Guidelines for a better understanding of ecosystem multifunctionality

Deliverable D.T1.2.2- Guidelines on the effective enhancement of ESS in regional GI networks. Interreg Alpine Space project n. 863 “LUIGI”- Linking Urban and Inner-Alpine Green Infrastructure – multifunctional ecosystem for more liveable territories.

Authors: Giombini V., Simion H., Marsoner T., Egarter Vigl L.

Eurac Research, Bolzano/Bozen

May 2022

Suggested Citation:

Giombini, V., Simion H., Marsoner T., Egarter Vigl L. (2022). Guidelines for a better understanding of ecosystem multifunctionality. Deliverable D.T1.2.2 of the Interreg Alpine Space project n. 863 “LUIGI”.

Introduction

This short report aims to present **key insights** gained whilst assessing and mapping the ecosystem service-based multifunctionality of alpine landscapes within the Interreg Alpine Space project "LUIGI" (Linking Urban and Inner-Alpine Green Infrastructure – multifunctional ecosystem for more liveable territories). This report is intended for those practitioners, decision makers, and academics who wish to explore and foster ecosystem service-based multifunctionality in alpine regions and beyond.

In the framework developed within the LUIGI project, we suggest that **multifunctional areas should be sustainably managed or protected as part of a Green Infrastructure network.** Green Infrastructures indeed aim to foster multifunctionality: instead of being managed to reach a single purpose (e.g., monocultures), natural and semi natural elements of the landscape can be designed and managed to maximise the quantity and quality of the ecosystem functions and services they provide (e.g., multifunctional forests). Multifunctionality allows to use space and resources in an efficient and sustainable way and provides win-win solutions to several policy requirements and societal needs.

In this report, we **refer to multifunctionality as the capacity of ecosystems to supply multiple ecosystem services on the same spatial area**. In the LUIGI project, multifunctionality was calculated as the average of 11 provisioning, regulation and maintenance, and cultural ecosystem services mapped at high resolution across 10 diverse alpine case study regions (Figure 1) (for more information, please refer to the document D.T1.2.1).

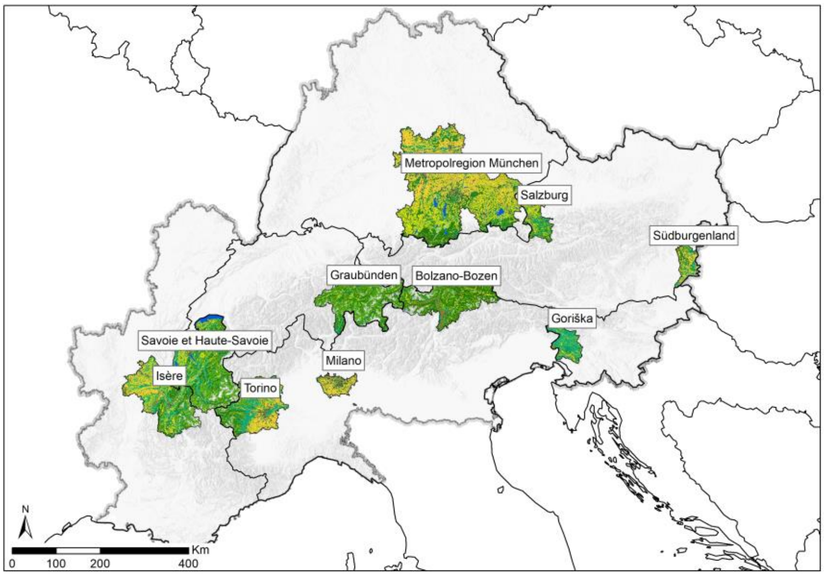


Figure 1: Case study regions of the LUIGI project where ecosystem services-based multifunctionality was mapped and assessed.

The insights presented in this report are summarized by the following statements:

1) Green Infrastructure are the backbone of ecosystem services supply
2) Ecosystem services come in bundles
3) Multifunctionality is linked to landscape complexity
4) Multifunctional areas support ecological connectivity and biodiversity
5) At the local scale, management is a key factor
6) Natural areas with low multifunctionality often provide unique habitats and services
7) Multifunctionality depends on which ecosystem services are considered
8) Multifunctionality metrics changes with different scales and approaches adopted

1) Green Infrastructure are the backbone of ecosystem services supply

Green Infrastructure elements provide many ecosystem services that are important for sustaining ecological processes and ensuring human well-being. Multifunctionality indeed means that many different ecosystem services are provided: not only provisioning services (like crops or timber) but also regulating and cultural services that enable life-supporting ecological processes to take place, and that maintain the cultural and aesthetic value of our landscapes. Multifunctionality fosters the resilience of ecosystems and increases their ecological, economic, and cultural value. In productive systems at lower elevation, multifunctionality ensures that agroecosystems are managed sustainably.

In the LUIGI project, we have identified the elements composing regional Green Infrastructure networks according to their capacity to supply multiple services. In our project we have proposed that the most multifunctional areas of our landscape (the top 10%) should be considered part of a Green Infrastructure network. Such “top” multifunctional Green Infrastructure elements identified across the LUIGI pilot regions are particularly important for sequestering carbon from the atmosphere, mitigating the risk of floods by absorbing rainwater, supporting pollination, retaining nitrogen from excessive agricultural applications, providing timber, and supporting outdoor recreation (Figure 2).

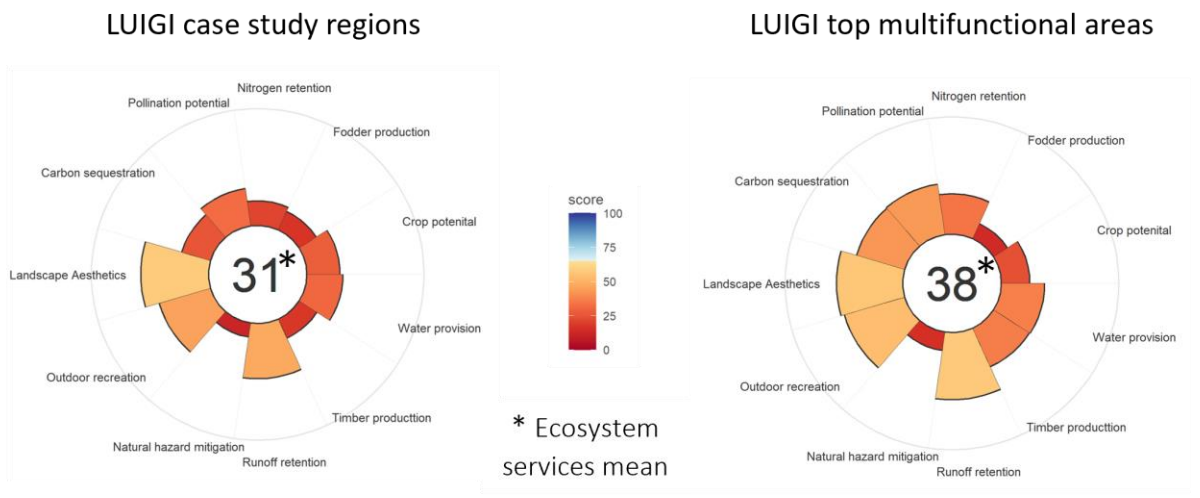


Figure 2: Ecosystem services provision and average multifunctionality in the LUIGI case study regions (left) and in their most (top 10%) multifunctional areas (right).

What are ecosystem services?

Ecosystem services are the **environmental**, **social,** and **economic benefits** humans receive from healthy and functioning ecosystems. Humans are dependent on the flow of these services, which represent the foundation of our society. Ecosystem services are grouped into three main categories:

- **Provisioning services** such as food, water, and timber provision
- **Regulation and maintenance services** such as climate, flood, and water quality regulation, nutrient cycling, and soil formation
- **Cultural services** such as recreation and spiritual benefits

2) Ecosystem services come in bundles

Some sets of ecosystem services are consistently positively or negatively correlated across space or time and give rise to ecosystem services bundles. Ecosystems services bundles often arise from the same or similar biophysical units, processes, and functions of an ecosystem. We suggest considering such **positive (synergies)** and **negative (trade-offs)** relationships occurring among ecosystem services to plan and apply correct management practices that enhance multifunctionality in different landscapes and minimize land use competition and conflicts between different interest groups.

Carbon sequestration and the potential supply of timber, for example, are positively correlated because these ecosystem services originate from the transformation of carbon dioxide into biomass through photosynthesis. On the other hand, some ecosystem services are negatively correlated because they usually originate from different geographical or ecological characteristics. Outdoor recreation is negatively correlated with agricultural ecosystem services such as crop potential and fodder production. This occurs because agricultural landscapes offer a limited possibility to perform outdoor activities, and the access to fields, pastures and hay meadows may even have a negative impact on crop yield. As expected, also in our statistical analyses some of the ecosystem services mapped displayed strong positive or negative correlations, indicating that some sets of ecosystem services are delivered in bundles (Figure 3).

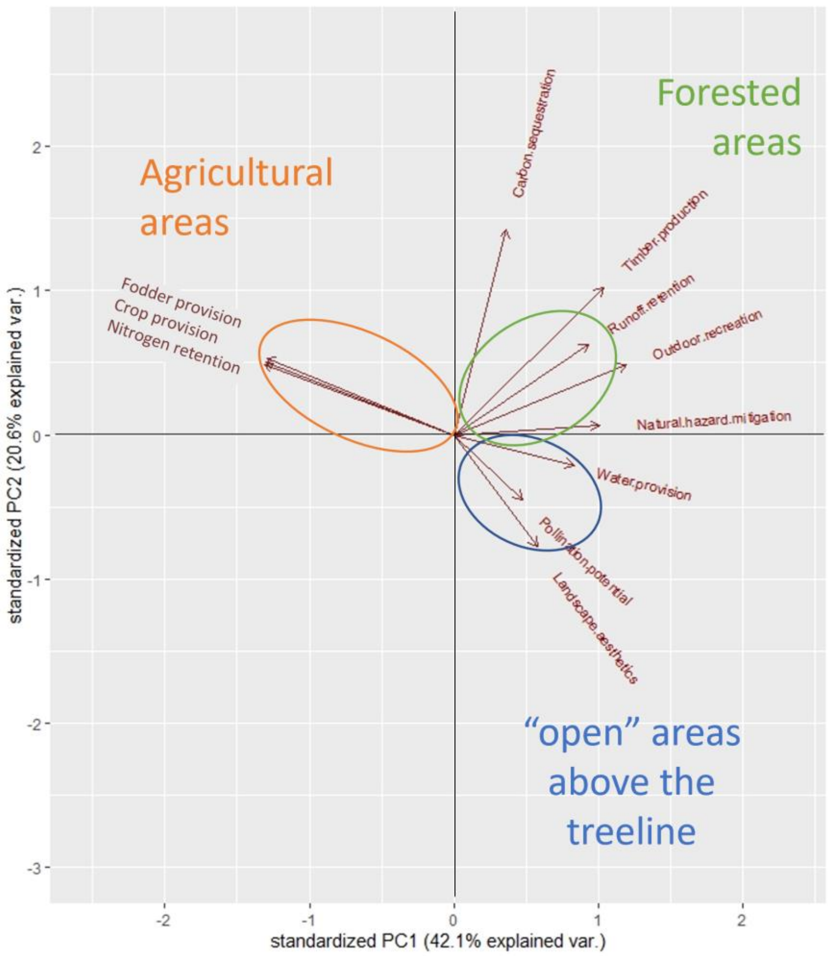


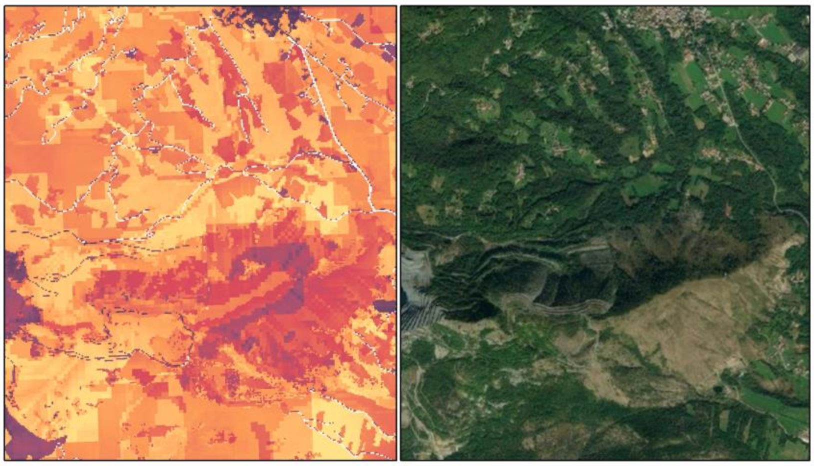
Figure 3: Ecosystem services plotted against the two Principal Components resulting from a Principal Componets Analysis show the trade-offs and synergies occurring among our set of ecosystem services. Moving clockwise in the different quadrants of the graph, the ecosystem service bundles related to agricultural areas (orange), to forested areas (green), and to "open" areas above the treeline (blue) can be observed. The two principal components together explain 62.7 % of the variance.

3) Multifunctionality is linked to landscape complexity

In the LUIGI project, we found that some of the **highest multifunctionality values are generally found in those areas at the feet of mountains displaying complex agricultural landscape patterns**, featuring a mix of **pastures, woods,** and green linear elements such as **hedgerows** (Figure 4). Multifunctional areas with a high share of these important landscape elements indeed create a landscape that can **sustainably support human activities, ecological processes, and biodiversity**. In the LUIGI project, we propose that such areas should be protected or sustainably managed as part of regional Green Infrastructure networks.

In a heterogeneous landscape featuring a mix of agricultural and forested areas, for example, a set of ecosystem services stemming from agroecosystems (crop production, fodder production) would be combined with a set of ecosystem services related to the presence of natural vegetation (carbon sequestration, timber provision, pollination, run-off retention, protection from natural hazards). The widespread presence of forests, woods, hedgerows, and trees can indeed help mitigate the negative impacts of agricultural activities, supply important services that regulate the environment, and provide habitat to biodiversity. Complex landscapes with natural vegetation, moreover, are usually more attractive to people and provide more opportunities for outdoor recreation in comparison to monotonous landscapes.

a)



Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

b)

Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 4: High ecosystem multifunctionality (yellow) is linked to landscape complexity (a), while Low ecosystem multifunctionality (violet/red) is linked to homogenous landscapes and intensive land uses (b). The presence of woods and hedgerows increases multifunctionality.

4) Multifunctional areas support ecological connectivity and biodiversity

Areas displaying high values of multifunctionality also support ecological connectivity and the movement of animals across the landscape (i.e., are permeable to animal movement) (Figure 5). Forests provide a habitat to many common and iconic alpine species, such as deer, lynx, or black grouse. Hedgerows and green linear elements support the movement of animals across more anthropized and agricultural areas, enabling individuals to find mates and new territories necessary for the survival of the population. Forested areas that support ecological connectivity also sequester carbon, absorb run-off in storm events, provide timber, and support landscape aesthetics and outdoor recreation.

Moving across the landscape allows animals to find resources, shelter, and mates. This increases genetic variability and the persistence of animal populations over time. Moreover, corridors allow species to move their range in response to climate change. **Landscape heterogeneity is also generally positively correlated to biodiversity**. Management actions that support biodiversity include limiting the use of pesticides and fertilizers, increasing the proportion of hedgerows and natural vegetation in agricultural landscapes, restoring natural ecosystems, and creating opportunities for animal crossing along highways and railways.

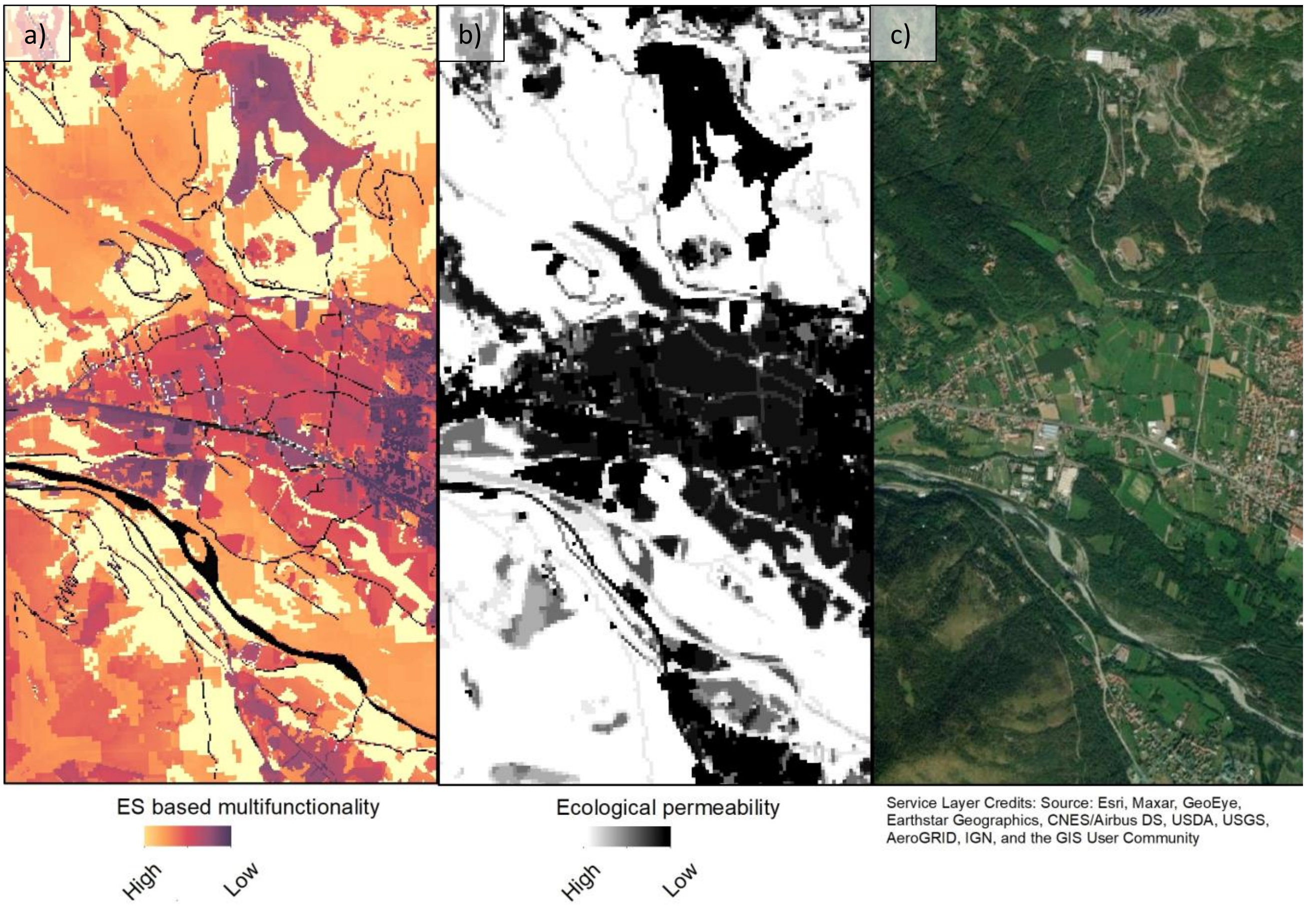


Figure 5: Low Multifunctionality (a, in red/violet) is associated with low ecological permeability (b, black areas) as intensive land uses and urban areas (c, for reference) hinder the movement of animals across the landscape.

5) At the local scale, management is a key factor

At the local scale, land use intensity and management practices determine local multifunctionality. Local management practices greatly affect the **ecological quality and the biodiversity of natural and semi-natural ecosystems**, influencing their **resilience** and their capacity to deliver multiple ecosystem services.

Intensively managed monocultures displaying low multifunctionality, for example, feature a single species planted at very high densities. This may be beneficial to maximize production and the delivery of a single ecosystem service, but it also reduces the supply of other important ecosystem services and the resilience of the agroecosystem to plant diseases and extreme weather events. The absence of diverse and native species indeed reduces habitat availability and limits the provision of ecosystem services such as nitrogen retention, pollination, run-off retention, landscape aesthetics and outdoor recreation. Finally, the presence of natural and semi-natural landscape elements in agricultural areas, such as hedgerows or woody features, besides supporting the provision of important ecosystem services, also improves the permeability of agricultural landscapes to animal movement.

Pollinators and alpine orchard meadows

In the alpine context, **orchard meadows** are a good example of a **traditional and extensive land use** that typically supplies high quality fruits while supporting **multiple ecosystem functions and services**. The **complex**, **multi-layered habitat structure** featuring perennial fruit trees and semi-natural grasslands indeed supports high levels of biodiversity. This contributes to biodiversity conservation, pest and disease control, crop pollination, and the production of hey, honey and other beekeeping goods. Ground vegetation, roots, and healthy and soil microbial community contribute to the regulation of water flow and quality, nitrogen fixation, organic matter accumulation, and soil formation.

In a study conducted within LUIGI in the pilot region of South Tyrol between May and August 2021, we investigated the effect of habitat on wild bees (*Apoidea)*. We tested the abundance (N of individuals) and the species richness (N of species) of wild bees in 5 orchard meadows and 5 intensive organic apple orchards. Using pan traps, we collected a total of 369 wild bees over three replications. Species identification was then carried out by the Fondazione Edmund Mach.

We found that orchard meadows supported a **higher number of individuals** (max= 69), and a **significantly higher number of species** (max=26) compared to intensive organic apple orchards (Figure 6). Site location and date of sampling did not have a significant effect, indicating that there was no systematic bias in the study design.

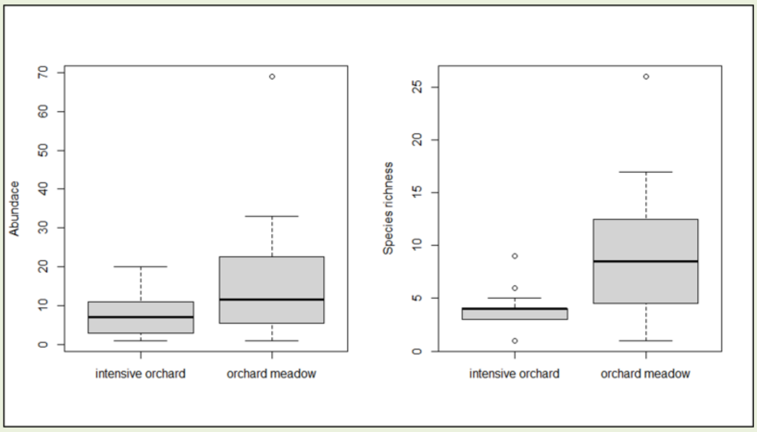


Figure 6: Abundance and Species richness of wild bees in orchard meadows and intensive organic apple orchards.

6) Natural areas with low multifunctionality often provide unique habitats and services

Areas at high elevations above the tree line, where the landscape is mainly dominated by alpine grasslands, sparsely vegetated areas, and bare rocks, **display low multifunctionality values but provide unique habitats to many plant and animal species**. In the LUIGI project, we recommend conserving these **fragile areas**, preserving them from infrastructure development and excessive tourist impacts.

High altitude areas display low multifunctionality because the provision of many ecosystem services in the Alpine socio-economic context tends to decrease following topographic and climatic gradients. At higher elevations, for example, the net primary productivity of forests and grassland decreases due to harsher climatic conditions. Such high-altitude areas, however, often have a high degree of naturalness, are marginally affected by human activities, and provide unique habitats to many rare and iconic species such as glacier buttercups, alpine ibex, or edelweiss. Moreover, they supply key ecosystem services such as ground water recharge, pollination, landscape aesthetics, and outdoor recreation (Figure 7). **Given the ecological, environmental, and cultural value of these high-altitude fragile areas, many protected areas have been established over the years**. In the LUIGI spatial planning approach, protected areas and other areas with limited human disturbance represent the core elements of Green Infrastructure networks due to their importance for biodiversity and ecological connectivity, although they may show lower overall multifunctionality values compared to lowlands.

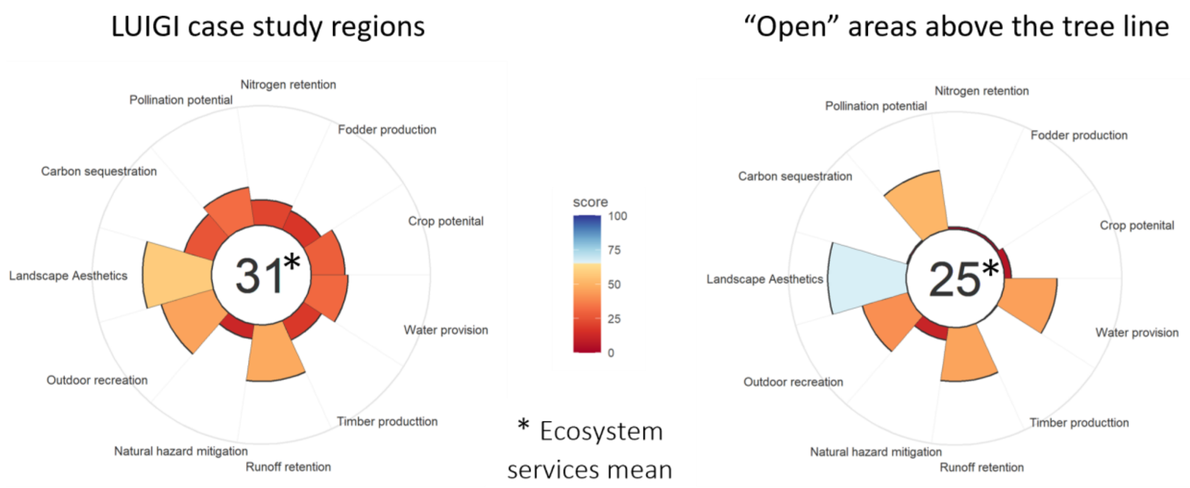


Figure 7: Ecosystem services provision and average multifunctionality in the LUIGI case study regions (left) and in "open" areas above the tree line (right).

7) Multifunctionality depends on which ecosystem services are considered

The outcome of multifunctionality assessments greatly depends on the number and types of ecosystem services included in the analysis (Figure 8). In the LUIGI project, we have analysed provisioning services along regulating and maintenance, and cultural services. This approach allowed us to analyse the relationship between sometimes contrasting sets of ecosystem services and to identify landscape planning strategies that can best exploit the synergies occurring between different ecosystem services.

Including only regulation and maintenance services in multifunctionality assessments would lead to the prioritization of areas that are important for **biodiversity and ecological processes**, such as forests. Considering also provisioning and cultural services allows to take in account also those ecosystem services that are important for **human demand and well-being**, highlighting possible **synergies and land use conflicts**. **Participatory processes** such as workshops and round table discussions with stakeholders and practitioners can help to understand which are the ecosystem services, the trade-offs, and the synergies important for each case study area. Such participatory processes can inform the prioritization and the selection of the ecosystem services that will be included in the multifunctionality assessment, increasing the value of planning and management recommendations. The availability of data and the feasibility of ecosystem services assessment models, however, also affect the choice of which ecosystem services can be finally considered in multifunctionality assessments.

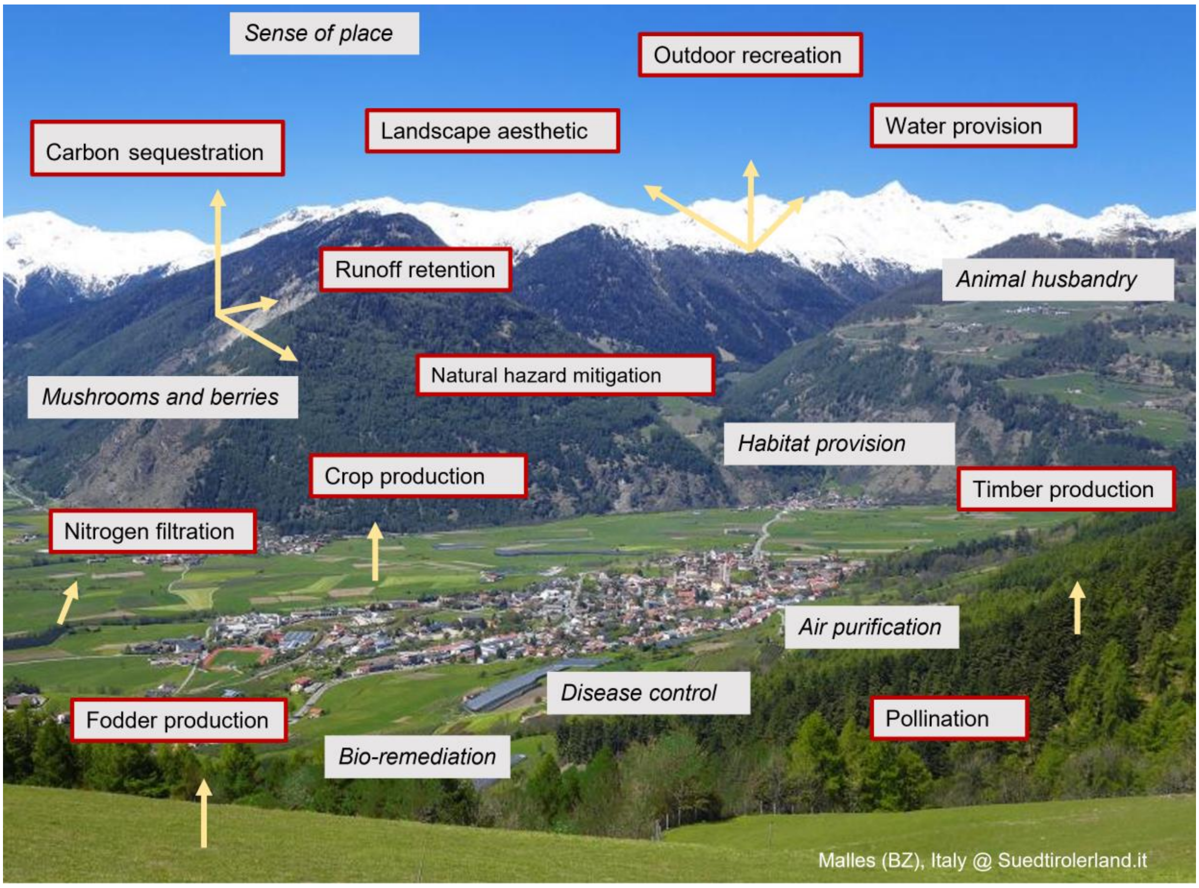


Figure 8: Multifunctionality assessments can take in account only a number of the many ecosystem services provided by nature. In the LUIGI project we mapped the following ecosystem services (in red): crop potential, water provision for drinking, fodder provision, timber provision, pollination potential, water flow regulation, water nitrogen filtration, carbon sequestration, natural hazard mitigation, outdoor recreation potential and landscape aesthetics.

8) Multifunctionality changes with different scales and approaches adopted

Assessments of multifunctionality might lead to different outcomes depending on the spatial and temporal scale considered, and on the method used to aggregate ecosystem services into a single multifunctionality metric (Figure 9).

The spatial scale of the analysis affects the way ecosystems, natural features, and their related ecosystem services are included in the analysis. At the **local** patch or plot level, multifunctionality is the result of the structure, processes, and functions of an ecosystem, and can be enhanced by increasing species diversity and the structural complexity of land plots. At the landscape and **regional** levels, multifunctionality is instead the result of greater landscape configurational complexity and is also driven by geographic (e.g., alpine *vs* plain) and climatic factors.

Temporal scale: multifunctionality assessments describe the capacity of ecosystems to supply multiple ecosystem services in a specific point in time, being the result of current management practices and ecological conditions of an ecosystem (i.e., it is a static assessment). Thus, **multifunctionality changes following land use change dynamics and management strategies** (e.g., urban sprawl, agricultural ex- and intensification, land abandonment and reforestation or tourism development) that affect the ecological quality of ecosystems and their capacity to provide ecosystem services.

Metrics: several methods to quantify multifunctionality have been proposed. Multifunctionality can be described by **different metrics** which underline the total supply (e.g., average value), the diversity of ecosystem services (e.g., biodiversity indices such as alpha- or beta- diversity), or the number of ecosystem services above a certain threshold value. Multifunctionality quantification approaches should be carefully chosen based on the type of information required and should always be **guided by the targeted policy application.**

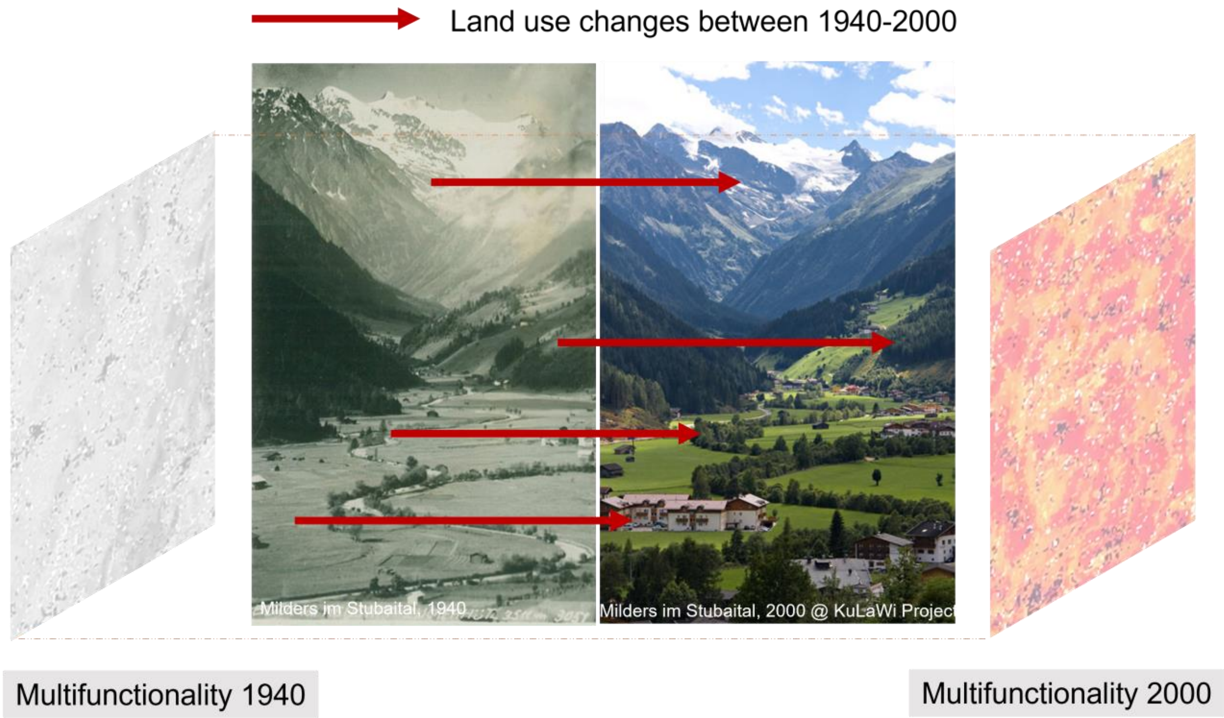


Figure 9: Land use changes between 1940 and 2000 determine changes also in ecosystem services provision and multifunctionality assessments

References and further resources

- Collier, M. J. (2021). Are field boundary hedgerows the earliest example of a nature-based solution? *Environmental Science & Policy*, 120, 73-80.
- Dainese, M., Montecchiari, S., Sitzia, T., Sigura, M., Marini, L. (2017). High cover of hedgerow in the landscape supports multiple ecosystem services in Mediterranean cereal fields. *Journal of Applied Ecology.* 54, 380-388 doi: 10.1111/1365-2664.12747
- de la Fuente, B., Mateo-Sánchez M.C., Rodriguez, G., Gastón, A., de Ayala R. P., Colomina-Pérez, D., Melero, M., Saura., S. (2018). Natura 2000 sites, public forests and riparian corridors: The connectivity backbone of forest green infrastructure, *Land Use Policy,* 75, 429-441. https://doi.org/10.1016/j.landusepol.2018.04.002
- Di Marino, M., Tiitu, M., Lapintie, K., Viinikka, A., Kopperoinen, L. 2019. Integrating green infra-structure and ecosystem services in land use planning. Results from two Finnish case studies. *Land Use Policy*, 82, pp. 643-656, 10.1016/J.LANDUSEPOL.2019.01.007
- European Commission, 2019. Review of progress on implementation of the EU green infrastructure strategy. COM (2019) 236. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52019DC0236&qid=1562053537296&from=EN
- García, A. M., Santé, I., Loureiro, X., & Miranda, D. (2020). Green infrastructure spatial planning considering ecosystem services assessment and trade-off analysis. Application at landscape scale in Galicia region (NW Spain). *Ecosystem Services*, 43, 101115. https://doi.org/10.1016/j.ecoser.2020.101115
- Giombini, V., Simion, H., Marsoner, T., Egarter Vigl, L. 2022. Enhancing landscape multifunctionality and ecological connectivity across the Alps. Policy briefs for stakeholders and decision makers. Deliverable D.T1.2.1 of the Interreg Alpine Space project “LUIGI”.
- Hölting, L., Jacobs, S., Felipe-Lucia, M. R., Maes, J., Norström, A. V., Plieninger, T., & Cord, A. F. (2019). Measuring ecosystem multifunctionality across scales. Environmental Research Letters, 14 (124083). https://doi.org/10.1088/1748-9326/ab5ccb
- Hölting, L., Beckmann, M., Volk, M., & Cord, A. F. (2019b). Multifunctionality assessments – More than assessing multiple ecosystem functions and services? A quantitative literature review. *Ecological Indicators*, 103, 226–235. https://doi.org/10.1016/j.ecolind.2019.04.009
- Laterra, P., Orúe, M. E., & Booman, G. C. (2012). Spatial complexity and ecosystem services in rural landscapes. Agriculture, *Ecosystems and Environment,* 154, 56–67. https://doi.org/10.1016/j.agee.2011.05.013
- Maes, J., et al. 2018. Mapping and Assessment of Ecosystems and their Services: An analytical framework for ecosystem condition. Publications office of the European Union, Luxembourg
- Manning, P., Van Der Plas, F., Soliveres, S., Allan, E., Maestre, F. T., Mace, G., Whittingham, M. J., & Fischer, M. (2018). Redefining ecosystem multifunctionality. *Nature Ecology and Evolution*, 2 (3), 427–436. https://doi.org/10.1038/s41559-017-0461-7
- Raudsepp-Hearne, C., Peterson, G. D., & Bennett, E. M. (2010). Ecosystem service bundles for analyzing tradeoffs in diverse landscapes. Proceedings of the National Academy of Sciences of the United States of America, 107 (11), 5242–5247. https://doi.org/10.1073/pnas.0907284107
- Turkelboom, F., Leone, M., Jacobs, S., Kelemen, E., García-Llorente, M., Baró, F., Termansen, M., Barton, D. N., Berry, P., Stange, E., & et al. (2018). When we cannot have it all: Ecosystem services trade-offs in the context of spatial planning. *Ecosystem Services*, 29, 566–578. https://doi.org/10.1016/j.ecoser.2017.10.011