Combined artificial intelligence, sustainable land management, and stakeholder engagement for integrated landscape management in Mediterranean watersheds

Itxaso Ruiz[1*], João Pompeu[1], Antonio Ruano[1], Paloma Franco[1], Stefano Balbi[1,2], María J. Sanz[1,2]

[1] Basque Centre for Climate Change (BC3), 48940 Leioa, Spain
[2] Ikerbasque – Basque Foundation for Science, 48009 Bilbao, Spain
* Corresponding author: itxaso.ruiz@bc3research.org

0. Abstract

In the context of water scarcity, soil erosion, and biodiversity decline, the Mediterranean basin urges to manage its nearly hundred coastal watersheds in a coordinated manner. To this end, we propose an integrated approach to model socio-ecologic scenarios with Sustainable Land Management (SLM) options at the watershed scale to strengthen the functioning of multiple Ecosystem Services (ES). This is tested in the Mijares watershed in eastern Spain. As a first step, we propose using integrated modeling technology to quickly assess areas of ecosystem goods and services supply and demand within the case study. To this end, we applied ARIES, an AI-driven online modeling platform widely used in the ES community. Then, we use this information to identify suitable SLM options documented in the WOCAT global database for providing the identified ES. Lastly, to adjust the results to the social-ecological context, we carry out consulting and participatory processes with key stakeholders to incorporate local knowledge of ES and capabilities to adopt SLM measures into the final proposal. As a result of this work, we can model various SLM scenarios, easing decision-making toward more integrated and sustainable land management in the watershed. Given the reproducibility of the used methodologies, our approach can be adopted in other Mediterranean contexts.

Keywords: interdisciplinary approach, climate change adaptation, ecosystem services, Sustainable Land Management scenarios

1. Introduction

The weather in the Mediterranean basin is characterized by dry warm summers, mild rainfall-dominated winters, and a rich abundance of microclimates resulting from the sharp orographic features of its shoreline (Lionello, 2012; UNEP/MAP, 2012) along with strong recirculatory mesoscale processes (Millán et al., 2005a). The whole region constitutes a climate hotspot with climate impacts projected to further endanger the resilience of its ecosystems and societies (Tuel and Eltahir, 2020). Together with intensified human activity and historical land use change (Ruiz & Sanz-Sánchez, 2020), forecasted climate change is expected to increase extreme temperatures, intensify drought and aridity, reduce snowfalls and glacier ice sheets, increase flooding, and rise fire weather risk (Masson-Delmotte et al., 2021), altogether further aggravating desertification, impacting biodiversity, and threatening the already altered hydrological cycle of the basin (MedECC, 2020).

Despite the environmental challenges, the Mediterranean basin has a large potential for successfully adopting Sustainable Land Management (SLM) in its watersheds (Ruiz et al., 2020), providing them and the whole region, with an enhanced capacity to adapt and mitigate climate change (Sanz et al., 2017). SLM encompasses soil, water and vegetation conservation measures, and is based on the key principles of enhancing the productivity and protection of natural resources, while being economically viable and socially acceptable (Schwilch et al., 2014). Addressing SLM in the Mediterranean basin is a challenging task in which the ''one model fits all'' paradigm does not apply. In addition to the extension of the catchment area, which has roughly 2M km^2, there is its intricate landscape, featured with elevated mountain ranges and narrow watersheds of less than 10 km^2 that cover 60% of the territory. This leads to diverse and complex terrain and local climatic conditions, requiring the use of innovative approaches that adapt land management to each watershed. To achieve this, integrated land management plans and tools need to be tailored to the specific Mediterranean context, whereby integrated land management is "a strategic, planned approach to manage and reduce the human footprint on the landscape" (Alberta Government, 2012).

Integrated land management should account for the benefits, risks, and trade-offs of environmental actions while considering the values and perceptions of the local populations. Accordingly, to capture SLM benefits, risks, and trade-offs we propose the use of a modeling technology aimed at identifying and quantifying areas of ecosystem goods and services supply and demand according to the implementation of different SLM options. To account for the values and perceptions of the local populations, we perform stakeholder engagement. Stakeholder engagement, and in particular co-production with stakeholders, is key to ensuring SLM effectivity and continuity in time, as participation in decision-making raises awareness of environmental issues and boosts willingness to adopt new SLM measures (Gómez Martín et al., 2021) while providing relevant information of local synergies.

Given the state of the adaptation and mitigation capacities of the basin (Masson-Delmotte et al., 2021), this work aims to provide an innovative approach to investigate how SLM can be used as a vehicle for strengthening the functioning of several Ecosystem Services (ES) in the rural and peri-urban Mediterranean areas. This approach introduces innovative digital tools that address knowledge integration and interoperability to leverage participatory processes and knowledge co-production processes. These processes help understand the larger social-ecological systems in which sustainable land management actions are nested, i.e. their social, institutional, and governance fabric while underpinning the values and preferences of relevant actors. To exemplify its use, we present a study case. The study case demonstrates the suitability of the proposed approach for its purpose and invites its implementation in other Mediterranean watersheds across countries.

2. Case study: the Mijares watershed

The Mijares watershed is located on the Eastern Mediterranean coast of Spain. It comprises an area of 4,075 km^2 and its altitude range is between 0 and 2,008 m a.s.l. The source of the Mijares River is in the Gúdar mountain range in the municipality of El

Castellar in the Aragón region. The river has a length of approximately 156 km and flows into the Mediterranean Sea through la Plana de Castellón in the Valencia region. Despite its modest flow and its Mediterranean character, i.e. with dry-hot summers, the Mijares River is quite regular in its seasonal distribution, with an average of 14.72 m^3/s. This is because the Iberian System acts as a barrier to the marine fronts and favors orographic precipitation at its headwaters, especially in summer, when air moisture transported inland is higher due to enhanced water evaporation in the Mediterranean Sea (Millán et al., 2005b). The watershed context and its land-use can be observed in Figure 1a-b and Figure 1c respectively.

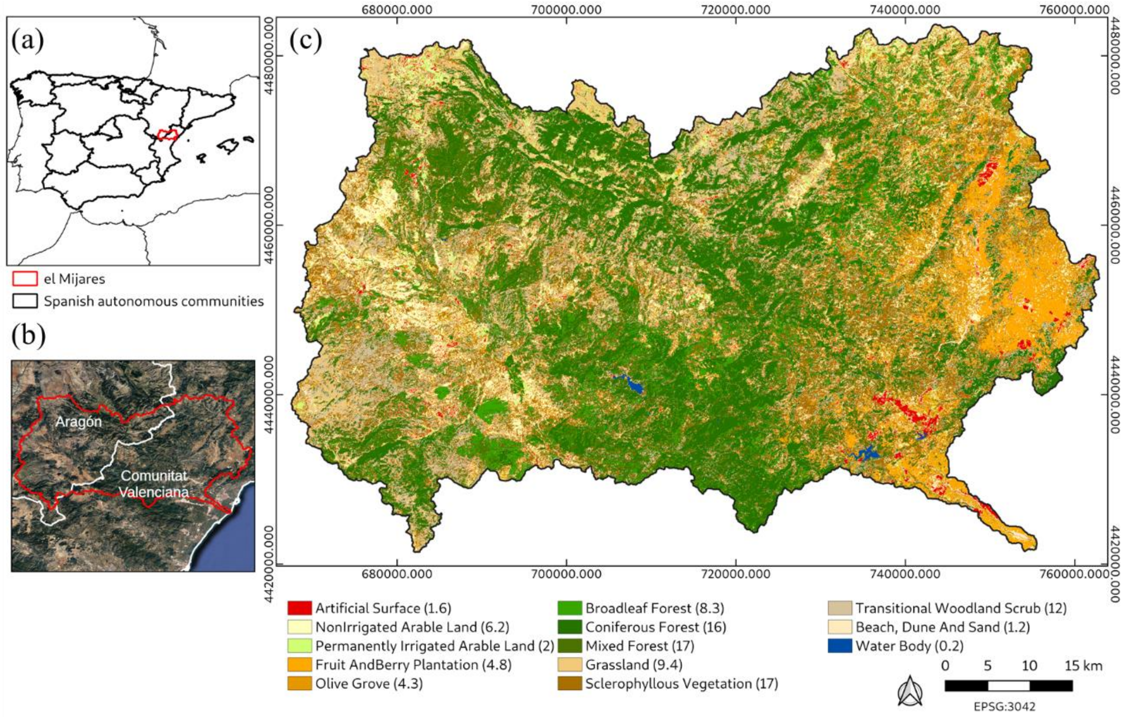


Figure 1.(a) Situation of the Mijares watershed within Spain; (b) Look up of the watershed; (c) Landsat-based Land-Use (LU) map of the watershed using 2018 satellite imagery. Modified from Pompeu et al. (2021).

The Mijares includes a wide variety of soils and land-uses (Pompeu et al., 2021). In the upper course of the watershed, the river runs embedded in karstified limestones (Figure 1c). This geology allows for the generation of water surpluses through the infiltration of rainfall into its aquifers, 2,742 hm^3/yr according to Confederación Hidrográfica del Júcar (2019) and the presence of natural springs. Here, coniferous and broadleaf forests stand out by extension together with sclerophyllous vegetation zones, grasslands and agricultural zones with natural vegetation. The population in this area is sparse and located in villages. Downstream instead, the presence of intensive fruit tree plantations and irrigated land along with urban areas and industry are predominant. Agriculture here is favored by the accumulation of nutrient-rich quaternary materials from the river's fluvial fan. These young sediment deposits are fed to a greater extent by groundwater from the coastal aquifer.

This heterogeneity in landscapes is translated to several water needs and uses, offering an ideal environment for studying the challenges posed by the planning and management of Mediterranean water resources. This is mainly due, beyond the dichotomy between the surpluses at the headwaters with the deficit at the lower course, to the fragile balance between available water resources (335.7 hm^3/yr) and water demands (268.23 hm^3/year). The agricultural sector is the major water consumer in Mijares, with 207.62 hm^3 in the year 2016/17, accounting for around 72% of the total water use in the watershed, followed by the urban use with 45.44 hm^3 (16%), and the industrial sector with 11.58 hm^3 (4.05%) (Confederación Hidrográfica del Júcar–Anejo 5, 2019). The high demand for water resources in Mijares gives rise to several challenges of social nature such as water conflicts, for which consensus among actors in the territory and regulatory bodies is necessary.

3. Framework of the study: integrated landscape management

To test the suitability of our approach in strengthening the functioning of ES through SLM and model potential scenarios, we used an interdisciplinary approach in the Mijares watershed that combines: (1) artificial intelligence, to quickly assess ES; (2) SLM knowledge from scientific literature and local communities, to learn about its potential in promoting social and ecological services; (3) stakeholder engagement, to identify priorities and capabilities on adopting SLM measures (*Figure 2*).

All three methodologies can be tracked and replicated elsewhere, namely, in other Mediterranean watersheds. This is possible as the artificial intelligence software chosen, ARIES, generates models that can fit into the context of analysis while the technology itself, assembles the most appropriate workflow to compute the requested outputs (Villa et al., 2014). Likewise, the SLM knowledge is documented in a global-scope database that uses a unified protocol for each SLM practice, allowing for the direct comparison of their environmental and social effects (WOCAT, 1992), while the stakeholder engagement avoids unsuitable standardization. Lastly, the methodology used for stakeholder engagement follows a consistent structure allowing for its reproducibility in other contexts.

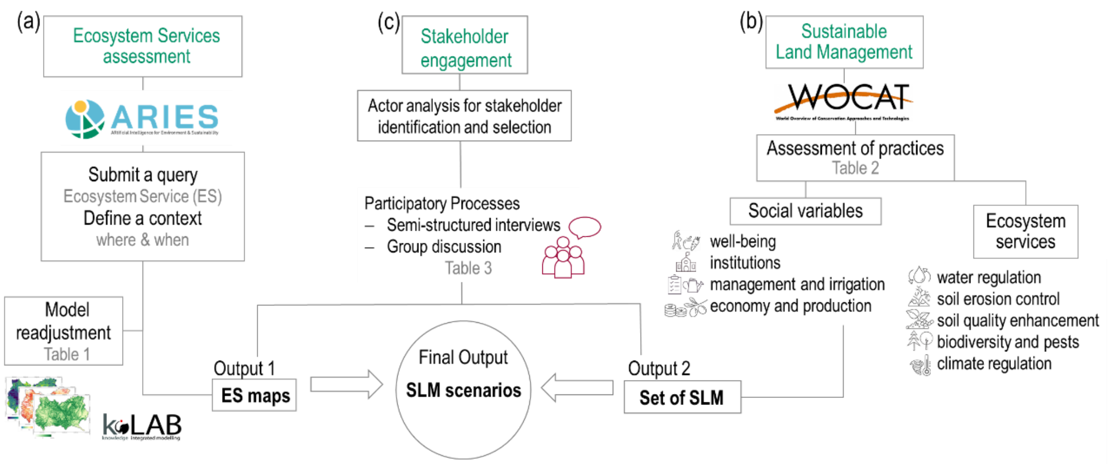


Figure 2. Schematic representation of the followed approach, with intermediate and final outputs. (a) Use of ARIES, and AI-driven software to generate Ecosystem Services (ES) maps by submitting a query, defining a context, and adapting available models to the case study. (b) Assessment of Sustainable Land Management (SLM) practices from the WOCAT database using 4 social variables and 5 ecosystem services. (c) Stakeholder

engagement through semi-structured interviews first and group discussion-workshop later. Intermediate outputs are (Output 1) modeling of the most important ES to stakeholders and (Output 2) set of SLM practices likely to be successfully adopted and fostered in the watershed. Final output: modeling of SLM potential scenarios considering ES and climate change projections.

3.1 Artificial intelligence for ecosystem services

To quickly assess areas of ecosystem goods and services supply and demand within the Mijares watershed, we used the ARtificial Intelligence for Environment and Sustainability (ARIES) platform. ARIES employs an integrated modeling technology that combines scientific data and models from multiple disciplines through a network of curated and web-accessible information (i.e. models and data) that are annotated with and related through shared semantics (Balbi et al., 2022; Villa et al., 2017). A simple user interface, the ARIES Explorer, allows a user to search for knowledge via the proposal of a query expressed in an English-like language through a search bar, for instance, "retained soil mass caused by vegetation", which is, in this example, the targeted ES (Table 1). Then, the user selects the spatial and temporal context in which to apply the query, for example, the Mijares watershed for the year 2021 (Fig. 2a). Following, ARIES uses deductive and inductive reasoning across its semantic knowledge base to assemble available data and models, to answer the query for the required context, while automatically mediating the potential differences in scales and units of measurement of the components utilized (Martínez-López et al., 2019). This approach makes it possible to integrate the different fields of knowledge needed to answer the query, namely for this example: soil sciences (soil erodibility), geomorphology (slope steepness and length), hydrology (rainfall runoff erosivity), and landscape ecology (land cover). Moreover, ARIES can be applied to build scenarios for multiple ES within any context, in this case, the Mijares watershed.

Behind the scenes, ES queries are expressed as logical statements and are resolved recursively by algorithms and input resources available in the ARIES semantic web. Such resources can be public global spatial datasets, often used as a default input option, or user-introduced input data, which can be prioritized to resolve the query in the user-selected context (Martínez-López et al., 2019). Additionally, the algorithms specifying the modeling components can be modified by tech savvy users, and/or new models can be developed building on the available building block. For each query resolved, the platform automatically documents the computational workflow assembled, including all of the input data, and the applied algorithms allowing its traceability and reproducibility elsewhere (Villa et al., 2014).

Beyond the integration of different fields of knowledge and the possible customization of the models to any context, a last reason to use ARIES was its appeal to several target users beyond academia, including ES modelers who can build and connect to other's work, and institutions that can publish research outputs freely and openly. Most of all, the user-friendly interface allows decision-makers and interested stakeholders to run models in an intuitive way and obtain a report out of it, without needing previous training, thus playing a major role in stakeholders' engagement.

Table 1. Globally customizable ARIES models applied in the Mijares watershed.

Available models	Brief summary
Organic carbon mass	Total amount of carbon (t/ha) from ecosystem processes. Include soil, roots and aerial vegetation.
Net value of pollination services	Balance between demand and provision of pollination service in the landscape, based on potential distribution of pollinator insects and crop dependent agricultural parcels.
Retained soil mass caused by vegetation	Sediment mass (t/ha) retained due to vegetation cover, based on the Revised Universal Soil Loss Equation (RUSLE). The equation is calculated twice, first with the actual land cover and then simulating soil loss with all land covered by bare soil. The difference is an estimation of the avoided soil erosion attributable to vegetation.
Value of outdoor recreation	Balance between demand (population density) and theoretical value of outdoor recreation, based on the time travel to places of interest for outdoor activities, such as water bodies, protected areas, mountains and beaches.
Hydrological model	Seasonal water yield model running at a monthly time step with three outputs: surface runoff, potential evapotranspiration, infiltration and baseflow.

3.2 Sustainable Land Management

Once characterized the areas of ecosystem goods and services supply and demand within the watershed, we considered SLM measures to foster the provision of these ES. SLM has been historically applied through the traditional use and the know-how of rural communities (Davis and Ebbe, 1993), yet it also comprises scientific evidence in promoting the resilience of socio-ecological systems (Sanz et al., 2017). Therefore, this is a widely studied vehicle proven to achieve long-term productive ecosystems all over the world, both from the traditional knowledge and the scientific spheres (Marques et al., 2016).

Although SLM are measures oriented to aid for a specific problem (e.g. crop cover to reduce soil erosion), overall, they constitute holistic actions to the landscape and beyond, as their adoption entails many interactions between the land and the indirect environment (e.g. crop cover to reduce soil erosion has effects on soil moisture, soil structure, evapotranspiration, biodiversity, etc.). Thus, instead of selecting individual SLM practices, we considered the combination of several actions aiming to have an impact at the watershed scale.

To create a portfolio of SLM measures that promote ES in a more integrated manner, we gathered information on those SLM practices that could be implemented in each land-use. The set of SLM practices that we used is documented in the World Overview of Conservation Approaches and Technologies global database (WOCAT, 1992), which provides a standardized assessment protocol for each practice, allowing for their direct comparison (Fig. 2b) along with local knowledge. Subsequently, we moved from the local scale of SLM application to the watershed scale by using the framework from Ruiz et al. (2020). This framework allows for the mainstreaming of practices by grouping similar but very specific practices and jointly determining their potential in assisting five ecosystem services: climate regulation, soil erosion control, biodiversity enhancement and pest/disease control, water regulation, soil quality enhancement; and four social functions: economy and production, management and irrigation, human well-being, institutions (Table 2). The ecosystem evaluation criteria help to identify those actions that best promote sustainable development at the watershed scale, while the social evaluation criteria provide information on the potential benefits of SLM application to the watershed stakeholders.

Table 2. Left column, SLM practices from the WOCAT database applied in the Mediterranean basin up to 2019. Central column, grouping of similar SLM measures assisting for their mainstreaming. Right column, evaluation criteria to each SLM practice.

SLM practices in the Mediterranean basin (fom WOCAT)	Grouping of specific SLM practices
Non tillage	No-till technology
Selective forest clearing to prevent large forest fires Prescribed fire Selective clearing and planting to promote shrubland fire resilience Cleared strip network for fire prevention (firebreaks)	Control of wildfires
Seedling	Seedling
Contour-felled log barriers	Contour bunds
Cover crops on olive orchards Cover crops in organic vineyard	Green covers in perennial woody crops
Aserpiado	Water harvest with microcatchments
Reforestation Natural revegetation	Reforestation
Vegetated earth-banked terraces Catch crop	Vegetated cropland
Reduced tillage of almonds and olive Reduced contour tillage of cereals in semi-arid environments	Reduced tillage
Phytostabilization of contaminated soils	Application of chemical fertilizers
Afforestation with Pinus Halepensis after the fire of 1979	Afforestation
Water harvesting from concentrated runoff for irrigation purposes	Water harvesting from concentrated runoff
Adding amendments to contaminated soils Organic amendment located in dripper point in organic citrus production Application of 'Preparation 500' in soils under a biodynamic management Ecological production of almonds and olives using green manure Annual green manure with Phacelia tanacetifolia in southern Spain	Application of organic fertilizers and biological agents
Straw mulching to improve soil quality Organic mulch under almond trees Chipped branches	Mulching in croplands and forestlands
Multi-specific plantation Multi-specific plantation of semiarid woody species on slopes	Multi-specific plantation

Ecosystem services
WATER REGULATION soil moisture, water quality, natural water regulation, downstream flow
SOIL EROSION CONTROL surface runoff, sediment transport, soil stabilization, overgrazing, wind velocity
SOIL QUALITY ENHANCEMENT soil cover, soil crusts, soil compaction, soil fertility
BIODIVERSITY AND PESTS plant and animal diversity, habitat diversity, pests and diseases, fodder for livestock
CLIMATE REGULATION C capture and stock, micro-climate regulation, impacts of extreme weather events

Social variables
WELL-BEING cultural and recreational opportunities, traditional knowledge, food security, multifunctional landscape
INSTITUTIONS support at the local and national level
MANAGEMENT AND IRRIGATION initial workload, versatility in application, natural landscape management
ECONOMY AND PRODUCTION initial economic investment, production, damage to infrastructure, rural economy, output diversification, sustainable exploitation of resources

3.3 Stakeholder engagement

After creating the portfolio of SLM measures, we initiated conversations with locals from the Mijares watershed with the purpose of capturing their knowledge, capabilities, and willingness to adopt SLM in relation to ES and climate change. The network of stakeholders within the watershed is diverse due to the various economic activities. To consider a maximum variation sample, we established key stakeholder categories upfront in an ex-ante approach by identifying already set networks and searching for regional and local decision-makers, associations and NGOs, experts, companies and cooperatives, local communities, and the tourism and recreation sector, among others (Table 3). Then, we selected a subset of them by applying stakeholder analysis techniques that include a matrix of interest/influence and semi-structured interviews (Durham et al., 2014). Lastly, following an ad-hoc approach, we checked with the interviewees for potentially relevant stakeholders missing in the conversation (i.e. snowball approach).

Then, we carried out a workshop combining top-down i.e. scientific data, and bottom-up i.e. participatory processes, methods to elaborate different proposals with the SLM practices that stakeholders agreed they were willing / were feasible to adopt within the watershed (Fig. 2c). We presented the participants with ES maps and climate change projections in the Mijares watershed for 2050. These served us to articulate bottom-up conversations on trade-offs between climate change impacts and the best ways to foster adaptation through SLM for the different proposals. Through these conversations, stakeholders gained awareness about the role of SLM in ES, as well as the influence of their actions on others. This task supports the transition of their perspectives beyond their ratio of individual-local action to a collective-watershed scale by discussing, and integrating others' perspectives and capabilities (García-Nieto et al., 2019). From these conversations, we elaborated a map of potential areas where to implement SLM measures within the watershed that was later validated by the stakeholders. This map was then used for the modelling of SLM potential scenarios within ARIES related to ES and climate change, constituting the final output of the research.

Stakeholder engagement is a crucial component for a sound understanding of the reality of the watershed and is key to a successful SLM strategy in promoting multiple ESs. This is a central issue in SLM adoption, as, beyond implementation, which can be approached as a top-down measure, i.e. from decision-makers to the people, continuity in time needs to be ensured for the success of the implemented measures by the stakeholders, thus becoming the drivers of change (Sanz et al., 2017). To this end, stakeholders are more likely to feel that SLM benefits are aligned with their needs, capabilities, and willingness, understand and accept potential trade-offs, and lastly, sense that they are the ones who put SLM in the forward of their rural activities (Newig et al., 2018; Reed, 2008; Reed et al., 2018).

Table 3. Stakeholder approach scheme.

Research question	– Which SLM actions are likely to be successfully adopted where in the watershed?
Goals	– Understand the impacts of SLM to the ES of the watershed – Modelling of socio-ecological scenarios in line with the context of the conversations
Sampling	– Identification of key stakeholders upfront based on stakeholder analysis techniques and already established networks – Selection of stakeholders based on matrixes of interest/influence, semi-structured interviews, and using the snowball approach
Approach	Stakeholder interaction process: 1. Semi-structured interviews – Understand the social-ecological context – Participatory mapping: individually map potential areas of SLM adoption 2. Workshop – Agree in areas of SLM adoption – Qualitative validation of benefits and trade-offs of SLM and ES in the projected climate changes scenarios 3. Presentation of the results, i.e. socio-ecological scenarios
Data collection and processing	– Interview notes – Flip chart for key ideas – Paper-based map (Flip chart and paper-based map: Contrasted with the stakeholders)
Ethical issues	– Freely consented participation – Identity confidentiality
Validation	– Record of results – External validation by stakeholders during the workshop

4. Results and Discussion

4.1 Modelling scenarios

Outputs of the followed approach are, as Output 1, a bottom-line visualization of the watershed's state involving ES supply and demand that results from applying ARIES (Table 1). All five resulting ES maps (Fig. 3.1a-e) consistently identify two areas with lower ES compared to the inner watershed, where forestlands predominate. The first area is the western side of the watershed's margin. There, steep and arid soils along patches of grasslands dominate the upper terrain, followed by a populated plain stretching out along the river course downstream. The other area is at the eastern boundary of the watershed and river mouth, where the presence of intensive citric tree plantations, urban areas, and industrial parks are predominant (Fig. 1). Thus, from this first output, that is, relying only on scientific data and models, it follows that the forest landscape of the Mijares encloses the highest value for the supply and demand of the five assessed ES. This result is in line with a large body of literature reporting high ES for forests compared to other land use types (Brockerhoff et al., 2017). Yet, it constitutes a relatively standard result that needs refinement to the specific context of the Mijares by including socio-economic aspects (Reed et a., 2008). To capture these along with the local knowledge of the people and their capabilities to adopt SLM in relation to ES, we followed with Output 2.

Output 2 is threefold: a) a geographical representation of where stakeholders aim at adopting SLM actions and b) a map with the most valued natural areas by the people residing in the watershed (Fig. 3.2b). These maps come together with c) a qualitative assessment of the benefits and trade-offs of ES. In a first step resulting from 25 semi-structured interviews, stakeholders redefined the list of SLM. They discarded some of the initial 15 measures (central column of Fig. 2) due to socio-economic unsuitability and re-designed others following the needs and capacities of the territory. This exercise resulted in 19 SLM measures likely to be successfully adopted across the watershed (Ruiz et al., 2022). Later on, during the workshop, the stakeholders concurred on five key SLM measures to the Mijares that responded to its environmental challenges and socio-economic settings. They agreed on:

1. promoting extensive grazing at the headwaters, where rough terrain, high-quality grasslands, abundance of cattle trails, and sparse population predominate;
2. shifting from a dense forest to a mosaic-like landscape in the inner watershed, where fire-prone and overly-densified forests dominate;
3. fostering the recovery of traditional orchards in the upper basin, where agricultural abandonment and sparse population shape the landscape;
4. maintaining rainfed crops in the middle course of the river, where sparse population and water scarcity influence economic activity; and
5. promoting more integrated agricultural systems in citrus plantations at the river plain, where intensive citric exploitations, high population density, and water scarcity conditions prevail (Ruiz et al., 2022).

With these results, we identified all potential bio-geographically suited areas within the watershed for each of the five key SLM measures (Fig. 3.2a). The criteria used to identify them were land-use type and spatial extensions bigger than 1 ha, so the proposed areas may be entitled to benefit from the EU Common Agricultural Policy. Moreover, in extensive grazing, we only chose areas with a slope of less than 16% and precipitation of over 472 mm/yr to ensure sustainable regeneration of the grasslands (Reiné Viñales, 2009). Forestry actions were limited to sites with slopes up to 31%, while agricultural activities were limited to areas with slopes less than 10%.

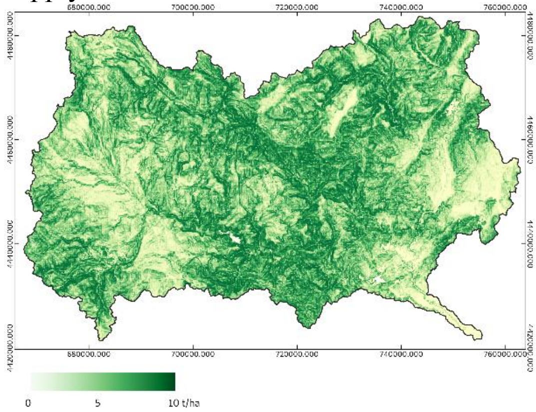
The qualitative assessment of the benefits and trade-offs of ES allowed us to integrate the information from Output 1 by bringing in the historical and socio-economic dimensions of the watershed. In this way, while ES were highest in forestlands, these were unanimously described as over-densified and largely homogeneous coniferous plantations of ~70 years old by all stakeholders (Fig. 3.2c). Overall, this nuance their total value on ecosystem services provisioning due to lower biodiversity, increased risk of wildfire (Delgado-Artés et al., 2022), and strong groundwater intake (Alloza et al., 2020, 2021). This is the rationale behind proposal number 2 on SLM. At the same time, stakeholders highlighted the income-g

enerating role of the four areas previously identified as with lower ES value by stating socio-economic reasons that foster the value of the historical Mediterranean multifunctional landscapes (Mercuri et al., 2019). In particular, the NW and W areas of the watershed's margin represent both economic i.e. grasslands for pasture and croplands for agriculture, and social spaces i.e. a network of towns, to combat rural depopulation and land abandonment while promoting the recovery of the cultural heritage. This reasoning is behind proposals 1, 3, and 4 on SLM. The E and SE areas with intensive citric plantations, while crucial for the local economy, require urgent SLM implementation due to the intensity of the activities taking place there, in line with Output 1. This justifies proposal number 5 on SLM. However, in line with Alloza et al. (2020, 2021), Figure 3.2e shows that these areas provide the highest component of atmospheric humidity at the coastline, likely due to the irrigation of the fields. This contribution of coastal humidity is of value to lessen the collision of marine sea breezes with the hot-dry air of the coast, potentially reducing the increasingly severe coastal storms (Lionello et al., 2017) and better enabling humid air masses to travel inland and orographically precipitate at the headwaters (Millán, 2014), strengthening the hydrological cycle.

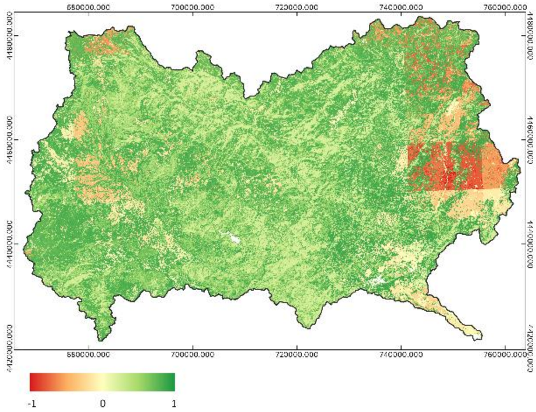
SLM potential scenarios constitute Output 3. These result from including stakeholders' preferences on SLM options (output 2, Fig.2) to the bottom line models of the watershed's ES (output 1, Fig.2) while considering climate change projections. Among all potential SLM scenarios, we show the one corresponding to ES retained soil by vegetation when applying SLM 5. Integrated agricultural systems in citrus plantations. The stakeholders defined this SLM as a measure involving growing natural vegetation between the strips of the main crop and cutting it once or twice a year as a nutritional cushion. Hence, we modeled the effect of three practices within the SLM 5: no-tillage, cover crop, and crop residues (Fig. 3.3). Integrated agricultural systems in citrus respond to the current challenges of water scarcity at the final course of the Mijares River and to climate change, projected to aggravate desertification and soil loss in the basin. Accordingly, to assess the potential contribution of this SLM measure to the watershed's current and future challenges related to soil loss, we modeled average annual erosion rates using the Revised Universal Soil Loss Equation (RUSLE) in the baseline scenario and RCP 4.5 and 8.5 projections for 2050 (Pompeu et al., 2023). Results show that if only changes in rainfall erosivity are considered, the average soil loss mitigated by this SLM measure in the river plain of the Mijares can be up to 4% i.e. 0.15t/ha, of the baseline scenario (Pompeu et al., 2023). Therefore, this result argues for the benefits of implementing SLM 5 in the intensive citric croplands in favor of climate change adaptation. Modeling all potential scenarios i.e. one for each ES associated with each SLM measure (5x5), both for the current baseline and projected climate change, may assist policy and decision-making toward integrated and sustainable landscape management of the Mijares watershed or elsewhere applied.

By following the three steps of the presented approach and applying them to the Mijares watershed, we have taken a snapshot of its potential adaptation capacities in rural areas. The resulting adaptation capacities are framed under five SLM measures that respond to the watershed's bio-geographical, socioeconomic, and climatic challenges while promoting several ES. All modeling results are accessible to any interested stakeholder and policy-maker through an ad-hoc user-friendly application available at (https://mijares.integratedmodelling.org/modeler/?app=appmijares#/login) providing model navigation and visualization into different SLM scenarios. All scenarios are based on globally available models easily customizable to other study areas, namely other Mediterranean watersheds. This, together with ARIES' capacity to aggregate results across, for example, watersheds (Martínez-López et al., 2019; Villa et al., 2014), can guide the development of a coordinated plan for managing the Mediterranean basin as a whole.

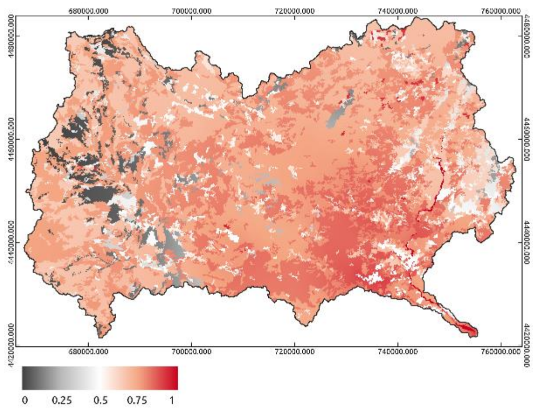
Output 1) Bottom-line visualization of the watershed's state in relation to Ecosystem Services supply and demand.



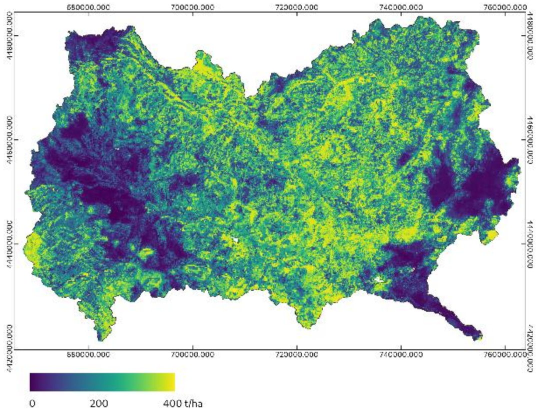
3.1a) Retained soil by vegetation



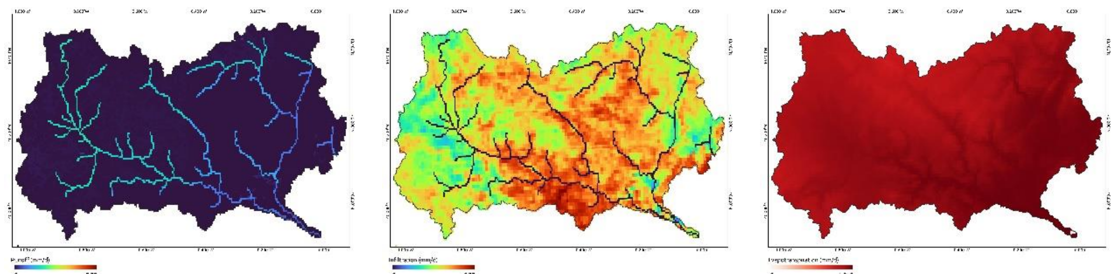
3.1b) Net value of pollination services



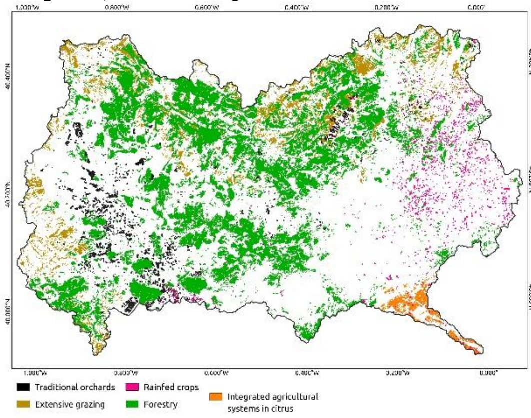
3.1c) Value of outdoor recreation



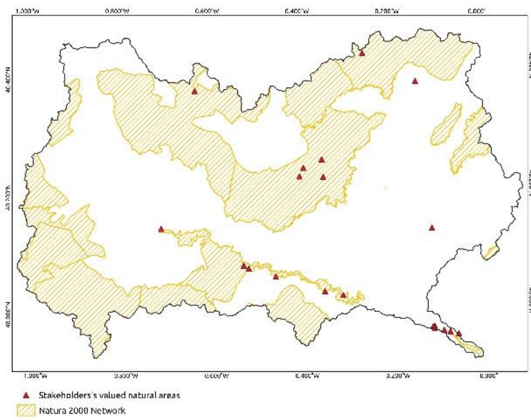
3.1d) Organic carbon mass


3.1e) Hydrological model. In order: surface runoff, infiltration, potential evapotranspiration

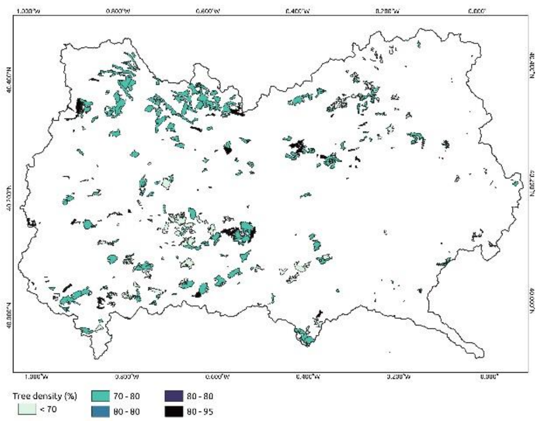
Output 2) Modelling results from the stakeholder engagement.



3.2a) Geographical representation of where stakeholders aim at adopting five key SLM actions. Modified from Ruiz et al. (2022)

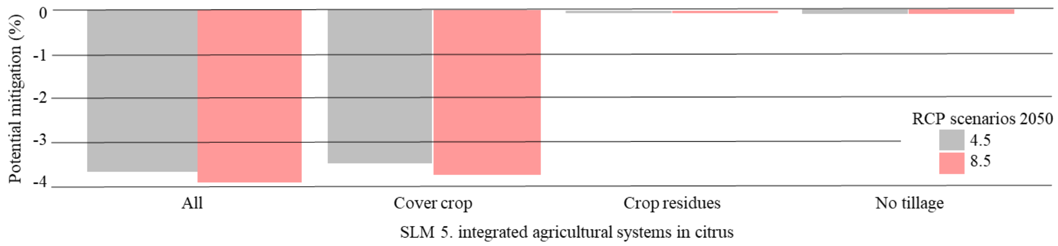


3.2b) Most valued natural areas by the participating stakeholders



3.2c) Forest areas of priority action, based on tree density

Output 3) SLM potential scenarios



3.3) Average soil loss mitigated by SLM 5. Integrated agricultural systems in citrus plantations. Modified from Pompeu et al. (2023)

Figure 3. Modelling results of the followed approach.

Potential limitations to this work are model availability, spatial scale considerations from local-to-broad regional, trade-offs in ES assessments, uncertainty of climate change projections, and ambiguity in stakeholders' knowledge. One main limitation is that end users currently dispose of a few models already implemented in ARIES (Table 1). However, as the platform evolves, more models can be explored, improving the understanding of local dynamics and potentially fitting better stakeholders' expectations on landscape management for several ES. A second limitation is the trade-offs inherent to ES assessments, resulting from either the users of the same ES, between ESs or as a combination of both. Nonetheless and although trade-offs related to ES assessment are key to decision-making, these are highlighted when comparing the different SLM scenarios with the baseline model of each ES, easing the understanding of the effects of the different scenarios. Uncertainties related to climate projections may affect the performance of SLM. Promoting SLM actions that account for such climate uncertainties is key to ensuring their success in promoting ES in the long term. Another limitation is the uncertainty surrounding the spatial scale at which ES are assessed and SLM implemented, which can also impact stakeholder participation. Ambiguities associated with stakeholders' knowledge of SLM and climate change projections constitute an additional potential limitation, as these may hamper SLM adoption or foster the selection of SLM actions with unfavorable effects on the environment. Properly communicating SLM and climate change uncertainties together with handling ambiguity in a way that is inclusive is key when engaging with stakeholders.

4.2 Policy implications at different scales

Beyond offering a fitting environment for analyzing the challenges posed by climate change in Mediterranean watersheds, the Mijares also exemplifies the opportunities that may arise from the study of ES and the implementation of SLM actions with the involvement of local stakeholders at the policy level. The presented approach can enable impacts beyond the physical limits of the watershed by promoting national and international objectives and priorities, resulting in multiple synergies at various scales. Following, we review plans and strategies to which the study of ES and the implementation of SLM impact positively at the local, national, regional, and global scale.

At the local scale, this can be reflected in the contribution to the master plan for water resources management, the Hydrological Plan of the Jucar's Demarcation, where the Mijares watershed is placed (Confederación Hidrográfica del Júcar, 2019). This study could have several positive impacts on the environmental objectives of the plan, namely: prevent the deterioration of the water bodies, reach a good state of the water bodies, and achieve particular environmental goals. Likewise, the study could improve resilience and reduce vulnerability to climate change, directly contributing to several goals of the Valencia strategy for climate change and energy 2030 (Generalitat Valenciana, 2018): carbon footprint mitigation; residential, commercial and institutional mitigation; agriculture and livestock mitigation and adaptation measures; biodiversity and forestry adaptation; water resources adaptation; landscape adaptation; and social adaptation and knowledge generation. Furthermore, this study could have direct impacts on climate change adaptation plans of cities and towns that align their objectives to brother plans such as the Green Deal going local (Green Deal Going Local Homepage) and the Local 2030 Agenda (Varela et al., 2020), or that aim at giving local answers to particular environmental challenges.

At the national level, this study could nurture the Climate Change National Adaptation Plan (PNACC), which is the general reference framework of climate adaptation in Spain (MITECO, 2020) and it is linked to several international compromises such as the European Green Deal (European Comission, 2019) and the UNFCCC commitments of Spain. Specifically, it could contribute to the following working areas: climate and climate scenarios; water and water resources; natural heritage, biodiversity and protected areas; agriculture, livestock, fishing, aquaculture and food; the forestry sector, desertification, hunting and inland fishing. Results from this study could also add to AdapteCCa, a collaborative platform that facilitates data and knowledge exchange on climate change adaptation (AdapteCCa homepage). It could likewise provide data to the Spanish Inventory of Natural Heritage and Biodiversity (IEPNB, 2018) on the forest map of Spain and the national forest inventory, the landscape inventory, the hydraulic public domain record, the Spanish inventory of traditional knowledge, and the national inventory of soil erosion. Also, it could contribute to the National Strategy for Green Infrastructure and Ecological Connectivity and Restoration, by promoting ES that supply ecological, economic, and social benefits (MITECO homepage), and to the Common Agricultural Policy (MAPA, 2018), which despite being a strategic plan of European coordination (IUCN and European Commission) it has a national development by the member states. It could directly support the following of its specific objectives in Spain: contribute to climate change mitigation and adaptation, as well as sustainable energy; foster sustainable development and efficient management of natural resources such as water, soil and air; and contribute to the protection of biodiversity, enhance ecosystem services and preserve habitats and landscapes.

At the European level, taking SLM actions based on ES and stakeholder knowledge can directly support the European Green Deal by contributing to preventing biodiversity loss and implementing more sustainable agricultural practices (European Comission, 2019). Within the Green Deal, there are several initiatives to which this study can impact: the Natura 2000 network, it can build upon it by reporting on the status of the watershed's environment (Natura 2000 homepage); the EU Nature Restoration Plan, improving information on ecosystems, soil, and water health and treatment (EU nature restoration targets homepage); the 2021 Forestry Strategy (within the Restoration Plan), supporting forest management, natural reforestation and afforestation (Forestry Strategy homepage); the Biodiversity Strategy for 2030 and the Strategy on Adaptation to Climate Change, providing information regarding sustainable actions at the watershed-scale (Biodiversity strategy homepage, European Commission, 2021); the Farm to Fork Strategy, with the implementation of sustainable agricultural practices (European Commission, 2020); and the Zero Pollution Action Plan for Air, Water and Soil, detecting pollution sites and pointing at potential solutions (European Commission, 2021a). Moreover, results from this type of study can likewise contribute to the European Environmental Information and Observation Network (Eionet) through its national focal point, by providing information on the environmental state of the watersheds and potential climate change adaptation actions (EEA homepage).

At the Mediterranean scale, the results of this research can positively impact the regional political framework of the Mediterranean Strategy for Sustainable Development (MSSD) 2016-2025 (Plan Bleu, 2016). The MSSD is a strategic guiding document to translate the 2030 Agenda for Sustainable Development at the regional-national level. It consists of six objectives, to which this study can contribute the following: promoting resource management, food production and food security through sustainable forms of rural development; addressing climate change as a priority issue for the Mediterranean; and improving governance in support of sustainable development. Results can likewise provide information to the periodical State of the Environment Reports emitted by the contracting parties to the Barcelona Convention (Barcelona Convention, 1977) and serve as a monitoring source for its Strategic Action Programmes (UNEPMAP homepage). It can also positively impact the Mediterranean Experts on Climate and Environmental

Change group (MedECC homepage), the Union for the Mediterranean (UfM homepage), and organizations such as the Mediterranean Network of Basin Organisations (MENBO homepage) in promoting enhanced regional cooperation and bridging the gap between research and decision-making. Overall, adding to Mediterranean-scale bodies is important to promote integrated management of water and landscape resources under a system of shared responsibility across nations.

At the global level, this type of work brings the opportunity to progress on the 2030 Agenda for Sustainable Development (SDGs homepage), either through its regional/local implementation, or the Nationally Determined Contributions set for each country (NDCs homepage). In particular, this type of study supports SDG3 good health and well-being, SDG6 clean water and sanitation, SDG13 climate action, and SDG15 life of terrestrial ecosystems. It, moreover, fully aligns with the purpose of the United Nations Decade on Ecosystem Restoration (Decade on Restoration homepage). Capturing the benefits and co-benefits of ES mapping, implementation of adaptation actions, and stakeholder involvement, gives the opportunity to achieve objectives across other global agreements and frameworks such as the Sendai Framework for Disaster Risk Reduction (Office for Disaster Risk Reduction, 2015), the United Nations Convention to Combat Desertification (UNCCD homepage), the United Nations Framework Convention on Climate Change (UNFCCC homepage) including the Climate Action Rise to Zero and Rise to Resilience initiatives; the Intergovernmental Platform for Biodiversity and Ecosystem Services (IPBES homepage); and the Food and Agriculture Organization (FAO homepage).

5. Conclusions

- The Mijares environmental challenges, heterogeneous landscapes, and intricate stakeholder map are common to other Mediterranean watersheds, serving as an exemplary pilot study.
- The modeling of ES, the selection of SLM practices to be adopted, and the participation of stakeholders are components of an interdisciplinary approach, traceable and replicable elsewhere. First, the combined use of the ARIES platform and the SLM database establishes the theoretical foundations of the effects of landscape management options on ecosystem structure and function, biodiversity, and climate change effects in the studied area. Then, with the engagement of stakeholders, the generated information is reshaped to constitute a central piece of an evidence-informed land management portfolio specifically for the watershed. As a result of this process, it is possible to model several SLM scenarios for the different ES and projected climate change that supports consensus building among actors and assists policy and decision-making towards sustainable landscape management of the watershed.
- If correctly framed, the formal and informal governance structure at all levels, from local to global, can promote SLM to achieve sustainable objectives and increase the added value gained from its implementation at the local scale. This is particularly significant in the context of the need for integrated management under a system of shared responsibility among the Mediterranean nations.

CRediT authorship contribution statement

I Ruiz: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Writing – original draft, Writing – review & editing, Project administration, Funding acquisition. J. Pompeu and A. Ruano: Data curation, Formal analysis, Investigation, Resources, Software, Validation, Visualization, Writing – review & editing. P. Franco: Methodology, Writing – review & editing. S. Balbi and M.J. Sanz: Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. Data Availability Data will be made available on request.

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