorio, dune e zona umida di Porto Pino	SCI
		Sassu - Cirras	SAC
		Stagno di S'Ena Arrubia e territori limitrofi	SAC
	3	Stagno di S'Ena Arrubia	SPA
		S'Ena Arrubia	Permanent oases of faunal protection
9		S'Ena Arrubia	Ramsar Site
		Stagno di Pauli Maiori di Oristano	SAC
		Stagno di Santa Giusta	SAC
	5	Stagno di Pauli Maiori	SPA
		Pauli Maiori	Permanent oases of faunal protection
		Stagno di Pauli Maiori	Ramsar Site
		Altopiano di Campeda	SAC
		Catena del Marghine e del Goceano	SAC
		Piana di Semestene, Bonorva, Macomer e Bortigali	SPA
		Monte Pisanu	Permanent oases of faunal protection
	80	Foresta Anela	Permanent oases of faunal protection
192		Anela	Public woods
		Bono	Public woods
		Monte Artu	Public woods
		Monte Bassu	Public woods
		Monte Burghesu	Public woods
		Monte Pisanu	Public woods
		Foresta Fiorentina	Permanent oases of faunal protection
	81	Fiorentini	Public woods
		Monte Pirastru	Public woods
119	43	Pabarile	Public woods
	142	Riu Sos Mulinos - Sos Lavros - M. Urtigu	SAC
		Parco Naturale Regionale di Molentargius saline	Natural regional park
14	4	Monte Sant'Elia, Cala Mosca e Cala Fighera	SAC
		Stagno di Cagliari, Saline di Macchiareddu, Laguna di Santa Gilla	SAC

<i>EC code</i>	<i>Core area code</i>	<i>Name of connected NPA</i>	<i>Typology of NPA</i>
		Stagno di Molentargius e territori limitrofi	SAC
		Torre del Poetto	SAC
		Stagno di Cagliari	SPA
		Saline di Molentargius	SPA
		Santa Gilla	Permanent oases of faunal protection
		Stagni di Quartu Molentargius	Permanent oases of faunal protection
		Stagno di Molentargius	Ramsar Site
		Stagno di Cagliari	Ramsar Site
15		Ovile Sardo	Permanent oases of faunal protection

With reference to the CWD/ED index, EC nos. 22, 112, and 122 show the lowest values and, as a consequence, the highest connectivity quality (see tab. 1 and fig. 5), whereas EC nos. 12, 228, and 9 show the highest values and, that being so, the lowest connectivity quality (see tab. 1 and fig. 6).

As regards the CWD/LCP index, EC nos. 192, 119, and 112 show the lowest values and, as a result (see tab. 1 and fig. 7), the lowest average resistance to species movement along the path, while EC nos. 12, 228, and 14 show the highest values and, for that reason, the highest average resistance to species movement (see tab. 1 and fig. 8).

### *3.3.2. Discussion on the overlay of ecological corridors and landscape components*

The estimated coefficients of the explanatory variables of model (3) show the correlations between the ECWD of a parcel included in an EC and the covariates of the multiple linear regression, identified by the LCFER and by the control variable ALTD.

The descriptive statistics related to dependent and explanatory variables of model (3) are shown in tab. 2, whereas tab. 3 reports the estimates of the multiple linear regression.

The estimated coefficient of the altitude-related variable shows significant p-values and a positive sign. This implies that a decrease in ECWD is associated with lower altitudes, everything else being equal, which is entirely consistent with expectations, since higher connectivity, or lower ECWD, is expected to take place in flat areas, generally characterized by

comparative lower altitudes. Our findings entail that a decrease of 100 meters in altitude will be correlated to a decrease of about 145 m in ECWD.

Since the estimate of the coefficient of the control variable is statistically significant and consistent with expectations, the estimated effects on ECWD generated by the covariates related to the LCFER can be considered reliable as regards the implementation of model (3).

*Tab. 2 - Definition of variables and descriptive statistics related to model (3)*

<i>Variable</i>	<i>Definition</i>	<i>Mean</i>	<i>St.dev.</i>
ECWD	Cost-weighted distance of a patch included in an EC (km)	4,947.08	2,865.14
SCRB	Scrub vegetation in dry areas and wetlands in a patch included in an EC (ha)	16,962.44	26,775.40
WOOD	Woodlands in a patch included in an EC (ha)	18,038.76	29,513.47
GRAS	Grasslands in a patch included in an EC (ha)	18,879.67	27,314.39
CCHW	Cork and chestnut woods in a patch included in an EC (ha)	3,190.58	12,865.24
SPTC	Specialized and tree crops in a patch included in an EC (ha)	3,107.70	11,326.36
ARWO	Artificial woods in a patch included in an EC (ha)	4,721.13	16,500.74
HAFU	Specialized herbaceous crops, agricultural and forest areas, and uncultivated areas, in a patch included in an EC (ha)	23,207.82	31,984.68
ALTD	Control variable which represents the average altitude in a patch included in an EC (m)	365.36	275.76

*Tab. 3 - Estimate of multiple linear regression model (3)*

<i>Variable</i>	<i>Coefficient</i>	<i>t-statistic</i>	<i>p-value</i>
SCRB	-2.77172	-1.60534	0.108428
WOOD	-7.20867	-4.16805	0.000031
GRAS	-5.80510	-3.35834	0.000785
CCHW	-6.91227	-3.49271	0.000479
SPTC	7.70003	3.69729	0.000218
ARWO	-5.33205	-2.85482	0.004309
HAFU	-3.16692	-1.84476	0.065081
ALTD	1.45191	22.37541	0.000000

The results of the coefficient estimates of model (3), reported in tab. 3, are related to the explanatory variables expressed by the percentage share of the area of a landscape component in the total area of a patch. Such estimates show the marginal effects of the explanatory variables on ECWD. The estimates exhibit p-values lower than 6.6%, with the exception of scrub vegetation in dry areas and wetlands (SCRB), which, at any rate, shows a weakly significant p-value (10.8%).

Moreover, the regression results put in evidence that all the LCFER are correlated to increases in the eligibility of a patch to be included in an EC,

i.e., an increase in the percentage area of an LCFER is correlated to a decrease in ECWD everything else being equal, except for specialized and tree crops (SPTC), whose coefficient is positive and indicates that an average increase of 1% in SPTC is associated to an average increase of 7.7 meters in the CWD of EC.

As for the other LCFER, the outcomes show that woodlands (WOOD) and cork and chestnut woods (CCHW) are the most suitable to enhance the effectiveness of EC, since their marginal effects on ECWD imply that a 1% increase is correlated to 7.2- and 6.9-meter decrease in average CWD, respectively. Less relevant positive effects on the eligibility of a patch to be included in an EC are exhibited by grasslands (GRASS) and artificial woods (ARWO), whose marginal effects on ECWD are 5.81 and 5.33 meters. The impacts of the covariates associated to scrub vegetation in dry areas and wetlands (SCRB), and to specialized herbaceous crops, agricultural and forest areas and uncultivated areas (HAFU), are definitely less important, since their coefficients entail that an average increase of 1% is correlated to a 2.77- and 3.16- meter decrease in ECWD, respectively.

These outcomes make it easy to identify relevant planning policy implications related to the enhancement of the regional network of protected areas through the protection and the improvement of its EC. Such implications are discussed in the concluding chapter of this volume.

### 3.4. Bibliography

- Adriaensen F., Chardon J.P., De Blust G., Swinnen E., Villalba S., Gulinck H. and Matthysen E. (2003), “The application of “least-cost” modelling as a functional landscape model”, *Landscape Urban Planning*, 64, 4: 233-247. DOI: 10.1016/S0169-2046(02)00242-6.
- AGRISTUDIO, CRITERIA and TEMI (2011), *Realizzazione del Sistema di Monitoraggio dello Stato di Conservazione degli Habitat e delle Specie di Interesse Comunitario della Regione Autonoma della Sardegna. Relazione Generale, Allegato 1b: Carta dell’Idoneità Faunistica* [Implementation of the Monitoring System Concerning the Conservation Status of Habitats and Species of Community Interest of the Autonomous Region of Sardinia. General Report, Attachment 1b: Habitat Suitability Map], MIMEO, Unpublished work.
- Balbi M., Petit E.J, Corci S., Nabucet J., Georges R., Madec L. and Ernoult A. (2019), “Title: Ecological relevance of least cost path analysis: An easy implementation method for landscape urban planning”, *Journal of Environmental Management*, 244: 61-68. DOI: 10.1016/j.jenvman.2019.04.124.
- Battisti C. (2004), *Frammentazione ambientale, connettività, reti ecologiche. Un contributo teorico e metodologico con particolare riferimento alla fauna selvatica* [Environmental Fragmentation, Connectivity, Ecological Networks. A

- Technical and Methodological Contribution with Particular Reference to Wildlife Species*], Provincia di Roma, Assessorato delle Politiche ambientali, Agricoltura e Protezione civile [Province of Rome, Board of Environmental Policy, Agriculture and Civil Protection], Provincia di Roma [Province of Rome], Rome, Italy.
- Baudry J. and Merriam H.G. (1988), *Connectivity and Connectedness: Functional versus Structural Patterns in Landscapes*, in *Proceedings of the 2<sup>nd</sup> IALE Seminar "Connectivity in Landscape Ecology"*, Vol. no. 29, Münsterche Geographische Arbeiten, Münster, Germany, pp. 23-28.
- Bera A.K. and Byron R.P. (1983), "Linearised estimation of nonlinear single equation functions", *International Economic Review*, 24, 1: 237-248. DOI: 10.2307/2526125.
- Burkhard B., Kroll F., Müller F. and Windhorst W. (2009), "Landscapes' capacities to provide ecosystem services - a concept for land-cover based assessments", *Landscape Online*, 15: 1-22. DOI: 10.3097/LO.200915.
- Burkhard B., Kroll F., Nedkov S. and Müller F. (2012), "Mapping ecosystem service supply, demand and budgets", *Ecological Indicators*, 2: 7-29. DOI: 10.1016/j.ecolind.2011.06.019.
- Cannas I., Lai S., Leone F. and Zoppi C. (2018a), "Green infrastructure and ecological corridors: a regional study concerning Sardinia", *Sustainability*, 10, 4 (1265): 1-21. DOI: 10.3390/su10041265.
- Cannas I., Lai S., Leone F. and Zoppi C. (2018b), *Integrating Green Infrastructure and Ecological Corridors: A Study concerning the Metropolitan Area of Cagliari (Italy)*, in Papa R., Fistola R. and Gargiulo C., eds., *Smart Planning: Sustainability and Mobility in the Age of Change*, Springer International Publishing, Basel, Switzerland, pp. 127-145. DOI: 10.1007/978-3-319-77682-8.
- Cannas I. and Zoppi C. (2017a), *Ecosystem Services and the Natura 2000 Network: A Study Concerning a Green Infrastructure Based on Ecological Corridors in the Metropolitan City of Cagliari*, in Gervasi O., Murgante B., Misra S., Borruso G., Torre C., Rocha A.M.A.C., Taniar D., Apduhan B.O., Stankova E. and Cuzzocrea A., eds., *17th International Conference on Computational Science and Its Applications (ICCSA 2017)*, Lecture Notes in Computer Sciences Series, Vol. no. 10409, Springer, Cham, Switzerland, pp. 379-400. DOI: 10.1007/978-3-319-62407-5\_39.
- Cannas I. and Zoppi C. (2017b), *Un'infrastruttura verde nell'area metropolitana di Cagliari: Corridoi ecologici come connessioni tra i Siti della Rete Natura 2000 [A Green Infrastructure in the Metropolitan Area of Cagliari: Ecological Corridors as Connections between the Sites of the Natura 2000 Network]*, in Aa.Vv. [Multiple Authors], *Atti della XX Conferenza Nazionale SIU. Urbanistica E/È azione pubblica [Proceedings of the 20<sup>th</sup> National Conference of SIU. Spatial Planning And/Is Public Action]*, Planum Publisher, Rome and Milan, Italy, pp. 1373-1386.
- Coulon A., Aben J., Palmer S.C.F., Stevens V.M., Callens T., Strubbe D. and Travis J.M.J. (2015), "A stochastic movement simulator improves estimates of landscape connectivity", *Ecology*, 96: 2203-2213. DOI: 10.1890/14-1690.1.



- Council of Europe - Directorate of Culture and Cultural and Natural Heritage (2010), *Biogeographical Regions' Map*, text available at the website <https://rm.coe.int/168074623f> [Accessed: 22 February 2022].
- D'Ambrogi S., Gori M., Guccione M. and Nazzini L. (2015), "Implementazione della connettività ecologica sul territorio: Il Monitoraggio ISPRA 2014" ["The implementation of spatial ecological connectivity: The 2014 Monitoring of ISPRA"], *Reticula*, 9 (2015): 1-7, text available at the website <http://www.isprambiente.gov.it/it/pubblicazioni/periodici-tecnici/reticula/reticula-n-9-2015> [Accessed: 22 February 2022].
- D'Ambrogi S. and Nazzini L. (2013), "Monitoraggio ISPRA 2012: La rete ecologica nella pianificazione territoriale" ["The 2012 Monitoring of ISPRA: The ecological network applied to spatial planning"], *Reticula*, 3 (2013): 1-5, text available at the website <https://www.isprambiente.gov.it/it/pubblicazioni/periodici-tecnici/reticula/reticula-n-3-2013> [Accessed: 22 February 2022].
- Directorate-General Environment, European Commission (2012), *The Multifunctionality of Green Infrastructure*, Science for Environment Policy, DG News Alert Service, In-depth Report, text available at the website [https://ec.europa.eu/environment/nature/ecosystems/docs/Green\\_Infrastructure.pdf](https://ec.europa.eu/environment/nature/ecosystems/docs/Green_Infrastructure.pdf) [Accessed: 22 February 2022].
- Directorate-General Environment, European Commission (2016), *Natura 2000 Barometer*, text available at the website [http://ec.europa.eu/environment/nature/natura2000/barometer/index\\_en.htm](http://ec.europa.eu/environment/nature/natura2000/barometer/index_en.htm) [Accessed: 22 February 2022].
- Dunning J.B., Danielson J.B. and Pulliam H.R. (1992), "Ecological processes that affect populations in complex landscapes", *Oikos*, 65: 169-175. DOI: 10.2307/3544901.
- Dutta T., Sharma S., McRae B.H., Roy P.S. and DeFries R. (2016), "Connecting the dots: mapping habitat connectivity for tigers in central India", *Regional Environmental Change*, 16: 53e67, 16 pages. DOI: 10.1007/s10113-015-0877-z
- EEA (European Environment Agency) (2014), *Spatial Analysis of Green Infrastructure in Europe*, EEA Technical Report no. 2/2014, Publications Office of the European Union, Luxembourg. DOI: 10.2800/11170.
- European Commission (2013), *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Green Infrastructure — Enhancing Europe's Natural Capital. SWD(2013) 155 final*, text available at the website <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52013DC0249> [Accessed: 22 February 2022].
- European Commission (2016), *The Natura 2000 Biogeographical Regions*, text available at the website [http://ec.europa.eu/environment/nature/natura2000/biogeog\\_regions/](http://ec.europa.eu/environment/nature/natura2000/biogeog_regions/) [Accessed: 22 February 2022].
- European Commission (2020), *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. EU Biodiversity Strategy for 2030. Bringing Nature back into Our Lives. COM(2020) 380 final*, text available at the website

- <https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1590574123338&uri=CELEX%3A52020DC0380> [Accessed: 22 February 2022].
- Feng H., Li Y., Li Y.Y., Li N., Li Y., Hu Y., Yu J. And Luo H. (2021), “Identifying and evaluating the ecological network of Siberian roe deer (*Capreolus pygargus*) in Tieli Forestry Bureau, northeast China”, *Global Ecology and Conservation*, 26: e01477, 14 pages. DOI: 10.1016/j.gecco.2021.e01477.
- Guo X., Zhang X., Du S., Li C., Siu Y.L., Rong Y and Yang H. (2020) “The impact of onshore wind power projects on ecological corridors and landscape connectivity in Shanxi, China”, *Journal of Cleaner Production*, 254: 120075, 14 pages. DOI: 10.1016/j.jclepro.2020.120075.
- Hess G.R. and Fischer R.A. (2001), “Communicating clearly about conservation corridors”, *Landscape Urban Planning*, 55, 3: 195-208. DOI: 10.1016/S0169-2046(01)00155-4.
- Issii TM, Lopes Pereira-Silva EF, López de Pablo CT, Ferreira dos Santos R. and Hardt E. (2020), “Is there an equivalence between measures of landscape structural and functional connectivity for plants in conservation assessments of the Cerrado?”, *Land*, 9, 459: 1-21. DOI:10.3390/land9110459 22.
- Kong F., Yin Y., Nakagoshi N. and Zong Y. (2010), “Urban green space network development for biodiversity conservation: Identification based on graph theory and gravity modeling”, *Landscape and Urban Planning*, 95: 16-27. DOI: 10.1016/j.landurbplan.2009.11.001.
- Lai S., Leone F. and Zoppi C. (2017), “Land cover changes and environmental protection: a study based on transition matrices concerning Sardinia (Italy)”, *Land Use Policy*, 67: 126-150. DOI: 10.1016/j.landusepol.2017.05.030.
- Larkin J.L., Maehr D.S., Hctor T.S., Orlando M.A. and Whitney K. (2004), “Landscape linkages and conservation planning for the black bear in westcentral Florida”, *Animal Conservation*, 7: 23-34. DOI: 10.1017/S1367943003001100.
- LaRue M.A. and Nielsen C.K. (2008), “Modelling potential dispersal corridors for cougars in Midwestern North America using least-cost path methods”, *Ecological Modelling*, 212: 372-381. DOI: 10.1016/j.ecolmodel.2007.10.036.
- Levins R. (1969), “Some Demographic and genetic consequences of environmental heterogeneity for biological control”, *Bulletin of the Entomological Society of America*, 15, 3: 237-240. DOI: 10.1093/besa/15.3.237.
- Liquete C., Kleeschulte S., Dige G., Maes J., Grizzetti B., Olah B. and Zulian G. (2015), “Mapping green infrastructure based on ecosystem services and ecological networks: A Pan-European case study”, *Environmental Science & Policy*, 54: 268-280. DOI: 10.1016/j.envsci.2015.07.009.
- MacArthur R.H. and Wilson E.O. (1967), *The Theory of Island Biogeography*, Princeton University Press, Princeton, NJ.
- McRae B.H., Dickson B.G., Keitt T.H. and Shah V.B. (2008) “Using circuit theory to model connectivity in ecology, evolution, and conservation”, *Ecology*, 89: 2712-2724. DOI: 10.1890/07-1861.1.
- McRae B.H. and Kavanagh D.M. (2017), *User Guide: Linkage Pathways Tool of the Linkage Mapper Toolbox - Version 2.0 - Updated October 2017*, text avail-

- able at the website [https://github.com/linkagescape/linkage-mapper/files/2204107/Linkage\\_Mapper\\_2\\_0\\_0.zip](https://github.com/linkagescape/linkage-mapper/files/2204107/Linkage_Mapper_2_0_0.zip) [Accessed: 22 February 2022].
- Osborn F.V. and Parker G.E. (2003), "Linking two elephant refuges with a corridor in the communal lands of Zimbabwe", *African Journal of Ecology*, 41: 68-74. DOI: 10.1046/j.1365-2028.2003.00413.x.
- Palmer S.C.F., Coulon A. and Travis J.M.J. (2011), "Introducing a 'stochastic movement simulator' for estimating habitat connectivity", *Methods in Ecology and Evolution*, 2: 258-268. DOI: 10.1111/j.2041-210X.2010.00073.x.
- Rosenberg D.K., Noon B.R. and Meslow E.C. (1995), *Towards a definition of "biological corridor"*, in Bissonette J.A. and Krausman P.R., eds, *Integrating People and Wildlife for a Sustainable Future, Proceedings of the International Wildlife Management Congress*, The Wildlife Society, Bethesda, MD.
- Saunders D.A. and Hobbs R.J. (1991), *The role of corridors in conservation: what do we know and where do we go?*, in Saunders D.A. and Hobbs R.J., eds, *Nature Conservation 2: The Role of Corridors*, Surrey Beatty & Sons, Chipping Norton, NSW, Australia.
- Sawyer S.C., Epps C.W. and Brashares J.S. (2011), "Placing linkages among fragmented habitats: do least-cost models reflect how animals use landscapes?", *Journal of Applied Ecology*, 48: 668-678. DOI: 10.1111/j.1365-2664.2011.01970.x.
- Shirabe T. (2018), "Buffered or bundled, least-cost paths are not least-cost corridors: Computational experiments on path-based and wide-path-based models to conservation corridor design and effective distance estimation", *Ecological Informatics*, 44: 109-116.
- Simberloff D., Farr J.A. and Mehlman D.W. (1992), "Movement corridors: Conservation bargains or poor investments?", *Conservation Biology*, 6: 493-504.
- Taylor P.D., Fahrig L., Henein K. and Merriam G. (1993), "Connectivity is a vital element of landscape structure", *Oikos*, 68: 571-573. DOI: 10.2307/3544927.
- Tischendorf L. and Fahrig L. (2000), "On the usage and measurement of landscape connectivity", *Oikos*, 90: 7-19. DOI: 10.1034/j.1600-0706.2000.900102.x.
- With K. A., Gardner R. H. and Turner M. G. (1997), "Landscape connectivity and population distributions in heterogeneous environments", *Oikos*, 78: 151-169. DOI: 10.2307/3545811.
- Wolman A.L. and Couper E. (2003), "Potential consequences of linear approximation in economics", *Federal Reserve Bank Economic Quarterly*, 11, 1: 51-67.
- Wu J., Delang C.O., Li Y., Ye Q., Zhou J., Liu H., He H. and He W. (2021), "Application of a combined model simulation to determine ecological corridors for western black-crested gibbons in the Hengduan Mountains, China", *Ecological Indicators*, 128: 107826: 1-13. DOI: 10.1016/j.ecolind.2021.107826.
- Zeller K.A., McGarigal K. and Whiteley A.R. (2012), "Estimating landscape resistance to movement: a review", *Landscape Ecology*, 27: 777-797. DOI: 10.1007/s10980-012-9737-0.

## *4. Assessing the potential of green infrastructure to mitigate hydro-geological hazard: evidence-based policy suggestions from a Sardinian study area*

This chapter focuses on the relations between the definition and implementation of a GI and hydro-geological hazard. GI are spatial structures supplying a wide range of ecosystem services, here related to the following: nature, natural resources and biodiversity conservation; landscape and recreation; agricultural and forestry production; local climate regulation; climate change impact mitigation through capture and storage of carbon dioxide. A methodological framework is defined to assess the relations between GI and hydro-geological hazard through inferential analysis based on dichotomous-choice Logit models, under the assumption that the implementation of GI within planning policies could enhance environmental protection and people's wellbeing. By applying the methodology to a coastal study area in Sardinia (Italy), this chapter shows that landslides are more likely to occur in areas showing high natural values and high carbon dioxide capture and storage capacity, whereas productive agro-forestry areas are comparatively more likely to feature severe floods, and areas with significant landscape assets and recreation potential are associated with low flood and landslide hazard. On these bases, a better understanding of the role that could be played by GI as regards hydro-geological hazard is gained, and policy recommendations aimed at mitigating the associated risks are identified.

### **4.1. Introduction**

Climate change negatively impacts on the hydrological cycle of the Earth and on phenomena connected with water management. Hydrogeological instability is conceptualized as a change of the natural flow of water

on, above and below the surface of the Earth due to its interaction with the anthropized spatial system (Margottini, 2015). Therefore, hydrogeological instability represents a hazard to local population, infrastructures, and economic and productive systems (Trigila *et al.*, 2018). For example, in 2018 in Italy 7,275 municipalities (91% of the Italian ones) were found to be exposed to landslide and/or flooding hazards. Moreover, 16% of the national territory is classified as high-hazard area, and 1.28 million people live in areas featured by landslide hazard and more than 6 million in flooding hazard areas (Trigila *et al.*, 2018; Di Giovanni, 2016).

Typical consequences of hydrological phenomena are landslides, flooding, coastal erosion, subsidence, and avalanche.

According to Cruden and Varnes (1996), «The term ‘landslide’ describes a wide variety of processes that result in the downward and outward movement of slope-forming materials including rock, soil, artificial fill, or a combination of these. The materials may move by falling, toppling, sliding, spreading, or flowing» (p. 36). The increase in rapid development, deforestation and urbanization results in higher probabilities of landslide events (Tiranti and Cremonini, 2019). Moreover, although several authors studied the impacts of climate change on landslide occurrence and magnitude through the use of model projections (Seneviratne *et al.*, 2012; Stoffel *et al.*, 2014), the influence of climate change on stability of slopes is still a matter of debate (Gariano & Guzzetti, 2016).

According to the European Union Directive 2007/60/EC on the management of flood risk, flood means «the temporary covering by water of land not normally covered by water. This shall include floods from rivers, mountain torrents, Mediterranean ephemeral water courses, and floods from the sea in coastal areas, and may exclude floods from sewerage systems» (art. 2, paragraph 1). Flood events are affected by sea level rise, heavy rainfalls, impervious surfaces, and ageing drainage infrastructures (Chen *et al.*, 2019).

Although for a long time gray infrastructure has represented the only operational tool to address landslide and flooding hazard and related environmental damages (Badiu *et al.*, 2019), more recently the implementation of nature-based solutions has revealed very effective in mitigating the impacts of such disasters (Caparrós-Martínez *et al.*, 2020). Therefore, the use of GI has gained increasing importance within the international debate. Caparrós-Martínez *et al.* (2020) argue that, even though the technical functions of GI are connected to the management of the integrated water cycle, GI should be mainly identified in relation to three issues: smart growth, climate change adaptation, and social health and wellbeing. According to the US-EPA (United States Environmental Protection Agency, 2017),

«Green infrastructure is a cost-effective, resilient approach to managing wet weather impacts that provides many community benefits. While single-purpose gray stormwater infrastructure - conventional piped drainage and water treatment systems - is designed to move urban stormwater away from the built environment, green infrastructure reduces and treats stormwater at its source while delivering environmental, social, and economic benefits». In other words, the US-EPA identifies GI as a provider of mitigation of landslide and flooding impacts, since GI is engineered to intercept rainfalls, increase the availability of permeable surfaces and soil water storage, and delay and decrease the intensity of peak flows (Bartens and Mersey Forest Team, 2009). For instance, large trees may potentially absorb 80% of precipitation, whereas little trees absorption is around 16% (Xiao and McPherson, 2002).

Caparrós-Martínez *et al.* (2020) identify three types of benefits, i.e., economic cost savings, multifunctional character and lower environmental cost, and ability to adapt to different territorial scales. In their view, GI includes healthy ecosystems that help to restore and reestablish spatial connections between damaged habitats and, in general, between natural and semi-natural areas, in contrast to gray infrastructure that requires continuous adaptations to social and economic factors, such as population growth (European Commission, 2013a). Furthermore, GI entails benefits such as water purification generated by natural wetlands, conservation and enhancement of biodiversity, and carbon capture and storage, while gray infrastructure, such as a treatment plants, are single-purposed, in that they only aim at purifying wastewater (European Commission, 2013a; 2013c). Finally, GI may be adapted to different scales, ranging from the regional to the urban level (Caparrós-Martínez *et al.*, 2020).

Moreover, several studies (Lai and Zoppi, 2017; Lai *et al.*, 2017a; 2018; Liqueste *et al.*, 2015; Ronchi *et al.*, 2020) highlight that GI may represent a tool to mitigate land-taking processes. In particular, Lai and Zoppi (2017) analyze how the provision of Natura 2000 sites, regarded by the EU as core areas within GI, affect land-taking processes. The results of this chapter put in evidence that the presence of natural and semi-natural areas, such as Natura 2000 sites, is negatively correlated to land-taking processes. Land cover transitions from natural and semi-natural areas to artificial areas due to urbanization, agricultural expansion and abandonment, and deforestation, entail habitat fragmentation and degradation and, as a consequence, biodiversity loss (Calvache *et al.*, 2016). GI as a network of natural and semi-natural areas reduces habitat fragmentation, and, that being so, policies aimed at increasing natural and semi-natural areas are strategically relevant to mitigate land-taking processes (Lai *et al.*, 2017b).

The relation between GI and hydrological instability is a matter of study in recent literature (Zucaro and Morosini, 2018). Mei *et al.* (2018) investigate the role of GI in mitigating flood events through the stormwater management model (SWMM) and life cycle cost analysis (LCCA), in order to support planning and decision-making processes. Chen *et al.* (2019) assess the effectiveness of the implementation of practices based on GI on water supply and quality. Papatoma-Koehle and Glade (2013) analyze how changes in vegetation and land cover influence landslide events in terms of occurrences, consequences, and implications.

Although the implementation of GI based on natural and semi-natural areas is quite effective to mitigate the negative impacts of landslides and floods, its use is still limited due to the difficulty to project and forecast economic impacts and feasibility (Caparrós-Martínez *et al.*, 2020; European Commission, 2013b). Indeed, the assessment of GI-related planning policies is generally based on counterfactual methodologies which imply the availability of huge databases and complex economic approaches that are often too expensive in terms of financial resources and time needed to obtain reliable outcomes (Palmer *et al.*, 2015).

The assessment of the effectiveness of GI practices on hydrological events is therefore an important issue in the current literature; however, available studies mainly focus on specific GI practices, such as green roofs, permeable pavements, bioretention cells, rain barrels, and vegetated swales (Palla and Gnecco, 2015; Liu *et al.*, 2014). This chapter aims at defining a methodological approach to investigate the relations between a regional GI (RGI) and hydrogeological hazards, identified by landslides and floods, by combining GIS-based analysis with regression models in order to define strategies and policies to mitigate the potential negative environmental impacts generated by such hazards. The methodological approach is implemented into a coastal area of Eastern Sardinia, Italy.

This chapter is structured into four sections as follows. The Introduction is followed by the second section, which describes the study area, shows how the dataset is built, and discusses the methodological approach, which combines a GIS-based spatial analysis with a regression model. The third section presents the results derived from the implementation of the methodological approach in relation to the study area. The results are discussed in the fourth section, while the implications of the chapter in terms of planning policy recommendations, its limitations and future research perspectives are presented in the fifth chapter of this volume.

## 4.2. Materials and methods

This section is organized as follows. In the first subsection the study area is described within the regional spatial context of Sardinia. Next, the discrete-choice Logit model estimated to detect the relations between RGI and environmental hazard is defined and discussed. In the last subsection, the data which operationalize the model are presented.

### 4.2.1. Study area

The area chosen for this chapter lies on the eastern side of Sardinia, one of the main islands in the Mediterranean Sea (fig. 1). With a size of approximately 24,000 km<sup>2</sup> and a population of 1,611,621 inhabitants<sup>1</sup>, Sardinia has a very low residential density of around 67 inhabitants/km<sup>2</sup>, mostly concentrated in coastal zones and peaking in the main urban areas. To the contrary, inner areas are sparsely populated and present worrying trends of steady depopulation, to which the persistent low levels of infrastructure and services greatly contribute. The climate of the island is typically Mediterranean, and the landscape is mostly hilly and rugged, with only a few plains that are significant for agriculture. Close to the coastline, several small valleys can be found in correspondence with rivers' estuaries and coastal wetlands, and in these valleys recent coastal urbanization, often connected to the tourism sector, has replaced traditional agricultural and grazing uses.

Bordering the Tyrrhenian Sea to the East, the study area chosen for this chapter stretches over 1306.12 km<sup>2</sup>, roughly amounting to one twentieth of the whole island. As shown in fig. 1 (panel "C"), fourteen coastal municipalities are fully comprised within the study area, with a fifteenth one (Gairo) only included as far as its coastal area is concerned; the latter is an enclave completely separated from the rest of the inland municipal territory to which it belongs and enclosed between the sea and the two municipalities of Cardedu and Tertenia. The morphology is quite hilly and rugged in the central part of the study area (i.e. the Gulf of Orosei), characterized by limestones and dolomites, and hosting canyons, steep cliffs and pocket beaches (Arisci *et al.*, 2000; Cossu *et al.*, 2007). The northern and southern parts, still hilly but with gentler slopes, host large sandy beaches (such as, for instance, Orri in Tortolì to the south, or La Cinta in San Teodoro to the

<sup>1</sup> Data from the National Census as of January 1<sup>st</sup>, 2020, available at the website <http://dati.istat.it/> [Accessed: 22 February 2022].



north: Batzella *et al.*, 2011), as well as rivers of significance in the regional context and their alluvial plains (for instance, Rio Quirra in Tertenia, Rio Cedrino in Orosei, and Rio Posada in the namesake municipality), lagoons and wetlands (for instance, in Tortolì, Orosei, and San Teodoro).

As in all of Sardinia, the climate in the study area is Mediterranean: winters are mild and moderately rainy, while summers are hot and dry. Concerning physiography, approximately 60% of the study area belongs to the thermo-Mediterranean zone and the remainder to the meso-Mediterranean zone, as per the map developed by Canu *et al.* (2015). Vegetation series are closely linked to physiography, and the study by Bacchetta *et al.* (2009) shows that nearly all the study area hosts species belonging to either the Sardinian thermo-meso-Mediterranean series or the Sardinian thermo-Mediterranean series, as follows: approximately 53% is taken by the holm oak tree series, 20% by the cork tree series, 12% by the wild olive tree series, and 6% by the *Juniperus turbinata* series; finally, negligible percentages of several other vegetation series concern the rest of the study area.

Hydrogeological hazard has historically been significant in the study area, hence its significance for this chapter. As for floods, extreme events in recent history took place in this part of the island in 1951, 2004, 2013 (Bodini and Cossu, 2010; Cossu *et al.*, 2007; De Waele *et al.*, 2008; Righini *et al.*, 2017). As far as landslides are concerned, approximately 175 events occurred up to 2007 have been recorded by the Italian landslide inventory (IFFI) project<sup>2</sup> in the study area. Such events are mainly clustered in the central and south-most parts of the study area; the former includes the municipalities of Baunei, Dorgali and Orosei, where fall and topple types prevail (Cinus *et al.*, 2007), while in the latter, only concerning the municipality of Tertenia, topples prevail<sup>3</sup>, although some translational slides have also occurred (Cinus *et al.*, 2007).

Finally, as for urbanization, tab. 1 provides data on population and land take in the study area. As per the definition by the European Environment Agency (2019), land take is here understood as the «change in the area of

<sup>2</sup> IFFI is the acronym of “Inventario dei Fenomeni Franosi in Italia”, which can literally be translated as “Inventory of Landslide Events in Italy”. For the Sardinian region, the full IFFI 2007 dataset can be retrieved from <https://idrogeo.isprambiente.it/app/page/open-data>. Moreover, a larger spatial dataset, which includes also more recent observations and provides additional information such as event date and pictures, can be visualized at the website <https://idrogeo.isprambiente.it/app/iffi/r/20> [Accessed: 22 February 2022].

<sup>3</sup> For the full taxonomy of landslide types the reader can refer to Varnes (1978) and to Crudern and Varnes (1996).

agricultural, forest and other semi-natural land taken for urban and other artificial land development», which, in Italy, is monitored on an annual basis by the National Institute for the Protection of the Environment (original Italian: ISPRA - Istituto Superiore per la Protezione e la Ricerca Ambientale). Data from the latest available report (Munafò, 2020) show that, if all of the 15 municipalities in the study area are taken into account, then land take is higher than that of the whole island, both in terms of quantity of land taken per unit of area, and in terms of land taken per capita (tab. 1, penultimate and last column respectively).

*Tab. 1 - Municipalities in the study area: size, population, population density, and land take*

<i>Municipality</i>	<i>Area [km<sup>2</sup>]</i>	<i>Population (*)</i>	<i>Population density [residents/km<sup>2</sup>]</i>	<i>Land take [%] (**)</i>	<i>Land take [m<sup>2</sup>/inhab.]</i>
Bari Sardo	37.43	3,908	104.40	5.97	572.20
Baunei	212.08	3,549	16.73	0.78	465.49
Budoni	56.17	5,191	92.40	8.74	945.69
Cardedu	32.35	1,953	60.36	4.32	715.93
Dorgali	224.82	8,502	37.82	2.51	662.83
Gairo (***)	78.32	1,365	17.43	1.79	1027.63
Girasole	13.23	1,320	99.77	6.73	674.59
Loiri Porto San Paolo	118.43	3,604	30.43	3.32	1090.79
Lotzorai	16.51	2,115	127.59	7.23	566.29
Orosei	90.55	6,928	76.51	6.33	826.93
Posada	33.07	3,041	91.97	6.56	713.18
San Teodoro	104.76	4,978	47.48	5.34	1124.93
Siniscola	199.87	11,509	57.57	3.86	670.20
Tertenia	117.76	3,883	32.97	2.12	642.77
Tortoli	40.47	10,769	266.11	13.09	492.01
Total 15 municipalities	1375.82	72,615	52.77	3.79	718.94
Sardinia	24,090	1,611,621	66.90	3.28	490.28

(\*) As of January 1<sup>st</sup>, 2020. Source: National Census (available at the website <http://dati.istat.it/> [Accessed: 22 February 2022]).

(\*\*) As of 2019. Source: Munafò, 2020. Defined as “Consumed soil” in the supplementary materials (available at the website <http://groupware.sinanet.isprambiente.it/uso-copertura-e-consumo-di-suolo/library/consumo-di-suolo/indicatori/> [Accessed: 22 February 2022]).

(\*\*\*) Data in this table refer to the whole municipality, but in this chapter only the coastal area (8.62 km<sup>2</sup>) is included; data on population and land take are not available for Gairo’s coastal enclave only.

However, a closer look at tab. 1 unveils a very uneven situation across municipalities in the study area, as land take as percentage of the “consumed soil” per unit of area ranges between 0.78% (Baunei) and 13.08% (Tortoli). However, such figures are highly dependent on the size of the municipal area. Hence, the unbalanced distribution of land take across the

15 municipalities is more significant if the share of “consumed soil” per capita is considered.

What is quite evident, here, is that in well-renowned coastal tourist destinations, such as Budoni, San Teodoro, or Loiri Porto San Paolo, land take per unit of resident population is approximately (or even higher than) twice as much as the regional figure, which exposes the impact of tourism and related infrastructure on urbanization in coastal areas.

#### 4.2.2. *Methodological framework*

Multiple or dichotomous choice models (DCMs) analyze phenomena characterized by multiple or dichotomous nominal alternatives. These models were originally formalized and applied by McFadden (1978; 1980) in order to characterize behavioral choices of consumers. McFadden (1978; 1980; 2000) built on William’s work (1977) through the implementation of choice models related to agents’ behavior on the basis of standard microeconomic theory. These models integrate sets of agents’ features as covariates, whose alphanumerical values may or may not be part of the available information; were they not available, they would be integrated into the model as random characteristics. A number of studies are points of reference to formalize multiple or DCMs (Ben-Akiva and Lerman 1985; Ortúzar and Willumsen 2001; Train 2009), which assume imperfection of agents’ rationality and information incompleteness (Tversky 1972).

In this chapter, DCMs are used because the variables which identify flood and landslide hazards are dichotomous, since both flood hazard and landslide hazard can be classified into the “relevant” and “weak” categories, by grouping the hazard classes of the Sardinian region as follows: in case of flood hazard, “presence of flood hazard” into the former and “no hazard” into the latter; in case of landslide hazard, “very high,” “high” or “medium” hazard into the former, and moderate or no hazard into the latter.

Building on Nerlove & Press’ (1973), Greene’s (1993), and Zoppi and Lai’s (2013), this chapter implements a Logit DCM. Logit models (LMs) associate a logistic probability distribution to the two events that characterize the phenomenon at stake.

The model considers a set of two events  $\{0,1\}$ , with probability of event “1” and “0” given by, respectively:

$$\text{Prob (1)} = \frac{e^{\beta_1'x_1}}{1+\sum_{k=0}^1 e^{\beta_k'x_k}} \quad (1),$$

$$\text{Prob} (0) = \frac{1}{1+\sum_{k=0}^1 e^{\beta'_k x_k}} \quad (2),^4$$

where  $\beta$  is a vector of coefficients and  $x$  is a vector of characteristics related to the event  $k$ ,  $k \in \{0,1\}$ . As per Greene (1993, p. 666, see footnote 3), a unique non-zero vector  $\beta_1$  can be identified, and, as a consequence, a unique vector of coefficients  $\beta$ , i.e. vector  $\beta_1$  of formula (1), is estimated by solving the maximization problem of the following log-likelihood function,  $\ln L$ , in the vector of coefficients  $\beta$ :

$$\ln L = \sum_{i=1}^M \sum_{k=0}^1 d_{ik} \ln \text{Prob} (k) \quad (3),$$

where  $M$  is the total number of observations, and  $d_{ik}=1$  if in the  $i$ -th observations the event  $k$  occurs, and  $d_{ik}=0$  otherwise. The vector of coefficients  $\beta$  is implemented into (3) through formulas (1) and (2), where the  $\text{Prob}(k)$ 's are expressed as functions of vector  $\beta$  through formulas (1) and (2).

The maximization of the likelihood function  $\ln L$  is identified by a system of  $N+1$  equations in the  $N+1$  coefficients of vector  $\beta$ . Each equation takes the following form:

$$\frac{\partial \ln L}{\partial \beta_j} = \sum_{i=1}^M [d_{ik} - \text{Prob} (k_i)] x_{ij} = 0 \quad (4),$$

where  $\beta_j$  is the  $j$ -th coefficients of vector  $\beta$ ,  $x_{ij}$  is the  $i$ -th observation concerning characteristic  $j$  of vector  $x$ ,  $k_i$  is the event associated to the  $i$ -th observation, such that  $k_i \in \{0,1\}$ , and  $j \in \{0,N\}$  is the number of components of vectors  $\beta$  and  $x$ .

The values of the vector of coefficients  $\beta$  which solve the maximization problem (4) make it possible to calculate the marginal effects of a change of the value of a characteristic  $x_i$  of vector  $x$  on the probability that the event  $k$  occurs,  $\frac{\partial \text{Prob} (k)}{\partial x_i}$ , as follows:

$$\frac{\partial \text{Prob} (k)}{\partial x_i} = [\text{Prob} (k)] \{ \beta_i - \sum_{j=0}^N [\text{Prob} (k)] \beta_j \} \quad (5)$$

<sup>4</sup> If  $\beta_j^* = \beta_j + q$  for any nonzero vector  $q$ , the identical set of probabilities result, as the terms involving  $q$  all drop out. A convenient normalization that solves the problem is to assume vector  $\beta_0 = 0$ . The probability for  $Y = 0$  is therefore given by (2) (Greene, 1993, p. 666).

The model’s estimates make it possible to derive the marginal effects of formula (5), for instance as regards the  $x_i$ ’s mean values, and the probabilities of the events  $k$ ’s. Furthermore, the model makes it possible to derive the standard errors of the components of vector  $\beta$  and of the marginal effects of formula (5).

A further assumption is that the random distribution of the event  $k$ ,  $k \in \{0,1\}$ , is such that observations are independent from each other, which entails that the observations concerning the explanatory variables are unrelated to each other, and deterministically identified by the available data. As a consequence, the random element of the distribution of event  $k$ ,  $\varepsilon$ , is featured as follows (Cherchi, 2012; Cannas and Zoppi, 2017):

$E(\varepsilon|x) = 0$ , i.e., the expected value of the random term conditional on the values of vector  $x$  equals zero;  $x$  is the set of explanatory variables;

$Var(\varepsilon) = \sigma^2$ , i.e., the variance of the random term is constant;

$E[\varepsilon_i\varepsilon_j|X] = 0$ , there is no correlation between the random terms of the observations, which entails that the covariance equals zero;  $X$  is the set of observations concerning vector  $x$ .

Model (1) through (5) operationalizes as follows.

Two models are estimated, where the dependent dichotomous variables are, respectively, flood hazard and landslide hazard. These variables correspond to the  $k$ ’s events in model (1) through (5),  $k \in \{0,1\}$ .

Tab. 2 - Definition of variables and descriptive statistics

Variable	Definition	Mean	St.dev.
FH	Flood hazard - dichotomous variable: 1 if any level of flood hazard but no hazard is detected; 0 if no hazard is detected	0.090	0.286
LH	Landslide hazard - dichotomous variable: 1 if the level of flood hazard is “very high,” “high” or “medium”; 0 if either the level of landslide hazard is moderate or no hazard is detected	0.448	0.497
Natval	Natural value. Continuous variable in the interval [0,1]. Potential capability of biodiversity to supply final ecosystem services in face of threats and pressures it is subject to.	0.844	0.269
The value was calculated using the software “InVEST” <sup>5</sup> ,			

<sup>5</sup> InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) is a free software program developed by the Natural Capital Project and available at the website <http://data.naturalcapitalproject.org/nightly-build/invest-users-guide/html/index.html> [Accessed: 22 February 2022].

<i>Variable</i>	<i>Definition</i>	<i>Mean</i>	<i>St.dev.</i>
	<p>tool “Habitat quality”, as per chapter 2 in this volume.</p> <p>Data inputs for the model were:</p> <p>land cover types as per the 2008 Regional land cover map (rasterized);</p> <p>raster maps of ten spatial threats listed in the standard data forms for Natura 2000 sites. The ten selected threats are as follows: cultivation; grazing; removal of forest undergrowth; salt works; paths, tracks, and cycling tracks; roads and motorways; airports; urbanized areas; discharges; fire and fire suppression;</p> <p>weights and decay distance for each threat from expert judgments;</p> <p>sensitivity of each land cover type to each threat from expert judgments;</p> <p>accessibility to sources of degradation, in terms of relative protection to habitats provided by legal institutions. The three categories we used are as follows: natural parks, areas protected and managed by the regional Forestry Agency, Natura 2000 sites</p>		
Consval	<p>Conservation value. Continuous variable in the interval [0,1]. Presence of natural habitat types of Community interest (as listed in Annex I of the Habitats Directive) and conservation importance thereof.</p> <p>As per chapter 2 in this volume, Consval=0 for areas where no habitats of Community interest have been identified; else <math>Consval = P * (R + T + K)</math> [normalized in the interval [0,1] where:</p> <p>priority habitats <math>P = 1.5</math> in case of priority habitat, <math>P = 1</math> in case of non-priority habitat;</p> <p>rarity <math>R = [1,5]</math> depending on the number of Natura 2000 standard data forms in which the habitat is listed within the regional Natura 2000 network; the higher the number of occurrences, the lower the value of R;</p> <p>threats <math>T = [1,5]</math> depending on the number of threats recorded in the standard data forms for the Natura 2000 sites in our study area; the higher the number of threats, the higher the value of T;</p> <p>knowledge <math>K = [1,4]</math> depending on the level of current knowledge (e.g. number of onsite surveys, existence of up-to-date and reliable monitoring data) of a given habitat within the regional Natura 2000 network; the lower the knowledge, the higher the value of K</p>	0.148	0.195
Landsval	<p>Landscape value. As per chapter 2 in this volume, discrete variable in the interval [0,1] accounting for whether, and to what extent, a given parcel of land is protected under the 2006 Regional Landscape Plan either as “Environmental landscape asset” or as “Cultural-historic landscape asset”. For each protection level defined in the Regional Landscape Plan, a score was assigned in the [0,1]</p>	0.521	0.497

<i>Variable</i>	<i>Definition</i>	<i>Mean</i>	<i>St.dev.</i>
	interval depending on the level of restriction. In case of overlapping protection levels, the maximum score was assigned to the parcel		
Recrval	Recreation value. Continuous variable in the interval [0,2.83]. Potential provision of daily, non-motorized, ecosystem-based recreation, assessed through the conceptual ESTIMAP model, as per chapter 2 in this volume, as the sum of three components; suitability landscapes and natural habitats to support recreation; nature-related elements; water-related elements	1.44	0.576
Agrofor	Agroforestry value. In the absence of comprehensive spatial data on agricultural and forestry productivity, estimated value of rural plots (k€/ha) as of 2017 was used as a proxy, as per chapter 2 in this volume	3.601	4.029
LST	Land surface temperature detected in August 2019 (K), retrieved as per chapter 2 in this volume	311.174	3.554
CO2Stor	Carbon dioxide storage per unit of area (Mg/(100 m <sup>2</sup> )), retrieved as per chapter 2 in this volume	1.098	0.350
Altitud	Elevation (m)	234.084	226.531
Slope	Slope. The inclination of slope is provided as percent rise, also referred to as percent slope. The values range from 0 to essentially infinity. A flat surface is 0% and a 45-degree surface is 100%, and as the surface becomes more vertical, the percent rise becomes increasingly larger. <sup>6</sup>	23.009	21.501

The characteristics which are the components of vector  $x = (1, x_1, \dots, x_N)$  and their descriptive statistics are reported in tab. 2. The occurrences of the  $k$ 's events are conditional upon the  $X_i$ 's characteristics, according to a logistic distribution estimated through the identification of the coefficients which are the components of vector  $\beta$ , by implementing model (1) through (5). The characteristics are the following: natural value, conservation value, landscape value, recreation value, agroforestry value, land surface temperature and carbon dioxide capture and storage capacity. Moreover, altitude and slope are used as control variables. These characteristics are described and discussed in the following subsection.

<sup>6</sup> Available at the website <https://desktop.arcgis.com/en/arcmap/10.7/tools/spatial-analyst-toolbox/slope.htm> [Accessed: 22 February 2022].

### 4.3. Data

Flood hazard and landslide hazard in Italy are mapped at the sub-national level, within a sectoral planning tool termed PAI (an acronym for “Piano di Assetto Idrogeologico”, verbatim “Hydrogeological Setting Plan”), with which municipal land use plans and their zoning schemes must conform. Notwithstanding several disasters occurred in the XX century, such as Polesine in 1951, Vajont in 1963, or Florence in 1966, it was only in 1989 that the first law (no. 183/1989) making provisions for basin management was passed. Such law made it compulsory to approve watershed management plans that were conceived of as knowledge-providing tools, as well as planning tools that ought to identify technical interventions to reduce hydrogeological risks and impacts on human activities and set up a financial program to be revised every three years. Because of the comprehensive character of such plans, the implementation process was extremely slow (Scolobig *et al.*, 2014). Therefore, when the Sarno debris flow disaster occurred in 1998, a new law (no. 267/1998) was quickly passed to speed up these planning processes and ensure that each River Basin Authority approved at least a “smaller” plan, the PAI. Albeit still part of the comprehensive watershed management plan, PAI’s focus only on hydrogeological risk and include assessment and mapping of flood and landslide risks, hence also assessment and mapping of flood and landslide hazards, as well as of vulnerable areas, buildings, and infrastructure<sup>7</sup>.

Because the island of Sardinia is identified as a macro-basin, a single watershed management plan and its PAI concern the whole region. The Sardinian PAI, first approved in 2004, in its initial version mapped hydrogeological risk and hazard only within specific parts of the island, such as, for instance, those in which severe landslides were known to have taken place in history, or those in which so-called “critic river segments” were identified through hydraulic models (RAS, 2000). Hazard classes within the PAI range in the 0-4 interval, as per tab. 3.

Since 2004, both flood and landslide hazard and risk maps in the Sardinian PAI have continuously been updated through two main mechanisms: first, studies commissioned by the regional administration; second, studies commissioned by municipal administrations, usually as part of their land-use plan-making processes, because updated flood and landslide assessments concerning the whole municipal territory are prerequisite for the ap-

<sup>7</sup> Within the Sardinian PAI, the traditional disaster risk equation is used:  $R=H*V$ , where R=risk, H=hazard, V=vulnerability.



proval of land-use plans. Municipal assessments make use of the same hazard levels as the PAI, i.e., those listed in tab. 3, and of the same methodologies as the River Basin Authority, which means that the outcomes of the regional and municipal assessments are comparable.

*Tab. 3 - Flood and landslide hazard classes as per the Sardinian PAI (RAS, 2004, pp. 23-25)*

<i>Hazard level</i>	<i>FH level definition</i>	<i>LH level definition</i>
0	Absent (not even mapped)	Absent
1	Low (return period: 500 years)	Moderate
2	Moderate (return period: 200 years)	Medium
3	High (return period: 100 years)	High
4	Very high (return period: 50 years)	Very high

Despite being thoroughly examined and approved by the River Basin Authority, not all the assessments and maps commissioned by the municipalities call for a revision of the PAI; in other words, it is up to the River Basin Authority to decide when the maps commissioned and produced at the municipal level are to be integrated within a new version of the regional PAI. Therefore, when looking for data on landslide and flood hazard in Sardinia, one must necessarily take account of four datasets, two for each type of hazard, freely available from the Regional geoportal<sup>8</sup> and enlisted in tab. 4: first, the most updated versions of the PAI maps; second, the maps commissioned by the municipalities and approved by the River Basin Authority.

In the study area, for each hazard type the two spatial datasets partly overlap in twelve of the fifteen municipalities, while for three of them (Bari Sardo, Dorgali, and Baunei) a study at the municipal level has not been produced and approved so far.

However, the area of interest for this research was analyzed within a study commissioned by the regional administration and approved in 2011<sup>9</sup> that led to an early revision of the Sardinian PAI, which means that both landslide and flood hazard data for the three aforementioned municipalities can be retrieved from the regional PAI, although in some parts of Dorgali's territory the landslide hazard map is void.

<sup>8</sup> Available at the website <http://www.sardegna.gov.it/webgis2/sardegnamappe/?map=pai> [Accessed: 22 February 2022].

<sup>9</sup> Available at the website <http://www.regione.sardegna.it/index.php?xsl=509&s=1&v=9&c=9305&tb=8374&st=13> [Accessed: 22 February 2022].

Tab. 4 - Landslide and flood hazard datasets used within this chapter

<i>Title of the spatial dataset (original)</i>	<i>Content of the spatial dataset</i>	<i>Latest update</i>	<i>Metadata and download URL [Accessed: 22 February 2022]</i>
Pericolo Geomorfologico Rev. 42 (Pericolo Frana PAI)	<i>LH</i> , PAI (revision 42)	31/01/2018	<a href="http://webgis2.regione.sardegna.it/catalogodati/card.jsp?uuid=R_SARDEG:eb38d6c0-b51f-4df1-acdc-f7a752e7664c">http://webgis2.regione.sardegna.it/catalogodati/card.jsp?uuid=R_SARDEG:eb38d6c0-b51f-4df1-acdc-f7a752e7664c</a>
Art.8 Hg V.09 (Pericolo Frana Art.8)	<i>LH</i> assessment commissioned by the municipalities and approved by the River Basin Authority	31/01/2018	<a href="http://webgis2.regione.sardegna.it/catalogodati/card.jsp?uuid=R_SARDEG:127d7692-14c0-4d85-a364-62476a0a3cc9">http://webgis2.regione.sardegna.it/catalogodati/card.jsp?uuid=R_SARDEG:127d7692-14c0-4d85-a364-62476a0a3cc9</a>
Pericolo Idraulico Rev. 41 (Pericolo Alluvioni PAI)	<i>FH</i> , PAI (revision 41)	31/01/2018	<a href="http://webgis2.regione.sardegna.it/catalogodati/card.jsp?uuid=R_SARDEG:9b3a1b64-2a59-4658-98ed-7f6ccc366128">http://webgis2.regione.sardegna.it/catalogodati/card.jsp?uuid=R_SARDEG:9b3a1b64-2a59-4658-98ed-7f6ccc366128</a>
Art. 8 Hi V.09 (Pericolo Alluvioni Art.8)	<i>FH</i> assessment commissioned by the municipalities and approved by the River Basin Authority	31/01/2018	<a href="http://webgis2.regione.sardegna.it/catalogodati/card.jsp?uuid=R_SARDEG:34d2c0f6-a8c3-4bcb-8a64-abbec8723574">http://webgis2.regione.sardegna.it/catalogodati/card.jsp?uuid=R_SARDEG:34d2c0f6-a8c3-4bcb-8a64-abbec8723574</a>

As for the other twelve municipalities, in case of overlapping patches where the PAI and the municipal maps identify two different hazard levels<sup>10</sup>, within this chapter we consider the latter, for the following three reasons: first, the municipal assessments and maps are more recent than the corresponding PAI ones; second, the municipal assessments and maps have already been approved by the River Basin Authority, which serves as a certification of their quality; third, the municipal assessments can in principle reply the PAI ones any time soon, whenever the River Basin Authority decides that they are to be integrated within a new revision of the PAI.

For each municipality in the study area, tab. 5 provides details on the most updated landside and flood hazard maps (bearing in mind that the PAI *LH* and *FH* maps concern all of the 15 municipal territories).

The methodology through which *Natval*, *Consval*, *Landsval*, *Recrval*, *Agrofor*, *LST*, *CO2Stor* were assessed and mapped has been presented in the second chapter of this volume, and their spatial distribution has been

<sup>10</sup> This is possible because the regional and the municipal assessment have different spatial and temporal resolution, and the hazard level can vary over time: for instance, it can be lowered through appropriate mitigation interventions.

provided in subsection 2.8.1. As for elevation (*Altitud*) and slope (*Slope*), their values were retrieved from the 10-m resolution digital terrain model available from the Regional geoportal<sup>11</sup>.

*Tab. 5 - Municipalities included in the study area: approval date of the most recent hazard maps*

<i>Municipality</i>	<i>Approval of the LH &amp; FH maps [year]</i>	<i>Study commissioned by</i>
Bari Sardo	2011	Sardinian regional administration
Baunei	2011	Sardinian regional administration
Budoni	2012	Municipal administration
Cardedu	2013	Municipal administration
Dorgali	2011	Sardinian regional administration
Gairo	2014	Municipal administration
Girasole	2012	Municipal administration
Loiri Porto	2012	Municipal administration
San Paolo		
Lotzorai	2015	Municipal administration
Orosei	2013	Municipal administration
Posada	2010	Municipal administration
San Teodoro	2015	Municipal administration
Siniscola	2013	Municipal administration
Tertenia	2015	Municipal administration
Tortoli	2011	Municipal administration

For each variable, tab. 6 summarizes data inputs and their sources, tool employed (when available; otherwise, ordinary GIS tools were used), and references.

*Tab. 6 - Spatial datasets developed for this chapter: input data, sources, tools, and references*

<i>Variable</i>	<i>Input data</i>	<i>Input data source(s)</i>	<i>Tool</i>	<i>References</i>
FH	PAI <i>FH</i> maps	Regional geoportal		---
	Municipal <i>FH</i> maps			
LH	PAI <i>LH</i> maps	Regional geoportal		---
	Municipal <i>LH</i> maps			
	Regional land cover raster map			
Natval	Protected areas map	Regional geoportal	InVEST - Habitat quality model	Lai and Leone, 2017
	Threats to biodiversity (spatial data only)			
	Expert judgments			
Consval	Habitats of Com-	Questionnaires		Cannas <i>et al.</i> , 2018
		Regional administra-		

<sup>11</sup> Available at the website <http://www.sardegnaegeoportale.it/areetematiche/modellidigitalidielevezione/> [Accessed: 22 February 2022].

<i>Variable</i>	<i>Input data</i>	<i>Input data source(s)</i>	<i>Tool</i>	<i>References</i>
Landsval	munity interest	tion		
	Regional monitoring report			
	Natura 2000 standard data forms	Environmental ministry's website		
	Regional landscape plan dataset	Regional geoportal		
Recrval	Study area	Regional geoportal	ESTIMAP model for assessing ecosystem based-recreation potential	
Agrofor	2018 Corine land cover map	Copernicus Land monitoring service		
	Land value (Agricultural areas)	National Research Council of Agriculture and Agricultural Economics' website		---
LST	Land value (Forestry areas)	National Revenue Agency's website		
	Landsat 8 TIRS and OLI satellite imagery	USGS's Earth Resources Observation and Science's website	LST QGIS plugin by Ndossi and Avdan (2016)	Lai <i>et al.</i> , 2020a Lai <i>et al.</i> , 2020b
CO2Stor	Regional land cover raster map	Regional geoportal		
	Carbon pool data	2005 National Inventory of Italian Forests Regional pilot project on land units and soil capacity in Sardinia	InVEST - Carbon storage and sequestration model	Floris, 2020
Altitud	10-m resolution Digital terrain model	Regional geoportal		---
Slope	10-m resolution Digital terrain model	Regional geoportal		---

Finally, through rasterization of vector maps and resampling of raster maps, a 30-m resolution raster map was developed for each variable; by overlaying such maps, an attribute table providing for each cell the corresponding value of each variable was produced to feed the regression model presented in Subsection 4.2.2.

Fig. 2 provides a complete overview of the methodology presented in Subsections 4.2.2 and 4.2.3.

## 4.4. Findings

This section contains two subsections. In the first, the spatial features of the hazard-related dichotomous variables and of the covariates of the Logit models are presented. In the following subsection, the estimates of the models are described and discussed.

### 4.4.1. Flood and landslide hazards and their drivers

Fig. 3 provides the spatial distribution of both dependent (left hand side panel) and independent (right hand side panel) variables.

Very high landslide hazard values concern less than the 5% of the study area; as the map shows, they form elongated clusters along the southwest-northeast direction due to geological and geomorphological reasons, along deep canyons in the Baunei, Dorgali, and coincident with the northern side of the Monte Albo karst mountain chain in Siniscola. Nearly 15% of the study area is classed as high hazard, while most of the study area is classed as either medium (about 25.5%) or moderate hazard (circa 40%). Only about 6% of the study area is classed as having no landslide hazard, while in the remaining part (approximately 8.5%), included in the municipality of Dorgali, landslide hazard was not assessed and mapped.

As for flood hazard, 90.5% of the study area shows null values; in the remaining parts, its level is mostly (6%) very high. The remaining 3.5% concerns high, moderate and low values. This is because flood hazard usually takes the maximum value in correspondence to riverbeds, river estuaries, coastal wetlands and their closest surroundings, while its level decreases (more or less quickly depending on factor such as morphology or soil type) as the distance increases. As shown in fig. 3, flood hazard is mostly found to the south and the north of the study area, and almost absent in the central part.

Concerning the independent variables, *Natval* takes extremely high values in most of the study area (around 72.8%) and medium values in around 23.5%, while the null value only concern the remaining 3.7% circa of the study area, corresponding to artificial surfaces such as villages and towns' footprints.

*Consval*, which in principle can range in the 0-1 interval, in the study area takes 0.76 as maximum value and it is null in around 61% of the territory. This is because habitats of Community interest are identified and mapped mostly within Natura 2000 site, while comprehensive assessments outside the network are missing. It is therefore not surprising that non-zero values are mostly found in the central part of the study area, hosting one of

the largest Sardinian Special Conservation Area (ITB020014 “Golfo di Orosei”).

*Landsval* is null in approximately 47.5% of the study area and, as clearly visible in fig. 3, takes the highest values along the coastline, because the Regional Landscape Plan strictly protects coastal landscapes, and along some the main rivers and creeks, also protected under the national landscape law.

*Recrval* takes the null value in a very negligible part of the study area (around 0.015%), while areas taking the maximum values are to be found mostly along the coastline, and, especially, along sandy beaches. This is not surprising, since, in compliance with the standard ESTIMAP methodology, a third of the total score is assigned based on the water-related elements, that account for proximity to the coast areas, type of geomorphology, and quality of bathing water, always excellent in the study area.

*Agrofor* is null in nearly a half (49.4%) of the study area. The highest values are observed in the southern and northern parts of the study area, especially in river valleys and coastal plains, as far as agricultural activities are concerned.

*LST* hot and cold values are quite clustered, and the clusters mostly correspond to those having high elevation or high slope values, as the maps in fig. 3 show.

Finally, *CO2Stor* ranges between zero and two Mg per hectare, with more than 61% of the study area above 1 Mg/ha, while low values are clustered mainly along the coastline to the north and along rivers and wetlands to the south.

#### 4.4.2. Estimates of the Logit models

Tab. 7 and 8 show the results of the estimates of the Logit models related to the dichotomous variables *FH* and *LH*, and its correlations with the seven environmental features which characterize the RGI. The outcomes partly differ for the two variables, and the differences can be explained through the environmental profiles of the two types of hazards.

In the case of *FH*, *Natval* and *Consval* reveal opposite impacts on the probability of a parcel to be associated either to a relevant or to a weak hazard condition. *Natval* shows a positive correlation to hazard decrease, i.e., a negative marginal effect, whereas *Consval* reveals a negative correlation, or a positive marginal effect.

The estimates of the Logit model concerning *LH* show the opposite correlations.

Secondly, *Recrval* and *Landsval* reveal impacts on the probability of weak flood and landslide hazards consistent with each other and positive in case of *Recrval* and negative as regards *Landsval*, which indicates that these two features of the RGI should be targeted in the opposite way with reference to prevention and control of flood and landslide hazards. This also implies that environmental and cultural attractiveness, and identification and protection of landscape and cultural resources, should be considered as points of reference to fight environmental hazard.

Thirdly, the impacts of *Agrofor* on *FH* and *LH* are opposite as well. Agricultural and forestry productive land shows a positive impact on decrease of landslide hazard and likewise a negative effect on flood hazard. As a consequence, effective control on environmental hazard implies that the most productive agricultural and forestry activities should not be located close to floodplains and their surroundings, where agricultural and forestry land should be used just to counter flooding. Productive agriculture and forestry should be implemented elsewhere, and in particular near areas characterized by a relevant landslide hazard.

Tab. 7 - Marginal effects on the probabilities of  $FH=1$  of variables described in subsection 4.2.3, whose definitions and descriptive statistics are reported in Tab. 2

Variable	Marginal effect	z-statistic	p-value
Marginal impact on $FH=1$ probability, $\partial \text{Prob}(FH=1)/dx_i$ , $\text{Prob}(FH=1) = 9.00\%$			
Natval	-0.0014	-5.555	0.0000
Consval	0.0120	24.578	0.0000
Landsval	0.0158	34.685	0.0000
Recrval	-0.0071	-31.487	0.0000
Agrofor	0.0011	32.863	0.0000
LST	-0.0018	-34.632	0.0000
CO2Stor	-0.0037	-18.252	0.0000
Altitud	-0.0001	-62.400	0.0000
Slope	-0.0002	-20.796	0.0000

Log-likelihood goodness-of-fit test

Log-likelihood ratio = 74241.04 - Prob. > chi-square = 0.00000 (9 degrees of freedom)

The sixth characteristic of the RGI is *LST*, which is an indicator of how, and to what extent, land covers help to mitigate negative phenomena such as heat islands and waves, and to improve the quality of the rural and urban environments (Lai *et al.*, 2020a). As in the cases of *Recrval*, the estimates of the two Logit models reveal impacts on the probability of weak flood and landslide hazards consistent with each other and positive, which indicates that this feature of the RGI does not need particular attention in terms of landslide and flood hazard control. Indeed, the estimates of the Logit models imply that the higher the *LST*, the lower the two hazards. Since the

question related to *LST* as regards climate regulation focuses on policies to decrease *LST*, it can be concluded that the issue of *LST* is not connected to control landslide and flood hazards.

Tab. 8 – Marginal effects on the probabilities of *LH=1* of variables described in subsection 4.2.3, whose definitions and descriptive statistics are reported in tab. 2

Variable	Marginal effect	z-statistic	p-value
Marginal impact on <i>LH=1</i> probability, $\partial \text{Prob} (LH=1)/\text{dxi}$ , $\text{Prob} (LH=1) = 44.80\%$			
Natval	0.3628	70.253	0.0000
Consva	-0.2474	-40.901	0.0000
Landsval	0.0901	27.937	0.0000
Recrval	-0.0948	-32.049	0.0000
Agrofor	-0.0186	-60.698	0.0000
LST	-0.0292	-76.328	0.0000
CO2Stor	0.0600	20.265	0.0000
Altitud	0.0002	40.777	0.0000
Slope	0.0089	130.201	0.0000

Log-likelihood goodness-of-fit test  
Log-likelihood ratio = 123488.80 - Prob. > chi-square = 0.00000 (9 degrees of freedom)

Furthermore, *CO2Stor* shows opposite impacts on the probability of a parcel to be associated either to a relevant or to a weak hazard condition. This is entirely consistent with expectations, since, in the case of flood hazard, areas vegetated and rich in soil are likely to increase the probability of weak hazard, since they work as drainage areas to absorb excess flooding and filter sediment, whereas, in the case of landslide hazard, the positive impact on the probability of hazard increase is likely to be connected to the fact that areas rich in soil are comparatively more suitable to debris flow, especially in zones characterized by steep slopes. That being so, adequate monitoring of environmental hazard implies that the RGI should encourage the conservation of vegetated and rich-in-soil areas in the surroundings of floodplains, even though not used as croplands, as it is put in evidence above as regards the impacts on flood hazard by *Agrofor*, while the most productive agricultural and forestry activities should be located not close to floodplains and their surroundings, and likewise not close to zones featured by steep slopes.

Finally, the estimated marginal effects of the two control variables, *Altitud* and *Slope*, reveal the expected signs in both cases, since, on the one hand, it is expected that the lower the altitude and the lower the slope, the higher the probability of severe flooding to take place, whereas the higher the altitude and the higher the slope, the higher the probability of serious landslide events. Moreover, all the estimated marginal effects are significant in terms of p-values, and, in general, the marginal effects on the prob-



ability of relevant flood hazard are much lower than the impacts on the probability of relevant landslide hazard since the cumulative probability of relevant flood hazard (lower than 10%) is much lower than the cumulative probability of relevant landslide hazard (about 50%). The goodness of fit of the estimates of the two models is excellent, as shown by the two log-likelihood ratios measures.

## 4.5. Bibliography

- Arisci A., De Waele J. and Di Gregorio F. (2000), “Natural and scientific valence of the Gulf of Orosei coast (central-east Sardinia) and its carrying capacity with particular regard to the pocket beaches”, *Periodicum Biologorum*, 102, Supplement 1: 595-603.
- Bacchetta G., Bagella S., Biondi E., Farris E., Filigheddu R. and Mossa L. (2009), “Vegetazione forestale e serie di vegetazione della Sardegna (con rappresentazione cartografica alla scala 1:350.000)” [Forest vegetation and serial vegetation of Sardinia (with map at 1:350,000 scale)], *Fitosociologia*, 46, 1: 3-82.
- Badiu D., Nita A., Ioja C. and Nita M. (2019), “Disentangling the connections: A network analysis of approaches to urban green infrastructure”, *Urban Forestry & Urban Greening*, 41: 211-220. DOI: 10.1016/j.ufug.2019.04.013.
- Bartens J. and Mersey Forest Team (2009), *Green infrastructure and hydrology*, text available at the website [https://www.merseyforest.org.uk/files/GI\\_Hydrology\\_Report\\_May\\_2009.pdf](https://www.merseyforest.org.uk/files/GI_Hydrology_Report_May_2009.pdf) [Accessed: 22 February 2022].
- Batzella T., Pusceddu N., Kalb C., Ferraro F., Ibba A. and De Muro S. (2011), “Bars/troughs dynamics and evolution trend of the La Cinta beach (San Teodoro OT) - NE Sardinia”, *Rendiconti Online della Società Geologica Italiana*, 17: 17-23. DOI: 10.3301/ROL.2011.13.
- Ben-Akiva M. and Lerman S. (1985), *Discrete Choice Analysis: Theory and Application to Travel Demand (Transportation Studies)*, The MIT Press, Cambridge, MA, United States.
- Bodini A. and Cossu Q.A. (2010), “Vulnerability assessment of Central-East Sardinia (Italy) to extreme rainfall events”, *Natural Hazards and Earth System Sciences*, 10, 1: 61-72. DOI: 10.5194/nhess-10-61-2010.
- Calvache M.F., Prados M.J. and Lourenço J.M. (2016), “Assessment of National Parks affected by naturbanization processes in Southern Europe”, *Journal of Environmental Planning and Management*, 59, 9: 1629-1655. DOI: 09640568.2015.1083416.
- Cannas I., Lai S., Leone F. and Zoppi C. (2018), “Green infrastructure and ecological corridors: a regional study concerning Sardinia”, *Sustainability*, 10, 4 (1265): 1-21. DOI: 10.3390/su10041265.
- Cannas I. and Zoppi C. (2017), *Ecosystem Services and the Natura 2000 Network: A Study Concerning a Green Infrastructure Based on Ecological Corridors in the Metropolitan City of Cagliari*, in Gervasi O., Murgante B., Misra S., Bor-

- ruso G., Torre C., Rocha A.M.A.C., Taniar D., Apduhan B.O., Stankova E. and Cuzzocrea A., eds., *17<sup>th</sup> International Conference on Computational Science and Its Applications (ICCSA 2017)*, Lecture Notes in Computer Sciences Series, Vol. no. 10409, Springer, Cham, Switzerland, pp. 379-400. DOI: 10.1007/978-3-319-62407-5\_39.
- Canu S., Rosati L., Fiori M., Motroni A., Filigheddu R. and Farris E. (2015), “Bioclimate map of Sardinia (Italy)”, *Journal of Maps*, 11, 5: 711-718. DOI: 10.1080/17445647.2014.988187.
- Caparrós-Martínez J.L., Milán-García J., Rueda-López N. and de Pablo-Valenciano J. (2020), “Green infrastructure and water: An analysis of global research”, *Water*, 12, 6 (1760): 1-25. DOI: 10.3390/w12061760.
- Chen J., Liu Y., Gitau M.W., Engel B.A., Flanagan D.C. and Harbor J.M. (2019), “Evaluation of the effectiveness of green infrastructure on hydrology and water quality in a combined sewer overflow community”, *Science of the Total Environment*, 665: 69-79. DOI: 10.1016/j.scitotenv.2019.01.416.
- Cherchi E. (2012), *Modelling Individual Preferences, State of the Art, Recent Advances and Future Directions*, in Pendyala R.M. and Bhat C.R., eds., *Travel Behaviour Research in an Evolving World*, Lulu Press, Raleigh, NC, United States, pp. 211-228.
- Cinus S., Demuru S., Deriu M., Farris M., Patteri G., Tilocca G. and Martelli R. (2007), *Analisi del Dissesto da Frana in Sardegna [An Analysis of Landslide Phenomena in Sardinia]*, in APAT, ed., *Rapporto sulle Frane in Italia*, APAT Rapporti no. 78/2007 [*Report on Landslides in Italy*, APAT Reports no. 78/2007], APAT, Rome, Italy, pp. 651-681, text available at the website [https://www.isprambiente.gov.it/files/pubblicazioni\\_rapporti/rapporto-frane-2007/Capitolo\\_25\\_Sardegna.pdf](https://www.isprambiente.gov.it/files/pubblicazioni_rapporti/rapporto-frane-2007/Capitolo_25_Sardegna.pdf) [Accessed: 22 February 2022].
- Cossu A., De Waele J. and Di Gregorio F. (2007), “Coastal karst geomorphosites at risk? A case study: The floods of 6-11 December 2004 in central-east Sardinia”, *Geological Society Special Publications*, 279, 1: 85-95. DOI: 10.1144/SP279.8.
- Cruden D.M. and Varnes D.J. (1996), *Landslide Types and Processes*, in Turner A.K. and Schuster R.L., eds., *Landslides: Investigation and Mitigation*, Transportation Research Board Special Report no. 247, National Academy Press, Washington DC, United States, pp. 36-75.
- De Waele J., Cabras S. and Sanna L. (2008), “Discharge estimates of the large December 2004 flood in some fluviokarstic watersheds in Central-East Sardinia”, *Rendiconti Online della Società Geologica Italiana*, 3: 312-313.
- Di Giovanni G. (2016), “Città a rischio: stato del sistema urbanistico italiano nella riduzione dei rischi sismici e idrogeologici”, *TeMA - Journal of Land Use, Mobility and Environment*, 9, 1: 43-62. DOI: 10.6092/1970-9870/3726.
- European Commission (2013a), *Building a Green Infrastructure for Europe*, European Union, Brussels, Belgium. DOI: 10.2779/54125.
- European Commission (2013b), *Green infrastructure (GI)—Enhancing Europe’s Natural Capital. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the*

- Committee of the Regions, text available at the website [https://eur-lex.europa.eu/resource.html?uri=cellar:d41348f2-01d5-4abe-b817-4c73e6f1b2df.0014.03/DOC\\_1&format=PDF](https://eur-lex.europa.eu/resource.html?uri=cellar:d41348f2-01d5-4abe-b817-4c73e6f1b2df.0014.03/DOC_1&format=PDF) [Accessed: 22 February 2022].
- European Commission (2013c), *The Economic benefits of the Natura 2000 Network*, Publications Office of the European Union, Luxembourg. DOI: 10.2779/41957.
- European Environment Agency (2019), *Land Take in Europe - Indicator Specification*, text available at the website <https://www.eea.europa.eu/data-and-maps/indicators/land-take-3> [Accessed: 22 February 2022].
- Floris M. (2020), *I Servizi Ecosistemici nella Pianificazione Spaziale come Strumenti Interpretativi per la Definizione di Tassonomie Territoriali Innovative [Ecosystem Services within Spatial Planning as Knowledge-Interpreting Tools for the Definition of Innovative Spatial Taxonomies]*, unpublished doctoral thesis discussed at the University of Cagliari on 6 March 2020.
- Gariano S.L. and Guzzetti F. (2016), “Landslides in a changing climate”, *Earth-Science Reviews*, 162: 227-252. DOI: 10.1016/j.earscirev.2016.08.011
- Greene W.H. (1993), *Econometric Analysis*, Macmillan, New York, NY, United States.
- Lai S. and Leone F. (2017), *Bridging Biodiversity Conservation Objectives with Landscape Planning through Green Infrastructures: A Case Study from Sardinia, Italy*, in Gervasi O., Murgante B., Misra S., Borruso G., Torre C., Rocha A.M.A.C., Taniar D., Apduhan B.O., Stankova E. and Cuzzocrea, A., eds., *17<sup>th</sup> International Conference on Computational Science and Its Applications (ICCSA 2017)*, Lecture Notes in Computer Sciences Series, Vol. no. 10409, Springer, Cham, Switzerland, pp. 456-472. DOI: 10.1007/978-3-319-62407-5\_39.
- Lai S., Leone F. and Zoppi C. (2017a), “Land cover changes and environmental protection: a study based on transition matrices concerning Sardinia (Italy)”, *Land Use Policy*, 67: 126-150. DOI: 10.1016/j.landusepol.2017.05.030.
- Lai S., Leone F. and Zoppi C. (2017b), “Anthropization processes and protection of the environment: An assessment of land cover changes in Sardinia, Italy”, *Sustainability*, 9, 12 (2174): 1-19. DOI: 10.3390/su9122174.
- Lai S., Leone F. and Zoppi C. (2018), “Implementing green infrastructures beyond protected areas”, *Sustainability*, 10, 10 (3544): 1-16. DOI: 10.3390/su10103544.
- Lai S., Leone F. and Zoppi C. (2020a), “Spatial distribution of surface temperature and land cover: A study concerning Sardinia, Italy”, *Sustainability*, 12, 8 (3186): 1-20. DOI: 10.3390/su12083186.
- Lai S., Leone F. and Zoppi C. (2020b), “Policies to decrease land surface temperature based on land cover change: An assessment related to Sardinia, Italy”, *TEMA - Journal of Mobility Land Use and Environment*, 13, 3: 329-351. DOI: 10.6092/1970-9870/7143.
- Lai S., and Zoppi C. (2017), “The influence of Natura 2000 sites on land-taking processes at the regional level: an empirical analysis concerning Sardinia (Italy)”, *Sustainability*, 9, 2 (259): 1-26. DOI: 10.3390/su9020259.
- Liquete C., Kleeschulte S., Dige G., Maes J., Grizzetti B., Olah B. and Zulian G.

- (2015), “Mapping green infrastructure based on ecosystem services and ecological networks: A Pan-European case study”, *Environmental Science & Policy*, 54: 268-280. DOI: 10.1016/j.envsci.2015.07.009.
- Liu W., Chen W. and Peng C. (2014), “Assessing the effectiveness of green infrastructures on urban flooding reduction: A community scale study”, *Ecological Modelling*, 291: 6-14. DOI: 10.1016/j.ecolmodel.2014.07.012.
- McFadden D. (1978), *Modelling the Choice of Residential Location*, in Karlqvist A., Lundqvist L., Snickars F. and Weibull J.W, eds., *Spatial Interaction Theory and Planning Models*, North Holland, Amsterdam, The Netherlands, pp. 75-96.
- McFadden D. (1980), “Econometric models for probabilistic choice among products”, *The Journal of Business*, 53, 3: 13-29.
- McFadden D. (2000), *Disaggregate Behavioral Travel Demand's RUM Side. A 30-Year Retrospective*, in Hensher D., ed., *Travel Behavior Research: The Leading Edge*, Pergamon Press, Oxford, United Kingdom, pp. 17-63.
- Margottini C. (2015), *Un Contributo per gli “Stati Generali dei Cambiamenti Climatici e l’Arte della Difesa del Territorio” [A Contribution to “General States of Climate Change and Soil Defense”]*, text available at the website [https://www.minambiente.it/sites/default/files/archivio/allegati/italiasicura/114\\_Contributodisses.pdf](https://www.minambiente.it/sites/default/files/archivio/allegati/italiasicura/114_Contributodisses.pdf) [Accessed: 22 February 2022].
- Mei C., Liu J., Wang H., Yang Z., Ding X. and Shao W. (2018), “Integrated assessments of green infrastructure for flood mitigation to support robust decision-making for sponge city construction in an urbanized watershed”, *Science of the Total Environment*, 639: 1394-1407. DOI: 10.1016/j.scitotenv.2018.05.199.
- Munafò M., ed. (2020), *Consumo di Suolo, Dinamiche Territoriali e Servizi Ecosistemici. Edizione 2020 [Land Take, Territorial Dynamics, and Ecosystem Services. 2020 Edition]*, Report SNPA no. 15/20, text available at the website <https://www.snambiente.it/2020/07/22/consumo-di-suolo-dinamiche-territoriali-e-servizi-ecosistemici-edizione-2020/> [Accessed: 22 February 2022].
- Ndossi M.I. and Avdan U. (2016), “Application of open source coding technologies in the production of Land Surface Temperature (LST) maps from Landsat: A PyQGIS Plugin”, *Remote Sensing*, 8, 5 (413): 1-31. DOI: 10.3390/rs8050413.
- Nerlove M. and Press S. (1973), *Univariate and Multivariate Log-linear and Logistic Models*, Report no. R1306-EDA/NIH, RAND Corporation, Santa Monica, CA, United States.
- Ortúzar J. de D. and Willumsen L.G. (2001), *Modelling Transport*, 3rd ed., John Wiley & Sons, Chichester, United Kingdom.
- Palla A. and Gnecco I. (2015), “Hydrologic modeling of low impact development systems at the urban catchment scale”, *Journal of Hydrology*, 528: 361-368. DOI: 10.1016/j.jhydrol.2015.06.050.
- Palmer M., Liu J., Matthews J., Mumba M. and D’Odorico P. (2015), “Water security: Gray or green?”, *Science*, 349, 6248: 584-585.
- Papathoma-Köhle M. and Glade T. (2013), *The Role of Vegetation Cover Change*

- for *Landslide Hazard and Risk*, in Renaud G., Sudmeier-Rieux K. and Marisol E., eds., *The Role of Ecosystems in Disaster Risk Reduction*, UNU-Press, Tokyo, Japan, pp. 293-320.
- RAS - Regione Autonoma della Sardegna, Assessorato Lavori Pubblici (2000), *Attività di Individuazione e di Perimetrazione delle Aree a Rischio Idraulico e Geomorfologico e delle Relative Misure di Salvaguardia. Linee Guida [Identifying and Mapping Areas Subject to Flood Risk and Landslide Risk, and Delineation of Safeguard Measures. Guidelines]*, text available at the website [http://www.regione.sardegna.it/documenti/1\\_26\\_20060913170604.pdf](http://www.regione.sardegna.it/documenti/1_26_20060913170604.pdf) [Accessed: 22 February 2022].
- RAS - Regione Autonoma della Sardegna, Assessorato Lavori Pubblici (2004), *Piano Stralcio per l'Assetto Idrogeologico (PAI). Relazione Generale [Hydrogeological Setting Plan. Comprehensive Report]*, text available at the website [http://www.regione.sardegna.it/documenti/1\\_26\\_20060913170906.pdf](http://www.regione.sardegna.it/documenti/1_26_20060913170906.pdf) [Accessed: 22 February 2022].
- Righini M., Surian N., Wohl E., Marchi L., Comiti F., Amponsah W. and Borga M. (2017), "Geomorphic response to an extreme flood in two Mediterranean rivers (Northeastern Sardinia, Italy): Analysis of controlling factors", *Geomorphology*, 290: 184-199. DOI: 10.1016/j.geomorph.2017.04.014.
- Ronchi S., Arcidiacono A. and Pogliani L. (2020), "Integrating green infrastructure into spatial planning regulations to improve the performance of urban ecosystems. Insights from an Italian case study", *Sustainable Cities and Society*, 53 (101907): 1-12. DOI: 10.1016/j.scs.2019.101907.
- Scolobig A., Linnerooth-Bayer J. and Pelling M. (2014), "Drivers of transformative change in the Italian landslide risk policy", *International Journal of Disaster Risk Reduction*, 9: 124-136. DOI: 10.1016/j.ijdr.2014.05.003.
- Seneviratne S.I., Nicholls N., Easterling D., Goodess C.M., Kanae S., Kossin J., Luo Y., Marengo J., McInnes K., Rahimi M., Reichstein M., Sorteberg A., Vera C. and Zhang X. (2012), *Changes in Climate Extremes and their Impacts on the Natural Physical Environment*, in Field C.B., Barros V., Stockerds., T.F., Qin D., Dokken D.J., Ebi K.L., Mastrandrea M.D., Mach K.J., Plattner G.K., Allen S.K., Tignor M. and Midgley P.M., eds., *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC)*, Cambridge University Press, Cambridge, United Kingdom, pp. 109-230, text available at the website [https://www.ipcc.ch/site/assets/uploads/2018/03/SREX-Chap3\\_FINAL-1.pdf](https://www.ipcc.ch/site/assets/uploads/2018/03/SREX-Chap3_FINAL-1.pdf) [Accessed: 22 February 2022].
- Stoffel M., Tiranti D. and Huggel C. (2014), "Climate change impacts on mass movements - Case studies from the European Alps", *Science of the Total Environment*, 493: 1255-1266. DOI: 10.1016/j.scitotenv.2014.02.102.
- Stolton S., Dudley N. and Randall J. (2008), *Natural Security. Protected Areas and Hazard Mitigation*, WWF International, Gland, Switzerland.
- Tiranti D. and Cremonini R. (2019), "Editorial: Landslide hazard in a changing environment", *Frontiers in Earth Science*, 7: 1-3. DOI: 10.3389/feart.2019.00003.

- Train K. (2009), *Discrete Choice Methods with Simulation*, 2nd ed., Cambridge University Press, Cambridge, United Kingdom.
- Trigila A., Iadanza C., Bussettini M. and Lastoria B. (2018), *Dissesto Idrogeologico in Italia: Pericolosità e Indicatori di Rischio - Edizione 2018*. ISPRA, Rapporti no. 287/2018 [*Hydrogeological Instability in Italy: Hazard and Risk Indicators - 2018 Edition*, ISPRA Reports no. 287/2018], ISPRA, Rome, Italy, text available at the website <https://www.isprambiente.gov.it/it/pubblicazioni/rapporti/dissesto-idrogeologico-in-italia-pericolosita-e-indicatori-di-rischio-edizione-2018> [Accessed: 22 February 2022].
- Tversky A. (1972), “Elimination by aspects: A theory of choice”, *Psychological Review*, 79, 4: 281-299. DOI: 10.1037/h0032955.
- United States Environment Protection Agency (2017), *What Is Green Infrastructure?*, text available at the website <https://www.epa.gov/green-infrastructure/what-green-infrastructure> [Accessed: 22 February 2022].
- Varnes D.J. (1978), *Slope Movement Types and Processes*, in Schuster R.L. and Krizek R.J., eds., *Landslides: Analysis and Control*, Transportation Research Board Special Report no. 176, National Academy of Sciences, Washington DC, United States, pp. 11-33.
- Williams H.C.W.L. (1977), “On the formation of travel demand models and economic evaluation measures of user benefit”, *Environment and Planning A*, 9, 3: 285-344. DOI: 10.1068/a090285.
- Xiao Q. and McPherson E. (2002), “Rainfall interception by Santa Monica’s municipal urban forest”, *Urban Ecosystems*, 6, 4: 291-302. DOI: 10.1023/B:UECO.0000004828.05143.67
- Zoppi C. and Lai S. (2013), “Differentials in the regional operational program expenditure for public services and infrastructure in the coastal cities of Sardinia (Italy) analyzed in the ruling context of the Regional Landscape Plan”, *Land Use Policy*, 30, 1: 286-304. DOI: 10.1016/j.landusepol.2012.03.017.
- Zucaro F. and Morosini R. (2018), “Sustainable land use and climate adaptation: a review of European local plans”, *TeMA - Journal of Land Use, Mobility and Environment*, 11, 1: 7-26. DOI: 10.6092/1970-9870/5343.



## 5. *Conclusions*

The concluding chapter discusses the outcomes of the studies presented in the volume and the related planning policy implications. It develops through three sections. The first highlights the relations and the advancements entailed by the spatial taxonomy which identifies the RGI. The next section focuses on the planning measures concerning the implementation of the Sardinian regional network of protected areas, with particular reference to its EC. The third section addresses the issue of the relations between the spatial framework of landslide and flood hazards, and the effectiveness of GI in decreasing the size of such hazards.

### **5.1. The spatial taxonomy to identify the RGI**

The availability of spatially explicit assessment of multiple ES makes it possible to identify priority areas for the inclusion in a regional GI. One possible approach is that of identifying those areas that have the highest potential to deliver several ES by calculating the sum of normalized bio-physical values (as, for instance, in Arcidiacono *et al.*, 2016; Lai and Leone, 2017; Cannas *et al.*, 2018) or by calculating the total economic value of the supplied ES. Although helpful in providing a quick, and easy to communicate, assessment of potential ES supply, such approaches oversimplify the multifaced characters of landscapes. Indeed, as stated in the introductory chapter of this volume, in the words of the European Commission (2013), a GI is «a strategically planned network of natural and semi-natural areas [...] designed and managed to deliver a wide range of ecosystem services» (p. 3). By using the phrase “a wide range”, this definition problematically implies that several ES can be delivered simultaneously. While research has consistently shown that some ES are often jointly provided and intertwined (Bennett *et al.*, 2009; Marsboom *et al.*, 2018), several studies



highlight that some interrelationships are negative and result in trade-offs (among many, Madureira and Andresen, 2014), especially as regards provisioning ES (Balbi *et al.*, 2015, Power, 2010; Raudsepp-Hearne *et al.*, 2010). Therefore, multifunctionality, that is, an area's capacity to provide simultaneously multiple ES, can be effectively investigated in terms of synergies and tradeoffs.

The analysis of bundles of ES provision at the municipal levels, carried out by integrating various types of spatial statistics, unveils, as expected, that agricultural and forestry productivity competes with the other ES; moreover, and this was less expected, it also reveals trade-offs between carbon capture and storage and the other ES. For this reason, areas that are relevant for the delivery of a certain ES might be not so important when another ES is considered. However, the key take-away message from the analysis carried out concerning multifunctionality, and therefore the identification of a potential spatial layout of a regional GI, is that such identification should be based on a thorough analysis of bundles of ES, rather than on single ES. Indeed, the presence of mutual interactions between ES, be they positive or negative, makes it possible to identify homogeneous subregions that supply different composite baskets of ES. By analyzing such interactions, spatial patterns emerge, which reflect both ecological and socio-economic patterns. Land-use planning and landscape planning should, on the one hand, use the assessment of potential ES delivery as a reference point to develop their strategies; on the other hand, when envisaging planning actions, planners and decision makers should have clear what the consequences of such actions would be on current and future levels of ES supply.

In the case of Sardinia, for instance, planning actions concerning group 3 should aim at preserving current levels of *Landsval* and *Recrval*, which are already very high, while there is scope for increasing *Natval*, *CO2Stor*, and *LST*, for instance through afforestation measures to be carried out in urban and peri-urban areas, as well as by developing green corridors along the coastal wetlands that characterize these municipalities, together with the pertaining traits of rivers and canals. Within group 3, actions to strengthen agricultural and forestry production, hence *Agrofor*, are to be carefully pondered, both because the morphology is not appropriate for forestry, and because intensive agriculture would risk being detrimental for *Recrval* and *Natval*.

As for group 2, maintaining current levels of agricultural productivity should be the main goal here, both because it contributes to local food security and because it generates revenues and jobs, hence strengthening social stability. While it is very difficult to envisage actions that might increase

*Consva*, as this depends on the presence of habitats of community interest, which would displace agricultural crops, actions to increase *LST* and *Recrval* might be put in place. As for the first, afforestation measures in this group should target not only urban areas, whose surface is negligible except for the municipality of Sassari, which stands out, to the north, for its size; rather, afforestation should target unused lots and land subject to the so-called *usi civici*. These represent the Italian way to the commons (Ostrom, 1990) in that, due to laws and customs that date back to the Middle Ages, they are at the disposal of the local community of the municipality in which the plots of land are located, for either grazing, or collecting firewood, or picking non-wood produce. As these areas cannot be privately owned and can be neither sold nor rented out by the public institution because they belong to the local community, afforesting these areas would pose no harm to economic activities, as it would do in private and farmed plots. As for the second, because the water-related component cannot be increased, to raise *Recrval* one would need to enhance either the suitability for nature-based recreation, or the nature-related elements, or both. To achieve this aim, afforestation of the commons could be complemented with the establishment of small natural parks in the same areas, which could attract visitors from the nearby settlements, especially if properly equipped with recreation facilities. Incidentally, this would also help dramatically reduce the unmet demand for ecosystem-based recreation mapped in fig. 5 of the second chapter in this volume, as unmet demand mostly concerns municipalities comprised in group 2.

Concerning groups 1 and 4, the main goal in both cases is maintaining the good levels of *CO2Stor*, by preventing new land take and, especially, new soil sealing. This would also contribute to preserving the good levels of *LST* observed in group 1, while, for group 4, policies similar to those identified as regards group 2 (i.e., afforestation of the commons and establishment of small natural parks) would be beneficial to increase *LST* and *Recrval*.

Finally, within group 5 the key objective should be that of preserving the levels of ES provided, which are all comparatively high except for *Agrofor*. Municipalities included in group 5 tend to have very limited agricultural areas, both due to morphological characters, as they include the island's main mountain areas, and due to the prevailing vegetation, which comprises maquis and forests. Hence, if *Agrofor* is to be enhanced, then a possible way would be that of raising the forestry value, rather than the agricultural one. This, however, is problematic for several reasons: first, forests are mostly publicly owned; second, the wood mass-market, such as that of paper and furniture, for instance, requires types of woods that grow

faster and higher than the Sardinian ones; third, Sardinian forestry was quite important in the past: during the XVIII and the XIX centuries, for instance, large forests were fell to export the wood for the naval industry (Costa, 2008), but in more recent times forestry was linked to local consumption only, for the construction of the railroad (Sistu and Perelli, 2011), for the paper industry, or for burning and producing coal (Beccu, 2000). Hence, it is quite unlikely that any efforts to position the island's forestry in the wood market would be successful.

To sum up, based on the analysis of spatial patters of bundles of ES, a case can be made for the existence of a territorial specialization (Queiroz *et al.*, 2015) that should be accounted for within land-use plans, whose actions can either enhance or degrade the supply of some ES. Awareness should be raised on the fact that planning provisions aimed at fostering some ES (first and foremost, agricultural productivity) are often detrimental to the maintenance of other ES, as, for instance, regulation and cultural ES (Martín-López *et al.*, 2012), while, in case of synergies, actions aiming at increasing a single ES end up with enhancing other synergic ES. Thus, such synergies and trade-offs call for careful ex-ante assessments in plan-making processes.

## **5.2. The EC of the regional network of protected areas**

The results of model (1), shown in the third chapter, make it possible to assess if, and to what extent, the current zoning code of the RLP can represent a solid basis for effectively protecting EC, and highlight important implications for spatial planning practice.

The transition from agricultural to forest land uses, which should be supported by financial grants aimed at compensating differential yields, is associated to a decrease in CWD, and, as a consequence, to a strengthening in the EC's spatial structure.

Planning measures focused on agroforestry transition are more straightforward and easier to implement as regards the areas classed as HAFU (as for specialized herbaceous crops, agricultural and forest areas, and uncultivated areas), and, even more, with reference to zones classed as SPTC (as for temporary crops related to other permanent crops). On the other hand, land cover transitions from intensive agricultural production areas, characterized by high crop yields, to less profitable woodlands (WOOD) or cork and chestnut woods (CCHW), can hardly be compensated by means of public grants, due to the size of the needed financial effort (Hyttiainen *et al.*, 2008). As regards intensive agricultural production zones, agroforestry

transition should be implemented through a cooperative and integration-oriented policy by the involved public administrations at different spatial scales, in terms of technical expertise and financial feasibility assessment (Sagebiel *et al.*, 2017; Hou *et al.*, 2018; Zavalloni *et al.*, 2021). For instance, in case of goat and sheep farming, land cover change from grazing land to wooded areas can be effectively financed through public grants, so as to mitigate or even fully compensate the yield decrease implied by such transition. Different is the case of cattle grazing areas, characterized by very high yields, whose transition would possibly generate relevant, and even dramatic and destabilizing, impacts on the regional livestock economy, since wooded pasture, such as the Spanish *dehesa*, is not economically suitable to cattle farming.

Furthermore, afforestation intensity should be carefully assessed. As per Li *et al.* (2021), an increasing trend in wooded areas may possibly be associated to a progressive rise in the ratio of costs to benefits of afforestation processes. Feng *et al.* (2005) show that unbalanced development of woodlands is likely to put at risk food safety. This implies that trade-offs between the provision of different ecosystem services and their economic and social benefits should be analyzed in detail.

A specific assessment of the question of afforestation, based on land cover transition from farming to forestry, is proposed in a study related to social and economic factors driving from croplands to afforestation, which are particularly focused on the identification of the determinants concerning policy-making decisions (Ryan and O'Donoghue, 2016). From this standpoint, the perception of benefits coming from farming are important obstacles as regards afforestation (Howley *et al.*, 2015). This is basically due to the farmers' strong perception of the positive effects related to the non-market value generated by flexible farming-related practices, and to their unwillingness to lose their durable expertise, which in their view is likely to be more important than the expected increase in income coming from afforestation (Ryan and O'Donoghue, 2016). Transition from intensive farming to forest land cover differs significantly from afforestation which originates from extensive croplands (Duesberg *et al.*, 2014) In the former case, a transition is quite unlikely, whereas it is much more probable in the latter, since the expected income from forestry is likely to exceed the income coming from extensive farming, while intensive farming, which develops from permanent agriculture through high-yielding crops, is expected to have the highest rent (Kumm and Hessle, 2020). Extensive and intensive farming should be targeted in terms of planning measures to decrease LST, based on incentive schemes. Agricultural farmers may possibly

engage in afforestation, and, by doing so, disengage from low-income farming. The incentive effectiveness is likely to be identified in afforestation coming from transitions from mosaic farmlands and grazing lands, whereas it is quite unlikely that this is case as regards intensive agriculture (Hyytiainen *et al.*, 2008). Moreover, the expansion of forest areas throughout rural zones featured by high-income farming should be carefully assessed by planning agencies in terms of financial feasibility as much as they should carefully consider the negative impact of afforestation on the traditional rural framework in terms of economic, social and landscape degradation (Behan *et al.*, 2006).

All in all, planning policies and measures to strengthen operational capacity and effectiveness of the regional network of protected areas through the protection and the improvement of the spatial framework of its EC have to be studied, structured and implemented by focusing on the ruling concept that habitat quality, ecological integrity and ecosystem conditions have to be enhanced and boosted-up (Samways *et al.*, 2010).

From this standpoint, it has to be highlighted that the methodological approach defined and implemented in the third chapter of this volume can be easily exported to the EU local, regional and national scales, since spatial databases consistent with each other are available for Sardinia and Italy as for the other regions and countries.

### 5.3. Natural hazards and GI

The methodological approach proposed in this volume and implemented in the previous chapter analyzes the relations between RGI and environmental hazards, represented by landslides and floods. In particular, the chapter focuses on nine variables that are here regarded as proxies for the RGI functions. The results imply the definition of planning policies based on ecosystem service conservation and enhancement (Baskent, 2020). The estimates of the Logit models highlight some issues worth discussing.

Landslides are more likely to occur in areas characterized by high natural values (Zhang *et al.*, 2018) and their negative impacts as regards these areas entail relevant systemic effects with respect to the complex environmental matrices which characterize such areas (Yousefi *et al.*, 2020), particularly sensitive to landslides and floods (Dragicevic *et al.*, 2011).

Areas characterized by high values of *Consval*, such as Natura 2000 sites, show a higher probability of flood hazard occurrences. Natural and semi-natural zones located within protected areas mitigate flood hazard and its potential negative impacts by providing permeable surfaces character-

ized by the presence of vegetation that absorbs floodwaters. Conservation planning theory focuses on the concept of vulnerability and deems the establishment of a widespread network of protected areas, such as Natura 2000, as a key planning tool to protect natural ecosystem services and mitigate natural hazards (Turner *et al.*, 2007). Recent natural disasters caused by floods have demonstrated how past planning choices have drained, dammed and diverted watercourses not paying any attention to the involved delicate environmental matrices (Stolton *et al.*, 2008; Isola and Leone, 2019). Moreover, protected areas are characterized by natural vegetation, such as forests, which prevent or mitigate landslides, snowslides and avalanches (Stolton *et al.*, 2008). According to Guareschi *et al.* (2020), natural and conservation values represent the potential capability of biodiversity to provide ecosystem services despite threats and pressures. Therefore, analyzing the probability of an area to be associated to specific hazard conditions is essential to the spatial and sustainable development of the area and to define appropriate planning choices aimed at protecting the environment (Dragicevic *et al.*, 2011).

High values of *Recrval* and *Landsval* are mainly concentrated in coastal areas characterized by significant environmental, social, and cultural qualities. As a result, in these areas planning policies and strategies are fundamental in order to mitigate the effects of flood and landslide hazard, especially in relation to problems concerning coastal erosion that affects the entire Sardinian regional coastal zones. Damages caused by floods and landslides threaten the integrity of coastal areas, whose protection requires a great effort to balance development pressures, and economic and environmental sustainability. According to the UNESCO's final report on the "Results of the second cycle of the periodic reporting exercise for the Europe Region and Action Plan" (UNESCO, 2015), landscape and cultural resources are extremely exposed to the adverse effects of natural hazards. This problem is also highlighted in the "Sendai Framework for disaster risk reduction 2015-2030" (United Nations, 2015), whose vision aims at supporting the implementation of the 2030 Agenda for Sustainable Development, one of which objectives is to «strengthen efforts to protect and safeguard the world's cultural and natural heritage» (Goal n. 11, target 11.4). In this regard, the study proposed by Ravankhah *et al.* (2019) is worth mentioning, because it defines a «taxonomy of natural hazards in relation to cultural heritage based on a theoretical and conceptual framework» (p. 1). By taking historic center of Réthymno, in Crete, as a case study, the authors identify and analyze those hazards that are likely to generate damages to the historic elements of the towns in order to support decision-making processes in designing and implementing mitigation interventions.

As regards *Agrofor*, the findings suggest that agricultural and forestry land should be used only to face flooding (O'Connell *et al.*, 2007), while the productive use of agricultural and forestry areas should be implemented elsewhere. However, riparian areas are particularly productive and, therefore, profitable for farmers due to their proximity to water resources. The study by Fedele *et al.* (2018), by looking at the provinces of West Kalimantan and Central Java in Indonesia, suggests that natural hazards ought to orient adaptation strategies in local contexts so as to reduce risks to which affected people are exposed; among such strategies, the authors propose to implement land use changes that entail trade-offs in the provision of different types of ecosystem services. Such aspects have to be carefully analyzed when designing policies to enhance the quality of RGI.

In relation to *CO2Stor*, the chapter's outcomes are entirely consistent with the findings of several studies which put in evidence direct positive correlations between carbon capture and storage, and mitigation of the impacts of climate change through abatement of greenhouse gases (among many, Aminu *et al.*, 2017; Floris and Zoppi, 2020).

According to the European Environment Agency (2015), the role of RGI in mitigating the impacts of natural hazards is crucial (Salata *et al.*, 2016). Indeed, the role that RGI plays in mitigating flood hazard in relation to *Natval* is straightforward; however, in the case of floodplains flood hazard the RGI should encourage the negative sign of *Natval* puts in evidence that encouraging conservation of vegetated and rich-in-soil riparian areas may possibly be associated to a decrease in the potential capability of biodiversity to supply final ecosystem services.

Furthermore, the issue of the potential damage generated by the interaction of different types of hazard should be carefully taken into consideration (Yousefi *et al.*, 2020) when designing and implementing risk-reduction projects at the regional and local scales (Pourghasemi *et al.*, 2020).

A number of policy implications and recommendations can be derived from the outcomes of the previous chapter.

The results concerning the influence of *Natval* and *Consval* on the probability of comparatively higher flood and landslide hazards imply that, in case of landslide hazard, prevention and control should target areas with a relevant natural value, that is, areas endowed with a significant potential supply of ecosystem services, while, in case of flood hazard, they should focus on areas featured by the presence of natural habitats types of Community interest, as identified under the Habitats Directive. Since areas showing high values of *FH* are mostly concentrated in the floodplains and their surroundings, while areas having high values of *LH* are widespread over the study area, and, in more general terms, over the whole Sardinian

island, these findings entail different implications concerning prevention and control hazards when defining spatial planning policies to implement the RGI. That being so, the definition and implementation of the RGI should carefully study and develop spatial policies related to waterways and their surroundings, which should entail strict regulations related to anthropic access and visits in floodplains areas characterized by significant values of *Consval*, i.e., by a relevant concentration of habitats of Community interest. Moreover, the RGI-related spatial policies should carefully balance the relationship between *Natval* and landslide hazard, that is, they should address the issue of the exploitation of natural ecosystem services located in areas endowed with high supply potentials, and likewise characterized by a relevant landslide hazard. This is entirely consistent with the position of the Commission of the European Communities, which recommends that «working with nature's capacity to absorb or control impacts in urban and rural areas can be a more efficient way of adapting than simply focusing on physical infrastructure» (Commission of the European Communities, 2009, p. 5). Since Natura 2000 sites within Sardinia include most coastal wetlands, estuaries, waterways, and large stretches of coastal areas, it is pretty straightforward that parcels located in these areas should show a relevant impact on flood hazard. Spatial planning policies should therefore include strict regulations related to new settlement development in floodplains, oriented to protect nature and natural resources belonging to riparian areas and their surroundings, which are characterized by high figures of *Consval*. Consistently with these observations, the Lower Danube Green Corridor Agreement focuses on the restoration of around 2,000 square kilometers of floodplains, side channels and associated habitats along the Danube as a control measure to mitigate the destructive impacts of floods in the region. The estimated cost (about 50 million euros) is lower than the cost related to the environmental damages caused by floods in 2010 (European Commission, 2010).

The impact of *Natval* on the probability of high landslide hazard entails that spatial policies should protect forests, which exert a relevant action to mitigate soil erosion, surface water runoff and slope instability, and, in so doing, to reduce landslide hazard (Trigila *et al.*, 2018). Moreover, silvicultural activities generate outstanding negative impacts on forests if they neglect best available practices related to forest management (Siry *et al.*, 2005). In terms of ecological stability, high forests should be preferred, with the exception of areas characterized by high values of *LH*, high slopes and low soil power, where shrub species are expected to be more suitable. Furthermore, forest road systems require appropriate planning, implementation, and maintenance in order to avoid concentration of surface water



runoff and erosion, and triggering of landslides along the slopes (Sapač *et al.*, 2017).

The outcomes of the regression model imply that forestry activities should be favored in riparian areas and their surroundings to mitigate flood hazard, while agricultural uses should be moved to more distant locations. Agriculture displacement may possibly be implemented by means of incentives, assigned to low rent farmers in order to become forest farmers (Lai *et al.*, 2020). Moreover, maintenance interventions in agriculture and forestry contribute to mitigating flood hazard. In areas characterized by arable land-pasture, terraces or permanent non-terraced crops, agro-forestry-pastoral interventions may entail benefits in terms of soil conservation, such as applications of specific innovative agricultural practices, crop diversification or buffer strip systems between agricultural areas and waterways (Regione Piemonte, 2018).

Spatial planning policies are potentially powerful in terms of mitigation of flood and landslide hazards (Hartmann and Spit, 2015); however, the normative frameworks of water resource management and soil protection are quite inconsistent with each other. At the European level, the EU Water Framework Directive (Directive 2000/60/EC) and the European Directive on the Assessment and Management of Flood Risk (Directive 2007/60/EC) represent the statutory policies concerning water resource planning and management at the European level. As for landslide hazard, a European normative framework is still missing. At the Italian national level, notwithstanding the approval of some specific laws, such as the already mentioned no. 183/1989 and no. 267/1998, a comprehensive and integrated normative system related to protection from landslide and flood hazards is missing as well, and the Italian legislation mainly focuses on water catchment management. Sardinia is characterized by high landslide and flood hazards (Trigila *et al.*, 2018), and its hydrogeological structure is quite unstable due to natural phenomena and anthropic actions. The Sardinian government has designed three regional plans concerning landslide and flood hazards: the already mentioned PAI in 2006, focusing on protection and conservation of soils and on prevention and management of landslide and flood hazards; a management plan for riversides and their surrounding areas in 2015; and finally a flood risk management plan consistent with the Directive 2007/60/EC in 2016, aimed at mitigating negative consequences of floods on life quality, environment, cultural heritage, and social and economic activities.

Moreover, the methodological approach implemented in this volume shows two innovative aspects. Firstly, the relationship between flood hazard and the implementation of GI is assessed at the regional level, whereas

the current literature mainly uses municipal and sub-municipal frameworks to analyze their interdependence, for instance, by making reference to green roofs and permeable pavements. The regional scale is much more suitable to deal with the integration of environmental hazards management and GI implementation, in terms of planning policy, awareness-building and decision-making processes. Secondly, the methodological approach uses data that are easily accessible to researchers, policy makers, and practitioners, and comparatively cheaper than complicated microeconomic estimates, in terms of both costs and time.

In conclusion, the methodological approach proposed in this volume may represent a tool in support of spatial decision-making processes that can be exported to other European contexts, due to its adaptability to the national planning and normative framework, on the basis of the European legislation concerning protection and improvement of nature and natural resources. The implemented methodology is effective in supporting civil officers, practitioners, and local public authorities to deal with the impacts of land cover and land use changes. From this perspective, the integration of GI-related and environmental planning policies may represent a basis to drive local decision-making processes towards prevention or, at least, mitigation of damages generated by landslides and floods, and towards the establishment of appropriate regulations.

Promising directions for future research can be identified as follows. A particular focus should be given to building a new normative framework to implement the RGI conceptual and technical category, conceived as a provider of ecosystem services, into the theoretical and technical approaches of the European and national spatial planning practices. Moreover, a relevant profile to be explored is represented by the role of local communities as regards the definition and implementation of planning processes aimed at managing environmental hazard through policies related to ecosystem service protection and enhancement. These processes should be based on the progressive improvement of the scientific, technical, and cultural expertise of the local societies concerning the provision of goods and services generated by the ecosystems, and are identified by the category of urban bioregion (Magnaghi, 2019). In this conceptual framework, the communities' incremental awareness can be identified as a main driver of the qualitative improvement of the spatial, environmental and landscape heritage at the local level. Under this perspective, mitigation and control of landslide and flooding hazards can be included in the planning practices implemented by the local governments representing societies fully aware of the importance of nature and natural resources as regards their potential in terms of life quality improvement (Magnaghi, 2020).

## 5.4. Bibliography

- Aminu M., Nabavi S.A., Rochelle C. and Manovic V. (2017), “A review of developments in carbon dioxide storage”, *Applied Energy*, 208: 1389-1419. DOI: 10.1016/j.apenergy.2017.09.015.
- Arcidiacono A., Ronchi S. and Salata S. (2016), “Managing multiple ecosystem services for landscape conservation: A green infrastructure in Lombardy Region”, *Procedia Engineering*, 161: 2297-2303. DOI: 10.1016/j.proeng.2016.08.831.
- Balbi S., del Prado, A., Gallejones P., Geevan C.P., Pardo G., Pérez-Miñana E., Manrique E., Hernandez-Santiago C. and Villa F (2015), “Modeling trade-offs among ecosystem services in agricultural production systems”, *Environmental Modelling & Software*, 72, 314-326. DOI: 10.1016/j.envsoft.2014.12.017.
- Baskett E.Z. (2020), “A framework for characterizing and regulating ecosystem services in a management planning context”, *Forests*, 11, 1 (102): 1-20. DOI: 10.3390/f11010102.
- Beccu E. (2000), *Tra Cronaca e Storia. Le Vicende del Patrimonio Boschivo della Sardegna [Between News and History. A Story of Forests in Sardinia]*, Carlo Delfino Editore, Sassari, Italy.
- Behan J., McQuinn K. and Roche M.J. (2006), “Rural land use: Traditional agriculture or forestry?”, *Land Economics*, 82, 1: 112-123. DOI: 10.3368/le.82.1.112.
- Bennett E.M., Peterson G.D. and Gordon L.J. (2009), “Understanding relationships among multiple ecosystem services”, *Ecology Letters*, 12: 1394-1404. DOI: 10.1111/j.1461-0248.2009.01387.x.
- Cannas I., Lai S., Leone F. and Zoppi C. (2018), “Green infrastructure and ecological corridors: a regional study concerning Sardinia”, *Sustainability*, 10, 4 (1265): 1-21. DOI: 10.3390/su10041265.
- Commission of the European Communities (2009), *White Paper. Adapting to Climate Change: Towards A European Framework for Action*, text available at the website <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52009DC0147&from=EN> [Accessed: 22 February 2022].
- Costa C. (2008), *Uomo, ambiente e istituzioni nella Sardegna della seconda metà dell'Ottocento: sfruttamento forestale e disordine idraulico [People, Environment and Institutions in Sardinia in the second Half of the XIX Century: Forest Exploitation and Hydraulic Instability]*, unpublished doctoral thesis discussed at the University of Cagliari.
- Dragicevic S., Filipovic D., Kostadinov S., Ristic R., Novkovic I., Zivkovic N., Andjelkovic G., Abolmasov B., Secerov V. and Djurdjic S. (2011), “Natural hazard assessment for land-use planning in Serbia”, *International Journal of Environmental Research*, 5, 2: 371-380. DOI: 10.22059/IJER.2011.322.
- Duesberg S., Ní Dhubháin A. and O’Connor D. (2014), “Assessing policy tools for encouraging farm afforestation in Ireland”, *Land Use Policy*, 38: 194-203. DOI: 10.1016/j.landusepol.2013.11.001.

- European Commission (2010), “Promoting the socio-economic benefits of Natura 2000”, *Natura 2000*, 29: 1-16, text available at the website [https://ec.europa.eu/environment/nature/info/pubs/docs/nat2000newsl/nat29\\_en.pdf](https://ec.europa.eu/environment/nature/info/pubs/docs/nat2000newsl/nat29_en.pdf) [Accessed: 22 February 2022].
- European Commission (2013), *Green infrastructure (GI)—Enhancing Europe’s Natural Capital. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions*, text available at the website [https://eur-lex.europa.eu/resource.html?uri=cellar:d41348f2-01d5-4abe-b817-4c73e6f1b2df.0014.03/DOC\\_1&format=PDF](https://eur-lex.europa.eu/resource.html?uri=cellar:d41348f2-01d5-4abe-b817-4c73e6f1b2df.0014.03/DOC_1&format=PDF) [Accessed: 22 February 2022].
- European Environment Agency (2015), *Exploring Nature-based Solutions. The Role of Green Infrastructure in Mitigating the Impacts of Weather- and Climate Change-related Natural Hazards*, EEA Technical Report no. 12/2015, Publications Office of the European Union, Luxembourg. DOI: 10.2800/946387.
- Fedele G., Locatelli B., Djoudi H. and Colloff M.J. (2018), “Reducing risks by transforming landscapes: Cross-scale effects of land-use changes on ecosystem services”, *PLoS ONE*, 13, 4 (e0195895): 1-21. DOI: 10.1371/journal.pone.0195895
- Feng Z., Yang Y., Zhang Y., Zhang P. and Li Y. (2005), “Grain-for-green policy and its impacts on grain supply in West China”, *Land Use Policy*, 22, 4: 301-312. DOI: 10.1016/j.landusepol.2004.05.004.
- Floris M. and Zoppi C. (2020), “Ecosystem services and spatial planning: A study on the relationship between carbon sequestration and land-taking processes”, *Archivio di Studi Urbani e Regionali*, 51, 127, Supplemento: 11-33.
- Guareschi S., Laini A., Viaroli P. and Bolpagni R. (2020), “Integrating habitat- and species-based perspectives for wetland conservation in lowland agricultural landscapes”, *Biodiversity and Conservation*, 29, 1: 153-171. DOI: 10.1007/s10531-019-01876-8.
- Hartmann T. and Spit T. (2015), “Implementing European climate adaptation policy. How local policymakers react to European policy”, *TeMA - Journal of Land Use, Mobility and Environment*, 8, 1: 51-68. DOI: 10.6092/1970-9870/2918.
- Hou Y., Li B., Müller F., Fu Q. and Chen W. (2018), “A conservation decision-making framework based on ecosystem service hotspot and interaction analyses on multiple scales”, *Science of the Total Environment*, 643: 277-291. DOI: 10.1016/j.scitotenv.2018.06.103.
- Howley P., Buckley C., O’Donoghue C., and Ryan M. (2015), “Explaining the economic ‘irrationality’ of farmers’ land use behaviour: The role of productivity attitudes and non-pecuniary benefits”, *Ecological Economics*, 109: 186-193. DOI: 10.1016/j.ecolecon.2014.11.015.
- Hyytiäinen K., Leppänen J. and Pahkasalo T. (2008), *Economic Analysis of Field Afforestation and Forest Clearance for Cultivation in Finland*, in *Proceedings of the International Congress of European Association of Agricultural Economists*, Ghent, Belgium, 26-29 August 2008, pp. 1-7. DOI: 10.22004/ag.econ.44178.

- Isola F. and Leone F. (2019), “Relations between green infrastructures and surface water management. A study concerning two towns in Sardinia, Italy”, *UPLand - Journal of Urban Planning, Landscape & Environmental Design*, 4, 1: 137-146. DOI: 10.6092/2531-9906/6206.
- Kumm K.-I. and Hesse A. (2020), “Economic comparison between pasture-based beef production and afforestation of abandoned land in Swedish forest districts”, *Land*, 9, 2 (42): 1-20. DOI: 10.1016/10.3390/land9020042.
- Lai S. and Leone, F. (2017), *Bridging Biodiversity Conservation Objectives with Landscape Planning through Green Infrastructures: A Case Study from Sardinia, Italy*, in Gervasi O., Murgante B., Misra S., Borruso G., Torre C., Rocha A.M.A.C., Taniar D., Apduhan B.O., Stankova E. and Cuzzocrea, A., eds., *17<sup>th</sup> International Conference on Computational Science and Its Applications (ICCSA 2017)*, Lecture Notes in Computer Sciences Series, Vol. no. 10409, Springer, Cham, Switzerland, pp. 456-472. DOI: 10.1007/978-3-319-62407-5\_39.
- Lai S., Leone F. and Zoppi C. (2020), “Spatial distribution of surface temperature and land cover: A study concerning Sardinia, Italy”, *Sustainability*, 12, 8 (3186): 1-20. DOI: 10.3390/su12083186.
- Madureira H. and Andresen T. (2014), “Planning for multifunctional urban green infrastructures: Promises and challenges”, *Urban Design International*, 19, 38-49. DOI: 10.1057/udi.2013.11.
- Magnaghi A. (2019), “La bioregione urbana nell’approccio territorialista” [The urban bioregion in the territorialist approach], *Contesti. Città, Territori, Progetti*, 1: 26-51. DOI: 10.13128/contest-10629.
- Magnaghi A. (2020), *I Caratteri Innovativi dei Contratti di Fiume: Il Contratto di Fiume del Torrente Pesa (Toscana)* [The Innovative Characteristics of the Contracts of River: The River Contract of the Pesa Stream (Tuscany)], in Angrilli M., ed., *BikeFlu. Atlante dei Contratti di Fiume in Abruzzo* [BikeFlu. Atlas of the Contracts of River in Abruzzo], Gangemi Editore International, Rome, Italy, pp. 30-39.
- Marsboom C., Vreboos D., Staes J. and Meire P. (2018), “Using dimension reduction PCA to identify ecosystem service bundles”, *Ecological Indicators*, 87: 209-260. DOI: 10.1016/j.ecolind.2017.10.049.
- Martín-López B., Iniesta-Arandia I., García-Llorente M., Palomo I., Casado-Arzuaga I., García Del Amo G., Gómez-Baggethun E., Oteros-Rozas E., Palacios-Agundez I., Willaarts B., González J.A., Santos-Martín F., Onaindia M., López-Santiago C. and Montes C. (2012), “Uncovering ecosystem service bundles through social preferences”, *PLoS One*, 7, 6 (e38970), 1-11. DOI: 10.1371/journal.pone.0038970.
- O’Connell P.E., Ewen J., O’Donnell G. and Quinn P. (2007), “Is there a link between agricultural land-use management and flooding?”, *Hydrology and Earth System Sciences*, 11, 1: 96-107. DOI: 10.5194/hess-11-96-2007.
- Ostrom E. (1990), *Governing the Commons: In the Evolution of Institutions for Collective Action*, Cambridge University Press, Cambridge, United Kingdom.
- Pourghasemi H.R., Kariminejad N., Amiri M., Mohsen E., Zarafshar M., Blaschke

- T. and Cerda A. (2020), “Assessing and mapping multi-hazard risk susceptibility using a machine learning technique”, *Scientific Reports*, 10, 3203: 1-11. DOI: 10.1038/s41598-020-60191-3.
- Power A.G. (2010), “Ecosystem services and agriculture: tradeoffs and synergies”, *Philosophical Transactions of the Royal Society B - Biological Sciences*, 365: 2959-2971. DOI: 10.1098/rstb.2010.0143.
- Queiroz C., Meacham M., Richter K., Norström A.V., Andersson E., Norberg J. and Peterson G. (2015), “Mapping bundles of ecosystem services reveals distinct types of multifunctionality within a Swedish landscape”, *AMBIO*, 44: 89-101. DOI: 10.1007/s13280-014-0601-0.
- Raudsepp-Hearne C., Peterson G.D. and Bennett E.M. (2010), “Ecosystem service bundles for analyzing tradeoffs in diverse landscapes”, *Proceedings of the National Academy of Sciences*, 107 (11): 5242-5247. DOI: 10.1073/pnas.0907284107.
- Ravankhah M., de Wit R., Argyriou A.V. and Chliaoutakis A. (2019), “Integrated assessment of natural hazards, including climate change’s influences, for cultural heritage sites: The case of the historic centre of Rethymno in Greece”, *International Journal of Disaster Risk Science*, 10, 3: 343-361. DOI: 10.1007/s13753-019-00235-z.
- Regione Piemonte (2018), *Le Fasce Tampone Vegetate Riparie Erbacee. Realizzazione e Gestione [The Vegetated Riparian Herbaceous Buffer Strips. Implementation and Management]*, text available at the website [https://www.regione.piemonte.it/web/sites/default/files/media/documenti/2019-01/le\\_fasce\\_tampone\\_vegetate\\_riparie\\_erbacee\\_0.pdf](https://www.regione.piemonte.it/web/sites/default/files/media/documenti/2019-01/le_fasce_tampone_vegetate_riparie_erbacee_0.pdf) [Accessed: 22 February 2022].
- Ryan M. and O’Donoghue C. (2016), “Socio-economic drivers of farm afforestation decision-making”, *Irish Forestry Journal*, 73, 1-2: 96-121.
- Sagebiel J., Glenk K. and Meyerhoff J. (2017), “Spatially explicit demand for afforestation”, *Forest Policy and Economics*, 78: 190-199. DOI: 10.1016/j.forpol.2017.01.021.
- Salata K.D. and Yiannakou A. (2016), “Green Infrastructure and climate change adaptation”, *TeMA - Journal of Land Use, Mobility and Environment*, 9, 1: 7-24. DOI: 10.6092/1970-9870/3723.
- Samways M.J., Bazelet C.S. and Pryke J.S. (2010), “Provision of ecosystem services by large scale corridors and ecological networks”, *Biodiversity and Conservation*, 19, 10: 2949-2962. DOI: 10.1007/s10531-009-9715-2.
- Sapač K., Humar N., Brilly M. and Kryžanowski A. (2017), *More Room for Landslides*, in Sassa K., Mikoš M. and Yin Y., eds., *Advancing Culture of Living with Landslides, World Landslide Forum 2017*, Springer, Cham, Switzerland, pp. 563-569. DOI: 10.1007/978-3-319-59469-9\_51.
- Siry J.P., Cabbage F.W. and Ahmed M.R. (2005), “Sustainable forest management: Global trends and opportunities”, *Forest Policy and Economics*, 7, 4: 551-561. DOI: 10.1016/j.forpol.2003.09.003.
- Sistu G. and Perelli C. (2011), *La transizione paesaggistica del sistema ferroviario della Sardegna [Landscape transition of the Sardinian railroad system]*, in Lai

- F. and Breda N., eds., *Antropologia del “Terzo Paesaggio” [Anthropology of the “Third Landscape”]*, CISU, Rome, Italy, pp. 101-132.
- Stolton S., Dudley N. and Randall J. (2008), *Natural Security. Protected Areas and Hazard Mitigation*, WWF International, Gland, Switzerland.
- Trigila A., Iadanza C., Bussettini M. and Lastoria B. (2018), *Dissesto Idrogeologico in Italia: Pericolosità e Indicatori di Rischio - Edizione 2018*, ISPRA, Rapporti no. 287/2018 [*Hydrogeological Instability in Italy: Hazard and Risk Indicators - 2018 Edition*, ISPRA Reports no. 287/2018], ISPRA, Rome, Italy, text available at the website <https://www.isprambiente.gov.it/it/publicazioni/rapporti/dissesto-idrogeologico-in-italia-pericolosita-e-indicatori-di-rischio-edizione-2018> [Accessed: 22 February 2022].
- Turner W.R., Brandon K., Brooks T.M., Costanza R., da Fonseca A.B.G. and Portela R. (2007), “Global conservation of biodiversity and ecosystem services”, *BioScience*, 57, 10: 868-873. DOI: 10.1641/B571009.
- UNESCO - United Nations Educational, Scientific and Cultural Organization (2015), *Final Report on the Results of the Second Cycle of the Periodic Reporting Exercise for the Europe Region and Action Plan*, text available at the website <https://whc.unesco.org/archive/2015/whc15-39COM-10A-en.pdf> [Accessed: 22 February 2022].
- United Nations (2015), *Sendai Framework for Disaster Risk Reduction 2015 - 2030*, text available at the website [https://www.prevention-web.net/files/43291\\_sendaiframeworkfordrren.pdf](https://www.prevention-web.net/files/43291_sendaiframeworkfordrren.pdf) [Accessed: 22 February 2022].
- Yousefi S., Pourghasemi H.R., Emami S.N., Pouyan S., Eskandar S. and Tiefenbacher J.P. (2020), “A machine learning framework for multi-hazards modeling and mapping in a mountainous area”, *Scientific Reports*, 10, 12144: 1-14. DOI: 10.1038/s41598-020-69233-2.
- Zavalloni M., D’Alberto R., Raggi M. and Viaggi D. (2021), “Farmland abandonment, public goods and the CAP in a marginal area of Italy”, *Land Use Policy*, 107 (104365): 1-12. DOI: 10.1016/j.landusepol.2019.104365.
- Zhang J., Connor T., Yang H., Ouyang Z., Li S. and Liu J. (2018), “Complex effects of natural disasters on protected areas through altering telecouplings”, *Ecology and Society*, 23, 3 (17): 1-9. DOI: 10.5751/ES-10238-230317.

## 6. *Figures*



# 6.1. Figures Chapter 2

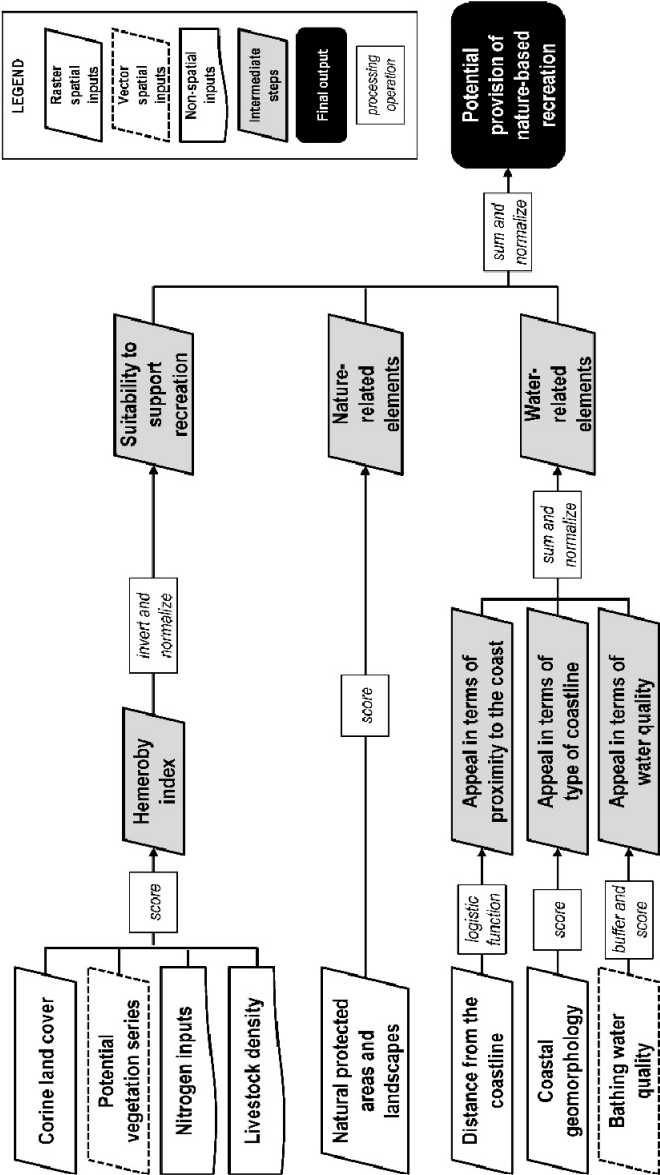


Fig. 1 - Flow chart of the process whereby the potential provision of nature-based recreation is mapped (adapted from Vallecillo et al., 2019a; Barton et al., 2019)

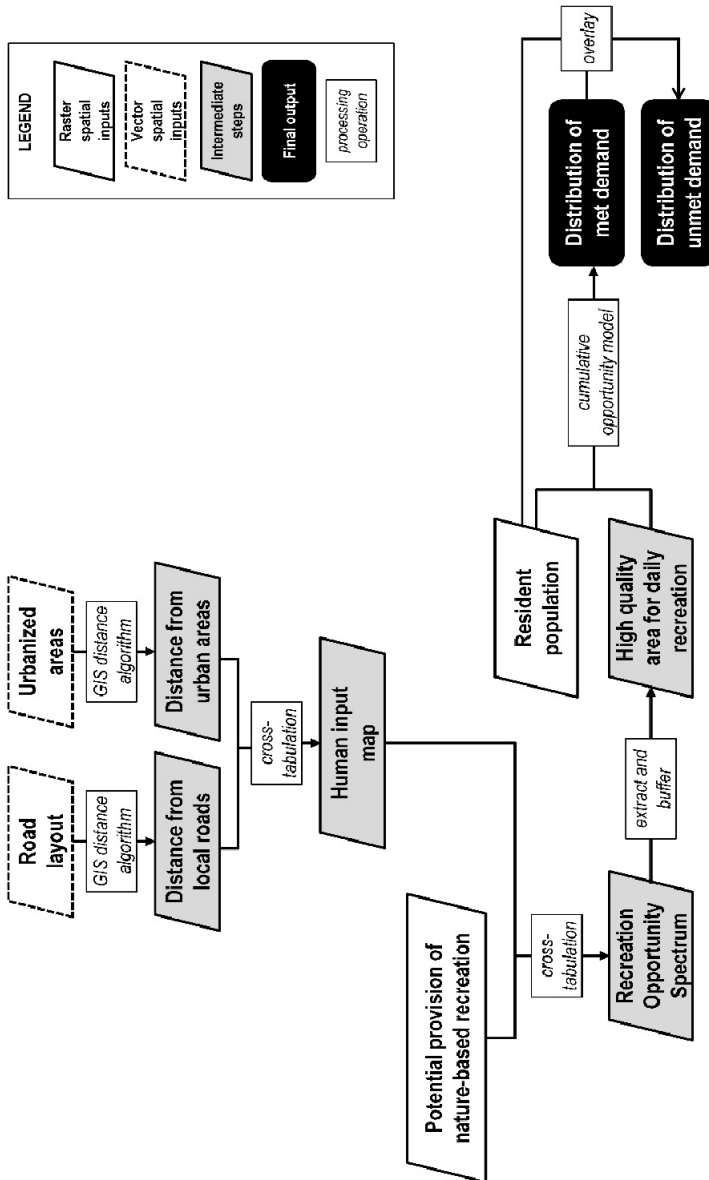
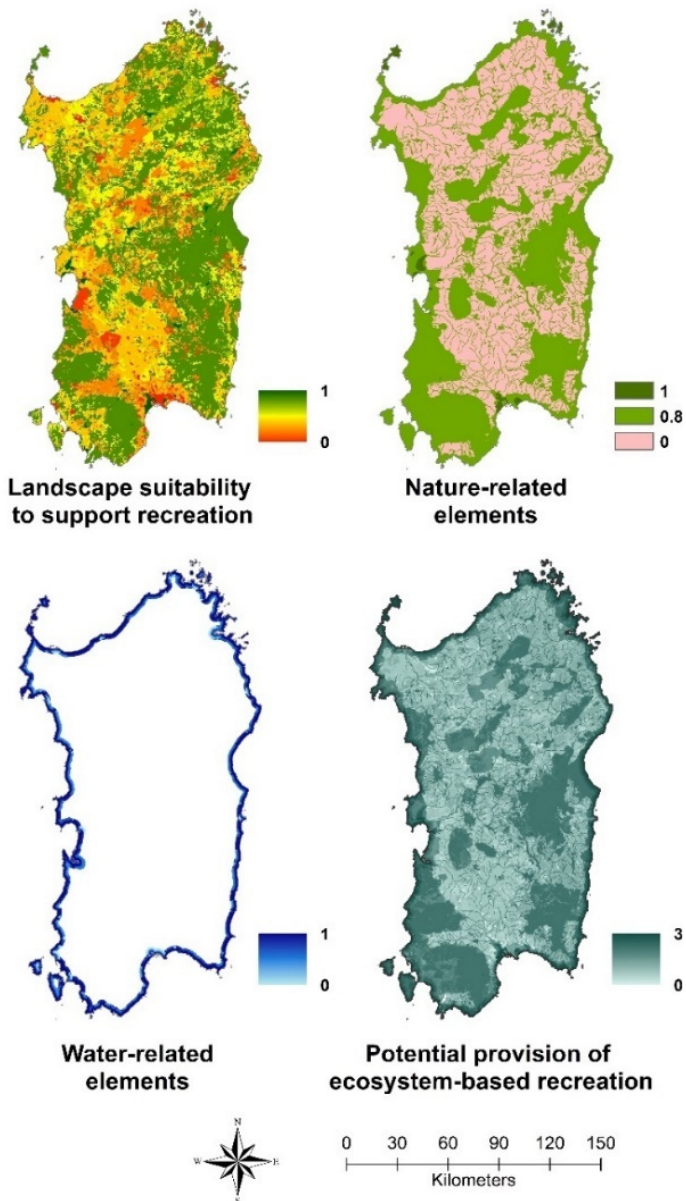
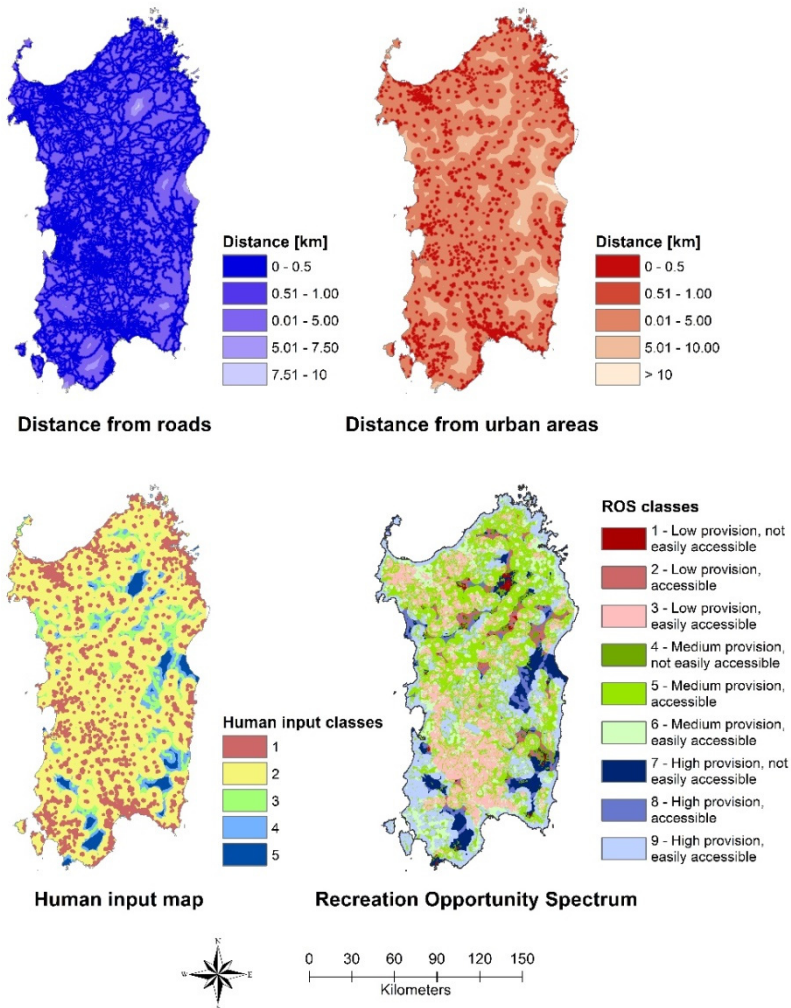


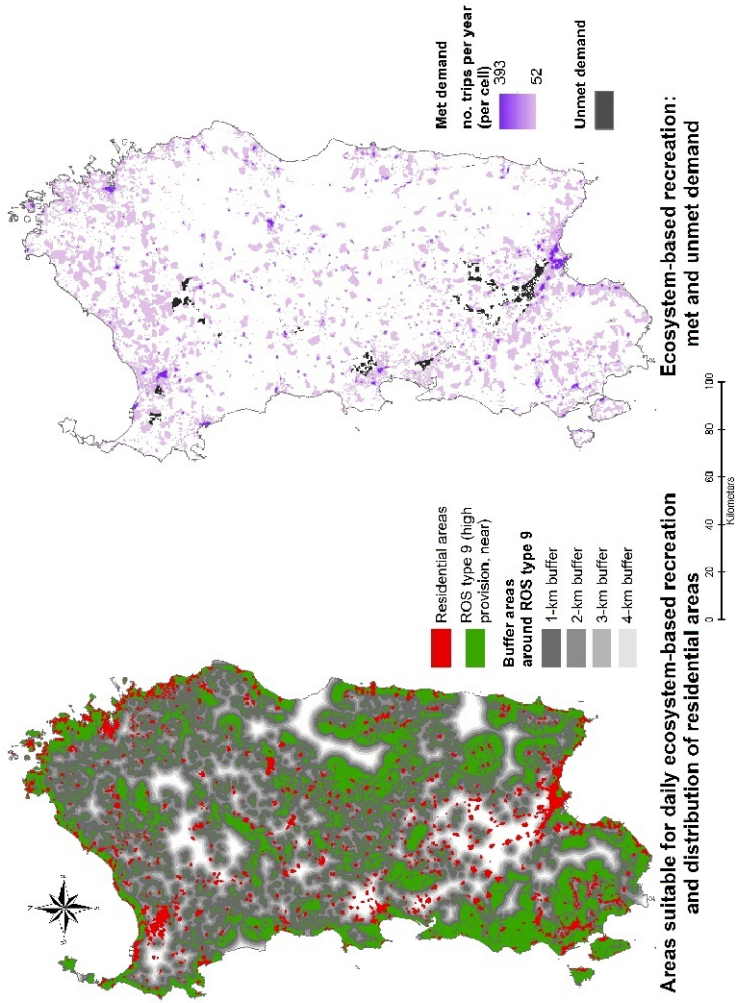
Fig. 2 - Global flow chart of the ESTIMAP model (after Vallecillo et al., 2019a; Barton et al., 2019)



*Fig. 3 - Spatial layout of the total potential provision of nature-based recreation (bottom right) and of its three components*



*Fig. 4 - Spatial layout of the distance from roads and urban areas; Human input map, retrieved by cross-tabulating the two; Recreation Opportunity Spectrum (ROS), retrieved by cross-tabulating the Human input map and the Potential provision of nature-based recreation map*



*Fig. 5 - Spatial layout of the met and unmet demand for ecosystem-based recreation (right-hand side), mapped by considering only round trips shorter than eight kilometers from the nearest high-providing area (left-hand side)*

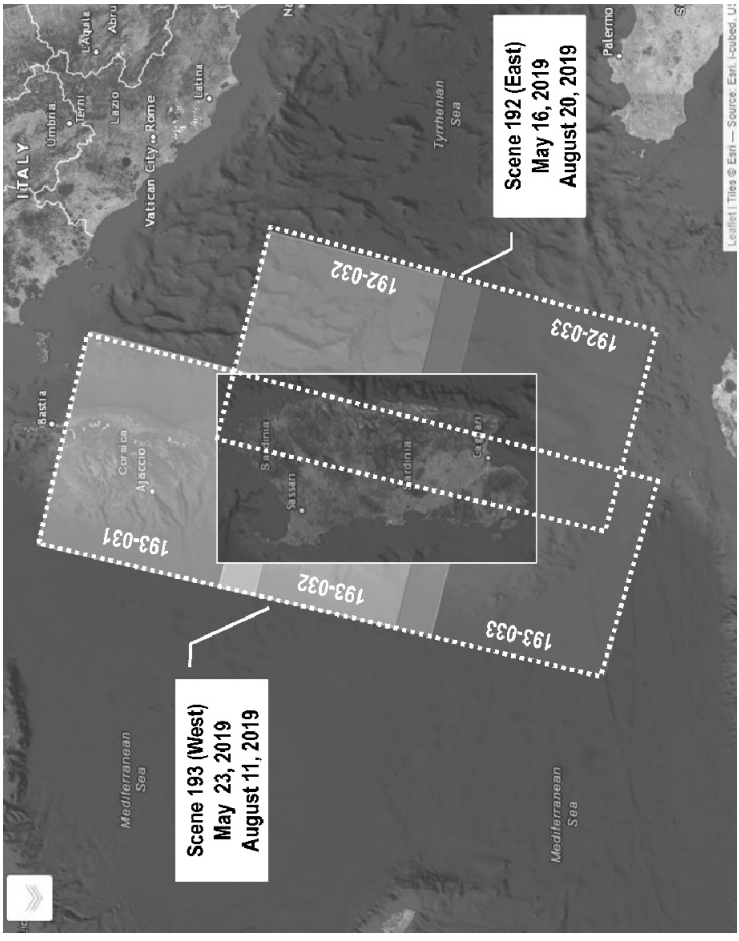


Fig. 6 – Spatial layout of the ten Landsat 8 OLI-TIRS images selected for this study (<https://earthexplorer.usgs.gov/>)

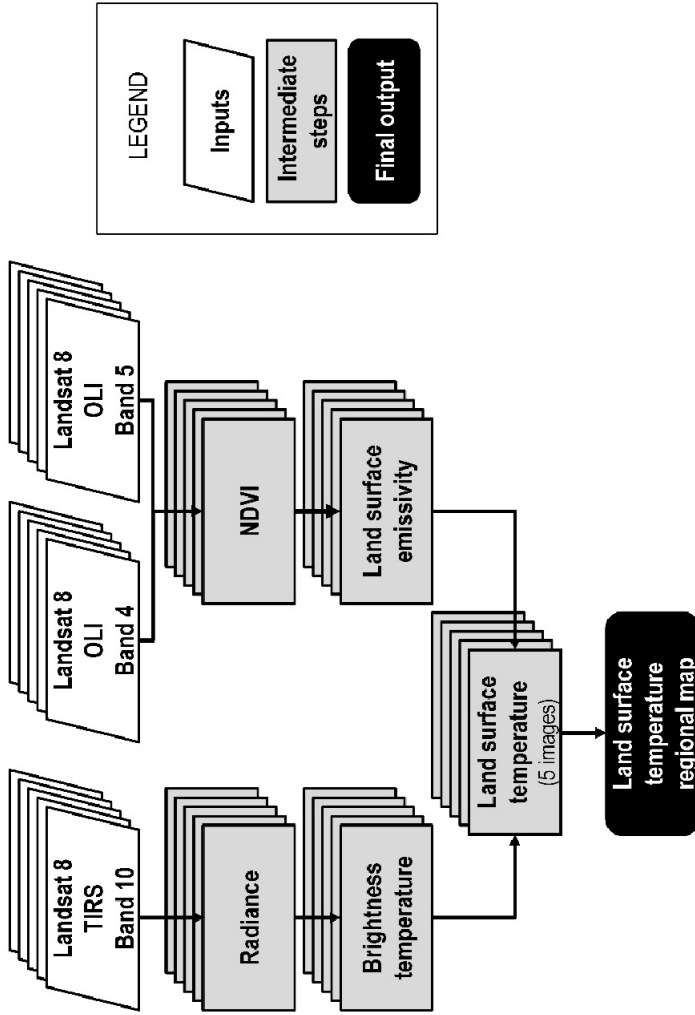


Fig. 7 - LST retrieval from Landsat images: an overview of the process

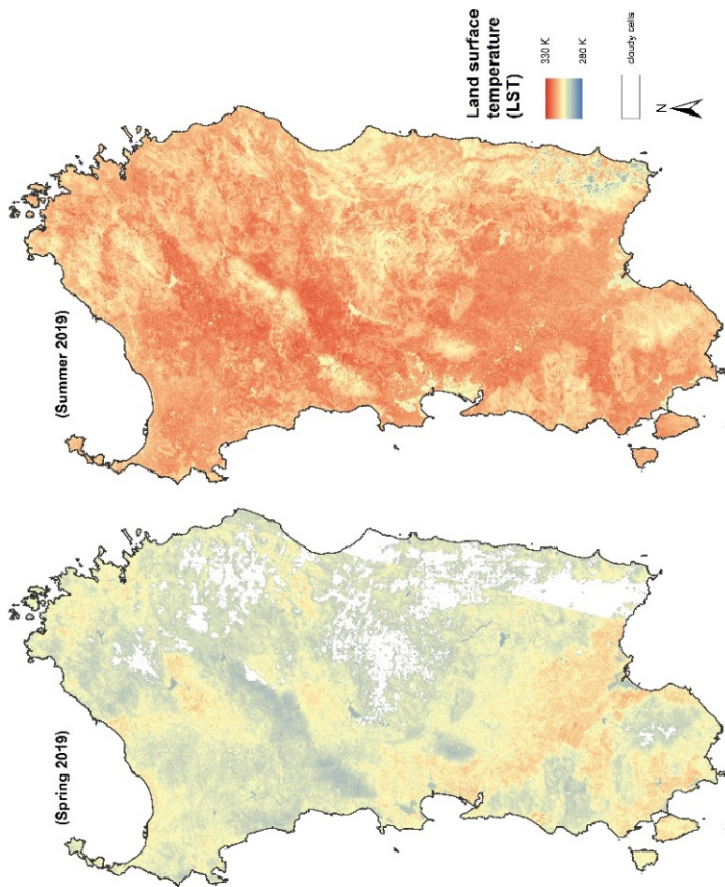
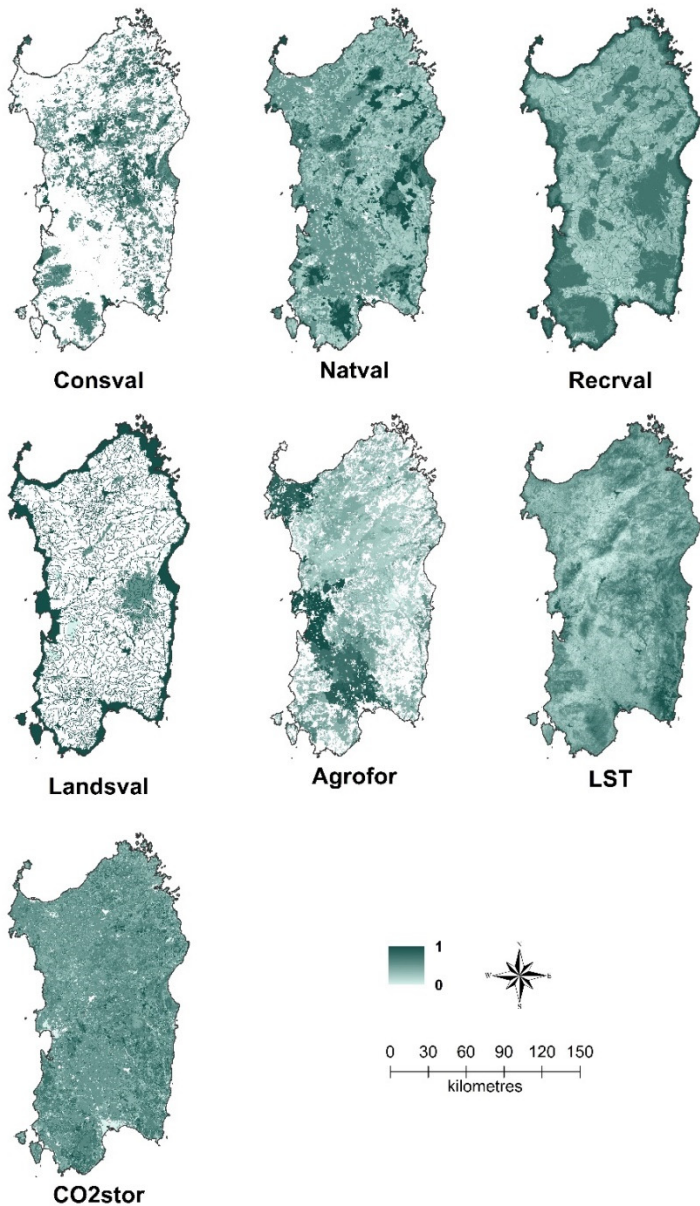


Fig. 8 - LST spring and summer maps





*Fig. 9 - Spatial distribution of the seven ES. Values are normalized in the 0-1 range.*

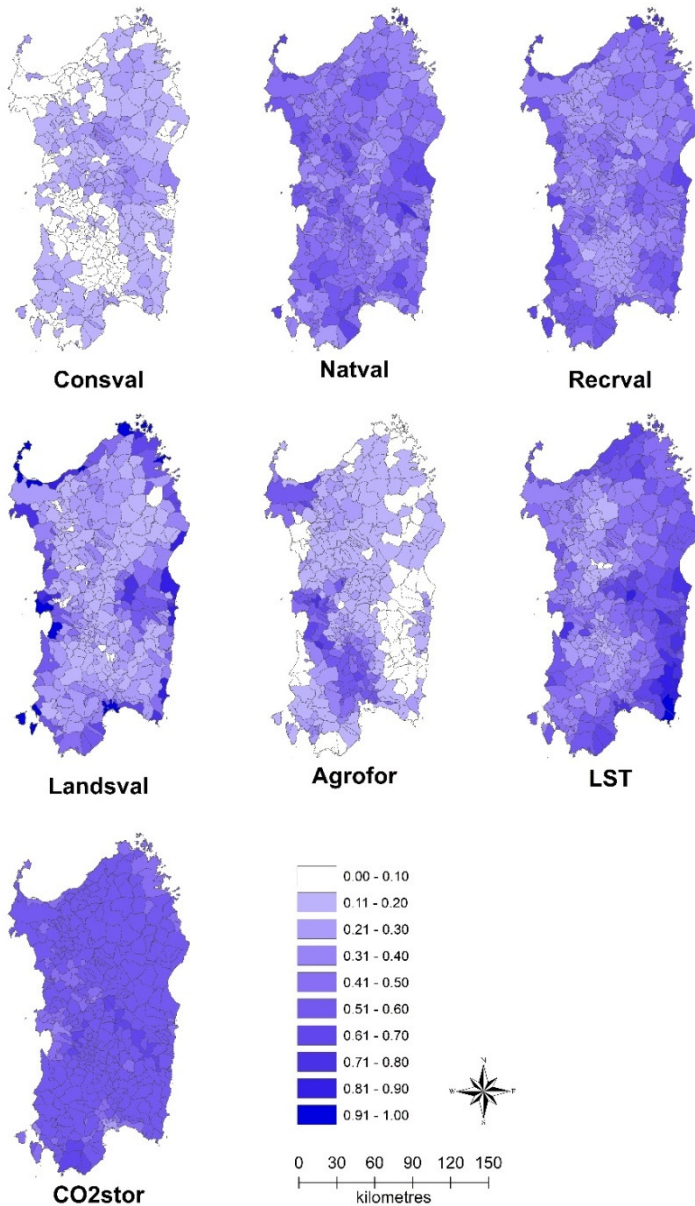


Fig. 10 - Spatial layout of the mean average values of the seven ES at the municipal level.

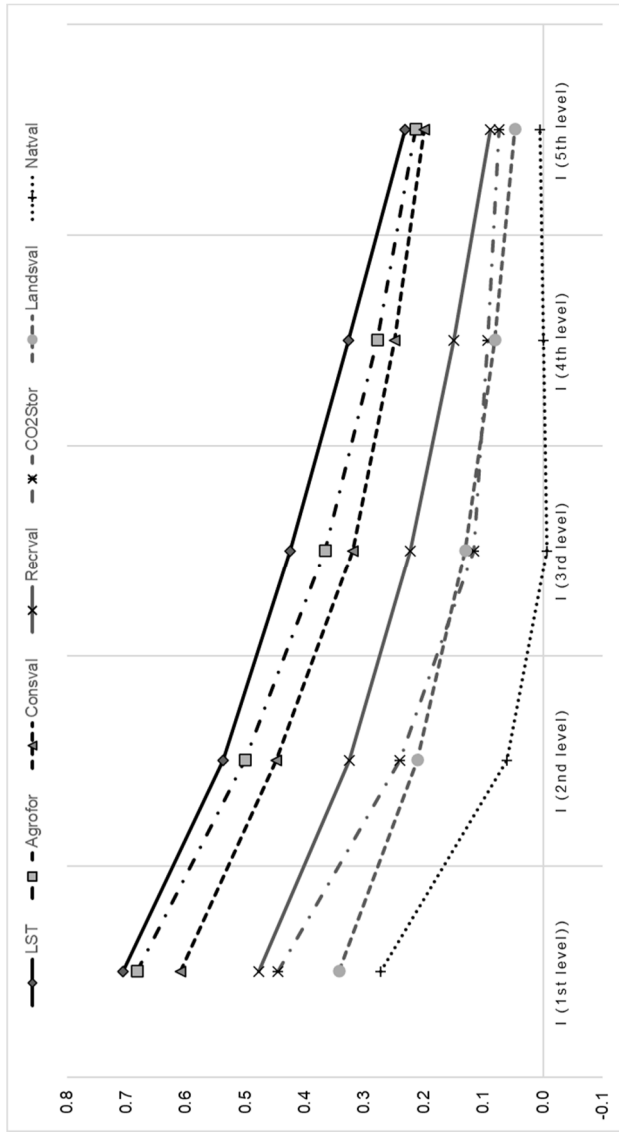


Fig. 11 - Results of the spatial autocorrelation analysis: Moran's I index

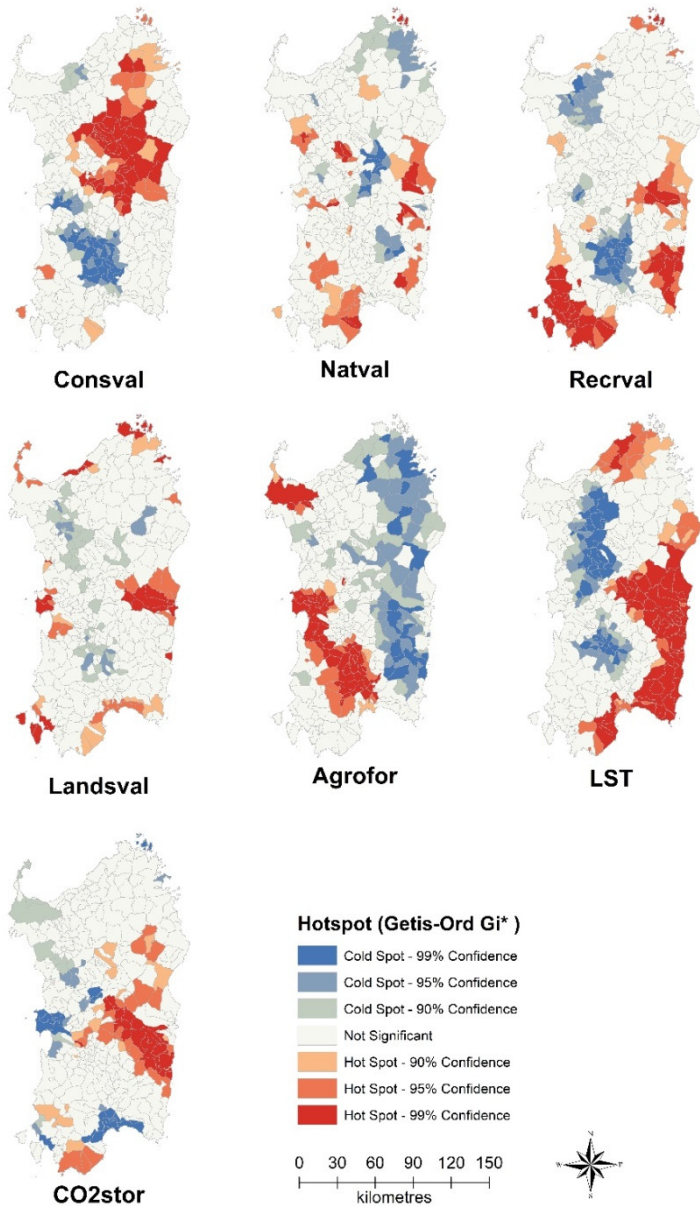
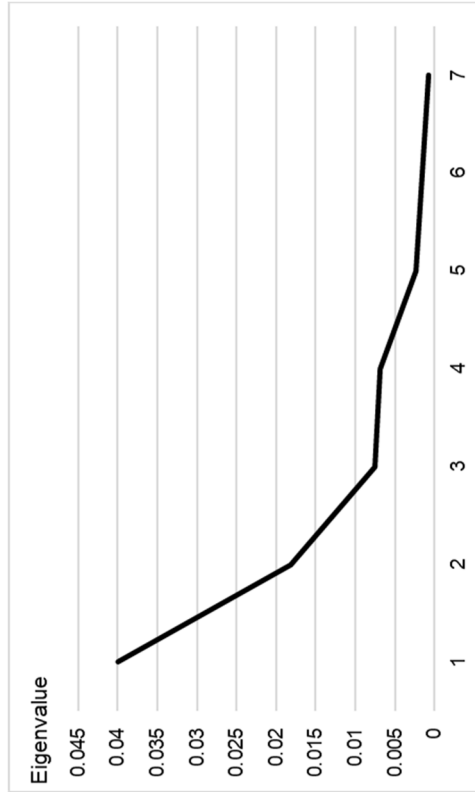


Fig. 12 - Hot spots and cold spots of ES provision (average values at the municipal level)



*Fig. 13 - Scree plot representing the eigenvalues on the vertical axis and the components in the horizontal axis*

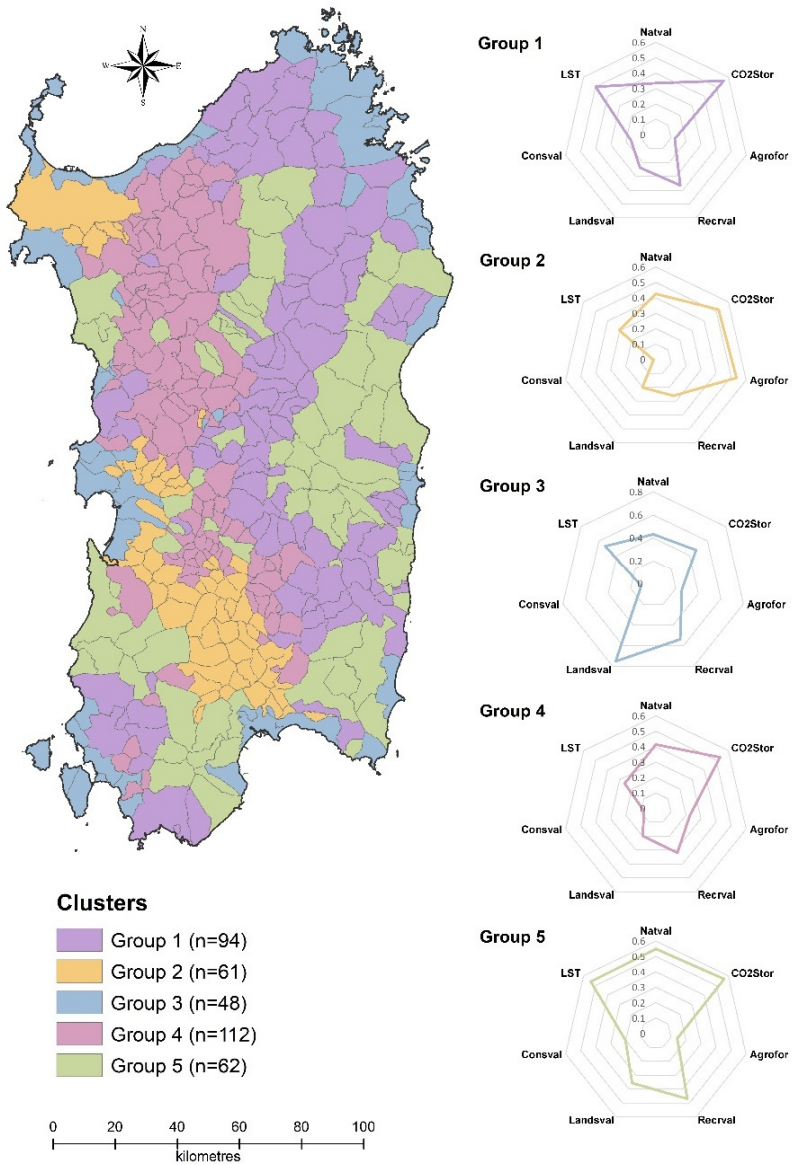


Fig. 14 - Cluster analysis: five groups of municipalities providing similar bundles of ES

## 6.2. Figures Chapter 3

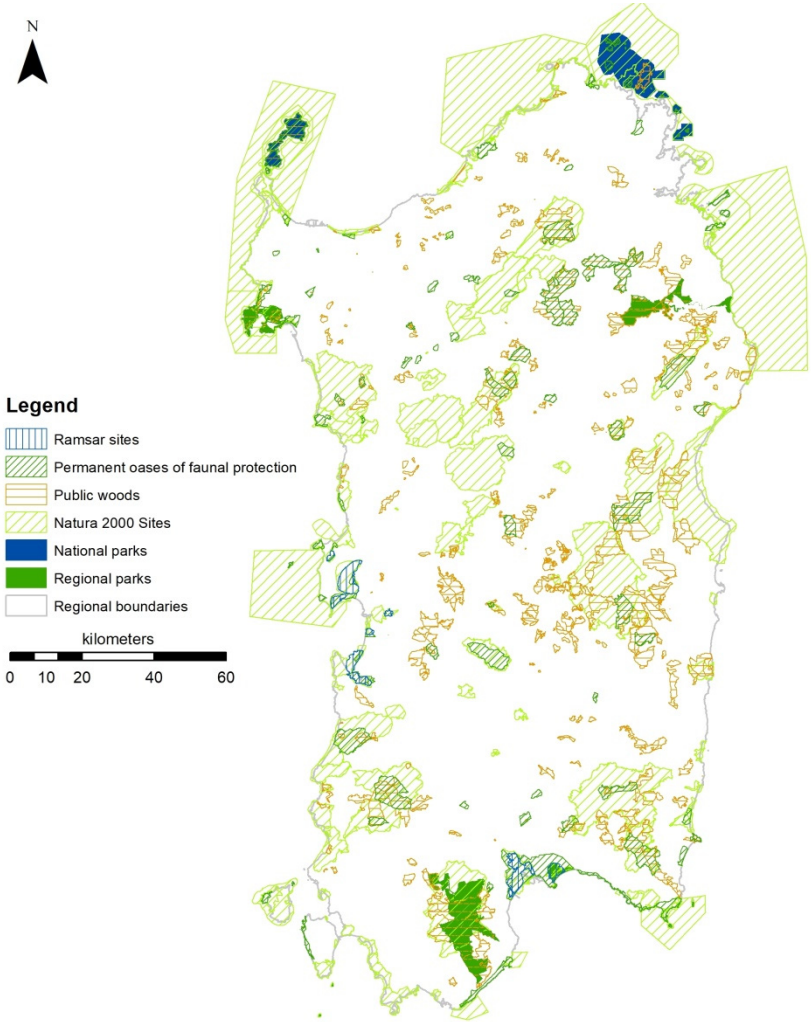


Fig. 1 - The system of the Sardinian protected areas

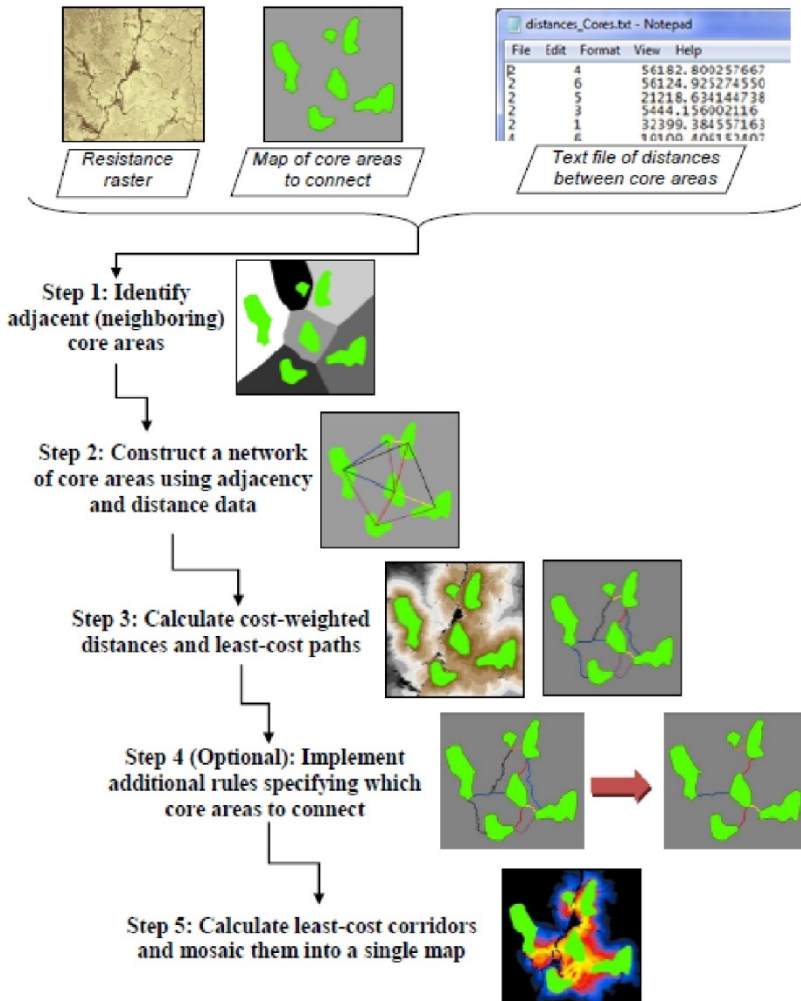
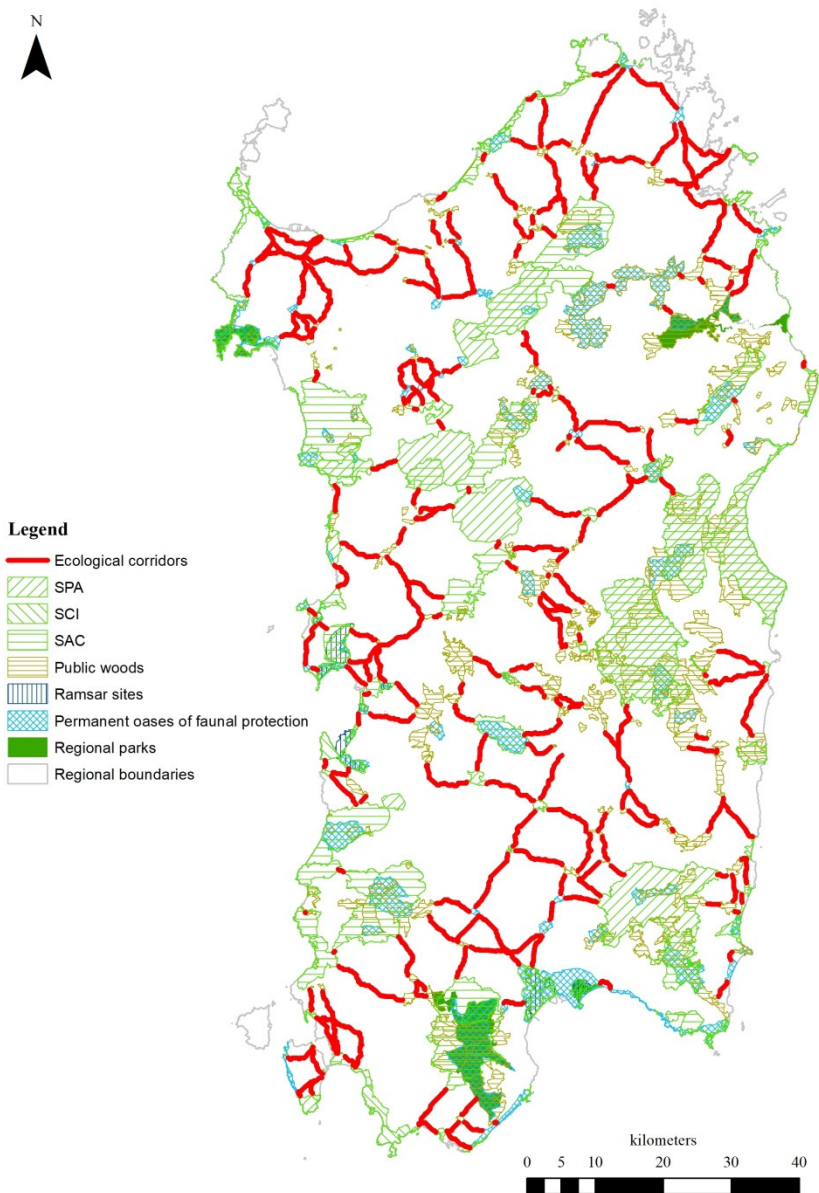


Fig. 2 - Processing process of LPT. Source: McRae and Kavanagh, 2017, p.11





*Fig. 3 - Ecological corridors connecting the NPA*

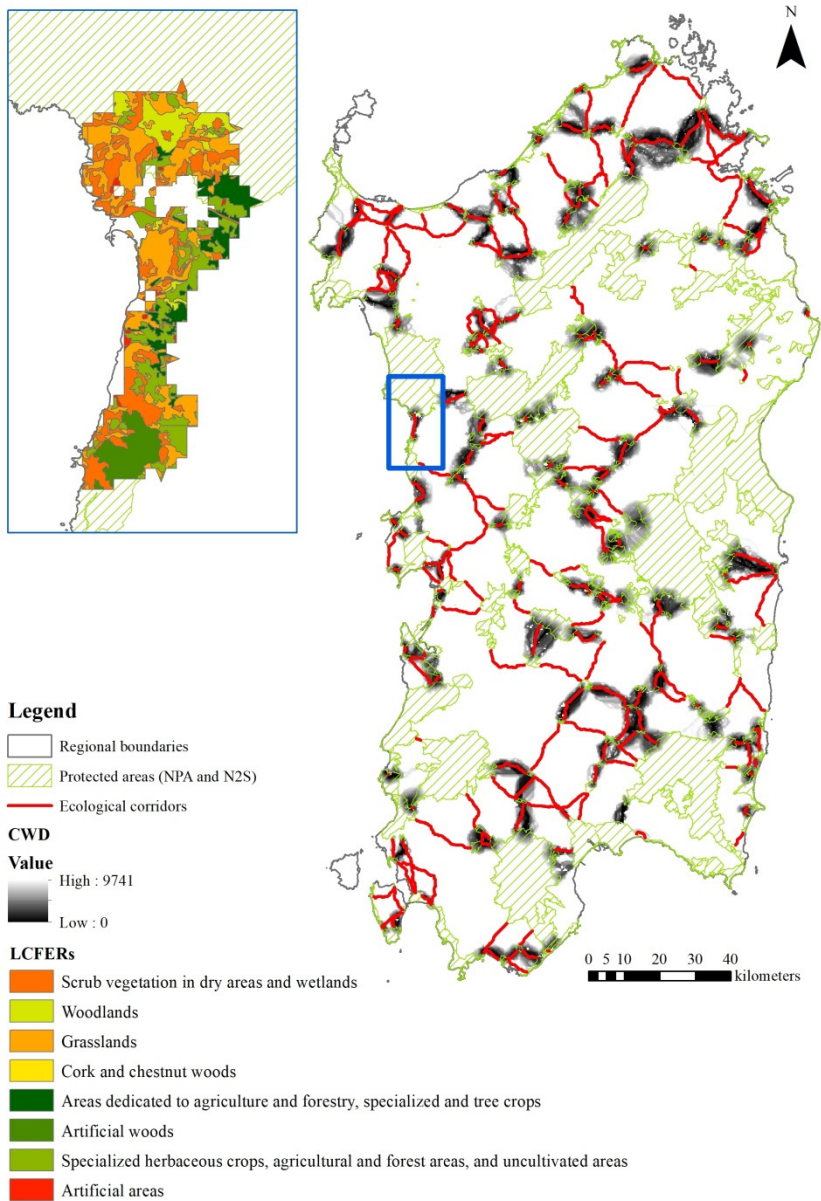
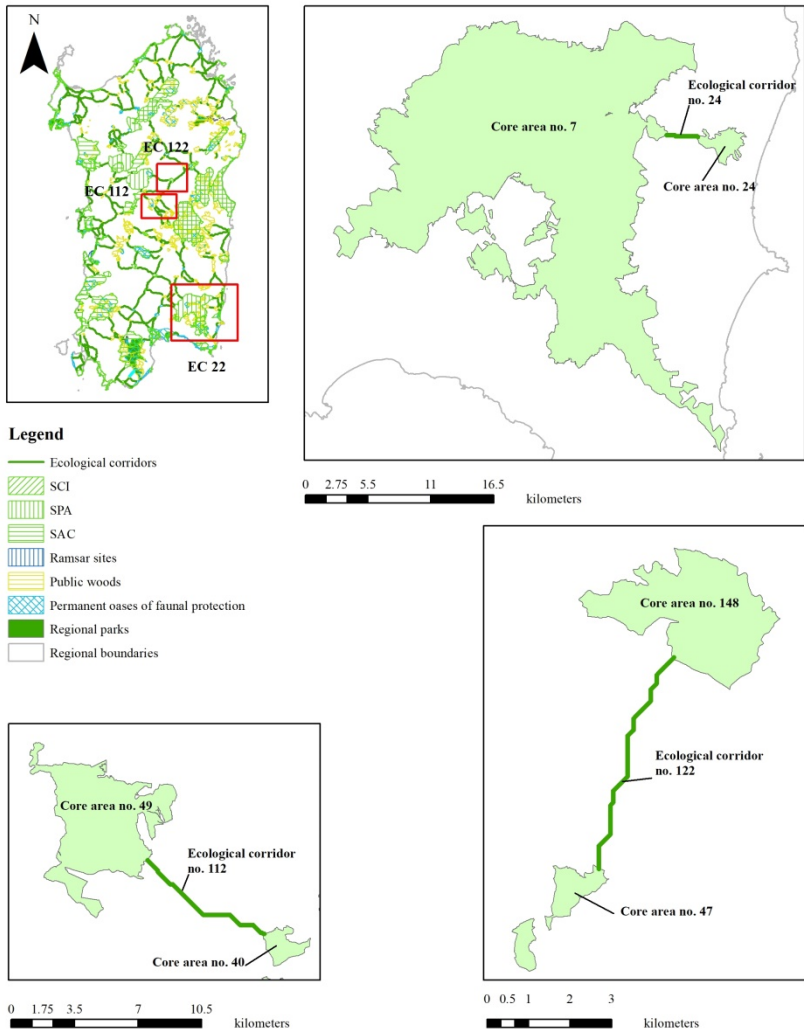
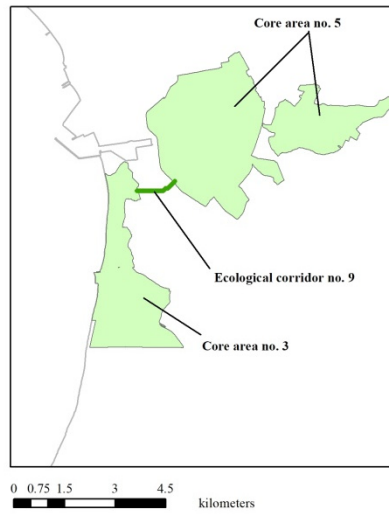
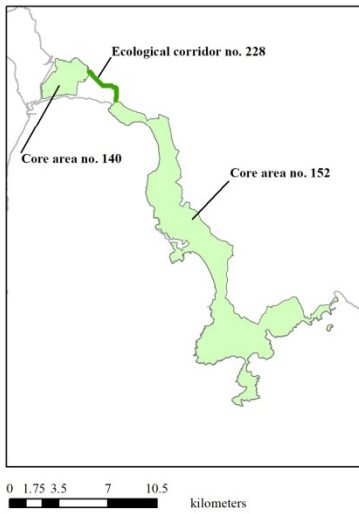
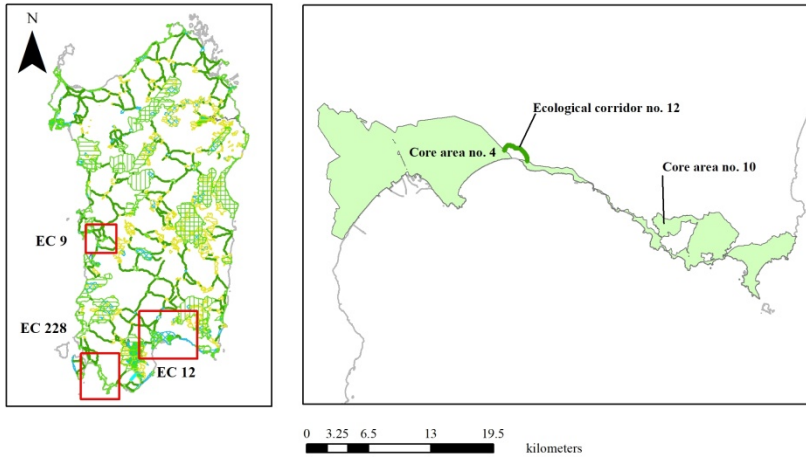


Fig. 4 - Identification of ecological corridors and of CWD values included in the second's upper limit decile (map on the right), and the overlapping map of CWD values and the LCFER (upper-left map)



The codes of the core areas are identified in tab. 1

Fig. 5 - Spatial identification of the EC which show the lowest values of the CWD/ED index

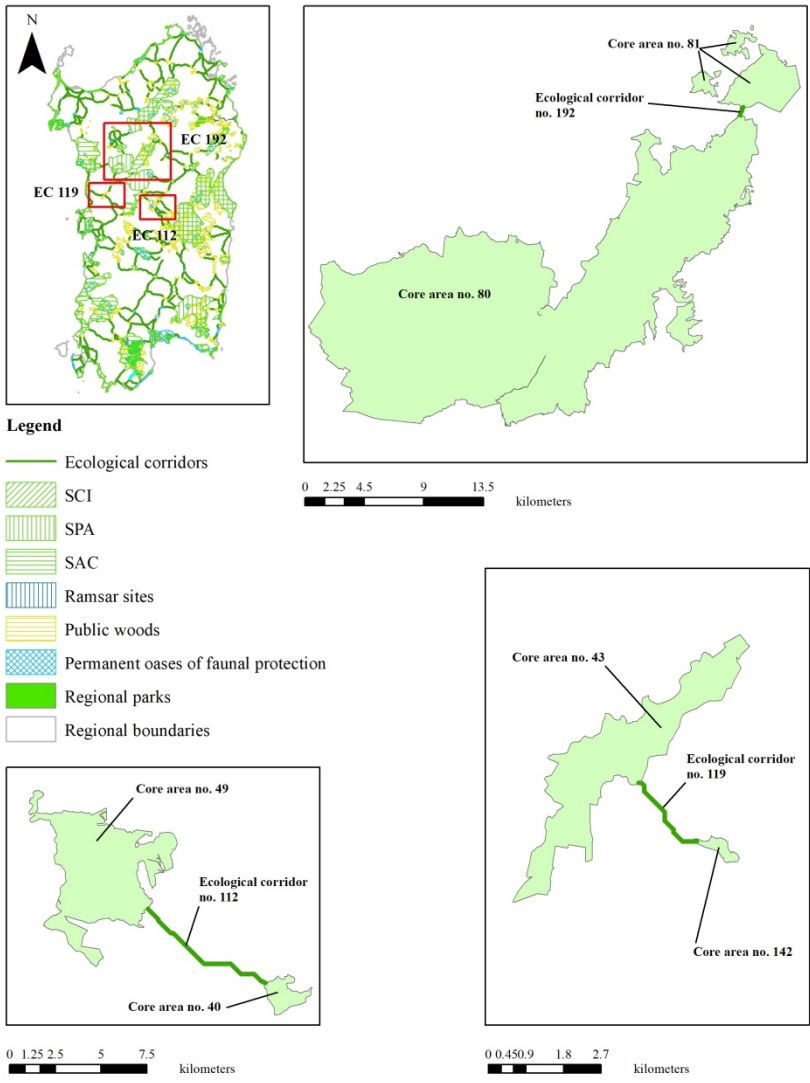


**Legend**

- |                      |                                      |
|----------------------|--------------------------------------|
| Ecological corridors | Public woods                         |
| SCI                  | Permanent oases of faunal protection |
| SPA                  | Regional parks                       |
| SAC                  | Regional boundaries                  |
| Ramsar sites         |                                      |

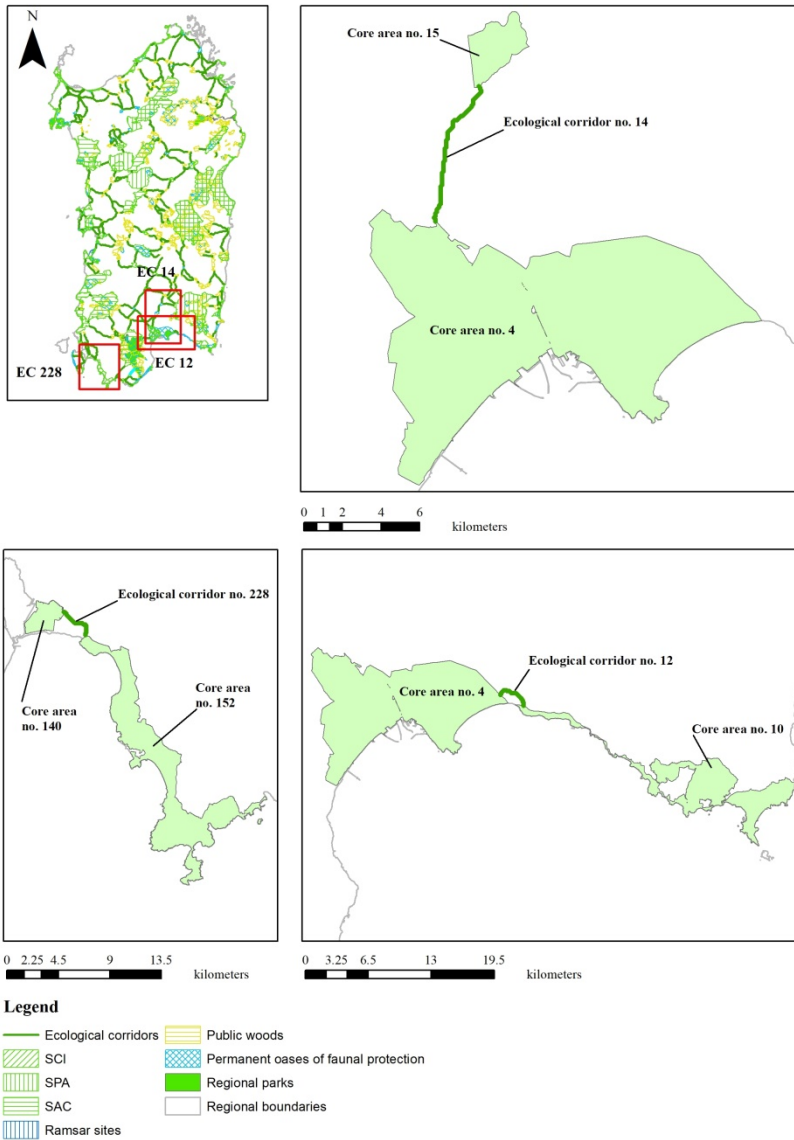
The codes of the core areas are identified in tab. 1

Fig. 6 - Spatial identification of the EC which show the highest values of the CWD/ED index



The codes of the core areas are identified in tab. 1

Fig. 7 - Spatial identification of the EC which show the lowest values of the CWD/LCP index



The codes of the core areas are identified in tab. 1

Fig. 8 - Spatial identification of the EC which show the highest values of the CWD/LCP index

### 6.3. Figures Chapter 4

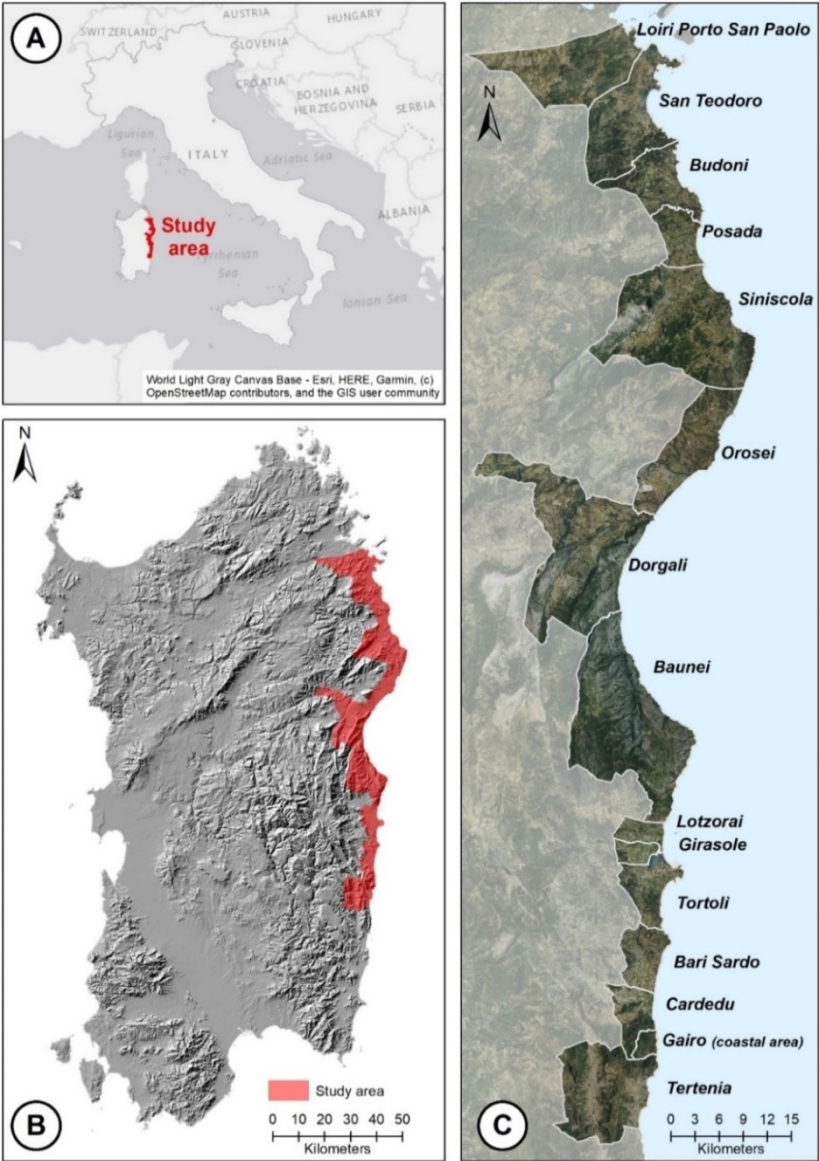


Fig. 1 – Location of the study area within Italy (A) and Sardinia (B), and municipalities included therein (C)

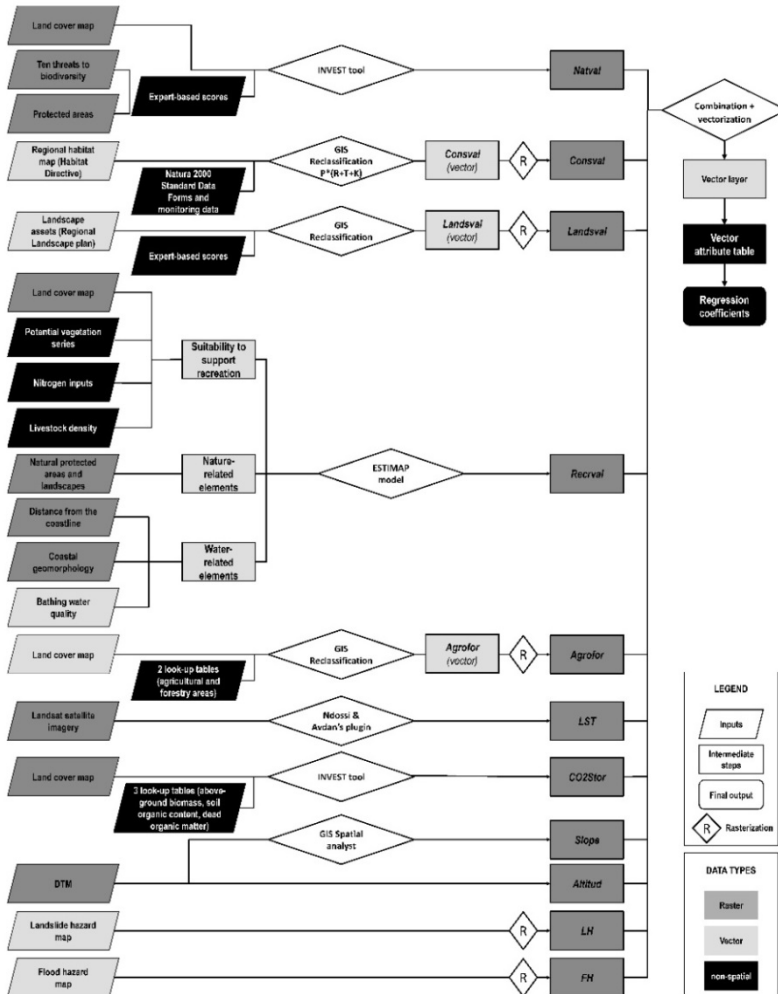


Fig. 2 – Full overview of the methodology



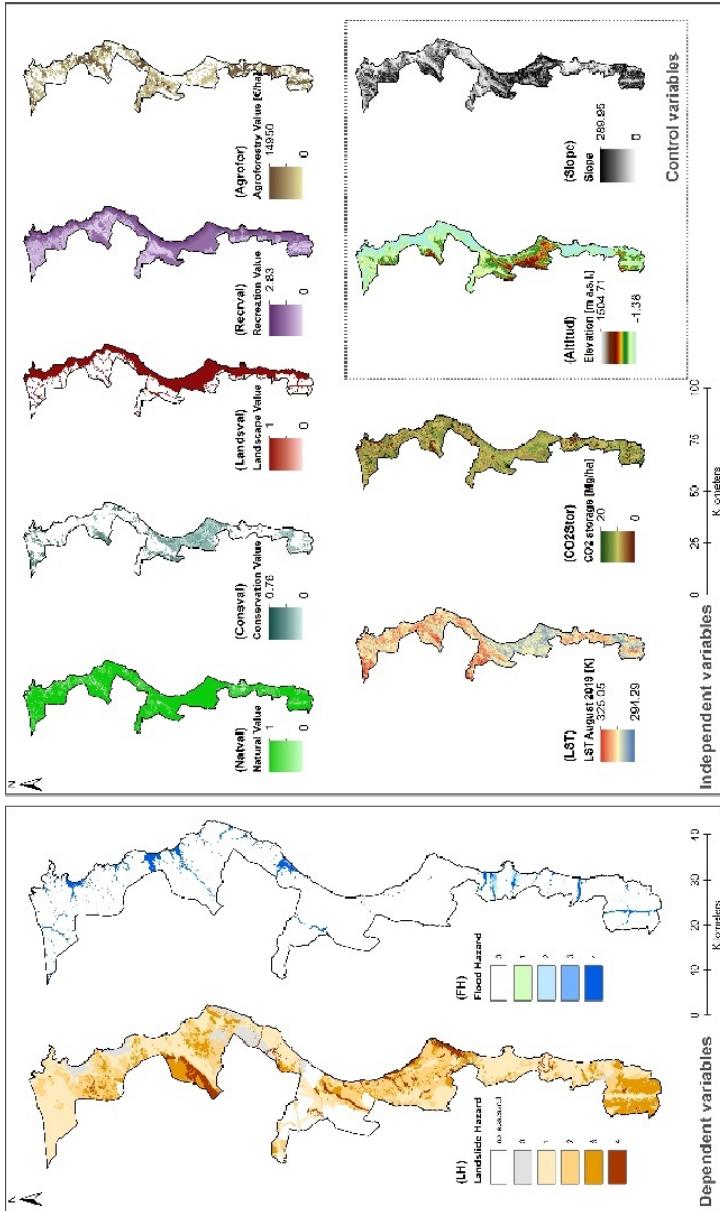


Fig. 3 – Spatial distribution of dependent and independent variables in the study area

Identifying and planning green infrastructures at the regional scale can be considered an intentional way of spreading the positive impacts of environmental conservation policies across spatial contexts much more complex and larger than protected areas.

In this volume, a methodological approach is defined and experimentally implemented into the Sardinian region (Italy), in order to identify both a regional green infrastructure, and a network of ecological corridors, conceived as edges connecting the regional protected areas. This approach supports spatial decision-making processes aimed at addressing environmental hazards connected to landslides and floods, as well as at establishing effective spatial planning rules.

**Federica Isola** is a building engineer, and a Doctor of Research in Engineering and Natural Sciences (Italy, 2012). She is currently a research fellow at the Department of Civil and Environmental Engineering and Architecture of the University of Cagliari.

**Sabrina Lai** is a civil engineer, a Doctor of Research in Land Engineering (Italy, 2009), and an MSc in International Planning and Development (UK, 2008). She is an Assistant Professor at the University of Cagliari (Sector ICAR/20 – Spatial planning), where she is presently teaching at the Department of Civil and Environmental Engineering and Architecture of the University of Cagliari in the Graduate Program in Environmental and Territorial Engineering (module leader for the Strategic Planning course).

**Federica Leone** is a building engineer, a Doctor of Research in Land Engineering (Italy, 2013), and an MSc in International Planning and Development (UK, 2012). She is currently a research fellow at the Department of Civil and Environmental Engineering and Architecture of the University of Cagliari.

**Corrado Zoppi** is a civil engineer, a Doctor of Philosophy in Economics (USA, 1997), a Doctor of Research in Spatial Planning (Italy, 1992), and an MSc in Economic Policy and Planning (USA, 1990). He is a Professor at the University of Cagliari (Sector ICAR/20 – Spatial planning). He is presently teaching at the Department of Civil and Environmental Engineering and Architecture of the University of Cagliari in the Undergraduate and Graduate Programs in Environmental and Territorial Engineering and in Sustainable Tourism Management and Monitoring (Regional and Urban Planning, Strategic Planning and Environmental Planning).