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The MIMOSE approach to support large-scale statisticsonforest ecosystem services

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ABSTRACT

In the last decades, Mediterranean landscapes have been transformed by anthropogenic processes, such as changes in land use and climate. In particular, forest transition in mountain areas, and urban sprawl in lowlands could strongly undermine the ability of ecosystems to provide benefits over time. Under these changing conditions, forest ecosystems have reduced their functionality, resilience and stability. In this way, important forest ecosystem services, such as timber, non-wood products, climate regulation, biodiversity conservation, and cultural and spiritual values, will be eroded if forest resilience is not effectively maintained. Accordingly, forest planning is called to spatially allocate management alternatives and strategies in order to balance the final provision of forest goods and services demanded by local communities with the ecosystem functionality. In this study, we implement the "Multi-scale mapping of Ecosystem Services" (MIMOSE) approach in Sicily region to (i) assess the forest ecosystem services bundle over a 20-year time period; and (ii) evaluate how ecosystem services can be balanced to support sustainable forest management at the regional scale. Through the MIMOSE approach, at first we spatially assessed, in biophysical and monetary terms, timber provision and carbon sequestration, according to three forest management alternatives: business as usual conditions, maximizing economic incomes, and prioritizing conservation purposes.We then calculatedthe trade-offs among these ecosystem services and carried out a cross-case analysis. Finally, sustainable future-oriented strategies for forest landscape planning were identified, in agreement with the best balanced set of ecosystem services. The most important outcomes are the following: (i) timber provision is in general a conflicting service, especially when adaptation strategies are promoted; (ii) the best balanced set of forest ecosystem services is achieved by adopting a more conservative approach; and (iii) the bundle of ecosystem services is generally influenced by ecological and management conditions (e.g., differences among forest landscapes in the two regions), and is sensitive to harvest intensity and frequency, as well as to the length of the period used for the simulation. The MIMOSE approach demonstrated to be a spatially-explicit tool particularly suitable to support landscape planning towards balancing forest ecosystem potentialities with local communities' needs. Moreover, the approach can be considered an easy-to-use and replicable tool to cope with sustainable development goals in the Mediterranean area. In this light, the MIMOSE approach can improve the monitoring and assessment of ecosystem services demand and budget from local to national scale, thus contributing to the statistics and environmental accounting for the forestry sector.

Keywords: MIMOSE, forest ecosystem services, forest management and planning, regional scale

1. Introduction

Forest ecosystems are important sources of goods and services (hereinafter Forest Ecosystem Services;FES) for people worldwide, such as(i) timber and non-timber products provision,(ii) habitats and species conservation, (iii) regulation ofthe biogeochemical regimes, and (iv)enhancement of cultural and recreational aspects of a given landscape (for the Italian context, e.g., Vizzarri et al. 2015a). The FES availability depends upon the forest resilience, health and stability (e.g., Proença et al. 2010). Especially in Mediterranean landscapes, often degraded by human-driven interactions, the forest resilience is undermined, and the associated benefits for local communities reduced. Considering these challenging conditions, forest management and planning are called to balance the FES availability with the ecological and socio-economic aspects at local scale. In particular, the acquisition of more detailed information (e.g., chemicals, soil parameters),and the implementation of both advanced tools (e.g., LiDAR techniques) and innovative approaches (e.g., agent-based models) are increasingly requiredto support forest management inmonitoring the spatial and temporaldevelopments of forest landscapes, and in turn quantifyingtherelated changes in termsof FES provided, both in biophysical and economic terms. Theuse of tools such asthe "Integrated Valuation of Ecosystem Services and Trade-offs" (InVEST) or the "Artificial Intelligence for Ecosystem Services"(ARIES), has proven to beeffective in several cases (Posner et al. 2016; and Villa et al. 2014, respectively). Nevertheless, the lack of input data on forest structure, health and productivity, the weak integration between the current management and the socio-economic conditions, and the absence of economic statistics on ES availability strongly reduce the effectiveness of forest management and planning, especially in theItalian landscapes. Tofacethese situations, the "Multiscale Mapping of Ecosystem Services" (MIMOSE)approachwasdeveloped and implemented forforest ecosystems in the Molise region, Central Italy, to map timber provision and carbon sequestration, and assess the related trade-offs (Bottalico et al. 2016). In thiswork, we applied the MIMOSE approach to the forests ofthe Sicily region(Southern Italy),with the aim of highlightingconstraints and potentialities for large-scale FES assessment, and mappingandcomparing different Mediterranean contexts.

2. Material and methods

2.1 Study area

The study area is located in Southern Italy, in the north-eastern part of the Sicily region, and covers 962,300 ha (Figure 1). The elevation ranges between the sea level to 3,350 m a.s.l. (Etna volcano). The climate is Mediterranean along the costs, and temperate on the inland reliefs (Rivas-Martinez 2004). Forests and other wooded lands cover approximately 21% of the study area (Figure 1). Downy oak (*Quercus pubescens* Willd.) (35% of the total forest area), Turkey oak (*Q. cerris* L.) (13% of the total forest area), and European beech (*Fagus sylvatica* L.) (9% of the total forest area) are the most widespread Forest Categories (FCs). Plantations cover 17% of the total forest area (Cullotta and Marchetti 2006). The study area is characterized by the presence of protected areas (60% of the total forest area), such as e.g., the Madonie, Nebrodi, and Etna Regional Parks, and several sites belonging to the Natura2000 Network. Part of the forest area (47%) is not actively managed, because mostly covered by neoformation forests, degraded forest lands, often abandoned, and coppice forests exceeding the standard rotation age(mainly left to natural evolution). The remaining area is actively managed, and covered by high andcoppice forests(31% and 20% of the managed forest area, respectively), and forests under "special" management conditions (2% of the managed forest area; i.e. chestnut and cork oak forests).

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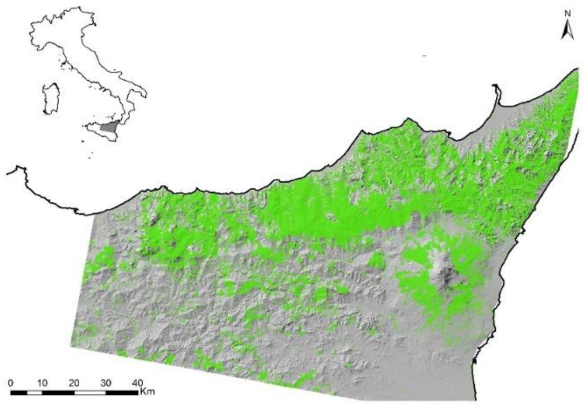

Figure 1: *Map of Italy (left-top) and zoom on the study area. The forest area is reported in green.*

2.2 The MIMOSE approach

MIMOSE is a spatially-explicit approach to assess, in both biophysical and economic terms, differentFES and related trade-offs in the Mediterranean region, according to alternative management strategies. In the present work, we implemented the MIMOSE approach through the following steps: (i) alternative management strategies (i.e. business-as-usual, BaU; nature conservation, NC; and wood production, WP) were applied at the Forest Management Unit (FMU) level in the study area;(ii) the modified InVEST modelwas implementedto quantify and map timber production and carbon sequestration over a 20-year period (from 2015 to 2035);and (iii) a qualitative trade-offs analysis was carried out. Finally, the results from this study were compared with those obtained from Bottalico et al. (2016), in the case of the Molise region. The trade-offs analysis concerns the comparison between the economic benefits derived by FES during the simulation periodby adopting different management strategies (BaU, NC and WP). As main economic benefits, the Total Net Present Value (TNPV; €), the Total Social Cost of Carbon (TSCC; €), and the Total Ecosystem Services Value (TESV; €) were calculated for timber production, carbon sequestration, and their sum, respectively. See Bottalico et al. (2016) for further details about the methodology adopted in this study.

3. Results and discussion

3.1 Forest ecosystem services provision and trade-offs

In the case of timber production, the resultsshowthat the total amount of wood harvested in the area during the 2015-2035 period is 8.8 million m^3, 4.7 million m^3, and 12.9 million m^3 for BaU, NC, and WP management strategy, respectively. The corresponding TNPV is 140.6 million €, 70.4 million €, and 236 million € for BaU, NC, and WP management strategy, respectively. In particular, the average amount of timber removals corresponds to 44.2 m^3 ha^{-1}, 23.7 m^3 ha^{-1}, and 64.7 m^3 ha^{-1} for BaU, NC, and WP management strategy, respectively. The corresponding average NPV is 707.6 € ha^{-1}, 354.4 € ha^{-1}, and 1187.3 € ha^{-1} for BaU, NC, and WP management strategy, respectively. In the case of carbon sequestration, the resultsshowthat the total amount of carbon stocked in the area during the 2015-2035 period is approximately1.4 million Mg C, 5 million Mg C, and -2.7 million Mg C for BaU, NC, and WP management strategy, respectively. For carbon sequestration, the negative values correspond to the carbon removed exceeding the current increment during the simulation period. The corresponding TSCC is 83.8 million €, 306.1 million €, and -167.2 million € for BaU, NC, and WP management strategy, respectively. In particular, the average amount of carbon stock increasesof 6.8 Mg C ha^{-1}, 24.9 Mg C ha^{-1}, and decreases of-13.6 Mg C ha^{-1} for BaU, NC, and WP management strategy, respectively. The corresponding average SCC is 421.6 € ha^{-1}, 1539.9 € ha^{-1}, and -841.4 € ha^{-1} for BaU, NC, and WP management strategy, respectively. TESV is 224.4 million €, 376.5 million €, and 68.8 million € for BaU, NC, and WP management strategy, respectively. In particular, the average TESV is 1129.2 € ha^{-1}, 1894.3 € ha^{-1}, and 345.9 € ha^{-1} for BaU, NC, and WP management strategy, respectively.Figure 2 shows some details related to TNPV, TSCC, and TESV in a specific locationof the study area.

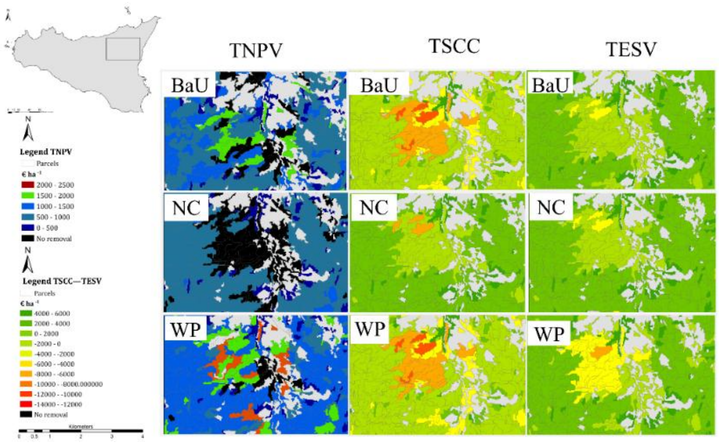

Figure 2: *Maps showing the spatial distribution of total Net Present Value (TNPV; € ha^{-1}), Total Social Cost of Carbon (TSCC; € ha^{-1}), and Total Ecosystem Services Value (TESV; € ha^{-1}) for the simulated forest management strategies (BaU=Business as Usual conditions; NC=Nature Conservation; WP=Wood Production) in the Etna volcano surrounding area.*

In general, TESV increases of approximately 67.8% when passing from the baseline (BaU) to the more conservative forest management strategy (NC), and decreases of approximately 69.4% towards a more productive strategy (WP). This dichotomous trend is explained by the combination of the forest management strategies (in terms of forest management system applied, harvesting intensity and frequency) and the characteristics of forest stands,such as, e.g., the averagestand age, which is 22 years (in the investigated stands),very close tothe theoretical end of the rotation period in coppice forests, depending on FC (e.g., 15-20 years;Rey et al. 2002). This aspect implies that certain simulated forest practices(e.g., the final cut in coppice with standards forests vs.no forestry intervention in coppice forests) may create a borderline between an increased TESV when adopting a more conservative approach, and a reduced TESV whenimplementing a more productive strategy,ofthe same magnitude.For example, in the case of downy oak forests (covering more than 35% of the total forest area), the reduction of the area subjected to the final cut in coppice forests with standards release (-40.4%) results in an increased TESV (+15.9 million €) when passing from BaU to NCmanagement strategy. On the contrary, for the same FC, increasing the area of coppice forestswith standards release (+8.1%) results in a strong reduction of TESV (-56.2 million €),when passing from BaU to WP management strategy. This discrepancy is due to the allocation of a large portion of the downy oak forest areaconverted from coppice to high forest, and left to natural evolution, in the caseof the NC management strategy over the considered period (approximately 40%). In this way, thecarbon accumulation in above-ground biomass in the future is facilitated (cf.Luyssaert et al. 2008). Concerningthe European beech forests (8.5% of the total forest area), thesimulated forestry interventions result in a decreased TESV (-25.7 million €), when passing from BaU to WP management strategy.This may be due to the fact that e.g., although most of the European coppice with standards forests are actively managed (i.e. harvested), the increasing of TNPV still remains lower in comparison with the decreasing in TSCC, when passing from BaU to WP management strategy. Accordingly, the period chosen for simulations (i.e. 20 years) seems to be short in order to effectively understand the future development of forest stands, and in turn to assess the implications of some forestry interventions on TESV, such as e.g., natural evolution, conversion of coppice forests to high forests. The results show the same trend as synthesized in Bottalico et al. (2016) for Molise region.Figure 3 reports a cross-case comparison of average TESV *per* hectare between Molise region and Sicily case study.

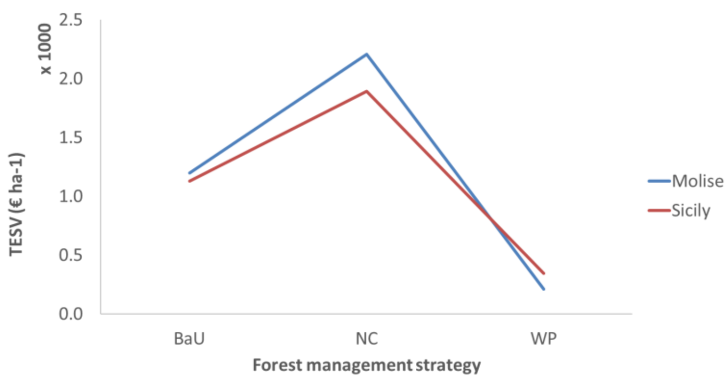

Figure 3: *Box plot showing the main differences in terms of TESV (€ ha^{-1}) between both the forest management strategies (BaU=Business as Usual; NC=Nature Conservation; WP=Wood Production), and the two Mediterranean case studies in Italy (i.e. Molise region and Sicily case study).*

The average TESV *per* hectare is higher in the Molise region for the NC management strategy than inthe Sicilian case study,while it is lower for the WP one. This mainly derives from the presence of younger stands, and the implementation of current less intensive forestry interventions in the Sicilycase study, in comparison with the conditions found in the Molise region. In addition, the harvesting rates during the simulation period for the NC management strategy are lower for Sicilian forests, if compared with the Molise ones (55% vs. 62%). On the other hand, the harvesting rates simulated for the WP management strategy are higher for Sicilian forests, if compared with the Molise ones (88% vs. 83%).This is due to the fact that e.g., the European beech forests in the Sicilian case study are mostly located at high elevations, and withinprotected areas. As a consequence, less intensive forestry interventions for these stands were hypothesized when simulating the stand development in the NC management strategy.

3.2 Management strategies for balancing Mediterranean forest ecosystem services

The results mainly show that timber provision and carbon sequestration (i.e. climate change mitigation) are in general conflicting services. The biomass removal originateshigh timber revenues (TNPV) and low carbon stock (TSCC), at least in the short run. This indicates that the 20-year simulation period should be extended in order to further understand the development of forest landscapes over time, and find a more balanced TESV. The forestry interventions have to be tailored on the interaction betweenforest management,the biophysical characteristics of the forest stands, and the objectives to be reached (e.g., maximization of timber provision, adaptation strategies). In particular, the combination of the harvesting frequency and intensity with the ecological status of forest stands strongly influences the future FES provision. This is particularly amplified in young stands, whereincreasingharvesting intensity may lead to a strong reduction of biomass, and subsequently of carbon stock in the short period. Especially in Mediterranean forest landscapes, which are often abandoned or degraded (e.g., Scarascia-Mugnozza et al. 2000), forest management and planning must balancetheeconomic incomes with increasedresilience and stability of forest ecosystems (e.g., Vizzarri et al. 2015b). This implies that forest management and planning strategies in these peculiar contexts should be aimed at (i) effectively implementing productive-oriented forest management strategies in healthy and stable forest stands; (ii) reducingharvesting intensity and frequency in less productive forest stands (i.e. conversion to high forests; natural evolution); and (iii) continuously monitoring themanagement outcomes, also with the aid of simulation tools to evaluate future FES provision at different spatial scales.At broader scale, the ecological footprint (China; e.g., Zhao et al. 2009), and the CICES classification (EU; Maes et al. 2016), were proposed as key approaches (i.e. indicators' frameworks) to further understand the human impact on natural capital, and improve the ES flow monitoring.

4. Conclusions

This study demonstrates that MIMOSE is an integrated approach for assessing the influence of alternative management strategies on the FES provision, as well as for understandingthe forest ecosystem dynamics,from the landscape to the regional scale, thus contributing to the statistics and environmental accounting for the forestry sector. In MIMOSE, the integration of spatially-explicit information (biophysical characteristics) with an expert-based approach (management strategies) plays a key role in supporting forest management and planning (Bottalico et al. 2016), at least in the following three ways: (i) current and future-oriented statisticson the development of forest stands are provided; (ii) a spatial distribution (location) of FES is given; and (iii) the effects of forest management alternatives on forest resources is assessed over space and time. Accordingly, the MIMOSE approach can be replicated in other Mediterranean contexts, with relatively low costs, since it is an effective tool for supporting decisionsaimed at implementing more adaptive strategies in changing landscapes, and balancing environmental constraints with socio-economic needs.Finally, the MIMOSE approach is consistent with the need to assess and map ES at multiple scales, in order to detect and monitor the relationships between local communities and natural resources, in terms of e.g., ecosystem structure, processes and final benefits provided (stocks and flows). This is crucial to promote and implement the sustainable development goals, especially in the Mediterranean region (e.g., www.planbleu.org).

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