INTEGRATED RESPONSE OPTIONS BASED ON LAND MANAGEMENT IN RURAL AREAS OF THE MEDITERRANEAN BASIN

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A mi familia y amigos

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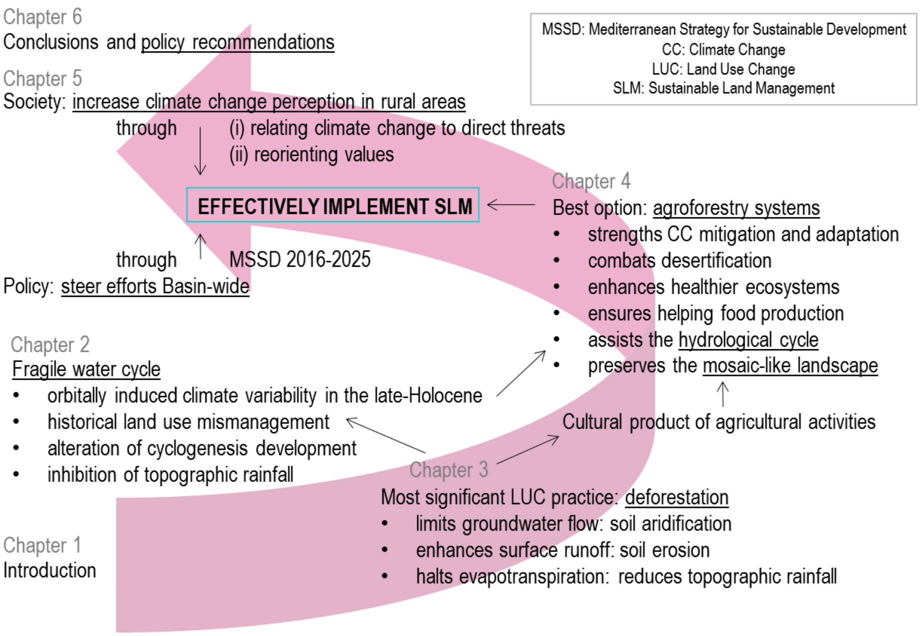
Abstract

The Mediterranean Basin faces a context of climate change aggravation (Chapter 2), enlarged demands of goods and services, and historical mismanagement of the landscape for the past millennia (Chapter 3). All these, push for the need of understanding how to better assist increasing climate change resilience while addressing current landscape degradation issues such as extended droughts, an impoverished water cycle, and the abandonment of traditional land-use systems. The here presented research is focused on the rural areas, for which sustainable land management is chosen as a holistic measure with high synergistic potential to address these issues (Chapter 4). To foster and facilitate the adoption of sustainable land management practices, links are drawn to climate change perception and currently available policy platforms to steer action (Chapter 5). This dissertation is based on academic literature, insight from development researchers, professional meetings, and agency reports on sustainable land management practices to provide evidence-based scientific outputs and policy recommendations. The main aim of this work is to contribute to closing the gap between scientific findings, expert stakeholders, and policy-makers by looking into the Mediterranean Basin's climate change challenges from a holistic point of view.



Resumen de la tesis

Introducción
El reciente informe presentado por el Panel Intergubernamental del Cambio Climático (IPCC, 2018) manifiesta que el cambio climático, y en concreto y a más corto plazo, los eventos climáticos abruptos, aumentan el riesgo en la disponibilidad de recursos hídricos, la aceleración de la degradación del suelo, la subida del nivel del mar, cambios irreversibles en los ecosistemas terrestres y marinos, olas de calor, y temperaturas más extremas en la Cuenca del Mediterráneo.

Esta tesis surge de la urgente necesidad de adaptación y mitigación de dichos impactos en el territorio Mediterráneo. Además, representa un nicho de oportunidad para dirigir esfuerzos hacia el objetivo común de mejorar su ciclo de agua, el cual se encuentra empobrecido. Se plantean así dos hipótesis principales y cinco objetivos:

- **Hip.1** El sistema hidrológico de la Cuenca Mediterránea ha sido modificado por prácticas de cambio de usos del suelo (LUC);
    - **Obj.1** Diferenciar entre la variabilidad climática natural y la antropogénica durante el Holoceno;
    - **Obj.2** Comprender cómo los patrones de lluvia topográfica se han visto modificados debido a la acción antropogénica;
- **Hip.2** La lluvia topográfica puede ser estimulada naturalmente a través de prácticas de manejo sostenible de la tierra (SLM) y esto ayudará a restaurar un sistema hidrológico más saludable;
    - **Obj.3** Identificar qué prácticas de manejo sostenible de la tierra pueden asistir en la restauración de la lluvia topográfica;
    - **Obj.4** Evaluar la viabilidad de adopción de tales prácticas;
    - **Obj.5** Inspeccionar mecanismos que favorezcan la implementación de tales prácticas de una forma efectiva y traducir los resultados de esta disertación en recomendaciones políticas;

Para abordar estas dos hipótesis, es necesario considerar el marco ecológico, social y político de la región Mediterránea. Dichos marcos han sido aquí examinados, haciendo de ésta, una disertación interdisciplinar. Por ello la disertación consta de un marco teórico que incluye: (a) visiones: paleoclima en el Capítulo 2, interacciones humanas con el clima en el Capítulo 3, y SLM en el Capítulo 4; (b) valores: percepción del cambio climático (CCP) en el Capítulo 5; (c) voces: barreras y oportunidades para la implementación de SLM en los Capítulos 4 y 5.

Capítulo 2
El Capítulo 2 da respuesta al Objetivo 1 contextualizando el clima de la Cuenca durante el Holoceno (últimos ~11,700 años) y resumiendo sus proyecciones futuras. En él, se detalla cómo la variabilidad climática del Holoceno tiene un origen orbital con

una disminución de la insolación solar hace unos 4,500 años. Desde entonces, el Mediterráneo ha presenciado patrones climáticos más inestables, una disminución sucesiva de las precipitaciones y un aumento lineal de sus temperaturas, alcanzando las condiciones actuales hace ~2,500–2,000 años (Fig. 2.3). En consecuencia, el sistema hidrológico de la Cuenca se ha visto afectado, con la modificación de sus dos tipos principales de precipitación, la lluvia sinóptica producto del movimiento atmosférico regional y la lluvia topográfica causada por la convección orográfica local. Asimismo, el ya menguado ciclo hidrológico se ve adicionalmente alterado por actividades antropogénicas intensas, lo que puede resultar en la modificación actual del desarrollo y consolidación de ciclones y en la inhibición de lluvia topográfica.

Entender qué ocurrió en la Cuenca en el pasado es clave para informar el futuro, pues nos permite comprender cómo respondió a la variabilidad climática natural y a las perturbaciones humanas, y así mismo, nos ayuda a predecir cómo se comportará en función de las proyecciones futuras.

Capítulo 3

El Capítulo 3 revisa cómo los cambios de uso del suelo (LUC, por sus siglas en inglés) interactuaron con el medio ambiente durante el Holoceno. El propósito de este capítulo es el de examinar las implicaciones que dichos cambios de uso del suelo ejercieron y siguen ejerciendo en el paisaje y en el clima de la Cuenca (Objetivo 2). En él se detalla cómo estas prácticas históricas han promovido la desertificación y degradación del paisaje y contribuido a la variabilidad climática. De entre todas ellas, la práctica con mayores consecuencias es la deforestación dirigida a la apertura de claros para la agricultura.

Se llega a esta conclusión después de inspeccionar el contenido de una revisión semiestructurada de literatura científica que se utiliza para desarrollar un mapa de red. La literatura revisada (N=23) describe cómo, aunque de forma limitada, la deforestación, el agotamiento de los recursos vegetales y el empobrecimiento del suelo se encuentran ligados a un régimen regular de incendios ya en el Holoceno temprano. En el Holoceno medio, se ejerce la intensificación del uso de la tierra y la explotación de recursos, lo que induce a condiciones más áridas en la Cuenca, a la pérdida de biodiversidad y al empobrecimiento del suelo. Por último, con el inicio del Holoceno tardío, se produce una transición de los paisajes naturales a los dominados por humanos, lo que agrava aún más las consecuencias de las prácticas anteriores (Tabla 3.1). Las prácticas que se usan para el cambio de uso del suelo quedan agrupadas en cuatro: Incendios regulares y deforestación; Actividades agrícolas y de cultivo; Pastoreo excesivo; Terrazas hidráulicas y acuíferos.

Con la información compilada se construye un mapa de red utilizando la técnica Fuzzy Cognitive Mapping (FCM) (Fig. 3.3). Esta técnica, aunque generalmente aplicada en ciencias sociales, se usa aquí para inspeccionar las relaciones causales entre los diferentes componentes encontrados del ciclo del agua en el Mediterráneo, ampliando de esta manera, su aplicabilidad como método de mapeo. La técnica FCM permite una integración flexible de componentes muy dispares pero relacionados entre sí del sistema hidrológico, que son demasiado complejos para ser cuantificados. De esta manera, esta técnica nos permite abarcar estudios que utilizan metodologías particulares y que tienen objetivos específicos, conectar de forma teórica todos los componentes encontrados, y sacar conclusiones integradas.

El mapa de red generado relaciona varios conceptos de muchas disciplinas, de entre los cuales se destacan las siguientes relaciones (Fig. 3.4). La deforestación disminuye la biomasa, lo que reduce la absorción de CO_2 atmosférico y, sin embargo, promueve la expansión de más biomasa debido a la disponibilidad de CO_2. También modifica el equilibrio del agua superficial al detener la evapotranspiración, lo que reduce el vapor de agua disponible para la lluvia topográfica y limita el flujo de agua subterránea al eliminar la infiltración a través de raíces. Al mismo tiempo, la disminución de la infiltración implica una mayor escorrentía superficial, lo que provoca una mayor aridificación y erosión del suelo. Además, la deforestación afecta la biodiversidad y la calidad y cantidad del agua, ya que la salud de los ecosistemas que regulan la calidad y la cantidad de agua superficial están determinados, en última instancia, por la misma.

Capítulo 4

El Capítulo 4 aborda los Objetivos 3 y 4, para los cuales se desarrolla un marco (Tabla 4.3) que evalúa la efectividad en el terreno y la viabilidad de implementación de diferentes prácticas de manejo sostenible de la tierra (SLM por sus siglas en inglés). Dichas prácticas están recogidas por la base de datos WOCAT[1].

Para construir el marco, primero se definen cinco variables ecológicas: Regulación climática; Control de la erosión del suelo; Mejora de la biodiversidad y control de plagas / enfermedades; Regulación del agua; Mejora de la calidad del suelo. Asimismo, se definen cuatro variables sociales: Economía y producción; Gestión y riego; Bienestar social; Instituciones. Estas nueve variables abarcan múltiples impactos evaluados por la WOCAT (Tabla 4.4). A continuación, se agrupan aquellas prácticas similares pero específicas, haciéndolas así lo suficientemente flexibles como para ser aplicables a toda la Cuenca (Tabla 4.2). Finalmente, se examina el área de potencial biofísico para la implementación da cada práctica, considerando cinco variables de entorno natural: tipo de uso del suelo, precipitación anual, agua disponible, altitud, pendiente (Fig. 4.1). Por último, se inspeccionan las posibles barreras y los posibles beneficios derivados de su implementación.

El desarrollo de este marco permite identificar aquellas prácticas cuyos beneficios van más allá de la escala local de implementación, permitiendo a los políticos dirigir esfuerzos de forma coordinada en toda la Cuenca Mediterránea

[1] https://www.wocat.net/en/

mediante la popularización en la implementación de dichas prácticas. Además, el marco desarrollado no sólo se basa en los impactos ecológicos, sino también en los biofísicos y socioeconómicos, ya que estos pueden resaltar posibles sinergias/barreras que pueden comprometer el éxito en la implementación de dichas prácticas (Obj. 4).

De entre todas las prácticas evaluadas (N = 25), los sistemas agroforestales, la cubierta verde en plantaciones perennes (como los olivares, viñedos o campos de almendro) y la reforestación, resultan ser las que mejor asisten a los servicios ecosistémicos. Dichas prácticas, no sólo aumentan la capacidad de mitigación y adaptación de la Cuenca mediante el secuestro y almacenamiento de carbono, sino que, además, asisten en la restauración de tierras degradadas, en la contención de la desertificación, en la mejora de la biodiversidad, en el manejo de los recursos hídricos y en la conservación de los humedales y de los paisajes típicos de mosaico.

El ciclo hidrológico de la región se ve afectado de dos maneras principales por estas prácticas: a través de una mayor infiltración de agua de lluvia en el suelo; y a través de un aumento de la humedad atmosférica causado por una tasa de evapotranspiración más elevada. Esto, disminuye las temperaturas diurnas en verano, reduce la intensidad y la duración de olas de calor y estimula la lluvia topográfica (causada por convección orográfica local). Además, las tres prácticas integran necesidades y valores de las comunidades en dónde se implementan, promueven el conocimiento tradicional y aumentan los productos de mercado. De acuerdo con las características biofísicas de la Cuenca, éstas ofrecen además, un alto potencial para su implementación (Tabla 4.7).

Capítulo 5

En el Capítulo 5 se aborda el último objetivo, el Objetivo 5. En él se identifican estrategias para mejorar la percepción del público sobre el cambio climático (CCP por sus siglas en inglés) y los marcos políticos desde dónde dirigir una acción coordinada a nivel de cuenca.

Por un lado, y siguiendo el enfoque metodológico de los capítulos anteriores, para identificar cuáles son las influencias en la percepción pública sobre el cambio climático, desarrollamos un marco teórico con el cual es posible determinarlas y cuantificarlas (Fig. 5.1). Este marco teórico nos permite también determinar y cuantificar interacciones entre influencias, exponiendo por primera vez, rutas indirectas de influencia sobre la percepción pública del cambio climático. Asimismo, es posible combinar información dispersa bajo una única terminología, facilitar su uso a través del desarrollo de una definición para cada término, hacerla comparable independientemente del contexto del estudio y desentrañar características dentro de una comunidad que de otra manera pasarían desapercibidas (Table 5.1). Finalmente, se desarrolla un mapa de red que relaciona influencias entre sí. Para construirlo usamos la técnica FCM del Capítulo 3.

Los resultados muestran que los cambios percibidos en la meteorología (o en el tiempo) son el mecanismo que con mayor frecuencia la gente asocia al cambio climático. Poseer valores socio altruistas y conocimientos sobre cambio climático son los dos mecanismos que seguidamente se asocian a la percepción del cambio climático (Fig. 5.2). Las interacciones entre influencias (Fig. 5.3) revelan que relacionar el cambio climático con amenazas y percepciones directas de cambio climático pueden ser una estrategia efectiva para promover la acción climática en zonas rurales, así como la reorientación de valores y comportamientos.

Por otro lado, se han identificado estructuras disponibles con las que canalizar esfuerzos desde un enfoque de arriba hacia abajo (institucional→individual) para impulsar la adopción de prácticas de manejo sostenible del suelo que asistan a objetivos comunes de la Cuenca (Sección 5.2). Se ha dado prioridad a los organismos internacionales/interregionales, capaces tanto de coordinar esfuerzos de arriba hacia abajo (de instituciones internacionales a gobiernos nacionales/locales), como de abajo hacia arriba (de gobiernos locales/nacionales a instituciones internacionales).

De entre todas las estructuras identificadas, se ha reconocido como mejor opción, la de dirigir esfuerzos bajo el Objetivo 2 de la Estrategia Mediterránea para el Desarrollo Sostenible 2016-2025 (MSSD 2016-2025), que dice así "*Promover la gestión de recursos, la producción de alimentos y la seguridad alimentaria a través de formas sostenibles de desarrollo rural*".

Además, al adoptar prácticas de manejo sostenible de la tierra se impulsan varios Objetivos de Desarrollo Sostenible (ODS) de la Agenda 2030 de las Naciones Unidas, así como múltiples objetivos y estrategias de gobiernos locales, regionales y nacionales (Fig. 5.4).

Capítulo 6

Con la realización de los Objetivos 1 y 2, se prueba que la Hipótesis 1 es correcta. Las prácticas de cambio de uso del suelo, en especial la deforestación, comenzaron a modificar el paisaje y el ciclo del agua de la Cuenca ya en el Holoceno temprano.

Con la realización de los Objetivos 3 a 5, se concluye que la Hipótesis 2 también es correcta. La lluvia topográfica se puede estimular naturalmente a través de la adopción de prácticas de manejo sostenible de la tierra, en particular a través de la adopción de cubierta vegetal en cultivos leñosos perennes y en la expansión de árboles mediante la reforestación manejada o el aumento de sistemas agroforestales. Estas prácticas pueden ser impulsada a través de diversas estructuras que promueven la adopción de prácticas de adaptación en la Cuenca Mediterránea.

Conclusiones

Para abordar los objetivos de esta tesis se requiere de un enfoque interdisciplinar que consolide el conocimiento científico sobre el medio ambiente con el de las ciencias sociales.

Con el trabajo desarrollado aquí, se han identificado acciones para abordar la desertificación (es decir, ayudar al ciclo hidrológico), la degradación de la tierra (es decir, preservar el paisaje típico de mosaico) y la adaptación y mitigación del cambio climático en las regiones rurales del Mediterráneo. Éstas se reflejan aquí como recomendaciones políticas:

- A la luz del estado actual del ciclo hidrológico de la Cuenca Mediterránea, y especialmente, de los escenarios climáticos proyectados para el futuro cercano, la adopción de medidas de adaptación y mitigación se convierte en una prioridad. Más allá de las ciudades, las zonas rurales son clave para la provisión de alimentos y de energía, y para el funcionamiento ecosistémico de la región. Actuar en estas zonas, no es sólo necesario sino posible mediante prácticas de manejo sostenible de la tierra;

- Las prácticas de manejo sostenible de la tierra están diseñadas y adoptadas a nivel local. Sin embargo, el desarrollo de políticas ambientales coordinadas, coherentes y consistentes para estas prácticas dentro de la Cuenca del Mediterráneo es clave para garantizar objetivos regionales que van más allá de la escala local de implementación. Promover la adopción de prácticas de manejo sostenible de la tierra en un marco que coordine las políticas ambientales puede generar oportunidades, lograr resultados más significativos y contribuir a múltiples objetivos establecidos regionales a internacionales, como los ODS;

- La disponibilidad de agua es el factor limitante para la prestación de servicios en la Cuenca del Mediterráneo y la adopción de prácticas de manejo sostenible de la tierra, así como la mayor amenaza para la adaptación al cambio climático en las regiones rurales. Los esfuerzos deben dirigirse hacia prácticas que aborden desafíos específicos locales y ayuden a garantizar una gestión más eficaz del presupuesto hidrológico de la Cuenca. Hay varias opciones que asisten a esta cuestión, de las cuales destacamos: (i) mejorar la eficiencia del riego a través de sistemas de micro-irrigación; (ii) reducir la evaporación directa del suelo mediante una aumento en la evapotranspiración a través de la reforestación manejada y la cubierta vegetal en cultivos leñosos perennes; (iii) impulsar la precipitación topográfica mediante la reforestación; (iv) mejorar la eficiencia del uso del agua por parte de la flora a través de la preservación del paisaje típico de mosaico;

- El paisaje Mediterráneo típico de mosaico ayuda a restaurar el sistema hidrológico de la Cuenca, a combatir la desertificación y a lograr un ecosistema más saludable, más productivo y más diverso. Los esfuerzos para reducir la pérdida de este paisaje cultural podrían estar dirigidos a limitar la intensificación del uso de la tierra y preservar los sistemas extensivos tradicionales de altos valores culturales y de productividad. Las opciones destacadas para lograr esto son: (i) promover el cultivo en terrazas; (ii) ampliar los sistemas agroforestales;

- Los marcos que tienen como objetivo la gestión de los problemas ambientales deberían poner en valor los conocimientos tradicionales sobre las prácticas de manejo sostenible de la tierra de los pueblos. Una forma de hacerlo es a través del establecimiento de plataformas intersectoriales que permitan la colaboración de agricultores con políticos. Con dicha colaboración intersectorial, se garantiza un aumento de la equidad en el proceso de toma de decisiones, se cierra la brecha existente entre los diferentes actores, y se impulsa la conciencia social sobre el cambio climático.

Contents

List of Tables

List of Boxes

List of Figures

Abbreviations and acronyms

AR5-WGI	Fifth Assessment Report - Working Group I (IPCC)
BA	Bølling-Allerød
CBD	Convention on Biological Diversity
CCP	Climate Change Perception
CH_4	Methane
CO_2	Carbon dioxide
COP15	15th Conference of the Parties
DFJ	December-January-February to refer to winter months
EMB	Eastern Mediterranean Basin
FAO	Food and Agriculture Organization of the United Nations
FCM	Fuzzy Cognitive Map
GAEZ	Global Agro-Ecological Zones
GHG	Green House Gas
HS	Heinrich Stadials
ID	Identification number/name
INDCs	Intended Nationally Determined Contributions
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Intertropical Convergence Zone
JJA	June-July-August to refer to summer months
ka	Kilo (thousands) years. This abbreviation is referred to particular events
kyr BP	Kilo (thousands) years before present (present as year 1950)
LIA	Little Ice Age
LUC	Land Use Change
MCA	Medieval Climate Anomaly
Myr BP	Million years before present (present as year 1950)
PAGES	Past Global Changes project
REVEALS	Regional Estimates of VEgetation Abundance from Large Sites model
SDG	Sustainable Development Goal
SMOW	Standard Mean Ocean Water
SOC	Soil Organic Carbon
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification

UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WMB	Western Mediterranean Basin
N	Number
WOCAT	World Overview of Conservation Approaches and Technologies
YD	Younger Dryas
years AD	Anno Domini, or number of years since the birth of Jesus Christ
years BC	Number of years Before Christ
$\delta^{18}O$	Measure of the ratio of stable isotopes oxygen-18 (^{18}O) and oxygen-16 (^{16}O)

Publications based on this dissertation

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- Award 'Manuel Fernández de Castro' (2019) to the best published article in 2018 by a novel author from the Boletín Geológico y Minero scientific journal.

1. Introduction

1.1 Background and Motivation

1.1.1 The Mediterranean Basin

The Mediterranean Basin is a biogeographical and environmental unit, home to some of the oldest human settlements in the world, and one of the 35 top global biodiversity hotspots (Pausas and Millán, 2018; Médail and Myers, 2004). With its ~2.6 million km^2 area, it encompasses 21 countries, seven marine eco-regions, and 75 coastal hydrological watersheds. Its long and rich natural and cultural heritage is largely due to the riverine systems within the Basin, source of nutrients and fresh water to ecosystems and societies (Benjamin et al., 2017). Over the centuries, commerce and communication within the region have taken place. These activities have not only united the different peoples across the Mediterranean, but also subjected the Basin to multiple pressures. Nowadays, it is estimated that one third of the population resides in the coastal regions, whereas more than the half are located in the coastal hydrological watersheds (Plan Bleu, 2016). On-land, the Plan Bleu report highlights chemical contamination of sediments and biota, and alterations in hydrographic conditions among the greatest impacts of anthropogenic action in the Basin.

A major driver of Mediterranean environmental degradation and up to a certain extent, regional climatic change, has been Land Use Change (LUC) resulting from long standing human pressure. Globally, LUC is altering the provision of water resources (MA, 2005; Portmann et al., 2010), causing the loss of biodiversity (Newbold et al., 2015), and increasing the emission of greenhouse gases (Foley et al., 2005) among others (i.e. altering the biophysical properties of Earth's surface and the cycles of nutrients, threatening soils, etc.) This situation is exacerbated today by economic growth, changes in the global diet, and increased demand for land aimed at bioenergy production (FAOSTAT, 2018; Weinzettel et al., 2013). Despite having improvements in agricultural productivity (Evenson and Gollin, 2003) competition for land use is increasing (Lambin and Meyfroidt, 2011).

At the same time, mismanagement of land resources endangers the future provision of food, water, and energy security (Jia et al. 2019; MA, 2005; World Bank, 2008;). In this way, the region's long history of land use and agricultural intensification (Chapter 3) together with the low levels of precipitation (Chapter 2), intense storms, droughts, high evapotranspiration, and steep slopes, has spread the promotion of erosion and water scarcity (García-Ruiz, 2011). The tremendous importance of water availability in the Basin underscores the necessity of understanding how to improve the water supply and better manage watersheds in an integrated manner (Plan Bleu, 2016). Within the Basin, 60% percent of the population are "water poor", i.e. less than 1,000 $m^3PC\ yr^{-1}$, as natural water resources are very unequally distributed among the northern (72%) and southern sides (23%) of the Sea. Likewise, land desertification rates among the top problems within the Basin, a challenge that is only expected to worsen with climate change (Mirzabaev et al., 2019). According to these authors, drylands cover 33.8% of northern Mediterranean countries with its expansion driven by land use, irrigation development, encroachment of cultivation on rangelands, population growth and agricultural policies and markets.

Furthermore, land mismanagement (e.g. overgrazing, slash and burn) increases the frequency and intensity of abrupt climatic events (Chapter 3) and threatens adaptation and mitigation capacities in the face of climate change (Neely et al., 2009). The latest Intergovernmental Panel on Climate Change (IPCC) special report (IPCC, 2018) states that climate change, and specifically shorter-term, abrupt climate events, increase the risk in the availability of water resources, the acceleration of soil degradation, sea level rise, the change in terrestrial and marine ecosystems, heat waves, and more extreme temperatures. In fact, the Mediterranean inland temperatures rise faster than the global mean, i.e. 1.4ºC above pre-industrial levels (Cramer et al., 2018), as well as the Sea's surface temperature, ~0.4ºC/decade for the past recent decades (Macias et al., 2013).

The rural areas of the Mediterranean Basin are more vulnerable to climate change because of their lower infrastructural, financial and technological development, together with their higher dependence on rain-fed agriculture. Thus, promoting their voices and assigning them the responsibility to take joint action to combat climate change, is not only key but achievable through Sustainable Land Management[1] (SLM).

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[1] Sustainable Land Management (SLM) was defined in 1992 by the UN Earth Summit as "*the use of land resources, including soils, water, animals and plants, for the production of goods to meet changing*

There is increasing evidence of the potential of SLM as a land-based solution to simultaneously address climate change mitigation and adaptation, desertification, land degradation, and drought (Chapter 4), while often achieving other co-benefits such as protecting biodiversity, promoting the traditional knowledge, and securing economic opportunities.

To face this complex and interlinked challenges in the Basin coordinated policy and management responses are thus, required to overcome present and future impacts of climate change while tiding the degradation of the Mediterranean ecosystems (Chapter 5).

1.1.2 Multilateral policy processes context

Governments develop regional/local mitigation and adaptation strategies, in which a series of measures are defined. These, have been ratified and reinforced after the 21st United Nations Conference of the Parties (COP21), through the Intended Nationally Determined Contributions (INDCs), proposed by each country. This opportunity arises from the strong commitment of governments to mitigate and adapt to climate change, as well as their commitments in achieving the UN Sustainable Development Goals (SDGs), in particular SDG13 "action for climate: take urgent action to combat climate change and its effects", SDG1 “no poverty”, SDG2 "zero hunger", SDG3 “good health and well-being”, SDG6 "clean water and sanitation" and SDG15 "life of terrestrial ecosystems".

Several frameworks and intergovernmental institutions exist within the Mediterranean Basin that aim to translate the 2030 Agenda for Sustainable Development at the regional level (i.e. downscaling) while stimulating regional cooperation (i.e. upscaling). Among them, there are the Mediterranean Strategy for Sustainable Development (MSSD 2016-2025), the Union for the Mediterranean (UfM), and the Mediterranean Experts on Environmental and Climate Change (MedECC). These transnational instruments, among others, can support national and local efforts, identify knowledge gaps and provide unbiased information to policy makers Basin-wide.

For the effective adoption of mitigation and adaptation strategies, their acceptance and implementation is necessary at all levels of society, as public support

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human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions”.

and commitment to environmental policies are directly related and influenced by public perception and social awareness (Howe et al., 2015; Lee et al., 2015). Therefore, an approach that includes public training and cooperation, including the civil society, governments and the private sector, is required. According to this, the United Nations Framework Convention on Climate Change (UNFCCC) governments have committed to educate, train and raise awareness of the challenges that climate change presents us. This common objective is reflected in Article 6 of the UNFCCC and in Article 10 (e) of its Kyoto Protocol. Likewise, its importance has been reflected in Article 12 of the Paris Agreement (Annex to decision 1 / CP.21, UNFCCC) recently ratified. In this context, the Coordinating Unit of the Mediterranean Action Plan (UNEP/MAP) developed the Mediterranean Strategy for Sustainable Development 2016-2025 (Plan Bleu, 2016), in where the action *“put more emphasis on emerging priorities, such as climate change adaptation”* was highlighted.

The here developed thesis arises from the strong commitment of international and regional governmental institutions to combat climate change, both in adapting and mitigating, while also achieving at the regional level the SDGs. To overcome current challenges, it is of vital importance to understand the links between: (a) the Mediterranean Basin in the current face of climate change and its consequences; (b) the evolution and changes of the land use; (c) the array of effective and appropriate sustainable land management practices in a Mediterranean context; (d) and the enhance of societal environmental awareness and capacity to steer policy action, in order to provide integrated response options.

1.2 Hypothesis and objectives

This dissertation stems from the importance of water in both ecosystems and societies within the Mediterranean Basin and the challenge that climate change poses to the region. It is framed from a Basin-wide approach as a niche opportunity for climate change adaptation and mitigation. The thesis aims to: (1) better understand the relevant processes that affected and continues affecting the hydrological system of the region; (2) identify good practices to address water scarcity while promoting climate change mitigation and adaptation in the rural areas. If these two aims are broken down into hypothesis and the related objectives, the following are addressed:

Hypothesis 1: The hydrological system of the Mediterranean Basin has been modified by LUC practices.

Objective 1: Differentiate between natural and anthropogenic climate variability throughout the Holocene[2] → Revision of the literature on the climatic, biogeographic and historical context of the Mediterranean Basin since the early Holocene until today's current state and future projections of climate change;

Objective 2: Elaborate on existing knowledge about how topographic rainfall might have been changed due to anthropogenic action → Review of the existing interactions and the resulting feedbacks between land use change and the local climate based on the literature. Discussion of its long-term diachronic relationship with the regional environment;

Hypothesis 2: Topographic rainfall can be naturally stimulated through SLM and this will help restoring a healthier hydrological system.

Objective 3: Identify which sustainable land management practices can better assist in restoring topographic rainfall → Identification of the best options for sustainable land use management in relation to adaptation and mitigation in the current state of the Mediterranean area;

Objective 4: Assess the viability of adopting such practices → Exploration of the mechanisms that hinder / facilitate the implementation of effective strategies;

Objective 5: Understand the social and political frameworks in where the research can be implemented and extend the results into policy recommendations of effective implementation → Highlight mechanisms that rise public support and commitment to environmental policies and reflect on capacity-building institutions that facilitate the adoption of sustainable land management practices.

1.3 Structure and methodology

This work is structured following the above five objectives: Chapter 2 provides a review of the climatic and biogeographic context of the Mediterranean Basin since the early

[2] Geological epoch that comprises the last ~11,700 years

Holocene (Obj. 1); Chapter 3 elaborates on the LUC-climate interaction and the resulting feedbacks (Obj. 2); Chapter 4 identifies the best options for sustainable land use management in relation to adaptation and mitigation (Obj. 3 and 4); Chapter 5 inspects mechanism to facilitate the implementation of effective climatic strategies (Obj. 5); Chapter 6 discusses all encountered results, provides with policy recommendations and concludes the work. Figure 1.1 displays all objectives assessed in each chapter together with the followed methodology for their completion.

The rationale behind its structure is the following: the historic-causal perspective of Chapter 3 paired with knowledge of climate change current and future impacts of Chapter 2 can inform anticipatory learning in the context of climate change mitigation and adaptation options (Chapter 5). This knowledge together with the inspection of effective and plausible sustainable land management options within the Mediterranean Basin (Chapter 4) can assist channelling efforts towards addressing landscape degradation and water scarcity in rural regions (Chapter 5).

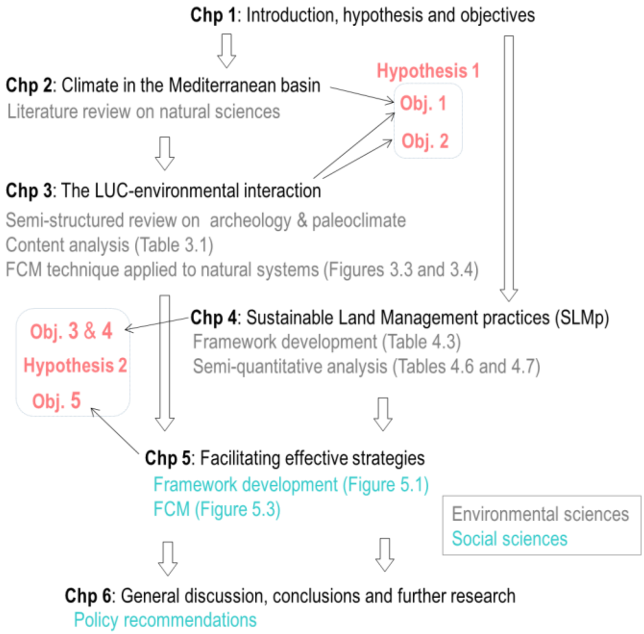


Figure 1.1. Scheme of the thesis' structure. In black the different chapters (Chp), in pink the assessed hypothesis and objectives (Obj.) and in grey/cyan the used methodologies and most relevant outputs.

2. Geography and climate in the Mediterranean Basin

This chapter contextualizes the Mediterranean Basin's climate throughout the Holocene and summarizes future projections.

As stated by Rohling et al. (2009): "*The Mediterranean is a small-scale coupled atmosphere-ocean system with a rather short response time, thus regional long-term changes may be the result of changes in the more slowly responding global system*". This statement highlights the adequacy of the region to study past and current climate variability and interactions, as its large sensitivity results in amplified signals of a more immediate response. Evidence of this is found in the Basin's annual mean temperatures, which are rising faster than the global mean, i.e. 1.4ºC above pre-industrial levels (Cramer et al., 2018) and in the temperature of the Sea's surface water, which have raised ~0.4ºC/decade for the past recent decades (Macias et al., 2013), among others.

To contextualize the Mediterranean climate, this chapter starts by briefly summarizing the geomorphology of the Basin, as it strongly influences its climate through land-atmosphere couplings (Section 2.1). It then overviews the Mediterranean's climatic context since the early Holocene (Section 2.2) and walks us to the current hydrological state by outlining the synoptic circulation (i.e. large-scale circulation) and the regional-to-local conditions that play an important role in shaping rainfall amount, distinguishing between the western and eastern Mediterranean sub-basins (Section 2.3). It afterward introduces how changes in land use and management can lead to regional to local rainfall variabilities and finishes by reflecting on the projected future climate change for the basin according to the IPCC (Section 2.4).

The rationale behind it is to **answer Objective 1, which aims at discerning the natural/anthropogenic share of the historical environmental evolution of the Basin** related to the human occupation and associated agricultural activities (Chapter 3).

2.1 Geophysical context

The Mediterranean Basin lies between 30–47°N and 10°W–35°E. Its nowadays landscape is the product of the long-term tectonic forces as the joining point of three continents, river watersheds and marine processes, orbital driven climate change, and human action.

The origin of the Mediterranean Sea and its reduced connectivity to the other water masses and oceans result from the collision between the African and European tectonic plates in the last ~30 Myr that led to the disappearance of the Tethys Ocean. This N-S driven compression isolated the Mediterranean during the Miocene ~5.8 Myr ago, which combined with its negative water balance gave way to the Messinian salinity crisis (Ryan, 2009). The Messinian salinity crisis consisted on an evaporitic drawdown of the Sea with up to a 1 km drop of the base level, causing the fall of 5% of world's ocean salinity and temporarily affecting the global thermohaline circulation with consequences to the climate (e.g. spread of sea ice, drop of world temperature). The reopening of the Sea to the Atlantic Ocean occurred soon afterwards (i.e. ~5–6 kyr after) as a response of a subduction rollback[3] orthogonal to the main direction of compression that opened the Strait of Gibraltar (Woodward, 2009).

Many of the mountain belts within the Mediterranean are likewise attributable to the combination of a N-S compression and its orthogonal subduction trenches, generating arcuate shapes around the Basin (Zanchetta et al., 2011). This type of orogenesis is mainly present at the northern side of the collision zone, where likewise occurs the highest seismic activity of the whole Basin nowadays, mostly condensed at the Aegean Sea (Thera/Santorini), central and southern Italy (Holocene volcanism), and the Hellenic arc (Greece and eastern Anatolia) (Fig. 2.1). Other mountain ranges such as the Beltic Rif of Spain and Morocco to the Apennine-Calabrian-Maghrebide of Italy and North Africa are instead, remnants of the extensional destruction of an older (Cretaceous-Oligocene) NE-SW Alpine belt (Woodward, 2009).

Over 160 rivers can be counted within the Mediterranean drainage Basin (Poulos and Collins, 2002). These are largely constrained by the uplifted mountains, making

[3] Subduction is the geological process that involves a tectonic plate moving under another one into the mantle. It occurs due to the collision of two tectonic plates at a convergent boundary and due the difference of densities between the two. When the subduction process happens and results in seaward motion of the trench, then it is referred as a rollback, making the subduction trench move over time (see Fig. 2.1).

their valleys and proximal to the Sea. There are three principal basins within the region related to the Po (~70 km^2), Rhône (~96 km^2), and Ebro (~84 km^2) rivers, apart from the exogenous Nile. All the Basin's main rivers exhibit km-scale incisions in the landscape as the result of the dramatic lowering of the base level during the Messinian salinity crisis. The Nile River moreover, has played a key role in altering the hydrography, salinity and circulation of the Mediterranean Sea, as due to its large flow, it can inhibit the formation of organic-rich layers (i.e. sapropel layers) in the deeps of the Sea, which historically occurred during the Messinian salinity crisis and the early-Holocene.

The intricate shoreline of the Mediterranean Sea and the lack of strong marine waves favour delta formation by river sedimentation aggradation (Lionello et al., 2006), overall exhibiting a complex geomorphology of arcuate mountain ranges and sedimentary basins, river and marine terraces, and alluvial fan sediments (see more in Benito et al., 2015). The Basin thus, has a highly diversified coastal morphology with a sediment-supply regime, containing, together with the Alpine river catchments, the highest catchment sediment yields in Europe (Vanmaercke et al., 2011). However, river discharge is strongly influenced by the seasonal distribution of precipitation (Section 2.2) and human activities (Chapter 3), influencing the hydrological budget of the whole area.

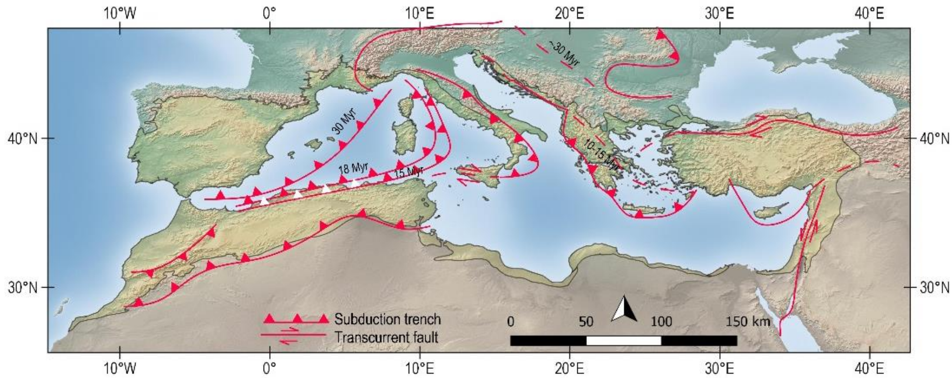


Figure 2.1. Geodynamical and morphological framework of the Mediterranean Basin. The yellow enclosed area corresponds to the Mediterranean biogeostrati-graphical zone. Topographic data from NaturalEarth[4].

[4] https://www.naturalearthdata.com

2.2 Climate setting for the past 11.7 kyr BP

The last ~11.7 kyr BP might appear as a climatically stable period when compared to past epochs (Fig. 2.2-top). However, significant climate variability is registered at a global scale in response to different parameters of the orbital forcing (Milanković, 1930). Differently from the traditional theory of Milankovitch that relates high latitudes summer insolation with glacial-interglacial cycles, Davis and Brewer (2009) propose the latitudinal insolation gradient, dominated by obliquity (41 kyr periodicity) in summer, and precession (21 kyr periodicity) in winter, to drive the global temperature gradient in the Holocene, and thus, the oceanic and atmospheric circulations. Abrupt climatic events occurred within the Holocene are likewise related to global redistributions of moisture and heat, that overwrite the orbital forcing and dominate the climate variability of this period (Fig. 2.2-bottom), controlling regional humidity and latent heat through vapour transport (Mayewski et al., 2004).

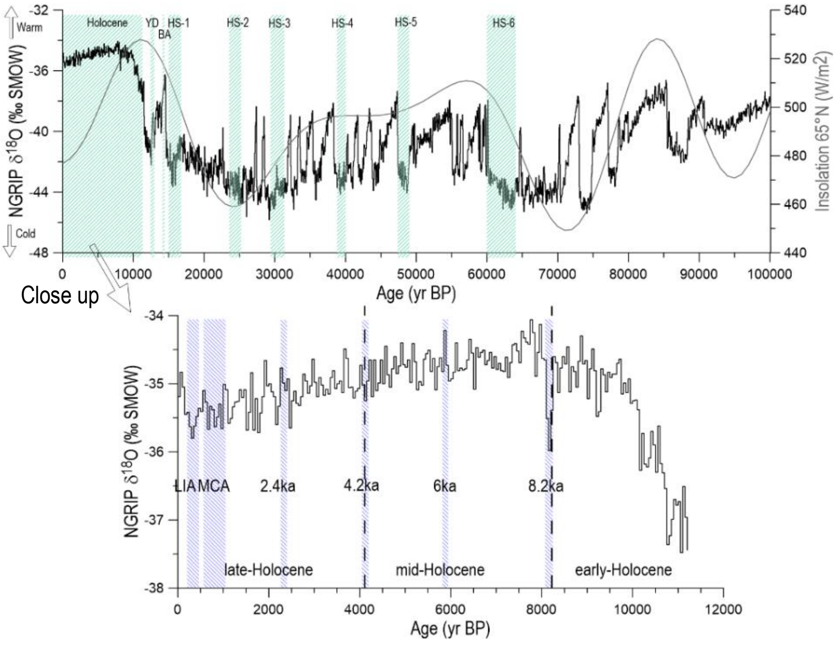


Figure 2.2. NGRIP $\delta^{18}O$ (‰ SMOW) ice record and insolation at 65ºN summer solstice (W/m^2) for the past 100 kyr (Laskar et al., 2011). Dashed vertical bars indicate the Holocene, YD: Younger Dryas, BA: Bølling-Allerød, HS-: Heinrich Stadials, LIA: Little Ice Age, MCA: Medevial Climate Anomaly, ka: different well-registered abrupt events.

2.2.1 The early-Holocene (11.7–8.3 kyr BP)

During the early-Holocene, the Earth experienced a boreal insolation maximum (10 kyr BP) that led to a dry/wet eastern/western Mediterranean Basin (Harrison and Digerfeldt, 1993). In the Eastern Mediterranean Basin (EMB) the Hadley circulation was reinforced. This enhanced the stronger North Atlantic anticyclone, which would block the wet Westerlies to blow moisture into the area (Fig. 2.3-10kyr BP). In the Western Mediterranean Basin (WMB) instead, the local convection was reinforced. This, weakened the Hadley cell in the area, allowing the Westerlies to provide both increased effective moisture and water availability (Magny et al., 2012). During the boreal insolation maximum, both summer and winter temperature anomalies were high in the dry NE Mediterranean region, while they were only slightly negative during summer in the wet NW Mediterranean (Davis et al., 2003). However, as the Earth remained significantly glaciated, changes in the massive ice sheets still played a salient role in climate variability, i.e. the 9.2 ka and 8.2 ka cold and abrupt climatic events (Alley and Ágústsdóttir, 2005; Rohling and Pälike, 2005).

2.2.2 The mid-Holocene (8.3–4.2 kyr BP)

The mid-Holocene (Fig.2.3-7kyr BP) presented less strongly contrasting seasonality and a general increase in the summer and winter precipitations over the Basin (Peyron et al., 2017). This increase in moisture availability was related to changes in the orbital forcing, with higher insolation at high latitudes compared to low latitudes, amplified by the marine and atmospheric circulation of the Basin (Davis and Brewer, 2009) . In this context, and although the summer insolation was stronger than in the present, climatic proxies indicate that Earth's high latitudes were warmer than nowadays, while low latitudes remained colder (Davis and Brewer, 2009). In particular, the Mediterranean reached a mid-Holocene thermal minimum by ~7 kyr BP (Davis et al., 2003), a time when the present atmospheric circulation of the North Hemisphere was established (Schulz and Paul, 2002). While dry conditions were present in the northern Basin, major floods took place in the center and southern areas around 7.6–7.1 kyr BP in response to the development of the mega-Monsoons (see Davis and Brewer, 2009). Floods have been reported to occur during this time span in southern Italy, southern France, the Levant coast, and in Tunisia (Benito et al., 2015). Likewise, the 6 ka event, related to an episode of declined solar output, is marked by a dry/wet spell in the WMB/EMB.

2.2.3 The late-Holocene (4.2–0 kyr BP)

With a generalized drying and warming of the conditions, the late-Holocene was marked by the reorganization of the general atmospheric circulation due to an orbitally induced decrease of solar insolation around 4.5 kyr BP (Davis et al., 2003). Back to a regime with a higher latitudinal temperature gradient, the InterTopical Convergence Zone (ITCZ) together with the Monsoons system migrated towards the south, leading to a general reduction of the Mediterranean's precipitation (Zhao et al., 2010). For the north-western side of the Basin, the transition to drier climate would occur more abruptly, related to important winter recharge periods during warm summers (Fig. 2.3-3kyr BP). Instead, in the south-western and EMB, the transition would take place more gradually with relatively stable temperatures throughout the year (Davis et al. 2003; Harrison and Digerfeldt, 1993). Ever since the decrease of insolation, the Mediterranean has witnessed more unstable weather patterns, a successive decline in precipitation (Peyron et al., 2017) and a linear increase of its temperatures, reaching present-day conditions around 2.5–2 kyr BP. Likewise related to orbital forcing, the 4.2 ka and 2.4 ka abrupt events in the late-Holocene, as well as the climate oscillation of the Little Ice Age (LIA) in 1300–1800 AD that followed the Medieval Climate Anomaly (MCA) in 800–1300 AD, were coincident with episodes of declined solar output (Bond et al., 2001).

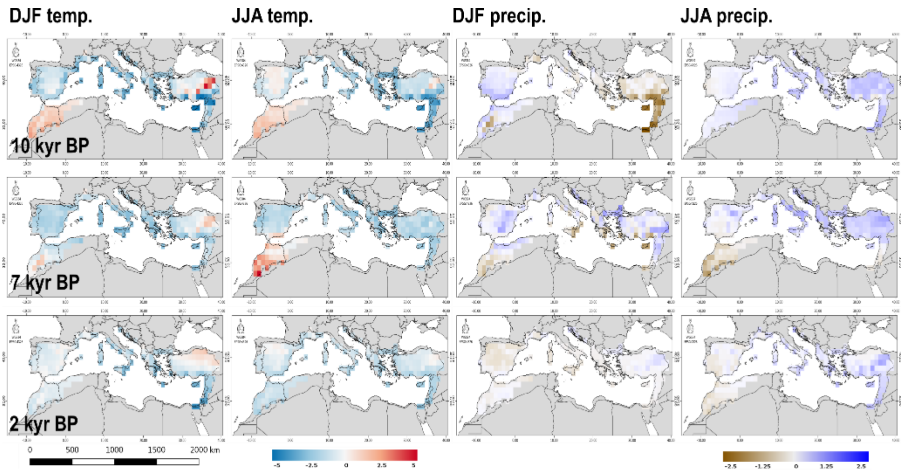


Figure 2.3. Reconstructed winter (DJF) and summer (JJA) temperature anomalies (°C) and precipitation anomalies (mm/month) relative to the pre-industrial (100 yr BP) period. Data source: Mauri et al. (2015).

2.3 Current climate and hydrological perspective

The climate dynamics of the Basin are strongly determined by the enclosed Mediterranean Sea and the mountain belts that surround it. Its climate is characterized by temperate wet winters and warm dry summers, with temperature rates of ~10 to ~25 ºC and rainfall rates of >3500 mm yr^{-1} to <200 mm yr^{-1}, according to WorldClim (Fig. 2.4). The lack of summer rainfall is a defining characteristic of the whole Mediterranean with an overall September to May wet season. Over the northern part, however, the Basin experiences a bimodal rain pattern with moister spring and fall seasons. In the eastern part, the rain season occurs in December-February (Dayan et al., 2015).

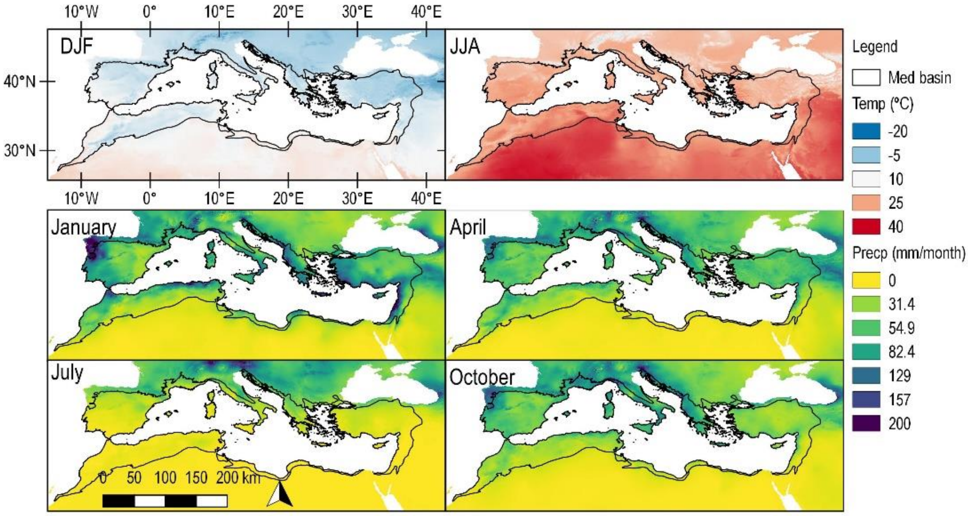


Figure 2.4. Mean average winter (DJF) and summer (JJA) temperatures (°C) and precipitation (mm/month). Data source: WorldClim[5].

The hydrological system of the basin has two main precipitation types, the synoptic rainfall, which is consequence of the large-scale atmospheric motion; and the topographic rainfall, which is the rain caused by local orographic convection. Like orography, other smaller scale processes such as the sea surface temperature or the land-sea interaction, also intervene on the regional rainfall variability. These though, have a limited influence in the overall precipitation of the basin (Xoplaki et al., 2004).

[5] https://worldclim.org/version2

2.3.1 Synoptic rainfall

The synoptic rainfall displays an anti-phase precipitation pattern for the EMB/WMB (Benito et al., 2015). Records from the WMB indicate high influence of the Westerly winds driven by the North Atlantic Oscillation and the East Atlantic/West Russia, favouring cyclogenesis during autumn, and also during spring in the south-western regions (i.e. Morocco, Algeria, S-Spain, and S-Italy) (Xoplaki et al., 2004). The EMB instead, is influenced by the descending branch of the Hadley cell in summer and the Siberian High in winter, with cold Levant fronts. Most of the winter rainfall of this area is attributed to the El Niño Southern Oscillation, which displaces the jet above this sub-basin (Lionello et al., 2006). As previously exposed, precipitation rates are minimum in the summer months for the whole Basin. Penetrating frontal lows are the main source of summer rainfall, although these, quickly vanish in the eastern and southeaster areas where there is the predominance of the Hadley cell (Raveh-Rubin and Wernli, 2015). In winter, the Hadley cell moves south, enabling the entrance of rainy synoptic systems.

2.3.2 Topographic rainfall

The topographic rainfall is produced by upslope winds and sea-breezes during summer when high amounts of sea surface vapour are accumulated throughout the day and transported over the coastal mountain ranges, where it precipitates. This phenomenon occurs due to the Basin's physical geography, which comprises several mountain belts around the Sea (Fig. 2.1). Although the distribution of arcuate-type mountain belts comprises both the EMB and WMB, topographic rainfall is mostly characteristic of the WMB. This is the case as the atmospheric regime of the EMB is dominated by convection and thus, despite its higher sea surface temperature and the presence of coastal mountains, moisture accumulation takes place in smaller amounts and does not result in high topographic rainfall (Goldreich, 2003; Millán et al., 1997).

2.3.3 Changes in the land use and rainfall patterns

Both the synoptic and the topographic rainfall can be affected by changes in the land use and land management of the Mediterranean Basin.

On the one hand, as previously exposed, the synoptic system is responsible for most of the EMB's rainfall through cold fronts of Mediterranean mid-latitude cyclones, i.e. Cyprus Lows and Syrian Lows. Contributing factors to cyclogenesis development are the relatively high sea surface temperature of the Mediterranean Sea compared to the colder layer of air above it, and orography orthogonal to the airflow, i.e. mountains. However, the main cause of cyclogenesis development in the EMB are heat lows that generate from the thermal heating over dry land (Nissen et al., 2010; Xoplaki et al., 2004). In this way, land mismanagement and land use changes can result in soil aridification, causing fluctuations on land surface heat fluxes through the increase of albedo or the decrease in evapotranspiration rates, affecting cyclone development (Fig. 2.5-a). The occurrence of cyclones has been found to be related to extreme precipitation events, as they feed the flow of air towards the area affected by heavy rain (Jansa et al., 2001). They are also associated with wind storms and surges, extreme events that impact very arid areas. In particular, the literature reports a number of small but exceptionally severe storms called Medicanes (from Mediterranean hurricanes) characterized by storms of the strongest intensity, an extremely small radius and short lifetime, that cause flooding and damages in the coastal areas (Cavicchia et al., 2014). Although no homogeneous tendency has been reported for extreme rainfall in the Basin (Brunet India et al., 2007), records indicate an increase of torrential rainfall together with a decrease of light-moderate precipitation, both in the WMB (e.g. Alpert et al., 2002) and in the EMB (e.g. Kioutsioukis et al., 2010).

On the other hand, topographic rainfall is the main source of precipitation in the WMB. Similarly to the EMB, topographic rainfall is declining as the cloud condensation level required for precipitation is not reached due to lack of inland moisture, i.e. aridification (Millán et al., 2005). As these authors explain, the lack of moisture occurs due to vapour accumulating over the sea and moving inland, where it decreases while temperature increases. This situation, forces vapour to rise by sensible heating, and eventually, if the cloud condensation level is not acquired, i.e. due to lack of moisture, it ascends above the coastal orography and leaves the Mediterranean Basin pushed by a cold air loft or a transitory depression. The consequent inhibition of local storms results in the reorganization of the evaporated water into a closed vertical loop above the sea that lasts for 4–5 days before travelling inland passed beyond the Mediterranean orography and that accumulates several layers of pollutants (Dong et al., 2017) (Fig 2.5-b).

Consequences of the alteration of the synoptic and topographic rainfall likely result in sparser and heavier rainfall events and more severe and extended droughts

(Steffen et al., 2015). These at the same time, enhance future aridification, reduce vegetation cover, lead to the decline temperate forests within the Basin, enhance soil erosion, boost the activation of floodplains or intensify aeolian sediment mobilization, among others (Fletcher and Zielhofer, 2013). Further effects are likewise propagated into the adjacent regions of the Mediterranean. In particular, to central Europe and to the Sahel through the export of the accumulated moisture (Park et al., 2016; Ulbrich et al., 2012).

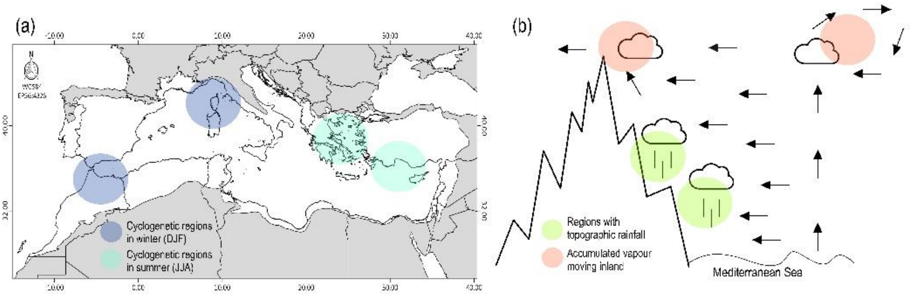


Figure 2.5. (a) Winter and summer cyclogenetic regions of the Mediterranean Basin according to Dayan et al. (2015) and Nissen et al. (2010). Dark-blue regions are associated to the positive phase of the North Atlantic Oscillation in winter with migrating cyclones into the basin, while light-blue regions are associated to heat lows that generate from the inland heating in summer within the basin. *(b)* Schematic representation of enhanced/prevented topographic rainfall. The green colour indicates could condensation, while orange indicates the reorganization of evaporated water in a vertical loop.

2.4 Future climate projections

Projections into the year 2100 presented by the IPCC exhibit an increase on global temperatures with more hot- and fewer cold-extreme temperatures; an increase on the frequency, length and magnitude of these events; a likewise intensification of individual storms and thus, a reduction on the number of weaker storms; a higher contrast between seasonal precipitation; an increase on surface evaporation and hence, on soil moisture; and a decrease in annual runoff (Collins et al., 2013).

In particular, climate change is estimated to strongly impact the Mediterranean region by increasing heat summer stress and heat waves (CDC, 2018; Lionello et al., 2017) and modifying precipitation patterns by a weakened Atlantic meridional overturning circulation product of the extension of the Hadley Cell (Combourieu-

Nebout et al., 2013) (Fig. 2.6). The expansion of the Hadley Cell is projected to inhibit precipitation on its poleward flanks, and therefore, on the Basin (see AR5_WGI_AnnexI for modelled projections of the Mediterranean and Sahara area). In this context and along with precipitation decreases (Lionello and Scarascia, 2018), storminess enhancement (Romera et al., 2017; Seneviratne et al., 2012), and evaporation increases due to temperature rise (Collins et al., 2013), large declines in riverine runoff (Sanchez-Gomez et al., 2011) are projected for the Basin. To this, it needs to be added up the expand of demands of goods and services due to projected population growth (World Bank Group, 2018), among which water resources are critical (Cramer et al., 2018).

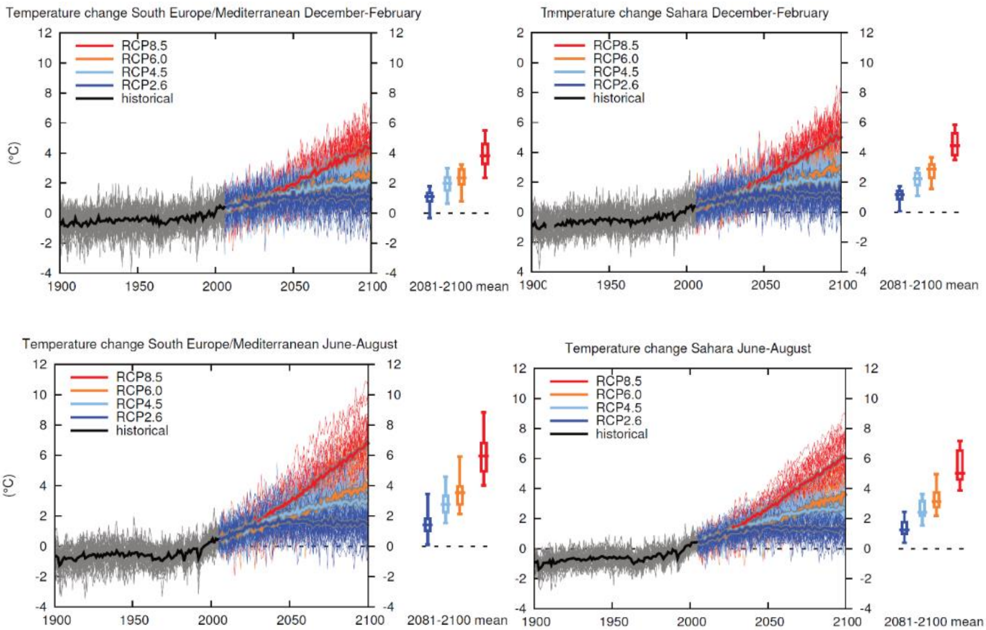


Figure 2.6. AR5-WGI time series of temperature change relative to 1986–2005 averaged over land grid points in the regions of South Europe/Mediterranean (30°N to 45°N, 10°W to 40°E) and the Sahara (15°N to 30°N, 20°W to 40°E). Thin lines denote one ensemble member per model, thick lines the CMIP5 multi-model mean. On the right-hand side the 5th, 25th, 50th (median), 75th and 95th percentiles of the distribution of 20-year mean changes are given for 2081–2100 in the four RCP scenarios. Source: IPCC, 2013: Annex I: Atlas of Global and Regional Climate Projections.

According to the Objective number four of the UNEP/MAP (Plan bleu, 2016), *“the consequences of climate change are expected to worsen already critical situations present in the region”.* Within this context, addressing climate change is a priority issue for the Mediterranean region.

2.5 Conclusions and connection

Orbitally induced climate variability set the conditions for an overall dryer Basin during the **late-Holocene** (4.2–0 kyr BP), with **more unstable weather patterns and reduced precipitation**.

The natural alteration of the hydrological system, however, has only been **exacerbated by human activities**, resulting in nowadays’ **alteration of the** cyclogenesis development that takes place in the EMB and inhibition of topographic rainfall in the WMB.

With the gathering of this information, **Objective 1 is accomplished**, which aimed at discerning between the natural and the anthropogenic share of the historical environmental evolution of the Basin.

In light of the current and projected climate scenarios, the adoption of sustainable land management measures (Chapter 4) becomes key in contributing to restoring and enhancing the water cycle of the Basin with implications not only to the hydrological budget of the Mediterranean (Chapter 3) but also, as a basis to perform climate change adaptation and mitigation actions.

3. LUC−environmental interaction

After the introduction to the Mediterranean's geomorphology and climate history throughout the Holocene presented in Chapter 2, this chapter reviews how past Land Use Changes[6] (LUC) interacted with the regional environment in the Basin. The aim to do so is to **answer Objective 2, which aims at better understanding the implications of LUCs in modifying the landscape and reinforcing climate variability, especially, the hydrological system.** LUC is not only among the largest anthropogenic impacts threatening the environment but also, a major driver of climate change. According to the IPCC's Fifth Assessment Report (AR5), Agriculture Forestry and Other Land Use (AFOLU) are responsible for about 10–12 $GtCO_2eq$ yr^{-1} anthropogenic GHG emissions.

For this purpose, we start by introducing the archaeological and vegetation evolution of the Mediterranean Holocene societies (Section 3.1). Next, we conduct a semi-structured review of 23 scientific case-studies carried out around the Basin and analyse their content as a basis of summarizing the fundamental LUC practices and LUC−environment encountered interactions (Section 3.2). Using these, we develop an integrative network map to holistically visualize and understand the different interactions and discuss the contribution of past LUCs in exacerbating climate change through positive feedbacks (Section 3.3).

The Mediterranean Basin is a key study area to discern the interaction between paleoclimate and anthropogenic activity, as this region is sensitive to the regional and global climate change, both due to its diversity in the configurations of land and sub-seas and due to its connection to the global ocean and atmospheric circulation. Further, it is home to ancient civilisations and rich with information on human and environment interaction, i.e. archaeological sites, Quaternary deposits product of anthropogenic activities, etc. (Holmgren et al. 2016 and references therein).

[6] Differently from the Land Use, Land-Use Change, and Forestry (LULUCF) defined by the United Nations Framework Convention on Climate Change (UNFCC), by Land Use Change (LUC) we here understand the straightforward change from one land use (e.g. forestland) to another form of land use (e.g. cropland).

The rationale behind this chapter is to follow up on this investigation by promoting sustainable land practices aimed at dampening the accumulated effects of LUC over the last millennia while combating climate change (Chapter 4).

3.1 Archaeological and vegetation evolution

Within the Mediterranean Basin, there are different chronologies on archaeological evolution that cannot be ignored. The heterogeneity of these is the result of the rich cultural, climatic, and geological diversity that characterizes this extended geographic region. To check into these, Roberts et al. (2011) assemble a summary of the different chronologies within the Basin by 9 regions, i.e. Iberia, North Africa, Italy, Balkans, Aegean, Anatolia, Levant, Egypt and Mesopotamia, for the 9–2.3 kyr BP time span. Here, we will shortly introduce the archaeological context of the Basin, treating it as a whole, and thus, generalizing its context as a basis of understanding the following sub-chapters.

3.1.1 The early-Holocene (11.7–8.3 kyr BP)

The significant human threshold of the Mesolithic−Neolithic transition consisted of a cultural revolution from a subsistence model of hunter-gatherer to herder-farmer, with the emergence of agriculture and animal husbandry that took place in the early-Holocene (Zeder, 2008). Neolithic settlements first developed in the Near East ~12 kyr BP, moved to Anatolia ~10–9 kyr BP (Flohr et al., 2016), and from there to south Europe ~8 kyr BP both via terrestrial migratory paths crossing Thrace and the Balkans, and maritime routes through Dodecanese and Crete (Paschou et al., 2014). This spread took place through the adoption of plant and animal domesticates by pre-existing Mesolithic populations (Roberts et al., 2011). During this time, a diverse range of economic activities took place in the Neolithic Mediterranean settlements, from pastoralism of sheep, goat, pig and cattle in the arid regions (Fig. 3.1, red 9−5 kry BP), to production of domesticated grain such as wheat and barley in the coastlines and in the steppes (Goring-Morris and Belfer-Cohen, 2011; Henry et al., 2017) (Fig. 3.1, green 9−5 kry BP). Settlements preferably developed close to perennial water sources and the coastline, from where they could access a richer variety of ecosystems (Benjamin et al., 2017).

3.1.2 The mid-Holocene (8.3–4.2 kyr BP)

Following to the Neolithic, Chalcolithic cultures flourished in the Near East, expanding their knowledge, control and cooperation on managing water, animal and soil resources (Roberts et al., 2011). These early societies of the mid-Holocene, allowed cultivation in low-precipitation areas and developed the production, craft and trade of metal goods. They also showed climate resilience to specific and frequently seasonal, local climate conditions. However, for abrupt climatic events, both evidence of civilization decline and even collapse have been reported (e.g. Clarke et al., 2016; Martín-Puertas et al. 2008), together with evidence of local adaptation through storage strategies and resource diversification (e.g. Clarke et al., 2016; Flohr et al., 2016; Roberts et al., 2018b).

3.1.3 The late-Holocene (4.2–0 kyr BP)

Throughout the final Chalcolithic/early-Bronze Age (4.5–3.05 kyr BP), settlements reached higher levels of social organization, and following, the first literate societies emerged in the eastern Mediterranean (Roberts et al., 2011). These larger societies, with their extended cultural networks, had a higher capacity of performing intensive land use, exercising more impact on the surrounding biodiversity and exerting more pressure in the immediate environment (e.g. Primavera et al., 2017; Sadori et al., 2016) (Fig. 3.1, 3 kry BP). In central and western Mediterranean, however, complex urban societies are linked with the arrival of the Greek and Phoenician trading colonies (Roberts et al., 2011). During the late-Holocene, thus, the Basin kept witnessing a progressive reduction in primary forest cover and major vegetation changes, creating new spaces functional to humans (e.g. Moser et al., 2017). LUC was exacerbated by the intensification of the different agricultural practices, aimed at providing resources to a more extended Mediterranean population (Fig. 3.1, 1 kry BP to 2016 AD). In this way, the climatic instability of the late-Holocene, followed by the increasingly significant anthropogenic LUC, pushed for the transition from climate-dominated systems to human-dominated environments (Roberts et al., 2011).

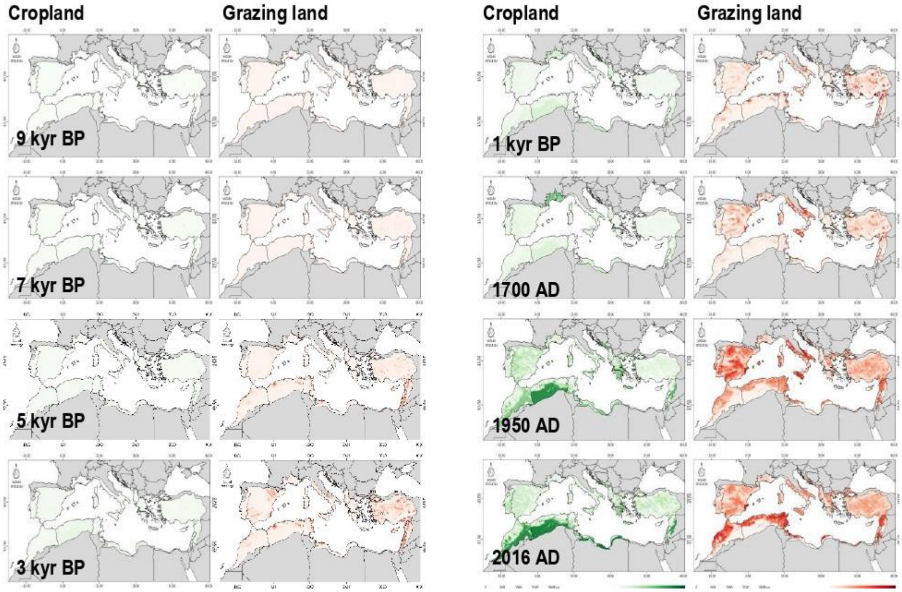


Figure 3.1. Historical share of cropland and grazing land in 5' longitude/ latitude grid resolution maps from 7000 years BC (9 kyr BP) to 2016. The coloured area corresponds to the Mediterranean biogeostratigraphical zone. Data has been acquired from the History Database of the Global Environment (HYDE version 3.2) presented by Goldewijk et al. (2017).

3.1.4 Vegetation evolution

Reconstructing the past vegetation cover of the Basin at a regional scale has proven challenging due to the patchy spatial coverage of data available today (e.g. European pollen dataset[7]; Changing the face of the Mediterranean[8]). To this, it has to be added the large uncertainties models need to account for, such as the distribution of cumulative CO_2 through time (Stocker et al., 2018) and other processes operating at smaller scales that are rarely accounted for (Pausas and Millán, 2018). Thereby, up to date, a reconstruction of the Holocene vegetation evolution in the whole Mediterranean

[7] http://europeanpollendatabase.net

[8] https://www.plymouth.ac.uk/research/centre-for-research-in-environment-society/changing-the-face-of-the-mediterranean-land-cover-and-population-since-the-advent-of-farming

region has not yet been conducted, although there are ongoing projects such as the PAGES: LandCover6k working group[9] that aim at disentangling this issue.

The PAGES-LandCover6k working group has developed the REVEALS model (Regional Estimates of VEgetation Abundance from Large Sites), which uses sedimentary pollen data to estimate plant abundance on a regional geographic scale (Sugita, 2007). Using this model, several studies have estimated forest loss and past regional land cover in northern and central Europe (e.g. Kaplan et al., 2017; Roberts et al., 2018a; Woodbridge et al., 2014). Other several snapshots of time intervals, as well as local paleoreconstructions, have been performed within the Basin (e.g. Collins et al., 2012; Jalut et al., 2009). These, estimate the dominance of deciduous broad-leaf forests during the early-Holocene with their later decline and contemporaneous spread of drought-tolerant xeric vegetation. Collins et al. (2012) report on mid-Holocene records with up to 35–50% higher arboreal pollen than during the late-Holocene and already confirm the widely widespread of xeric vegetation in the southern margins of the Basin. Moreover, in agreement with Fyfe et al. (2018), the authors conclude that anthropogenic LUC did not only transform the Mediterranean landscape from a forest vegetation type to the nowadays open and fragmented landscape, but it also transformed much of the other vegetation communities of the Basin.

Nowadays, the Mediterranean Basin has a traditional mosaic-like landscape of agro-silvio-pastoral systems and xeric shrubs (~26%), annual-, permanent-, irrigated-, rain-fed-, extensive-, and intensive- croplands (~35%), temperate forests (~21%), settlements, (~3.5%), wetlands (~1.5%) and other lands (13%) (FAO and Plan Bleu, 2018; Malek et al., 2018-Fig.3). According to Malek and colleagues, typical plant associations of the region include deciduous oak forests, conifer formations with pine, cypress, and cedar. Livestock mainly consist of bovines, goats, and sheep. Annual crops are largely of cereals (i.e. wheat, maize, barley, and rice) and vegetables (fresh vegetables, potatoes and tomatoes). Permanent crops include olives, grapes, and citrus, which by themselves, amount >20% of the total crop production of the region.

[9] http://pastglobalchanges.org/science/wg/landcover6k/intro

3.2 Land Use Change practices

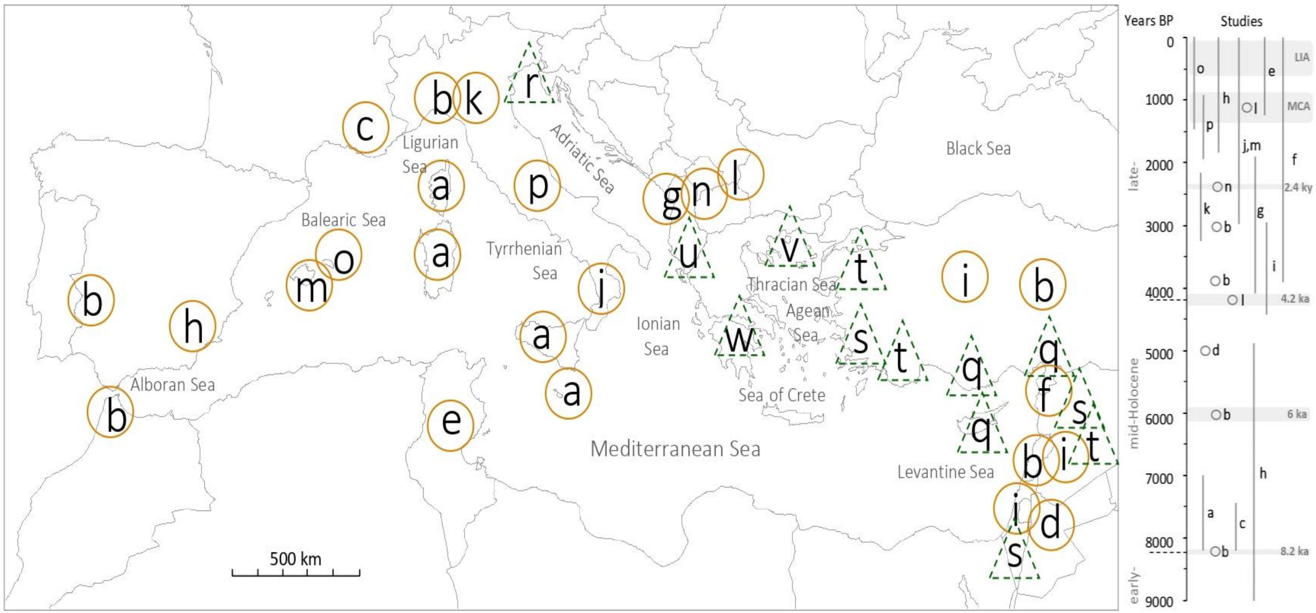
Far from attempting to construct a comprehensive analysis of the anthropogenic record on the Basin, we conduct a semi-structured systematic review of case-specific studies that focuses on the LUC−environment interaction in the Holocene epoch. For this, we (1) execute a literature search and (2) perform an analysis of the content of the selected studies.

3.2.1 Literature search

We started by conducting a search in the Web of Science™ database and the Science Direct® collection with the following keywords: *paleoclimate, land use, archaeology, Mediterranean, Holocene, and the names of all countries with Mediterranean coasts or antique Mediterranean cultures*. The obtained results (N>500) were filtered following these three criteria: i) time restriction to the 2008–2018 time span, as during these past years methodological developments have allowed for more transdisciplinarity, permitting climate scientists, historians, and archaeologists to interact and provide more holistic views of the results presented; ii) selection of studies taking place only within the Mediterranean sensu stricto biogeographical zone; iii) selection of studies that provide both, archaeological and environmental data (e.g. archaeological sites, pollen, charcoal, river geomorphology) related to paleoclimatic records (e.g. lake sediments, cave speleothems, deep sea cores). After screening the abstracts and conclusions of the resulting filtered studies (N>45), we selected 16 studies that fulfilled the criteria of particularly assessing the LUC−environment interaction, i.e. LUC−landscape−climate interaction (Fig. 3.2 continuous-yellow circles). Note that no study was found on the coast of North Africa or the Ionian, Aegean, and Adriatic Seas. That is why we also considered seven additional studies obtained from the review that inspected the LUC−landscape interaction but did not reflect on the effects on the local climate (Fig. 3.2 dashed-green triangles). We have shortly discussed these as well, in order to offer a more complete snapshot of the LUC−environment interaction in the Mediterranean Basin.

For the documentation of the paleoclimate, studies predominantly use speleothems, lacustrine and deep-sea sediment cores as proxy records, while information on past LUCs is commonly recorded by inland sediment assemblages, archaeological sites, and pollen records. Most of the current work relates to the late-Holocene and reports on anthropogenic LUC intensification.

Figure 3.2. Geographical location and time-span of the reviewed studies. Continuous yellow circles denote, studies that report Land Use Change (LUC) practices in relation to the environment (i.e. landscape and climate) of the Holocene. Dashed green triangles indicate studies that only document LUC practices with no relation to the landscape. The shaded areas of the time-span represent major abrupt climatic events in years before present (BP, i.e. 1950), LIA refers to Little Ice Age, MWP to Medieval Warm Period, and ky/ka to thousand years. **LUC−environment**: **a.** Médali (2017); **b.** Mercuri et al. (2011); **c.** Berger et al. (2016); **d.** Meister et al. (2017); **e.** Zerai (2009); **f.** El Ouahabi et al. (2018); **g.** Mazzini et al. (2016); **h.** Baartman et al. (2011); **i.** Pustovoytov and Riehl (2016); **j.** Moser et al. (2017); **k.** Cremaschi et al. (2016); **l.** Thienemann et al. (2017); **m.** Picornell-Gelabert and Carrion-Marco (2017); **n.** Vogel et al. (2010); **o.** Balbo et al. (2018); **p.** Mensing et al. (2015). **LUC−landscape**: **q.** Zeder (2008); **r.** Fontana et al. (2017); **s.** Clarke et al. (2016); **t.** Flohr et al. (2016); **u.** Morellón et al. (2016); **v.** Gogou et al. (2016); **w.** Weiberg et al. (2016).



3.2.2 Analysis of the content of the selected studies

Following the review of case-specific studies, we analyse their content by collecting all identified effects on the environment, and in particular, on the hydrological cycle as a consequence of a LUC practice. The selected literature provides a collection of different case-studies exemplifying many particular LUC−environmental interactions. We text-analyse the content of these studies and collect all the identified interactions in Table 3.1.

Overall, we find that in the still climate-dominated environment of the early-Holocene, evidence of Mediterranean Neolithic impacts on the landscape was limited and likely overprinted. Despite the difficulty in distinguishing between human-induced versus natural LUC, some studies report unequivocally anthropogenic pressures in close relation to the landscape and climate. In particular, and following the propagation of the Neolithic front from Africa into Europe, the first recorded LUC practices have been found in the NE ancient world at around ~10,000 years, while in the western basin it was not until ~7,500 years when communities of farmers were established (Zeder, 2008). In contrast to the early- and mid-Holocene, many authors report the environmental consequences of the past 4,000 years, i.e. late-Holocene, of anthropogenic LUC pressures on the Mediterranean Basin.

In the climate-dominated system of the early-Holocene (~11,700–8,200 years) pressures on the environment were local and limited. Nevertheless, deforestation, depletion of plant resources and soil impoverishment have been found in connection to a regime of sustained fires aimed at land opening for settlement establishment, farming and cropping. During the mid-Holocene (~8,200–4,200 years), several studies register LUCs related to an intensification of the land use by the development of runoff infrastructures, the onset of mining, and the exploitation of aquifers, among others. These practices induced further aridity, biodiversity loss, and soil impoverishment. With the onset of the late-Holocene (last ~4,200 years), a transition from climate- to human-dominated landscapes occurred. This transition is likely to have been triggered by an enlarged LUC capacity aimed at adapting to the contemporary drier and warmer climate, further exacerbating aridification. In this way, LUC in the late-Holocene further aggravates the consequences of earlier practices by exercising them in a more intense manner, while exhibiting evidence of adaptation to aridification by developing storage systems, enlarging infrastructures that rise pressures to the natural system and extending trading networks.

Table 3.1. Highlighted LUC−environment interaction for each of the 23 reviewed studies.

ID	Reference	Highlighted LUC−environment interaction
a	Médali (2017)	Landscape fragmentation, soil erosion, disruption and extinction of multiple plant species related to a regime of sustained and regular fires.
b	Mercuri et al. (2011)	Reinforcement of soil erosion and aridification through overgrazing.
c	Berger et al. (2016)	Enhanced hydrosedimentary activity product of increased fire regime and upstream pastoralism. Soil erosion and lost of vegetation with decreased soil organic carbon storage capacity due to river instability.
d	Meister et al. (2017)	Development of sophisticated water storage complex and terraces enabling conditions for settlement establishment in desertic areas.
e	Zerai (2009)	Enhanced wind activity leading to erosion due to clearing and grazing. Downstream dunes expansion and increased geomorphic activity due to clearing and grazing.
f	El Ouahabi et al. (2018)	Processes of aggradation and changes in the chemistry of the soils and the watershed product of strong deforestation, large upland cultivation, stripping of thin soil covers, pastoralism practices, and ore exploitation.
g	Mazzini et al. (2016)	Higher turbidity and impoverished lake's biodiversity by deforestation and cultivation around the lake. Enhanced swamp transformations into lakes due to greater amounts of water availability (decrease of precipitation via evapotranspiration). Reduction of water quality and biodiversity induced by soil erosion.
h	Baartman et al. (2011)	Episodes of erosion and sedimentation linked to deforestation, pastoral and agricultural activities.
i	Pustovoytov and Riehl (2016)	Changes in the local water regime, salinization of soils and increased resilience towards aridification by cause of aquifer exploitation.
j	Moser et al. (2017)	Soil erosion, sedimentary aggradation, and enhanced surface runoff due to natural cover removal.
k	Cremaschi et al. (2016)	Soil erosion, decrease of woods, and expansion of pasturelands induced by deforestation for timber and overexploitation of intensive cereal cropping.
l	Thienemann et al. (2017)	Loss of vegetation resilience to climatic events related to a previously degraded environment.

m	Picornell-Gelabert and Carrion-Marco (2017)	Landscape fragmentation due to deforestation.
n	Vogel et al. (2010)	Enhanced soil erosion, surface runoff and lake turbulence product of higher deforestation.
o	Balbo et al. (2018)	High sediment discharge in relation to inland erosion. Amplified erosion due to LUC−environmental feedbacks.
p	Mensing et al. (2015)	Widespread deforestation and erosion during climatic optimums.
q-w	Zeder (2008); Fontana et al. (2017); Clarke et al.(2016); Flohr et al.(2016); Morellón et al. (2016); Gogou et al. (2016); Weiberg et al. (2016)	Emergence, adaptation, and expansion of settlements thanks to farming and cropping intensification, watershed exploitation, storage strategies development, and deforestation.

From the review of studies, we have categorized the different observed LUCs in four groups: (a) regular fires and deforestation; (b) farming and cropping activities; (c) overgrazing and upstream pastoralism; (d) hydraulic terraces and aquifers.

(a) Regular fires and deforestation. Vegetation changes and man-induced landscapes have been reported by Médail (2017) on the islands of Sicily, Malta, Sardinia, and Corsica; Moser et al. (2017) in Calabria, south Italy; and Picornell-Gelabert and Carrión Marco (2017) in Mallorca, Spain. These authors, outline environmental degradation and extinction of multiple plant species related to a regime of sustained and regular fires. Vogel et al. (2010), Thienemann et al. (2017) and Mensing et al. (2015) moreover, describe how such past changes in the land use likely destabilized ecosystems, making them less resilient to climatic changes and especially vulnerable to abrupt climatic events.

(b) Farming and cropping activities. Cremaschi et al. (2016) and Mazzini et al. (2016) describe how deforestation, farming and cropping activities induced to soil erosion and expansion of pasturelands in the Po Plain, and to the disappearance of Characeae algae in Lake Shkodra, respectively. El Ouahabi et al. (2018) document erosion phases on the Amik Basin in the Levant coast as a product of large upland cultivation, stripping of thin soil covers, deforestation, pastoralism and ore exploitation. Baartman et al. (2011) instead, discuss the drivers of river dynamics at the Upper Guadalentín Basin, Spain, and correlate some of them to deforestation, pastoral and agricultural activities. Balbo et al. (2018) argue the implications of LUC−environment interactions amplifying fluctuations in watershed activity and enhancing sediment discharge in the island of Menorca, Spain.

(c) Overgrazing and upstream pastoralism. The increase in the dominance of grassland and open areas is presented in the different study sites of Mercuri (2011) in SW Libya, N of Morocco, SW Spain, N Italy, and central Turkey; and Zerai (2009) in the Wadi Sbeïtla basin, Tunisisa; who discuss the role of landscape clearing and grazing as powerful mechanisms enforcing aridity. Berger et al. (2016) instead, document geomorphological riverbed changes of the Citelle River in France, synchronous to periods of enhanced fire regime and upstream pastoralism.

(d) Hydraulic terraces and aquifers. The role of aquifers and hydraulic terrace systems as potential measures to increase resilience towards aridification has been explored by Meister et al. (2017) and Pustovoytov and Riehl (2016) respectively, in the Levantine coast. In the margins of the Ionian and Aegean seas, the increase in clastic input, intensification of farming, watershed exploitation, and deforestation processes have been discussed by Morellón et al. (2016), Gogou et al. (2016), and Weiberg et al. (2016). In the Adriatic Sea, Fontana et al. (2017) document Holocene settlements' activities and locations in relation to the constant sea-level rise during the 4,000–2,000 year time-span. Zeder (2008) instead, reports on the emergence of agriculture and animal husbandry in the eastern Mediterranean around 11,000–8,000 years, while Clarke et al. (2016) and Flohr et al. (2016) describe local efforts of adaptation through storage strategies and resource diversification of the early-Holocene societies, showing climate resilience. These studies report LUCs but do not connect them to the effects of the local or regional climate. However, they are important to contextualize societies' development and level of excreted pressure on their surroundings.

3.3 Environmental interactions

3.3.1 Development of a network map

Following the review of case-specific studies, we build a network map that includes the collected interactions of Table 3.1. We then use the identified interactions to build a network map applying the Fuzzy Cognitive Mapping technique (FCM).

FCM is a systems mapping method that computes the direct connections between elements (e.g. concepts, processes, actions). According to the number of connections incident on each element, it depicts its centrality (Kosko 1986). Without entering into the rationale of its statistical analysis, it might be said that the more interactions an element has, the more central its placement in the network (degree centrality). Thus, the resulting network map not only shows the different elements (input data) and how they interact among themselves (output 1), but it also allows us to inspect the importance (i.e. centrality) of each element (output 2).

To build the network map, both elements and connections had to be defined. First, we provided the FCM software with a total of 24 elements (keywords) that were identified when carrying out the text-analysis of the studies, namely: Regular fires / Deforestation; Hydraulic terrace / Aquifer; Farming and cropping; Overgrazing / Upstream pastoralism; Biodiversity; Salinization; Turbidity / Organic matter; River instability; Surface runoff; Biomass; Aridity & Soil erosion; Atmospheric [CO_2]; Aggradation / Increased sediment discharge; Temperature; Redistribution of species; Flooding; Evapotranspiration; Water availability in wetlands; Topographic rainfall; Water quality; Groundwater flow; Soil Organic Carbon; Albedo; Pedogenesis. Following this, we assessed the presence of a positive and/or negative interaction for each pair of elements. For example, the following interaction "Reinforcement of soil erosion and aridification through overgrazing" was introduced into the FCM software by (1) identifying the elements related to this statement: 'Aridity & Soil erosion' and 'Overgrazing/ Upstream pastoralism'; and (2) identifying the interaction between the elements: we identified a positive connection from 'Overgrazing/ Upstream pastoralism' to 'Aridity & Soil erosion'.

For the network analysis, which calculates the centrality of each element (degree centrality), we normalized centrality measures to [0,1] for direct interactions between elements. For its layout, we applied the Yifan Hu algorithm, which is an algorithm for visualizing large networks.

FCM is mainly applied in social sciences, yet it has also been used in transdisciplinary studies such as climate change (Olazabal et al. 2018). Here, we apply FCM to capture in a synthetized manner the complex structure of the hydrological system of the Mediterranean Basin and identify causal connections among the encountered components. FCM allows for flexible integration of very interdisciplinary but related components of the water system, which are too complex to be overall quantified. As the latest IPCC report quotes: *"the complexity of the land-climate interactions requires multiple study approaches embracing different spatial and temporal scales*" (Arneth et al., 2019). We thus, benefit from the adaptability that this technique from the social sciences offers by allowing the integration of the encountered particular relationships (Table 3.1) among the different components of the hydrological cycle. Moreover, FCM enable us to encompass studies each of which, use a particular methodology with a specific (different) aim, theoretically connect all components, and draw integrated conclusions.

3.3.2 Results

The regional LUC−environment interactions, highlighted by the review of the selected studies, allow for the construction of a network map (Figure 3.3). This is possible because the selected studies take into account both paleoclimatological and archaeological data independent of each other, from the same time frame and geographic setting.

Rather than trying to review all possible existing interactions, we focus on the effects of local LUC practices that lead to broad regional variability (i.e. Basin-wide scale) in the hydrological cycle. Reflecting upon the different time scales and the non-linear behaviors of the exposed interactions is beyond the scope of this study. Bear in mind, however, that responses to these may vary due to sub-regional differences in the natural conditions (i.e. vegetation, orography, etc.) or internal thresholds (von Suchodoletz and Faust, 2018).

Considering the reviewed information on fires, it can be said that during the whole Holocene, fires have been extensively and recurrently used in the Mediterranean Basin during the whole Holocene for LUC purposes. They have cleared the landscape for farming, developing settlements, killing pests, etc., substantially enlarging the extension of grasslands. In addition to this, natural fires also occurred along the Holocene, as they are part of the seasonal dynamics of the Mediterranean vegetation. These mainly consist of an alternation of drier season with fuel burning and wetter seasons with biomass growth (Mercuri et al. 2019b; Vannière et al. 2016). As shown in the network map, besides affecting the vegetation cover through the expansion of grassland and the biodiversity once encountered there (Fig. 3.3 interaction between ‘Regular fires/Deforestation’, ‘Biomass’, and ‘Biodiversity’), fires also have the capacity of modifying the atmospheric chemistry, since they are a major source of CO_2 and ^{13}C-enriched CH_4 (see Marlon et al., 2008 and references therein). In this way, regular fires and deforestation have cleared large extensions of Mediterranean landscape for centuries, up to the point that grasslands are the second more extended land use type in the Basin, with an estimated ~26% of coverage, after croplands ~35% (FAO and Plan Bleu, 2018).

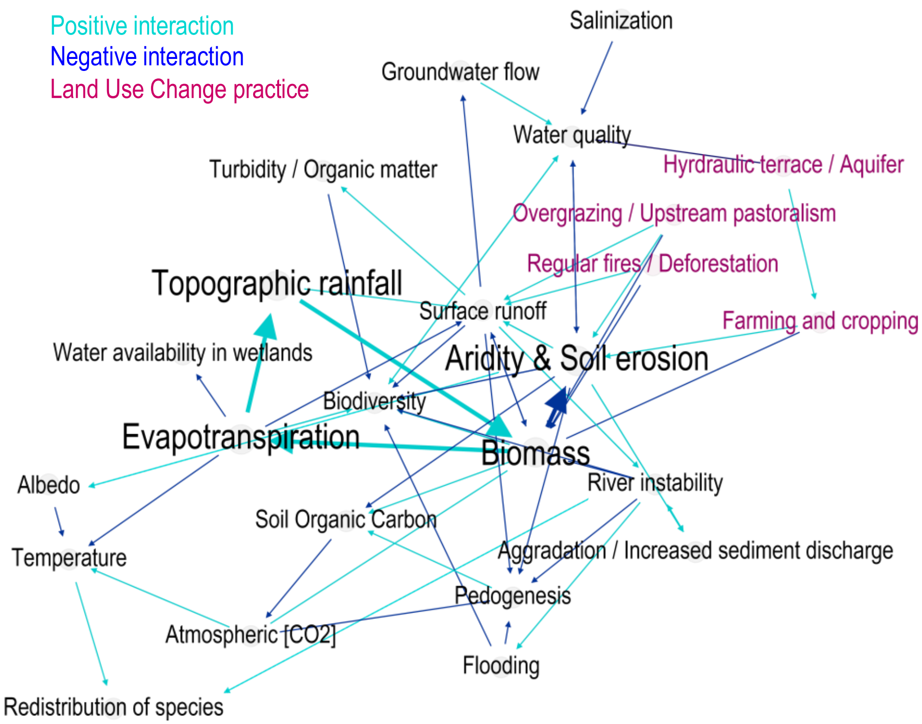


Figure 3.3. Network map framing the descriptive LUC–environment identified interactions. The most important elements, i.e. those with more interactions, are more centrally placed. Lines between elements represent interactions, with the arrow indicating direction and color indicating whether it is positive or negative.

Grasslands, on the other side, have higher surface albedo than forestlands, and thus, retain less heat from the sun (Fig. 3.3 'Overgrazing/Upstream pastoralism', 'Aridity & Soil erosion', and 'Albedo'). Additionally, they have less litter, shallower rooting plants, and lower leaf areas capable of capturing sunlight and SOC (Fig. 3.3 'Biomass', 'Aridity & Soil erosion', and 'Soil Organic Carbon'). This also reduces the uptake of atmospheric CO_2, enhancing the rise of temperatures and yet, promoting the expansion of biomass, which will uptake more CO_2 and increase SOC levels (Fig. 3.3 'Biomass', 'Soil Organic Carbon', 'Atmospheric [CO_2]', and 'Temperature'). As a result, grasslands have lower control over the surface water system and a decreased ability for water recycling than forestlands, with major effects on the land-surface water balance and local temperatures (Costa et al. 2003). These interactions shape the network map, which also conveys the many effects that they have on the broader environment. These can be summarised into three key effects.

First, promoting deforestation or biomass reduction limits the water vapour available for local precipitation coming from evapotranspiration (Fig. 3.3 'Biomass', 'Evapotranspiration', and 'Topographic rainfall'). Lack of evapotranspiration is also connected with the increase in temperatures (Fig. 3.3 'Evapotranspiration' and 'Temperature'), since evaporation has a cooling effect (Patz and Olson 2006). An increase in the availability of moisture, otherwise used for evapotranspiration, might instead promote wetland formation and expansion (Fig. 3.3 'Evapotranspiration' and 'Water availability in wetlands'), and induce swamp transformations into lakes (Mazzini et al. 2016).

Second, the network map shows that eliminating biomass and, thus, deep rooting infiltration, restricts groundwater flow and enhances surface runoff, causing aridification and soil erosion (Fig. 3.3 'Biomass', 'Aridity & Soil erosion', 'Surface runoff', and 'Groundwater flow') (Moser et al., 2017). The lack of biomass also negatively affects biodiversity by harming inland ecosystems and fostering higher contents of organic material and sediment discharge in runoff waters, which increases turbidity and diminishes the photic zone of riverine ecosystems (Fig. 3.3 'Biomass', 'Biodiversity', 'Surface runoff', and 'Turbidity/Organic matter') (Mazzini et al., 2016). Similar to deforestation, increased farming and cropping also has a negative impact on water quality and biodiversity, as these practices boost nutrient-enriched soils that cause water quality degradation, altogether reducing biodiversity (Fig. 3.3 'Biodiversity', 'Turbidity/Organic matter', and 'Water quality').

Third, the lack of biomass caused by deforestation also appears to be connected to river discharge and seasonal peaks that respond to rainfall patterns. This is due to the increase in surface runoff (Fig. 3.3 'Aridity & Soil erosion', 'Surface runoff', and 'River instability'). Both enhanced river discharge and peaks in river discharge also affect river stability, by increasing soil erosion, and promoting flooding, sediment reallocation, and aggradation (Fig. 3.3 'River instability', 'Aggradation/Increased sediment discharge', and 'Flooding') (von Suchodoletz and Faust 2018). Thus, in times of river instability, soil formation and pedological processes are prevented, hampering the densification of the vegetation, biodiversity expansion and Soil Organic Carbon storage (Fig. 3.3 'River instability', 'Aggradation/Increased sediment discharge', ‘Pedogenesis’, ‘Soil Organic Carbon’, and ‘Redistribution of species’) (Berger et al. 2016).

The three resulting highlighted interactions are in line with empirical findings documenting a reduction of the local precipitation, i.e. topographic rainfall, and thus, a modification of the hydrological system of the Mediterranean Basin as a product of land-use change (Millán et al., 2005) (Fig. 3.3 ‘Biomass’, ‘Evapotranspiration’, and ‘Topographic rainfall’).

Besides deforestation, anthropogenic changes in vegetation have been directed towards weather-resistant crops (e.g. cereals resistant to dry conditions during the late-Holocene) or fruit supplying crops (e.g. grapevines or hazelnut trees), suppressing the natural regeneration of regional vegetation (Cremaschi et al. 2016) (Fig. 3.3 ‘Farming and cropping’ and ‘Biomass’). Past changes in the land-use have been recorded to destabilize ecosystems, making them less resilient to climatic changes and especially vulnerable to abrupt climatic events (e.g. Thienemann et al., 2017), although this might differ according to the characteristic of the environment of a particular place (Fig. 3.3 ‘Farming and cropping’ and ‘Aridity & Soil erosion’).

Lastly, the network map shows how in addition to altering the surface water balance in several ways and modifying inland water properties, humans have also increased water exploitation through artificial measures like cultivation terraces, water reservoirs and storage systems, among others. Water infrastructure development has been used to enhance agricultural production and settlement expansion, creating both environmental benefits and problems (Rosegrant et al. 2002). On the one hand, rainfall harvesting and water storage constructions have reduced soil erosion and increased water availability, while on the other hand, overexploitation and inappropriate management of water sources have caused water pollution, depletion of groundwater, soil erosion, waterlogging, and salinization (Fig. 3.3 ‘Hydraulic terrace/Aquifer’, ‘Salinization’, and ‘Water quality’).

3.3.3 Knowledge transfer

Adaptation strategies in the rural landscape are often motivated by historical arguments. While such knowledge is passed along generations of land-users and learned by scientists through the investigation of archaeological records (among others), policy-makers and stakeholders might remain oblivious to it. Moreover, they often face time limitations to decision-making that pushes them to rely on their intuitive thinking. In this line, and with the focus of transmitting the here obtained science-based results to the policy/practice interface, we provide a synthesized analysis of these, followed by two key messages.

Foremost, to assist the need for quick thinking and understanding, we highlight the key concepts of the environmental interactions from the network map (Figure 3.3) and develop a synthetized causal loop diagram (Figure 3.4). Besides unravelling and simplifying the network map, the causal loop diagram upscales the identified LUC—environmental interactions and reflects on those interactions, which are reinforced through feedback processes and affect the regional climate of the Basin, contributing to climate variability, and further aggravating climate change.

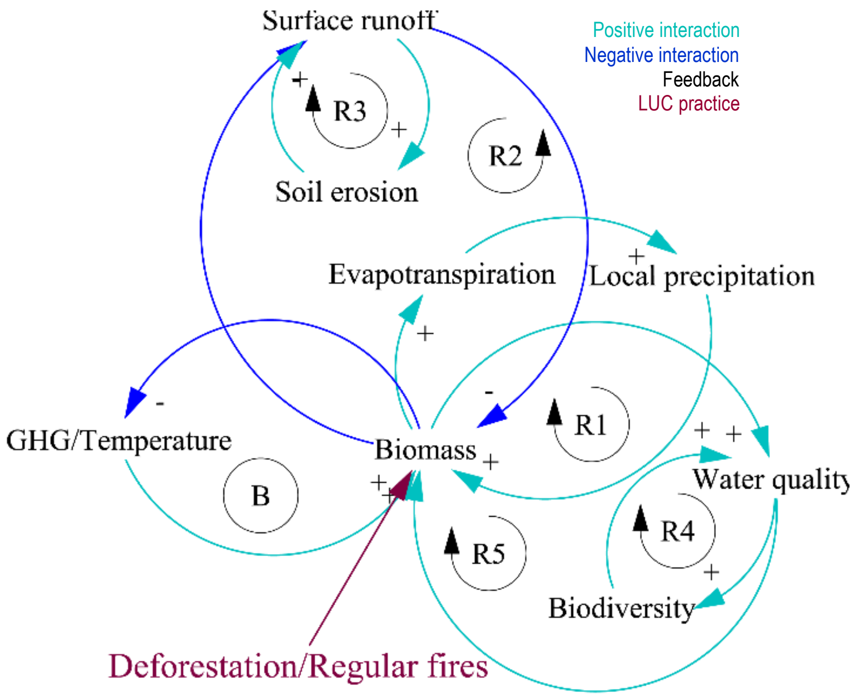


Figure 3.4. Causal loop diagram summarizing the encountered key feedback processes among the key environmental aspects altered by deforestation practices in the Mediterranean Basin. R refers to feedback processes. Clockwise feedbacks reinforce themselves in a positive manner, while anti-clockwise feedbacks do it on a negative one. B refers to feedback processes that balance themselves.

The causal loop diagram shows that deforestation for farming and cropping (Fig. 3.4-red) leads to the decrease of biomass, reducing the uptake of atmospheric CO_2 and yet, promoting the expansion of more biomass due to CO_2 availability (Fig. 3.4-B). It also modifies the surface water balance by halting evapotranspiration, which reduces water vapour available for topographic rainfall (Fig. 3.4-R1); and limits groundwater flow by eliminating wood cover deep rooting infiltration (Fig. 3.4-R2). At the same time, diminished deep rooting infiltration implies enhanced surface runoff, which causes higher aridification and further soil erosion (Fig. 3.4-R3). In addition, deforestation affects biodiversity and water quality and quantity, as the health of the ecosystems regulating the quality and the quantity of surface water, are ultimately determined by the quality and the quantity of it (Fig. 3.4-R4 and R5).

Demonstrating these basic interactions and understanding how small changes in land use may simultaneously affect multiple components of the environment, enables decision-makers to have a more holistic perspective when making decisions involving land use, one which addresses both locally-specific needs, as well as broader, regional effects. This is important as only with the implementation of coordinated, consistent and coherent policies across regions and watersheds of the Mediterranean, basin-wide challenges such as its impoverished water cycle, might be addressed. Related to this, we argue that before focusing on local scales, it is important to consider the wider (i.e. regional) context wherein rural adaptation actions will be implemented.

In addition to the four types of LUC practices here identified that have unfavourable effects on the environment (i.e. Regular fires and deforestation; Farming and cropping activities; Overgrazing and upstream pastoralism; Hydraulic terraces and aquifers), we also identified sustainable land management practices aimed at rural adaptation. For example, the presence of multifunctional landscapes, which are a mix of sylvopastoral and crop systems that allow the land for a better distribution of nutrients and water use, common since the early-Holocene (Mercuri et al., 2019). These findings highlight the importance of learning from historical practices in order to inform rural adaptation strategies that intend to limit environmental degradation and promote climate change adaptation. From this perspective, learning from past land use practices and subsequently knowing what to avoid and/or promote, could serve as an important tool for managing the rural landscapes of the Basin in a sustainable way (e.g. future policies and programs could learn from past LUC practices aimed at decreasing pressures on freshwater resources and conserving the cultural mosaic-like landscape of the Basin).

3.4 Conclusions and connection

Historical LUCs and mismanagement practices carried out within the Mediterranean Basin have **promoted desertification and landscape degradation,** contributed to climate variability through feedback reinforcement, and **further aggravated climate change**. With this study, thus, it is possible to accomplish **Objective 2**, which aimed at understanding how topographic rainfall might have been reduced through LUCs.

Among all, **the most significant LUC practice fostering desertification and rainfall inhibition is deforestation** aimed at land opening for framing and cropping, which **can be traced back to the early-Holocene.** Deforestation is found to have **modified the hydrological system of the Basin** in several ways: (1) limiting groundwater flow by eliminating deep rooting infiltration, causing soil aridification; (2) enhancing surface runoff by limiting infiltration, causing soil erosion; (3) halting evapotranspiration by slashing canopy, causing a reduction of the available moisture necessary to further induce topographic rainfall.

By understanding these basic relationships, future decisions on land use can consider a more holistic perspective, one that takes into account the effects of LUC beyond the local scale, tackling both, specific local needs and broader challenges of the Basin. In this line, promoting SLM practices aimed at the recovery of precipitation via evapotranspiration and the preservation of traditional mosaic systems (Chapter 4) are two strategies that assist to naturally restore the Mediterranean's impoverished hydrological system (Chapter 2) while dampening the accumulated LUC effects over millennia in the Basin that lead to land degradation and desertification (Chapter 3).

4. Sustainable Land Management (SLM) practices

Besides land use change altering the environment of the Mediterranean Basin, poor land management practices and traditional agricultural systems have been put forward to explain the region's desertification and land degradation trend (Vanwalleghem et al., 2016 and references therein), as the Mediterranean coastline was once fully vegetated and rich in marshes and lagoons that contributed to the local water cycle (Pausas and Millán, 2019).

This chapter identifies the potentials of a variety of Sustainable Land Management (SLM) practices to increase climate change resilience in rural areas while addressing current landscape degradation issues such as extended droughts and the abandonment of traditional land-use systems.

The aim of doing so is to achieve **Objective 3, focused to identify SLM practices that can better assist in restoring the water cycle, in particular rainfall triggered by topographic features.** To this objective, and given the results from Chapter 2, we will likewise highlight those **SLM practices that assist in preserving the Mediterranean's traditional mosaic system.** Moreover, and to **explore the viability of adopting such practices, which is Objective 4,** we will assess possible co-benefits and trade-offs associated with the implementation of the selected SLM choices.

For this purpose, we use the World Overview of Conservation Approaches and Technologies (WOCAT) database to test a novel framework that evaluates SLM practices carried out in the Mediterranean Basin in three steps: i) classify all impacts assessed by the WOCAT into nine variables and group similar practices, making them flexible enough to be applicable Basin-wide (Section 4.1); ii) based on the assessments collected by the WOCAT, evaluate their level of on-ground success (Section 4.2); iii) explore the potential barriers and opportunities for their implementation (Section 4.3).

The rationale behind choosing SLM practices for combating current hydrological treats in the rural Mediterranean Basin is that scientific evidence unveils these as successful tools for increasing resilience of societies and ecosystems, by integrating both their needs and values. Thus, SLM practices represent a holistic approach to achieving long-term productive ecosystems at low-income efforts (Sanz et al., 2017) while dampening the accumulated effects of land use changes over the last millennia.

Sustainable Land Management was defined in 1992 by the UN Earth Summit as "*the use of land resources, including soils, water, animals and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions*". SLM practices can be designed as adaptation actions at the local scale that address land desertification and degradation, prevent loss of biodiversity, and assist overcoming water scarcity in land managed systems.

4.1 Framework development

4.1.1 Data collection

With the aim of identifying SLM actions that, beyond the local scale assist to address current landscape degradation issues in the broader Mediterranean Basin, we use the WOCAT network[10] (WOCAT, 1992). The WOCAT network has an openly available database of standardized and integrated assessment protocols oriented to holistically assess the impacts of land management practices, i.e. identify their ecological, socioeconomic, and sociocultural effects at the site. This network gives the opportunity to practitioners (i.e. project implementers, decision-makers, researchers, etc.) that they call experts, to share their SLM initiatives by providing field-tested data and documentation, allowing for SLM mainstreaming. The WOCAT database is accredited and internationally standardized by the United Nations Convention to Combat Desertification (UNCCD).

We collect all SLM practices that have been implemented within the Mediterranean Basin up to the year 2018, resulting in a total of 104 practices (Table 4.2) spread along the Mediterranean coast in Portugal (N=7), Spain (N=29), France (N=1), Italy (N=7), Greece (N=13), Turkey (N=5), Syria Arab Republic (N=5), Egypt (N=1), Tunisia (N=7), and Morocco (N=29). Each practice includes information of its authorship, date, location, technical specifications, etc. and a series of indicators that specify the impacts that it exhorts on the environment, called *ecological and off-site impacts*, and on society, called *socio-economic* and *socio-cultural impacts*.

[10] https://www.wocat.net/en/

From the 104 practices, we gather information on all the assessed *ecological* and *off-site impacts* and all *socio-economic* and *socio-cultural impacts*, with a total of 109 different impacts (Table 4.3 and Box 4.1). The experts implementing each SLM practice assigned a number from -3 to 3 (i.e. 7 possibilities) to the impacts related to the practice, among all the ones provided by the WOCAT assessment. Based on these, we evaluate the level of success of each SLM practice. Additionally, each SLM practice provides information on the geo-climatic characteristics of the site of implementation, called *natural environment variables*. We likewise gather these variables and together with information from the GAEZ v3.0–Global Agro-Ecological Zones portal (GAEZ, 2012), use them to display potential areas of SLM implementation within the Mediterranean Basin. Figure 4.1 shows a diagram of the developed framework.

Box 4.1. Description of the used terminology

- Practices: sustainable land management actions
- Impacts: consequences of each practice on different evaluated aspects by the WOCAT
- Natural environmental variable: information on the geographical and climatic characteristics where a practice has been implemented by the WOCAT
- Ecological & Social variables: grouping of impacts

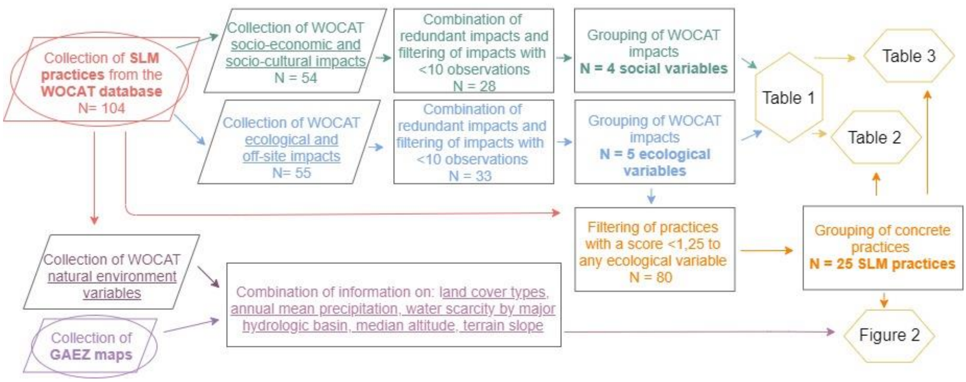


Figure 4.1. Diagram of the followed methodology for the construction of the multi-objective assessment of SLM practices. Oval shapes correspond to starting points, parallelograms to input data, rectangles to processes, and hexagons to results.

4.1.2 Selection criteria for the WOCAT impacts

To evaluate the performance of the different SLM practices, we consider four scenarios taking into account the possibility of filtering some redundant, very specific, and/or less salient data (Annex-A1):

- Scenario 1: no filtering of practices and/or impacts. All selected 104 practices and all resulting 109 assessed impacts (i.e. N=55+54) are considered. The rationale behind this consideration is that although a specific practice might not give information about many impacts, the ones being assessed might be very highly scored. Therefore, a practice that is very directed to a specific aim, might be implemented together with other very specific aimed practices. Likewise, impacts with few of observations are considered in this scenario, as these observations might be highly scored;
- Scenario 2: no filtering of practices and filtering of impacts. All the selected 104 practices are considered, while some impacts are aggregated to avoid redundancies (e.g. soil loss/erosion: soil loss; soil erosion; wind erosion). Results of the aggregated impacts are averaged throughout the aggregation process. After the combination of the impacts, we filter further those that have less than 10 observations. With this process, we reduce the number of impacts from 109 to 61 (i.e. N=28+33);
- Scenario 3: filtering of practices and no filtering of impacts. All original impacts are considered. Instead, those SLM practices that do not assist with an averaged >1.25 (from the -3 to 3 expert evaluation) to each ecological variable, are excluded. Through this process, we reduce the amount of practices from 104 to 80;
- Scenario 4: filtering of practices and of impacts. This scenario takes into account both the reduction in number of SLM practices, and the aggregation and filtering of impacts.

To determine which of the above scenarios best captures all information of the assessed impacts and allows for a robust comparison of the practices, we conducted a descriptive statistics of the four resulting datasets. Results of the statistical analysis (Table 4.1) show that mean values and standard deviation values are best for Scenarios 3 and 4, with Scenario 4 as the best in terms of means in three of the five services (see below). Since no information is lost with the filtering and grouping, we base our discussion on results from Scenario 4.

Because grouping similar but specific data offers more flexibility and allows us to extract context-generalized results that are more likely to be applied Basin-wide, we group all impacts into five overall ecological variables and four social variables (Table 4.3), and further cluster similar but concrete practices (e.g. 'afforestation with *Pinus halepensis'* and 'afforestation with *Ceratonia siliqua'* to 'afforestation', see Table 4.2). The grouping of the practices is done following Sanz et al. (2017), which, like the WOCAT database, is under the framework of the UNCCD. A definition for each variable and each group of practices can be found in Tables 4.2 and 4.3.

Table 4.1. Summary of all extracted descriptive statistic of each scenario.

Scenario 1				
Climate regulation	**Biodiversity […]**	**Soil quality**	**Soil erosion control**	**Water regulation**
N:20	N:48	N:33	N:9	N:20
Mean: 1.51	Mean: 1.32	Mean: 1.43	Mean: 1.5	Mean: 1.23
Sd: 0.87	Sd: 1.06	Sd: 0.95	Sd: 1.02	Sd: 0.91
Scenario 2				
Climate regulation	**Biodiversity […]**	**Soil quality**	**Soil erosion control**	**Water regulation**
N:24	N:48	N:34	N:9	N:20
Mean: 1.49	Mean: 1.32	Mean: 1.41	Mean: 1.54	Mean: 1.24
Sd: 0.88	Sd: 1.06	Sd: 0.93	Sd: 1.05	Sd: 0.91
Scenario 3				
Climate regulation	**Biodiversity […]**	**Soil quality**	**Soil erosion control**	**Water regulation**
N:12	N:34	N:20	N:5	N:13
Mean: 1.76	Mean: 1.59	Mean: 1.63	Mean: 1.79	Mean: 1.45
Sd: 0.73	Sd: 0.91	Sd: 0.86	Sd: 1.00	Sd: 0.83
Scenario 4				
Climate regulation	**Biodiversity […]**	**Soil quality**	**Soil erosion control**	**Water regulation**
N:15	N:34	N:21	N:5	N:13
Mean: 1.74	Mean: 1.59	Mean: 1.62	Mean: 1.80	Mean: 1.46
Sd: 0.74	Sd: 0.91	Sd: 0.84	Sd: 1.00	Sd: 0.83

Table 4.2. Cluster of the practices together with their definitions. Numbers correspond to the 104 SLM practices from the WOCAT database.

Afforestation / 'Land reclamation by introducing native forest species' in the UNCCD report: Native trees, shrubs and grasses planted through participatory action	
13	Afforestation with Pinus Halepensis after the fire of 1979
56	Grazing land afforestation with Ceratonia siliqua (carob trees) in the Mediterranean
104	Reboisement
Reforestation / 'Reforestation in former forest lands' in the UNCCD report : Establishment of new forest areas in formerly (less than 50 years according to UNFCCC, 2002) deforested lands	
28	Natural revegetation
72	Area closure and reforestation with Acacia
89	Assisted cork oak regeneration
Control of wildfires: Forest fire control comprises three activity components: prevent forest fire from occurring; extinguish forest fires rapidly while they are still small; use fire only for certain purposes and on a limited scale	
17	Prescribed fire
33	Prescribed fire
38	Selective cutting
3	Selective forest clearing to prevent large forest fires
41	Unvegetated strips to reduce fire expansion
21	Selective clearing and planting to promote shrubland fire resilience
32	Post-fire salvage logging; post-fire traditional logging
Eco-graze: An ecologically sound and practical grazing management system, based on rotation, wet season resting and getting the right balance between stock numbers and the forage resource	
40	Controlled grazing in deciduous woods as an alternative to grazing on rangeland
58	Rotational Grazing
69	Rangelands resting: Stopping grazing for pre-established periods of time
Application of organic fertilizers and biological agents: Organic fertilizers (compost; straw pen manure with litter or household waste) or green manure to enhance productivity by improving the structure and fertility of the soil, as well as its capacity for infiltration and water retention. It stimulates biological activity in the soil and increases yields and production	
10	Organic amendment located in dripper point in organic citrus production
23	Annual green manure with Phacelia tanacetifolia in southern Spain
22	Ecological production of almonds and olives using green manure
15	Application of 'Preparation 500' in agricultural soils under a biodynamic management
80	Fumier
46	Application of biological agents to increase crop resistance to salinity

No-till technology: Growing crops (or pastures) without disturbing the soil through tillage, direct seeding/planting	
50	Olive groves under no-tillage operations
55	No tillage operations, plastic nets permanently on the soil surface
76	No-till technology
Green covers in perennial woody crops: Growing perennial grasses in the strips between the main crop to provide permanent soil cover	
2	Cover crops in organic vineyard
6	Cover crops on olive orchards
Vegetated earth-banked terraces: Earth-banked terraces are constructed by carefully removing a superficial soil layer from one part of a field, concentrating it on the lower end of that field in order to reduce slope gradient and length. Another terrace is created directly downslope to form a cascade of terraces	
8	Vegetated earth-banked terraces
53	Land terracing in olive groves
97	Terrasse
Water harvest with micro-catchments: Water harvesting system collecting the runoff from hillslopes and the rainfall through micro-depressions within a field	
11	Aserpiado
71	Jessour
74	Tabia
64	Furrow-enhanced runoff harvesting for olives
Micro-irrigation systems: Drip irrigation - delivering small amounts of water directly to the plants through pipes.	
52	Application of water by drip irrigation
61	Drip irrigation
83	Récupération d'eau de pluie dans les plantations arboricoles avec irrigation en goutte à goutte par des buttes en terre
Recharge of groundwater: water collection to enable off-season irrigation: Storage efficiency in off-seasons a water management practice in which water is applied in advance of the growing season	
47	Integrated water-harvesting and livestock water-point system
57	Rainwater harvesting for greenhouse irrigation
49	Transport of freshwater from local streams
73	Recharge well
75	Cistern
81	Citerne
Water harvesting from concentrated runoff for irrigation purposes: Water harvesting systems, collecting the runoff from hillslopes, can be found at regular distances to supply water points	

37 Construction en pierres sèches
70 Gabion check dam
62 Woven Wood Fences
103 Seuils en gabion

Area closure to grazing: Area closure is a land management practice aiming to address severe soil degradation, loss of vegetation cover and low water holding capacity of degraded lands by rehabilitating and restoring the natural resource bases (soil, vegetation and soil water) and enhancing the productive and environmental functions through community consultation and collective actions

44 Metallic fences to prevent damages to pastures from wild boars
85 Interdiction provisoire d'accès du cheptel aux peuplements d'arganier
87 Période de fermeture du pâturage de l'almou collectif servant aux équins

Establishment of protected forest areas: Establishment of protected forest areas, such as natural and national parks. Protecting forest in reserves, and controlling other anthropogenic disturbances.

77 Réhabilitation par mise en défens
78 Gestion des parcours sans coupe ni ébranchage des arbres

Agro-forestal systems / 'Plantation crop combinations, multipurpose trees on crop lands' in the UNCCD report: Agroforestry is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as agricultural crops and/or animals, in some form of spatial arragament or temporal sequence

82 Parcelle agro-forestière à base de plantation d'arbres fruitiers et forestièrs
94 Jardins en agroforesterie irrigués par des seguia
100 Banquettes en terre combinées avec de l'Agroforesterie
88 Plantation d'arbres fruitiers avec mesures de contrôle de l'érosion

Soil / stone bunds: Soil / stone bund is an embankment of soil/stone constructed across the slope following the contour

63 Semi-circle bunds
65 Stone Wall Bench Terraces

Multi-specific plantation: Plantation of native woody species on degraded ravines and gullies to control erosion, mitigate landscape degradation, prevent flooding and restoring the diversity and cover of vegetation

29 Multi-specific plantation of semiarid woody species on slopes
20 Multi-specific plantation

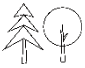
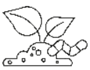
Reduced tillage: Reducing tillage intensity to allow the establishment of a native plant cover in annual and perennial woody crops under semiarid conditions

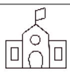
4 Reduced contour tillage of cereals in semi-arid environments
9 Reduced tillage of almonds and olives
30 Minimum tillage in Mediterranean vineyards

95	Labour minimum couplé à la mise en défens partielle des chaumes
Application of chemical fertilizers: Application of chemicals to the soil to increase yields and production	
12	Fitoestabilización de suelos contaminados
7	Adición de enmiendas a suelos contaminados
68	Calcareous soils management
Mulching in croplands and forestlands: In croplands, mulching involves spreading waste crop after harvesting. Covering the soil with mulch protects it against wind and water erosion and provides nutrients which has a positive effect on yields and food security. In forestlands, and after forest fires, slash mulch is spread immediately after a wildfire in order to prevent soil erosion and reduce overland flow	
34	Post-fire Forest Residue Mulch
36	Post-fire Natural Mulching
24	Organic mulch under almond trees
31	Hydromulching for reducing runoff and soil erosion
Crop rotation / intercropping: Crop rotation is an agronomic practice that consists in the successive cultivation of different crops in a specified order on the same fields, in contrast to a one-crop system or to haphazard crop successions. Intercropping consists on growing two or more crops on the same land simultaneously in a given growing season	
54	Crop rotation for green manuring in greenhouse
90	Crop rotation: cereals / fodder legumes (lupin)
96	Olive tree plantations with intercropping
Fodder crop production and maintenance: Production of fodder crops every year both for feeding livestock and increasing soil fertility, including pruning forage trees to allow their regeneration	
102	Taille de frêne dimorphe (Fraxinus dimorpha) en têtard pour l'utilisation comme fourrage
59	Fodder Crop Production
Strips and tree farming against soil erosion: Plantation of strips and trees to prevent from wind and surface runoff erosion	
60	Strip farming
84	Gully control by plantation of Atriplex
No grouped practices	
93	**Silvopastoral plantations**: Fodder shrubs are planted on the same land-management units as animals, in some form of spatial arrangement or temporal sequence
66	**Range Pitting and Reseeding**: This technique is used to restore degraded rangelands (steppe areas) and it is based on the pitting technique that uses the 'Camel Pitter' implement

Likewise, we group all impacts into five overall ecological variables and four social variables. The definition of each variable can be found in Table 4.3. Grouping similar but data allows us to extract context-generalized results that are more likely to be applied Basin-wise.

Table 4.3. WOCAT ecological impacts (in blue), off-site impacts (in violet), and socio-economic and socio-cultural impacts (in green) grouped under five ecological variables (top) and four social variables (bottom). A definition for each variable is provided.

ECOLOGICAL VARIABLES	
 **Climate regulation:** variable that assists in tackling extreme events, mitigating climate change, and regulating the micro-climate	
SOC/below ground carbon	Emissions of carbon and greenhouse gases
Biomass/above ground carbon	Fire risk
	Downstreaming flooding
 **Soil erosion control:** variable that assists in preventing and/or controlling soil loss by land degradation, wind and water erosion	
Soil cover	Buffering/filtering capacity
Soil loss/erosion	Wind transported sediments
Surface runoff	Damage on neighbour's fields
Excess water drainage	Damage on pubic/private infrastructures
Wind velocity	
 **Biodiversity enhancement and pest/disease control:** variable that assists in protecting and preserving ecosystems and their primary functions by promoting diversity and preventing pests	
Animal diversity	Habitat diversity
Plant diversity	Pest/disease control
Beneficial species	
 **Water regulation:** variable that assists in providing water quality and continuous availability by halting overexploitation and contamination while enhancing soil moisture	
Water quality	Harvesting/collection of water
Water quantity	Water availability
Groundwater table/aquifer	Downstream flow
Evaporation	Groundwater/river pollution
Soil moisture	
 **Soil quality enhancement:** variable that assists in enhancing soil fertility and soil structure by increasing its nutrient content and reducing hard-setting characteristics	
Soil crusting/sealing	Salinity
Soil compaction	Downstream siltation
Nutrient cycling/recharge	

SOCIAL VARIABLES	
 **Economy and production:** variable that includes impacts related to income and expenses, and production area, amount and quality	
Crop production	Fodder production
Crop and forest quality	Animal production
Wood production	Product diversity
Risk of production failure	Expenses on agricultural inputs
Farm income	Energy generation
Production area	Fodder quality
Diversity of income sources	
 **Management and irrigation:** variable that includes impacts related to water demand and availability, land management and workload	
Irrigation water availability	Demand for irrigation water
Drinking water availability	Workload
Land management	
 **Human well-being:** variable that includes impacts related to social services such as health care, culture, education, or food that improve living conditions	
Health situation	Improved livehoods and human well-being
Cultural opportunities	Food security/Self-sufficiency
Recreational opportunities	SLM/land degradation knowledge
Conflict mitigation	Situation of disadvantaged groups
 **Institutions:** variable that includes impacts related to both, community and national institutions	
Community institutions	National institutions

4.1.3 Evaluation of the practices

On the one hand, we use the assessment of ecological and off-site impacts to evaluate the level of on-ground success of each SLM practice and provide an appraisal of their effectiveness in a comparable way (Section 4.2). On the other hand, we use the assessment of socio-economic and socio-cultural impacts to explore possible economic, social, and/or technological barriers for the selected SLM practices (Section 4.3).

To evaluate the level of on-ground success of each SLM practice (i.e. ecological variables) and to explore possible economic, social and/or technological barriers of implementation (i.e. social variables), we firstly collect the numbers (from -3 to 3) that the experts who implemented each SLM practice assigned to each of the impacts. Then, we compute the averaged performance of each practice in each of the five ecological variables (Section 4.2) and four social variables (Section 4.3). The average performance of each practice is calculated by aggregating all the impacts under each of the variables.

Results can be found in Tables 4.5 and 4.6, where the standard deviation and percentage of observations are also available.

We emplaced three criteria for the selection of the best practices. First, we considered a score of >1.8 (from -3 to3) as the lowest threshold to label a SLM practice as successful. We agreed on 1.8 because it allows a significant number of SLM practices to be considered without a strict restriction of the results. Moreover, the value 1.8 represents a higher score than the average of most variables (i.e. Climate regulation= 1.73; Biodiversity enhancement and pest/disease control= 1.49; Soil quality= 1.71; Soil erosion control=1.88; Water regulation= 1.68). Second, beyond scoring >1.8, the scores had to present <1 of standard deviation. Third, to ensure further consistency, the number of assessed impacts, here called observations, had to be >40%. That is, we only consider as best practices those that beyond scoring >1.8 with a <1 of standard deviation were evaluated for at least 40% of the impacts grouped under each variable. Because the experts implementing each SLM practice only filled out the impacts that they considered appropriate or related to the practice and not all the impacts provided by the WOCAT assessment (here N=109), it happens that some SLM practices offer a total of <40% of observations for a variable. These SLM practices were, thus, not considered due to lack of robustness. We chose a threshold of 40% to ensure that the consideration of practices was not too restricted by the number of observations, yet was higher than the average (i.e. Climate regulation = 27%; Biodiversity enhancement and pest/disease control = 31%; Soil quality = 30%; Soil erosion control = 32%; Water regulation = 40%).

4.1.4 Construction of maps

The assessed natural environment variables gathered by the WOCAT display information on the geographical and climatic characteristics of each practice's location. We cross this information with five map layers (i.e. land-use, average annual rainfall, available surface water, altitude, and slope) from the GAEZ v3.0–Global Agro-Ecological Zones portal[11] (GAEZ, 2012) with a maintained scale resolution of 30 arc-seconds, i.e.~1 km^2 (Fischer et al., 2008).

For the land use layer, we cross the information of the six land cover types from the WOCAT database and the data from the five land cover types from the GAEZ portal

[11] http://www.fao.org/nr/gaez/en/

(Table 4.4). To allocate the different pixels of our maps to a particular land use, we consider that any pixel with an area ≥30% intended for a particular land use is allocated to that land use. For instance, in a particular pixel, if the forest area is ≥30% then the pixel is considered forestland. Following this reasoning, one pixel might, therefore, be considered in more than one land uses if these cover an area ≥30%, or to none if all land uses occupy an area <30% of the pixel. We have created a layer called mixedland and assigned to that layer those pixels with an area of ≥30% of a combination of cropland, forestland, and/or grassland. Thus, if, for example, both forestland and cropland cover an area ≥30% respectively, the pixel is considered as mixedland. This layer has been created because multiple SLM practices can be effectively applied in a combination of two or all three types of land.

For the rainfall layer we use the annual mean precipitation (mm) data, which represents the average annual precipitation for the 1961−1990 time span. For the available surface water layer, we apply the water scarcity by major hydrologic basin map. Note, however, that while SLM practices offer on-site local information about water availability, the maps plotted here contain averaged data for a whole major basin, as defined by GAEZ. For the altitude and slope layers, we use the median altitude (m a.s.l.) and terrain slope (%) from 0 to >30% maps, respectively. Lastly, for the plotting or our maps, we generate two super-imposed maps for each practice, one in light brown with the three first layers that contain the restrictive characteristics of SLM practices implementation (i.e. land-use, rainfall, water availability), and a second in green with the two other layers that contain optimum characteristics of the landscape (i.e. altitude and slope).

Table 4.4. Crossed information used from the WOCAT database the GAEZ portal to plot the natural environment of the 25 SLM practices.

GAEZ classification	WOCAT classification	This study
Land use		
Total cultivated land	Woody; herbaceous cropland rain-fed/irrigated	Cropland
Forestland	Forestland	Forestland
Grassland & woodland	Grazingland	Grazingland
Barrenland sparsely vegetated land	-	
Built-up land	Settlement	Built-up land
-	Mixedland	Mixedland

Rainfall (mm/yr)		
no relation has been needed		
Available surface water layer		
Very high	Excess	Very high
High	Good	High
Moderate	Medium	Moderate
Low	Poor/none	Low
Altitude (m a.s.l.)		
no relation has been needed		
Slope (%)		
0−2	Flat (0−2)	0−2
2−5	Gentle (3−5)	3−5
5−8	Moderate (6−10)	6−10
8-16	Rolling (11−15)	11−15
16−30	Hilly (16−30)	16−30
30−45	Steep (31−60)	>31
>45	Very steep (>60)	

4.2 Most ground efficient practices

Among the whole array of SLM practices the two performing overall best (i.e. score >1.8 with <1 standard deviation and >40% of observations) correspond to practices promoting green cover in perennial woodlands (i.e. vineyards, olive and almond fields) and agro-forestal systems. However, for each ecological variable different SLM practices appear as best choices. For example, when intending to implement SLM actions in line with soil erosion control, reforestation and green cover in perennial woodlands stand out as best practices.

In the remainder of this section, we discuss green cover in perennial woodlands and agroforestry as the best overall SLM practices (Table 4.5), which besides addressing local and specific needs, assist in tackling Basin-wide challenges, such its impoverished hydrological cycle and the loss of the multifunctionality of its landscape.

Green cover in perennial woodlands is a practice that consists of establishing *“perennial grasses in orchards and vineyards between rows to provide permanent soil cover”* (Sanz et al., 2017). Agroforestry *“is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as agricultural crops and/or* *animals, in some form of spatial arrangement or temporal sequence"* (Sanz et al., 2017).

On the one hand, green cover in perennial woodlands not only prevents soil erosion by wind and surface water but enhances soil quality by nutrient and water storage (Almagro et al., 2016), helps promote biodiversity (Plaza-Bonilla et al., 2015), and strengthens the capacity of vegetation to address climate change mitigation and adaptation by enhancing SOC and regulating the micro-climate (Vicente-Vicente et al., 2016). Caution however, needs to be taken when choosing the species of cover to avoid competition for water resources with the perennial woodland (Celette et al., 2008). Green cover in perennial woodlands, moreover, robustly contributes to all five ecological variables, is supported at the local level by practitioners and rural development programmes (World Bank, 2006) and has a large application potential due to the extensive geographical area of woody croplands within the Mediterranean Basin.

On the other hand, agroforestry practices promote soil quality by permanent cover and the natural introduction of organic amendments (Cabrera et al., 2014); dampen runoff velocities and sediment transport through terracing, enhances soil stabilization and crop production (Mosquera-Losada et al., 2012); fosters animal and plant diversity together with natural management of the landscape (Enne et al., 2004; Mbow et al., 2014); and they also induce pleasant and better regulated micro-climates through tree cover and gravity irrigation systems. Agroforestry hence, also robustly contributes to all five assessed services.

These two practices can be implemented on their own or can be easily combined to promote synergies in all five assessed environmental variables. In particular, if we are to promote SLM practices that help mitigate climate change and better adapt to it by regulating the hydrological system of the Basin and promoting its multifunctional landscape, these two choices offer several benefits.

To help mitigate climate change, both practices contribute to carbon sequestration and stock. Between the two, however, agro-forestry soils are more efficient in capturing C, with a calculated global mitigation potential of 0.11−5.68 $GtCO_2$ -eq yr^{-1} between 2020 and 2050 (Jia et al., 2019 Figure 2.24 and references therein). In comparison, cover crops are estimated to have a technical potential of 0.32±0.08 tCO_2 ha^{-1} yr^{-1} (Poeplau and Don, 2015), which needs to be jointly accounted for with the mitigation potential of croplands themselves, i.e. 0.25−0.78 $GtCO_2$ -eq yr^{-1} (Jia et

Table 4.5. Evaluation of the most ground efficient practices. The symbol – is used to indicate no data.

Ecological variables → / Sustainable Land Management (SLM) practices ↓	Climate regulation	standard deviation	% observations	Biodiversity enhancement & pest/disease	standard deviation	% observations	Soil quality	standard deviation	% observations	Soil erosion control	standard deviation	% observations	Water regulation	standard deviation	% observations	Overall	standard deviation	% observations
Afforestation	1.52	0.7	73	1.12	1.3	60	1.63	0.3	53	1.53	0.2	56	1.63	0.7	70	1.48	0.7	63
Reforestation	2.33	0.5	20	1.67	2.3	27	2.25	0.4	27	2.22	0.8	41	2.25	0.4	37	2.14	0.9	30
Control of wildfires	1.70	1.1	40	1.53	0.4	29	0.17	1.5	29	0.55	1.3	22	0.45	1.3	40	0.88	1.1	32
Eco-graze	2.00	0.0	20	1.00	0.7	33	2.00	–	–	1.92	0.1	30	2.17	0.3	26	1.82	0.3	27
Application of organic fertilizers [...]	2.13	0.3	23	2.42	0.4	23	1.83	0.8	43	2.35	0.4	20	1.44	1.1	22	2.03	0.6	27
No-till technology	2.78	0.4	27	–	–	0	2.50	0.0	20	2.33	0.3	22	2.22	0.4	37	2.46	0.3	21
Green cover in perennial woody crops	1.88	1.6	40	1.80	–	30	2.25	0.4	60	2.61	0.2	44	0.75	1.1	67	**1.86**	0.8	48
Vegetated earth-banked terraces	1.17	0.2	27	1.00	0.0	33	3.00	–	20	2.17	0.3	30	1.56	0.8	44	1.78	0.3	31
Water harvest with microcatchments	1.33	0.6	5	1.50	–	45	1.33	0.6	5	2.33	0.8	31	1.42	0.5	33	1.58	0.6	24
Micro-irrigation systems	1.50	2.1	7	–	–	7	1.00	1.4	13	2.50	0.7	26	2.19	0.7	26	1.80	1.2	16
Recharge of groundwater [...]	1.67	0.6	7	–	–	13	2.67	0.6	10	-0.25	1.3	17	1.83	0.7	28	1.48	0.8	15
Water harvesting [...]	1.88	1.6	15	0.25	–	35	1.44	0.5	20	2.13	1.0	31	1.44	1.2	33	1.43	1.1	27
Area closure to grazing	1.67	0.6	27	1.50	–	7	2.00	–	7	2.08	0.9	15	–	–	15	1.81	0.7	14
Establishment of protected forest areas	2.00	0.0	30	2.33	–	20	2.00	–	20	1.83	0.2	22	–	–	22	2.04	0.1	23
Agro-forestal systems	1.67	0.5	50	2.19	0.6	50	1.90	0.9	40	2.15	0.8	58	1.43	0.6	64	**1.87**	0.7	52
Soil / stone bunds	1.33	0.9	40	1.00	–	40	1.25	0.4	30	1.54	1.1	17	1.00	0.0	50	1.23	0.6	35
Multi-specific plantation	1.67	0.0	30	1.75	0.4	60	2.00	0.0	40	2.00	0.0	22	1.33	0.5	56	1.75	0.2	42
Reduced tillage	1.33	0.6	15	1.00	0.0	25	0.88	0.3	25	1.92	0.5	25	1.00	0.0	50	1.23	0.3	28
Application of chemical fertilizers	2.00	0.0	47	1.88	0.9	40	1.25	1.1	40	1.85	1.1	44	1.72	1.3	19	1.74	0.9	38
Mulching in croplands and forestlands	1.21	0.6	30	0.75	0.4	10	2.00	0.0	20	2.19	0.3	53	1.00	0.4	69	1.43	0.3	36
Crop rotation / intercropping	2.33	0.6	7	1.33	1.5	33	1.17	0.3	40	3.00	0.0	11	1.67	0.6	22	1.90	0.6	23
Fodder crop production and mantainance	1.33	–	10	1.33	–	40	1.00	–	40	1.58	0.1	33	0.40	–	44	1.13	0.1	34
Strips and tree farming against soil erosion	2.00	–	10	2.50	0.7	20	1.50	–	10	1.25	1.1	17	2.17	1.2	44	1.88	1.0	20
Silvopastoral plantations	1.00	2.5	60	1.00	2.3	60	1.67	0.6	60	1.00	1.2	80	1.00	1.3	60	1.13	1.6	64
Range pitting and reseeding	–	–	20	2.00	0.0	40	2.00	–	40	2.22	–	40	2.00	0.5	20	2.06	0.3	32

al., 2019 Figure 2.24 and references therein). Specifically, the average potential of the Mediterranean agro-forestal systems to sequester C ranged between 5−20 tC ha^{-1} for the year 2010 (Zomer et al., 2016), whereas green cover in Mediterranean perennial woodland crops is estimated to have a technical potential of increasing 1 tC ha^{-1} yr^{-1} (Vicente-Vicente et al., 2016). Bear in mind that these estimated potentials reflect a range of methodologies and, thus, may not be directly comparable yet provide an idea of the different magnitudes on their mitigation potential (see Jia et al., 2019 Figure 2.24).

To assist in regulating the hydrological system of the Basin (help adapting to climate change), by themselves, these two practices have the capacity to naturally store water and evapotransporate it, making it available again. With this process the hydrological cycle of the region is impacted in two main ways:

(1) Through increased infiltration. This relates to the concept of blue and green water that refers to the reduction of direct soil evaporation (blue water) whereby increased plant transpiration (green water) without reducing the amount of blue water. Soil water storage, for example, was measured to be higher under tree cover than outside the canopy, both in las Dehesas-Spain by Joffre and Rambal (1993) and in the Californian oak woodlands, of Mediterranean climate, by Moody and Jones (2000), although this situation might reverse during extended droughts (Moreno and Rolo, 2011). Moreover, if combined, the two SLM practices have the potential to further improve the water-use efficiency by distributing trees and plants in a heterogeneous way, promoting rooting and associated infiltration, retention, water access at different depths, i.e. shallow-lateral rooting plants and shrubs with deep rooting trees, and further boosting the Mediterranean mosaic-like landscape (Cubera and Moreno, 2007). Overall, minimizing water stress while maximizing biomass.

(2) Through a rise of atmospheric moisture led by evapotranspiration. Increased evapotranspiration decreases temperature (Mueller et al., 2016) and heat wave duration (Thiery et al., 2017) with potential to enhance topographic rainfall. Taking into account the crop coefficient approach from FAO to calculate crop evapotranspiration (ET_c), it can be approximated without calculations, that only by comparing the crop coefficient (K_c) of different Mediterranean fruit trees (K_c = ~0.4−0.7) with those of vegetables (K_c = ~0.7−1.05) and cereals (K_c = ~0.3−1.15), and knowing that the reference crop evapotranspiration (ET_o) is independent of crop type and management practice, ET_c is higher for croplands than for fruit-trees alone (Allen et al., 1998 chapter 6). In agro-forestal systems however, both the evapotranspiration rates of (fruit)-trees

and crops might be added up. At the same time, irrigation in croplands further raises evapotranspiration (e.g. Alter et al., 2015) and thus, if more efficiently managed (see Jägermeyr et al., 2016), irrigated cropland may contribute to adaptation and mitigation in this region. Crop coefficients for fruit trees with- and without-ground cover (i.e. green cover in perennial woodlands) have also been calculated (Allen et al., 1998 chapter 6). In this case, evapotranspiration of ground-covered orchards (K_c = ~0.5−0.9) is clearly higher than those without one (K_c = ~0.4−0.7). In any case however, both in croplands and agro-forestry systems, soil water content is higher than in open pasture due to larger infiltration and reduced evaporation, out-weighing water uptake by plants and canopy.

Among all SLM practices however, reforestation offers the highest mitigation potential with an estimated global 0.5−10.12 $GtCO_2$ -eq yr^{-1} between 2020 and 2050 (Jia et al., 2019 Figure 2.24 and references therein) and the highest capacity of groundwater recharge through deep rooting infiltration. The potential of temperate forests to increase topographic rainfall though evapotranspiration is nonetheless discussed (Bonan, 2008; Layton and Ellison, 2016). Despite the low number of observations that ensures the consistency of this practice (i.e. 30% in Table 4.5), the literature suggests that, if planned and managed, reforestation should be likewise considered as a good and mainstreamable choice to regulate the water cycle of the Mediterranean Basin while preserving its multifunctionality.

4.3 Barriers and Opportunities

Despite the scientific advances in understanding land degradation (e.g. Geist and Lambin, 2004; Mortimore et al., 2009; Reynolds et al., 2010) and the increasing promotion of SLM practices at the policy and cooperation level (Sanz et al., 2017; World Bank, 2006), land degradation further expands within the Mediterranean Basin, threatening its adaptation and mitigation capacities. This situation evidences the existing gap between the acknowledgment of the need to effectively adopt SLM practices and their actual implementation. Thus, in order to complete the evaluation of the most ground efficient practices with a more comprehensive and multi-objective assessment, we next assess possible barriers and opportunities associated with their implementation. Exploring the creation of enabling environments for SLM practices implementation is key to overcome potential issues that slow down their adoption. The

UNCCD report by Sanz et al. (2017) classifies these in four: ecological; technical; institutional; socio-economic and cultural.

4.3.1 Environmental barriers

Environmental barriers refer to the specific environmental conditions wherein a practice might be implemented and to the availability of land and water resources to adopt it, recognizing that these need to be balanced in the short and long term.

We evaluate this possible barrier by taking into account five of the natural environment variables that the experts from the WOCAT network provide to characterize each SLM practice in its geographic context: i.e. land use, average annual rainfall, available surface water, altitude, and slope. With this information, we generate a map for each of the 25 practices, highlighting all regions within the Basin that meet the baseline conditions wherein each practice has been previously implemented according to the WOCAT database (Annex-A2). Only the biophysical characteristics of reforestation, agro-forestal systems, and green cover in perennial woodlands are discussed, as according to our work, these are the SLM practices with a higher potential to mitigate climate change and regulate the hydrological system of the region.

Maps show that the practice most widely applicable in terms of biophysical restrictions is reforestation (Fig. 4.2-a), followed by agro-forestal systems (Fig. 4.2-b) and green cover in perennial woodlands (Fig. 4.2-c). Reforestation practices have been successfully adopted in arid to sub-humid environments with annual rainfalls within <250–750 mm/yr, with none-to-medium availability of surface water, from plains to steep slopes (3–60%), and between 100–1000 m altitude. Agro-forestal systems and green cover in perennial woodlands have been previously adopted in arid and semi-arid environments with annual rainfall between <250–500 mm/yr, with medium to limited surface water availability, from plains to steep slopes (3–60 %), and within 100–2000 m altitude conditions.

However, beyond these defined geo-climatic conditions, the three SLM practices have been historically applied in a wider range of environmental conditions, evidencing their further implementation potential. Reforestation, for example, has been successfully adopted in many Northern Mediterranean areas as a means to restore degraded lands (e.g. Bautista et al., 2010 and references therein; Valdecantos and et al., 2019), while green cover in perennial woodlands has been widely implemented across the whole Basin (Palese et al., 2014) and beyond, in the Mediterranean climate area of California, USA (Celette et al., 2008). Similarly, agroforestry systems have been extensively implemented in Northern Mediterranean areas (e.g. Enne et al., 2004; Rota and Sperrandini, 2009; Valdecantos and et al., 2019) and in North Africa and West Asia areas (e.g. Ben Salem and Nefzaoui, 1999; Enne et al., 2004), as well as in a 40,000 km^2 area called La Dehesa in central Spain.

These examples evidence that the representation of the potential area of implementation of the SLM practices is limited. Such limitation is due to the five considered variables and to the geo-climatic conditions where the different practices have been previously implemented under the WOCAT network. Therefore, it should be understood that the adoption of each practice is not restricted to these conditions but rather that the maps estimate their geographical potential within the Basin.

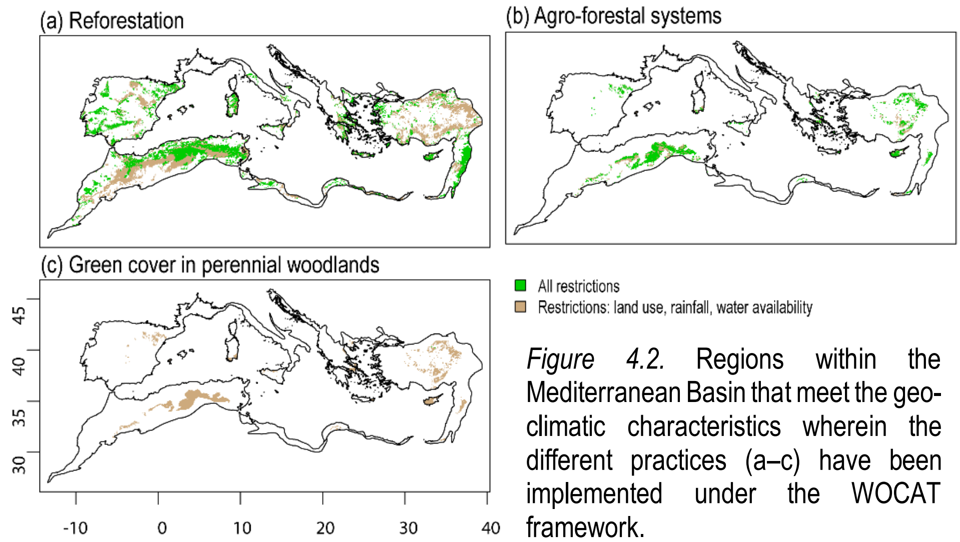


Figure 4.2. Regions within the Mediterranean Basin that meet the geo-climatic characteristics wherein the different practices (a–c) have been implemented under the WOCAT framework.

4.3.2 Technical, institutional, socio-economic and cultural barriers

As described by Sanz et al. (2017) technical barriers refer to the potential access to appropriate technologies, equipment or knowledge; institutional barriers refer to governance structures that aggravate or inhibit decision-making; and socio-economic and cultural barriers refer to the potential limits of public capability, acceptance and effective adoption of SLM practices.

We evaluate these possible barriers by inspecting the socio-economic and socio-cultural impacts provided by WOCAT for each practice, and shortly discuss reforestation, agro-forestal systems, and green cover in perennial woodlands. As explained in Figure 4.1, we generate Table 4.6, which helps in understanding the social framework wherein the different SLM choices might be implemented.

Table 4.6. Evaluation of the socio-economic and socio-cultural impacts. The symbol – is used to indicate no data.

Social variables → / Sustainable Land Management (SLM) practices ↓	Economy and production	Management and irrigation	Human well-being	Institutions	Overall
Afforestation	1.43	-0.33	1.33	0.00	0.61
Reforestation	1.63	-1.00	2.00	2.00	1.16
Control of wildfires	1.07	-0.25	1.11	2.00	0.98
Eco-graze	1.83	-2.00	1.58	1.50	0.73
Application of organic fertilizers [...]	1.31	0.92	1.68	3.00	1.73
No-till technology	2.25	0.67	1.33	2.00	1.56
Green cover in perennial woody crops	0.58	1.00	1.65	–	1.08
Vegetated earth-banked terraces	0.72	1.33	1.56	–	1.20
Water harvest with microcatchments	1.60	0.00	1.50	–	1.03
Micro-irrigation systems	1.17	1.11	0.94	–	1.07
Recharge of groundwater [...]	1.15	1.08	1.29	2.00	1.38
Water harvesting [...]	1.50	-0.67	0.81	0.00	0.41
Area closure to grazing	1.17	1.75	2.06	–	1.66
Establishment of protected forest areas	1.30	1.00	0.75	–	1.02
Agro-forestal systems	2.23	0.02	1.48	2.33	1.52
Soil / stone bunds	1.00	-0.50	2.17	0.00	0.67
Multi-specific plantation	–	–	1.00	–	1.00
Reduced tillage	0.44	1.33	1.33	–	1.04
Application of chemical fertilizers	0.56	0.00	0.58	2.50	0.91
Mulching in croplands and forestlands	-0.33	1.25	1.33	–	0.75
Crop rotation / intercropping	1.22	-0.25	1.33	–	0.77
Fodder crop production and mantainance	1.20	-2.00	0.50	–	-0.10
Strips and tree farming against soil erosion	1.90	2.00	2.00	1.00	1.73
Silviopastoral plantations	1.13	0.00	0.25	1.00	0.59
Range pitting and reseeding	2.00	–	2.00	–	2.00

Table 4.6 shows that to effectively implement SLM practices, on-ground proved efficiency and biophysical availability for adoption are necessary but incomplete conditions. Together with these, coordinated environmental policies (i.e. institutions), the recognition of socio-cultural characteristics (i.e. human well-being), and appropriate market access and management tools (i.e. economy and production, management and irrigation) need to be taken into account.

In this regard, reforestation and agroforestry can provide high benefits to the economy and human well-being, as these practices provide market products (e.g.

timber, mushrooms, honey, and cork) and have the potential to increase profitability through diversification of output (i.e. agroforestry), while also improving health and food security (Mosquera-Losada et al., 2012). Mediterranean forests, therefore, support agriculture and human well-being. However, in the first stage of their implementation, these practices may need of economic investment due to the delay between tree plantation and economic return, and they may challenge management and irrigation due to substantial water requirements and workload (Mbow et al., 2014). Afterward, both economic and water needs reverse due to the availability of market products and the canopy's capacity of increasing ecosystem services and naturally managing the landscape, respectively. Implementing these two practices more effectively may, thus, require initial investment and improvements of rain-fed systems and/or efficiencies of irrigated systems.

Green cover in perennial woody crops likewise positively impacts all four assessed variables, although this practice does not directly increase crop or fodder production. Nevertheless, it indirectly contributes to raising production by conserving the soil and maintaining its fertility, and by returning its cost of implementation (i.e. positive cost-benefit analysis). Moreover, like agro-forestal systems, these two practices establish key nodes across multiple sectors (i.e. climate change, food production, biodiversity, land degradation, etc.), facilitating the development of a coordinated framework for their implementation (Sanz et al., 2017).

All three practices benefit from land-user's traditional knowledge (Marques et al., 2016) and are supported by local-level capacities, especially agro-forestal systems and green cover in perennial woody crops (Plan Bleu, 2016). They prevent perpetuating vulnerabilities encountered in the different regions of the Mediterranean Basin as they are inexpensive and the spatial scale at which their success is demonstrated is broad. The three practices, moreover, integrate biodiversity and autochthonous species conservation, are flexible to accommodate new weather regimes, and thus, can adapt to climate change.

4.3.3 Opportunities

On the one hand, opportunities may stem from the fact that the different practices can be implemented in a set of very wide environmental conditions, with multiple benefits to the landscape, climate, and society. For this reason, SLM practices assist in restoring degraded lands, combating climate change, and alleviating poverty, contributing simultaneously to several Sustainable Development Goals. The adoption of such practices within the Mediterranean Basin can, hence, promote the recognition of the synergies these provide, boosting their acceptance while raising awareness about the different environmental issues among the public.

On the other hand, many opportunities can arise from the fact that implementing SLM needs from cross-sectoral collaboration. First, for the correct implementation and monitoring of SLM practices, both policy-makers and non-state actors need to work together. Through the establishment of cross-sectoral platforms that enable collaboration, the views of both groups can be gathered from the first involvement stage of SLM design and implementation, enhancing the capacity building of the different actors and bridging the existing gap between the two. Moreover, with this approach, the valuable yet often overlooked traditional knowledge and experience of the land-users is highlighted. Second, with the involvement of different actors, attention is paid to the social system where the practice will be implemented. This will provide information and tools on how to overcome technical, socio-economic, and cultural barriers by exposing different capacity-building measures and resources. Third, because SLM impacts multiple adaptation and mitigation sectors (i.e. water, land planning, energy, etc.), new funding sources for their promotion and implementation might arise.

4.4 Conclusions and connection

SLM practices cannot only strengthen the Basin's potential to mitigate and adapt to climate change but also to assist restoring degraded lands, stopping desertification, enhancing biodiversity, and improving the state of water resources, wetlands, and traditional landscapes. However, to develop coordinated and successful strategies across the Mediterranean region that steer efforts in the same direction, basin-scale assessments as the one developed here, are necessary.

Within this chapter, Objective 3 has been completed by compiling science-based cases that exhibit how SLM practices assist in restoring several elements of the Mediterranean landscape, overall improving its hydrological system. Furthermore, the viability of adopting different practices, which is Objective 4, has been inspected.

Although SLM practices can be easily combined to promote synergies, **agro-forestal systems represent on their own, a holistic approach** to strengthen climate change mitigation and adaptation capacities, combat desertification and achieve healthier, more productive and more diverse ecosystems (Chapters 2 and 3). **If combined**, the practices with a higher proven capacity (i.e. with consistent results) to assist the impoverished hydrological systems and to promote traditional mosaic systems are **agro-forestal systems together with green cover in perennial woodlands.** Another remarkable SLM practice to enhance and preserve the Mediterranean landscape and watershed while combating climate change is **reforestation**, yet this practice shows no consistent results in our evaluation. Overall, multifunctional land use is a promising strategy to reduce pressures on the environment, preserve the traditional agriculture, and develop the rural economy.

SLM choices should not only be based on integrated ecological methods of evaluation (Section 4.2) but also on biophysical and socio-economic ones (Section 4.3), as these, might either reveal potential synergies overlooked otherwise or compromise their success of implementation. Understanding these, are key to encourage land users to preserve agro-forestal systems and implement SLM measures that conserve soil and water (Chapter 5).

5. Facilitating effective strategies

The Mediterranean Basin represents a niche of opportunity to steer SLM efforts towards the common goal of managing its hydrological budget. However, the effective adoption of SLM practices crucially depends on the Climate Change Perception (CCP) of its society, that is, on the take of values and views into consideration. Despite the growing impetus of governments worldwide to implement local and regional measures (IPCC, 2018), the current understanding of CCP remains modest. Moreover, the spread of successful SLM practices adopted at the local scale is limited, even though SLM multidimensional benefits can reach larger scales (Marques et al., 2016).

Section 4.3 evidenced the gap between the acknowledgment of the need to effectively adopt SLM practices and SLM actual implementation. Here, this issue is the point of departure for this chapter, building on the opportunities that SLM implementation entails in facilitating the adoption of effective strategies. The aim to do so, it to answer **Objective 5, which seeks to understand the social and political framework in where the research can be implemented in order to extend the obtained results into policy recommendations of effective implementation.**

The rationale behind this chapter is twofold. First, to search for different leverage points with which to enhance SLM adoption as a vehicle to achieve climate change action against Mediterranean desertification, led by the rural communities. Second, to replicate successful SLM practices within the Basin by promoting coordinated action among policy-makers across the region.

To achieve them, we inspect on bottom-up and top-down strategies. For the bottom-up approach aimed at determining CCP effective drivers, we investigate mechanisms that rise social perception and awareness about climate change and associated environmental policies (Section 5.1). For the top-down approach aimed at steer policy efforts basin-wide, we explore capacity-building institutions that facilitate the adoption of SLM practices (Section 5.2).

5.1 Rising social climate change perception in rural areas

Public perception of climate change can either facilitate or hinder the implementation of SLM, climate action, and policies and thus, a better knowledge of the ways different socio-cultural groups perceive climate change is crucial for their effective adoption (Tesfahunegn, 2018). In this way, identifying a comprehensive array of CCP drivers and their pathways of action, should prove useful for decision-makers, to take better-informed decisions and formulate policies that are more in line with the stakeholder's perceptions, needs, and capabilities.

In this context, it is the objective of this sub-chapter, to reveal CCP drivers (direct leverage points) and their connections (indirect drivers or leverage points). For that: (1) we first identify and expose a comprehensive array of CCP driving mechanisms obtained from a systematic literature review that covers a wide array of research methods, scales, locations and communities. (2) Following this, we carry out a semi-structured analysis of the selected literature, with which to (3) quantify the strength of the identify drivers of CCP. (4) More importantly, and in the same way, we also identify and count interactions among drivers themselves using the FCM technique. Figure 5.1 schematically summarizes the followed methodology.

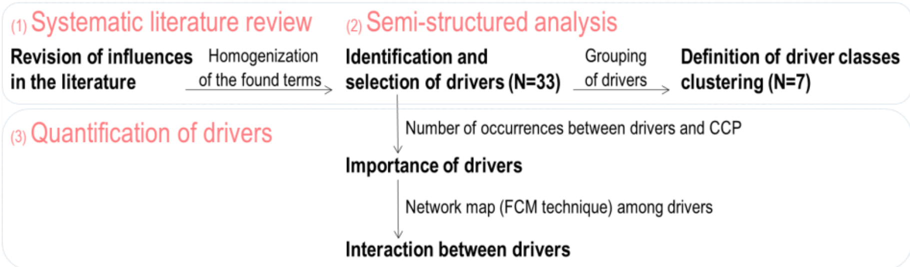


Figure 5.1. Schematic representation of the followed methodology for the identification and quantification of CCP drivers.

5.1.1 Systematic literature review

The starting point of this work is a literature search on the educational, cultural, and political variables that determine climate change opinion at the community level. Although some of the collected studies were originally performed at the level of individuals, we have treated their outcomes on the community level, with the aim of providing results relevant to policy makers and to the understanding of community needs. For this compilation, we executed a search in the Web of Science database using the search term: “climate change opinion”. The review revealed the term "opinion" with a variety of meanings, most often as a synonym to perception or awareness. For consistency purposes, we decided to adopt the term "perception" as a metonym for opinion, awareness and related terms. Therefore, we here define Climate Change Perception as a state of opinion and awareness of anthropogenic climate change, with anthropogenic climate change being defined as a persistent direct and indirect change added to the natural climate variability, largely attributed to carbon dioxide emissions.

We imposed no temporal, geographic, or methodological restrictions. Therefore, national and international data, peer-reviewed and grey literature, quantitative and qualitative studies were all considered. We selected studies in three stages. We conducted a first selection of 300 articles out of 2,214 titles with the condition that the terms “climate change” or “global warming” appeared in the title. In the second stage, we screened the abstracts of the 300 articles and shortlisted 184 that clearly related “climate change” with behaviour, opinion, perception or awareness. After examining if these works either identified many CCP drivers or analysed few CCP drivers in depth, 35 articles remained (see Annex-B1). In contrast to other recent multi-variable studies (van der Linden et al., 2017; Hornsey et al., 2016; Shi et al., 2016; Capstick et al., 2015; Lee et al., 2015), these 64 studies consider a wide spectrum of disciplinary perspectives by including meta-analyses, secondary analyses, social disclosures, and survey-based studies.

However, the literature search, which is not without limitations, is more inclined towards quantitative longitudinal surveys rather than in-depth community contextualized studies, due to data availability; and towards more developed countries than developing countries.

5.1.2 Semi-structured analysis

To perform the semi-structured analysis of the 64 studies, we started by collecting meta-information for each study, which included the date of publication, location of study, data provenance and type of study (Annex-B2). Controlling for the geographic area was important to test the effectiveness of the developed terminology on multiple scales (from small groups to large populations).

Across the studies we identified 132 key words that describe potential drivers. Subsequently, we reduced those 132 key words (potential drivers). To do so, we used three criteria: i) number of occurrences across studies, as larger numbers of occurrence indicate higher scientific consideration; ii) transferability across scales and sites, for the correct integration of studies of different nature; and iii) quantifiability. In order to ensure transferability between disciplines we developed a common terminology, that is, we proposed a definition for each of the final 33 drivers and grouped them into seven classes (Table 5.1).

In a first step we then examined each study for the presence of a positive, negative, and/or neutral influence of each of the 33 drivers onto CCP (Annex-B3). For example, the following sentence by Shi et al. (2016) was interpreted as a positive influence of Socio-altruistic values (ID:86) on CCP: *"…have been found to be important in the formation of perceptions regarding environmental risks: egoistic values, socio-altruistic values and biospheric values*", whereas this influence of Self-perceived knowledge (ID:71) on CC and CCP has been interpreted as neutral: "*In this work, general scientific knowledge appeared not to be a robust predictor of perceived climate change…*". Neutral here means that the study did analyse the connection but found no effect (observed no-effect). This is different to drivers not having been considered at all.

In a second step, and following the same methodology of positive, negative and neutral relations, we study the connections between drivers themselves (Annex-B4). An example of a positive connection between the driver Self-perceived knowledge on CC (ID:71) and Emotional concern about CC (ID:81) by Shi et al. (2016) is: "*knowledge about the causes of climate change was correlated with higher levels of concern about climate change in all countries*". With this information, we developed a network diagram and determined the centrality (strength of connectedness) of the drivers by use of Fuzzy Cognitive Mapping (FCM). We used the number of connections incident on one driver to compute its connectedness (so called degree centrality) (Kosko 1986). The centrality measures were normalized on [0,1]. For the visualization we applied the Yifan Hu algorithm and filtered out variables without connections.

Table 5.1. Drivers of climate change perception. List of drivers (N=33) with their grouping into driver classes (N=7) in bold, and corresponding definitions. Abbreviations: CC: climate change, ID: identification number of each driver.

	Driver class Driver	ID	Definition
Instrumental drivers	**Education and awareness of scientific work**		Processes related to receiving formal instruction on the scientific basis of CC and to interacting with CC experts
	Consumption of scientific articles	1	Reading of scientific articles on climate change
	Direct dealing with experts	2	Amount of interaction and exchange of information with climate experts
	Awareness of scientific climate consensus	3	Knowledge of the fact that > 90% climate experts currently agree that climate change is happening and that it is, at least, partly anthropogenic
	Self-perceived knowledge of CC	4	Self-assessed level of knowledge about climate change
	CC science literacy	5	Ability of understanding, communicating and gaining useful knowledge about climate change
	Media exposure		Exposure to mass media such as television, newspapers and radio
	Media access	6	The opportunity to use mass communication means to be informed about CC
	Volume of CC coverage	7	Level of climate change coverage in the media
	Popular media reports	8	Exposure to largely available and understandable spoken or written accounts about climate change in the media
	Transdisciplinary communication	9	Exposure to climate change information in a way that it is related to more than one branch of knowledge
	Online platforms	10	Use of Internet to obtain and exchange information on climate change
	Influence of corporations		Level of influence of powerful groups
	Conservative public relations firms	11	Influence of establishments engaged in promoting interests related to climate change denial
	Conservative elite cues	12	Influence of prominent individuals and small groups promoting climate change counter-movements
	Conservative think tanks	13	Influence of conservative bodies of experts providing advice and ideas on the non-existence of climate change
	Energy and oil sectors	14	Influence of individuals or groups from the energy and oil sectors promoting their own interests related to climate change denial

Socio-political drivers	**Ethnography**		The characteristic features of societies and cultures with their customs, values, habits, and mutual differences
	Emotional concern about CC	15	Self-assessed emotional concern about climate change
	Trust	16	Belief in the reliability of peers, civil institutions and climate experts
	Collectivistic culture	17	Level of influence of community norms, which emphasizes the needs and goals of the group as a whole over the needs and desires of the individual
	Socio-altruistic values	18	Possession of a set of altruistic, egalitarian and communitarian values
	Belief in anthropogenic CC	19	The acceptance that anthropogenic climate change is true
	Religiosity	20	Possession of religious feeling or belief in a community
	Liberalism supporter	21	Position with respect to the political activity supporting liberalism
	Wealth		Material prosperity
	Prosperity	22	Income and assets; total value of goods produced and services provided in a community during one year (GDP/capita)
	Willingness to pay for CC polices	23	Willingness to support taxes and energy price rises to reduce greenhouse emissions
	Free-market support	24	Position that prices for goods and services are determined by free market
	Personal experience and perception		Events or occurrences that leave an impression and/or perception of changes
	Extreme weather events	25	Experience of an extreme weather event (e.g. drought, hurricane)
	Changed weather	26	Perception of changed local/regional weather (e.g. reduced precipitation, increase on head wave frequency)
	Loss of agricultural activity	27	Experience and/or perception of agricultural activity decrease due to climate change (e.g. soil acidification, plagues)
	Threatened cultures and ecosystems	28	Perception of climate change threatening cultures and/or ecosystems
	Health impact	29	Experience/perception of human health risks related to climate change
	Demographics		Statistical data related to the population structure of a community
	Non-white fraction	30	Fraction of non-white people in a community
	fraction	31	Fraction of people below 30 years old in a community

	Female fraction	32	Fraction of women in a community
	Urban community/ developed nation	33	Presence of high technological infrastructure in a community

(a) Instrumental drivers define the level of information about climate change within a community.

Education and awareness of scientific work. Educational attainment has been found by many authors to be the strongest predictor of climate change opinion worldwide. However, knowledge about climate change is relatively limited in developing countries in comparison to developed ones (Lee et al., 2015; Leiserowitz, 2007). On the other hand, in developed countries, political commitments and promotion of particular views can threaten education and lead to the adoption of opposing positions (Plutzer et al., 2016). Furthermore, higher literacy is not necessarily related to a broad acceptance of anthropogenic climate change, but instead, it seems to be associated with stronger polarization (Drummond and Fischhoff, 2017; Kahan et al., 2012). Even when the public at large recognizes that scientists play a valuable role in society, public disengagement still can ensue when only a minority of citizens are exposed to scientific works directly(Castell et al., 2014). As a consequence, it is argued that most people in developed countries perceive climate change as a complex and distant topic (Leiserowitz et al., 2015; Smith et al., 2014) and are either unaware of or apathetic towards the scientific consensus that climate change is occurring and is at least partially anthropogenic (Cook et al., 2013). Communicating the scientific consensus, although vital to raise CCPs (van der Linden et al., 2019) has been proven to be not always necessarily effective (Capstick et al., 2015).

Media exposure. Traditional media play a decisive role in the communication of climate science. Adults obtain most of their news from radio, television and printed press and rely on the interpretations of scientific results to understand climate change research, governance, and decision-making (Shi et al., 2016; Kahan et al., 2012). In contrast to the predominant top-down strategies of traditional media, online platforms are proving to be powerful pathways for engaging individuals more effectively and broadening climate change literacy (Leas et al., 2016). Open access reports and popular science magazines also directly impact public concern and understanding(O'Neill et al., 2015; Brulle et al., 2012). Likewise, media coverage of major scientific advances and assessment reports are found to have a positive effect on public knowledge and understanding of climate change (Boykoff, 2012; Brulle et al., 2012). The media influence thus, extends far beyond the pure delivery of information, by having the capacity to polarize, shape, enhance or inhibit people's engagement (O'Neill et al., 2015).

Influence of corporations. Corporations have been found to enhance public exposure to polarized information according to their own interests, i.e. powerful organizations and/or NGOs asking for climate action vs. powerful organizations and/or private companies casting doubts about climate change. While the effect of the first has been inspected through the drivers "Popular media reports" and "Trans-disciplinary communication", the second has been inspected through this driver class, which assesses the confusion these corporations provoke in the population and the resulting reduction of risk perception (Stern, 2016; Farrell, 2015). Thus, corporations do not only have the capacity to influence the media but also to influence a wide range of variables related to personal experiences and beliefs, which can ultimately undermine established knowledge (van der Linden et al., 2017).

(b) Socio-political drivers account for the convictions of climate change based on social norms, as well as cultural, religious, and moral values.

Ethnography. Ethnography turns out to be one of the strongest drivers, as the natural, cultural and political environment shared by a community powerfully shapes perceptions on climate change (Kahan et al., 2012). This induces similar strategic reasoning (Howe et al., 2015; Lee et al., 2015) and leads individuals to form opinions compatible with the values of the groups they identify with (Clayton et al., 2015; Leiserowitz et al., 2015). Communitarian people tend to attribute a stronger role to the anthropogenic cause of climate change than those holding hierarchical values (Cook and Lewandowsky, 2016; Hornsey et al., 2016; Shi et al., 2016; Kahan et al., 2012). Although differences in climate change perception exceed what political orientation alone can explain, it is consistently found that these orientations influence a wide range of beliefs (Bliuc et al., 2015; Hamilton et al., 2015; Huxster et al., 2015; Givens, 2014; Brulle et al., 2012). Further, studies show that whenever climate change polarization is high in the media, citizens rely on their political affiliation as a source of credibility to form an opinion (Hornsey et al., 2016; Stern, 2016; Leiserowitz et al., 2015). Similarly, trust in climate scientists, civil institutions, government or religion, has proven to shape individual perceptions (McCright et al., 2016; Hope and Jones, 2014; Tjernström and Tietenberg, 2008).

Wealth. Wealth is largely responsible for shaping the specific mitigation and adaptation capacities of a community. In this manner, while developed countries are as likely to experience high exposure to hazards as developing countries, they exhibit lower vulnerability, which may lead to a further disengagement from action (Cook and Lewandowsky, 2016; Hamilton et al., 2015; Leiserowitz et al., 2013). Beyond this, several authors report on the gap found between the early application of climate policies for mitigation and a later response to an obvious need for action (Leiserowitz et al., 2013; Brulle et al., 2012; Leiserowitz, 2007). Citizens generally transfer most of the climate responsibilities to corporations and governments, and although they might be willing to support pro-environmental policies, they often put their own economic interests first (Hanemann et al., 2011; Meira et al., 2009). Similarly, it has been pointed out that in times of economic recession, belief in climate change fades as a result of a rearrangement of priorities (Scruggs and Benegal, 2012). Also, driven by economic interests, free-market supporters are more likely to share corporative ideologies and beliefs related to climate change, consequently manifesting higher levels of skepticism (Cook and Lewandowsky, 2016; Hornsey et al., 2016).

Personal experience and perception. The cognitive association between experiences of extreme weather events and climate change (Howe et al., 2019; Brügger et al., 2015; Capstick et al., 2015) is still under debate, although there is a broad consensus that such experiences raise awareness (Clayton et al., 2015; Hornsey et al., 2016; Lee et al., 2015; van der Linden, 2015). People in developed countries judge negative health, agricultural and cultural impacts as more likely to occur to others than to themselves, viewing climate change as a threat distant in space and time (Maibach et al., 2015; Smith et al., 2014; Akerlof et al., 2010; Moyano et al., 2009; Patz and Olson, 2006; Patz et al., 2005). Moreover, besides extreme weather events, perceived recent local weather changes influence the broad climate change perception, as people become aware of the multiple climate change-related environmental threats to their communities (Howe et al., 2019, 2012; Hornsey et al., 2016; Zaval et al., 2014; Doherty and Clayton, 2011).

Demographics. Race, age, and gender have been found to have a weak influence on climate change perception (Shi et al., 2016; Hesed and Paolisso, 2015; Howe et al., 2015; Leiserowitz et al., 2011). However, climate change perceptions vary geographically, both between and within nations (i.e. rural vs. urban areas) as the result of cultural and ideological factors (Howe et al., 2015; Lee et al., 2015).

5.1.3 Quantification of direct drivers of CCP

For each study and identified driver (N=33), the presence of a positive, negative, and/or neutral influence on CCP was assessed (Figure 5.2).

Results show that perception of 'Changed weather' is the mechanism most frequently associated to CCP (ID: 26). Other drivers with high influencing capacity are 'Collectivistic culture' and 'Socio-altruistic values' (ID: 17, 18), followed by the 'Self-perceived knowledge of CC' (ID: 4). Among these drivers, the one with more positive correlations to CCP is 'Socio-altruistic values' (ID: 18) closely followed by 'Changed weather' (ID: 26). In contrast, the ones with the highest share of negative influences are the 'Influence of corporations' (ID: 11, 12, 13, 14).

This counting exercise provides clues of which are the most studied drivers of CCP in different settings, as well as whether their influence was found to be positive, negative, or neutral (observed no-effect). It also exhibits how drivers included under 'Demographics', 'Wealth', and 'Media exposure' play a limited role in determining CCP.

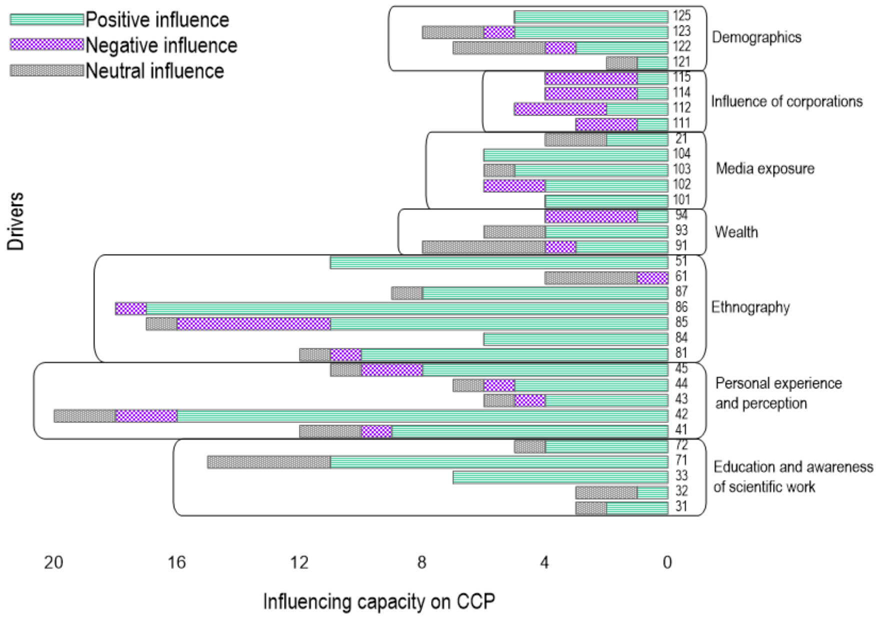


Figure 5.2. Quantification of the number of times a driver has been found to influence climate change perception for. The sub-drivers are grouped into the seven drivers (black rectangles). See description of IDs in Table 5.1.

5.1.4 Quantification of indirect drivers of CCP

Due to potential interactions among drivers, crucial information about what drives CCPs may be overseen when only assessing direct influences. Thus, in a second step and following the same methodology of positive, negative and neutral encountered connections, we collected the occurrences of links between drivers. With this information, we have developed a network diagram and determined the centrality (degree of connectedness) of the drivers (Figure 5.3). For its construction we used the methodology (network analysis with normalized centrality measures) and visualization technique (Yifan Hu algorithm and filtration of unconnected drivers) explained in Chapter 3.4.

As a result of the FCM, 'Socio-altruistic values' (ID: 18) is found to strongly and positively impact 'Emotional concern about CC' (ID: 15and 'Belief in anthropogenic CC' (ID: 19). 'Urban community/developed nation' (ID: 33) instead, display negative connections to 'Personal experience and perception' (ID: 25, 26, 27, 28, 29). 'Awareness of scientific climate consensus' (ID: 3) is negatively impacted by 'Influence of corporations' (ID: 11, 12, 13, 14), 'Free-market supporter' (ID: 24), 'Volume of CC coverage' (ID: 7), and 'Popular media reports' (ID: 8).

The network diagram hence, reveals how people's CCPs are not only shaped by direct drivers (Fig. 5.2), but also by the interactions among the drivers themselves (Fig. 5.3). Two of these interactions that are closely related to rural communities are highlighted here:

(1) The driver 'Urban community / Developed nation' exhibits little influence on CCP directly, while in the network diagram this driver is quite central with several negative connections to the drivers grouped under 'Personal experience and perception'. This finding suggests that the more developed a community is, the less connected to the physical experiences of climate change it becomes. Literature indicates that the rationale behind this observation is that developed communities with high levels of resilience towards climatic adverse effects perceive climatic threats as distant in space and time, while the opposite occurs for less developed communities (Cook and Lewandowsky, 2016; Hamilton et al., 2015; Leiserowitz, et al., 2013). A consequence of this, combined with the fact that the drivers under 'Personal experience and perception' positively influence 'Emotional concern about CC' and 'Belief in anthropogenic CC', is that a possible strategy for promoting climate action could be prioritizing the knowledge of the

science behind climate change (i.e. promoting education and awareness of scientific work) in developed communities, while relating climate change to direct threats and perceptions in less developed communities.

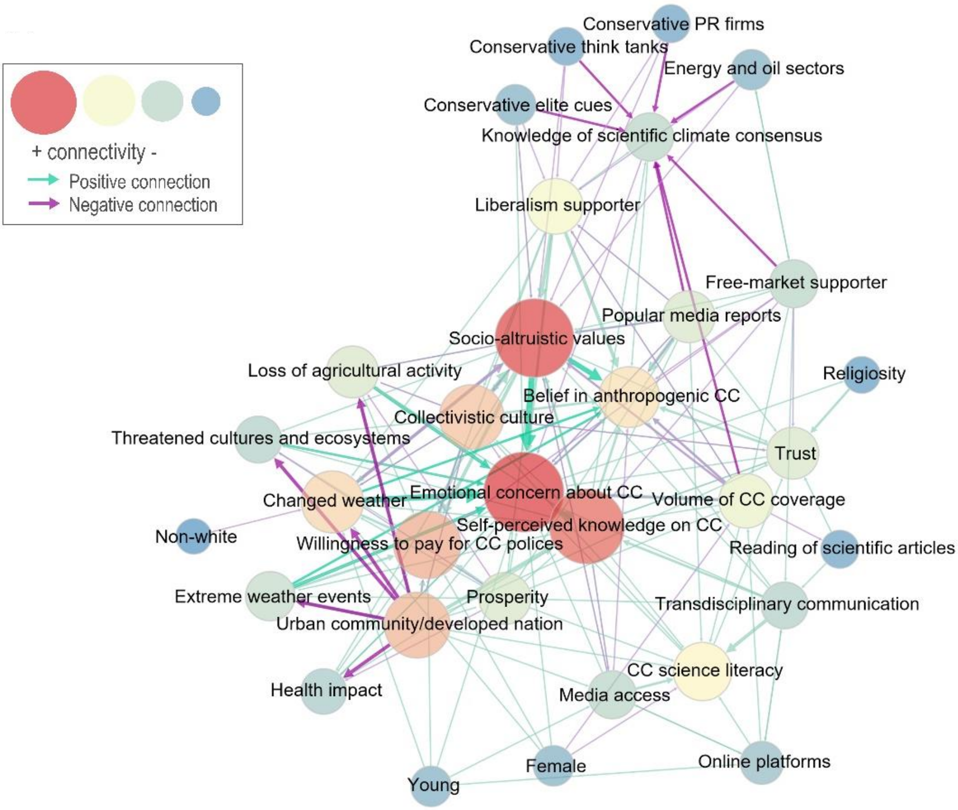


Figure 5.3. Interactions among drivers. Each line represents a connection, with the arrow indicating its direction, its width indicating its influencing capacity (number of occurrences), and its color indicating its nature (positive, negative). Size-color of the nodes indicates centrality, calculated as the number of links incident upon each driver (i.e. degree centrality). The most relevant connections have been highlighted. Abbreviations: CC: climate change, PR: public relations.

(2) People's CCPs are strongly affected by ethnographic factors directly. The network diagram reveals that many of the drivers within this class reinforce each other, leading to a stronger influence. In this way, powerful positive connections exist between 'Socio-altruistic values', 'Emotional concern about CC', and 'Belief in anthropogenic CC'. Past studies have hypothesised that this might be the case as principles and ideals shared within a community are powerfully transmitted and induce similar strategic reasoning (Howe et al., 2015; Kahan et al., 2012; Lee et al., 2015). Hence, in order to achieve climate action, different strategies might be need to be followed in collectivistic (rural) vs. more individualistic (urban) communities.

5.2 Platforms that steer SLM adoption

"Cross-scale, cross-sectoral and inclusive governance can enable coordinated policy that supports 8 effective adaptation and mitigation (high confidence)" (Arneth et al., 2019).

Taking action to combat climate change is an emerging priority in the Mediterranean Basin (Chapter 2), especially within the rural regions, where exposure is higher. Acting in these areas will be vital for achieving basin-wide adaptation and mitigation goals, as well as for tackling future climate projections.

SLM represents an effective and holistic approach to combat climate change while managing healthy ecosystems, combatting land degradation and desertification, and assisting overcoming water scarcity (Chapter 4). This is the case, as strong links among land management, the water cycle, and the re-circulatory atmospheric processes in the Mediterranean region exist (Chapter 3; Millán et al 2005). Moreover, well design actions for land use and forestry are key to achieve basin-wide adaptation and mitigation to climate change, and these can be effectively achievable through SLM (Sanz et al., 2017).

SLM practices that are documented in the literature, are in most of the cases designed and adopted at the local scale, as these, are tightened to the site-specific characteristics in where they are implemented. However, the wide region of the Basin (30–47°N, 10°W–35°) represents a niche of opportunity to steer SLM efforts towards the common goal of managing the hydrological budget and restoring its impoverished water cycle. The greatest challenge that this entails is that while the hydrological system of the Basin is driven by global climate change and regional anthropogenic action, adaptation actions are locally addressed, mixing different time and regional scales that encompass non-linear behaviours and distinct internal thresholds. That is to say, that while SLM actions consider that vulnerabilities and risks are local or proximal, there are wider non-straightforward challenges (and solutions) that affect the whole region, as for example, the state of the water cycle.

In light of this, the development of coordinated, coherent and consistent environmental policies for SLM actions within the Mediterranean Basin is key to ensure regional objectives that go beyond the local scale of SLM implementation. For that, mainstreaming of SLM could be a solution (Akhtar-Schuster et al., 2011).

Mainstreaming of SLM is understood as systematically integrating *“decision-making processes, policies and laws, institutions, technologies, standards, planning frameworks, educational curricula and public awareness-raising activities”,* ensuring their continuity in the political and institutional agenda (UNDP, 2008). It is therefore aimed at integrating cross-sectoral and multi-stakeholder knowledge, translating it from national to wider regional (i.e. Mediterranean Basin) policies and frameworks. Mainstreaming thus, does not mean implementing successful SLM elsewhere, but seeking ways to replicate success stories by making local SLM relevant to polices wider than the scale of their implementation.

5.2.1 Barriers/opportunities and institutional infrastructures for the adoption of SLM

There is an extended body of literature inspecting barriers and opportunities of SLM implementation (e.g. Akhtar-Schuster et al. 2017; ELD Initiative, 2013; Kirui and Mirzabaev 2015; UNCCD, 2017). As a summary, these can be condensed into four broad areas: economic, educational, institutional and monitoring. Together with an overview of these, we will reflect on different available capacity-building infrastructures/systems that help to overcome these challenges and channel opportunities.

(1) Economic: facilitate access to appropriate technologies, practises or equipment; fairly distribute subsidies and loans among Mediterranean countries; incentive schemes for SLM implementation through sustainable business models and/or payments for ecosystem services; carry out cost-benefit analyses of planned actions; develop compensation schemes for land owners for the maintenance costs of SLM.

There is a rising number of institutional structures that allocate funds to SLM adaptation actions. Among them are the World Bank's Climate Funds (https://climatefundsupdate.org/), the UNDP National Adaptation Programmes of Action, NAPAs (https://www.adaptation-undp.org/), the UNCCD's LDN fund action (https://www.unccd.int/actions/impact-investment-fund-land-degradation-neutrality), and the FAO's Forest and Farm Facility (http://www.fao.org/forest-farm-facility/en/). There is likewise a rise in business across sectors initiated by Small and Medium Enterprises that aim for SLM implementation such as the Commonland Foundation (https://www.commonland.com/en).

(2) Educational: increase opportunities for local training; promote well-trained stakeholders that facilitate and guide SLM implementation; support the direct implication of scientific bodies that align outputs to national frameworks; support transdisciplinary research programs; seek for arenas of communication that facilitate knowledge exchange, through the translation of scientific findings into a policy-relevant language and the transmission of local skills, experience and knowledge to stakeholders and scientists (i.e. downscaling and upscaling lessons that inform policy frameworks).

There are increasing interdisciplinary research teams and centres focused on climate change such as the BC3 (https://www.bc3research.org/) that engages in climate policy recommendation, or the multiple international research programmes built through the Future Earth global network (https://futureearth.org/), which raises social awareness and scientific knowledge on climate change and SLM options. At the same time, the Mediterranean region is included under the Mediterranean Experts on Environmental and Climate Change, MedECC (http://www.medecc.org/), which is an international network of more than 400 scientists that identify knowledge gaps and provide unbiased information to policymakers. Similarly, the Climate-Smart Agriculture program from FAO (http://www.fao.org/climate-smart-agriculture/en/) provides guidance for stakeholders to identify the best SLM strategies

(3) Institutional: provide infrastructures to co-create objectives and means of adaptation among scientists, policy-makers and landusers; decentralize action, that is, promote existing regional and local bodies to design, coordinate, evaluate and monitor the implementation and impacts of SLM; develop frameworks with short-, medium- and long-term priorities; improve land tenure security and rights; adequate / develop policies and regulations that facilitate

the implementation and maintenance of SLM; assure long-term government commitment.

The Mediterranean Strategy for Sustainable Development, MSSD 2016-2025 (https://web.unep.org/unepmap/mediterranean-strategy-sustainable-development-mssd-2016-2025) is an integrative policy framework under the coordination unit of the United Nations Environment Programme / Mediterranean Action Plan (UNEP/MAP) that aims to translate the 2030 Agenda for Sustainable Development at the regional level (i.e. downscaling) and stimulate regional cooperation (i.e. upscaling). Similarly, the Union for the Mediterranean, UfM (https://ufmsecretariat.org) is and intergovernmental institution that brings together 43 countries to likewise, promote dialogue and cooperation within the Mediterranean region.

(4) Monitoring: develop qualitative and quantitative indicators at different spatial and temporal scales; make results of monitoring available in a cross-sectoral format; understand the base-line condition of the landscape and calculate the share between human- and climate-induced degradation; recognize that SLM assessment needs to take place within the context of broader monitoring; scale up results through meta-analyses and modelling studies; identify barriers to implementation and opportunities for creating an enabling environment.

Monitoring activities might be carried out through the UNCCD monitoring and evaluation framework (Decision 22/COP 11), as well as through the guidelines of the MSSD 2016-2025 framework.

5.2.2 SLM implementation as a means to achieve SDG and further goals

The opportunity of adopting SLM as a means to contribute to SDG's arises from the strong commitment of governments to combat climate change. That is why SLM in the Mediterranean Basin has the potential to create a common framework within which efforts promote the goals of several international bodies such as the FAO, UNFCC, UNCCD, and CBD; as well as regional, national and local strategies and action plans (Fig. 5.4).

Moreover, beyond assisting the restoration of the Mediterranean's impoverished water cycle (i.e. SDG6 "clean water and sanitation") and helping to adapt to and mitigate climate change (i.e. SDG13 "climate action"), the setting of shared goals across sectors also contributes to the alleviation of the multiple other impacts of climate

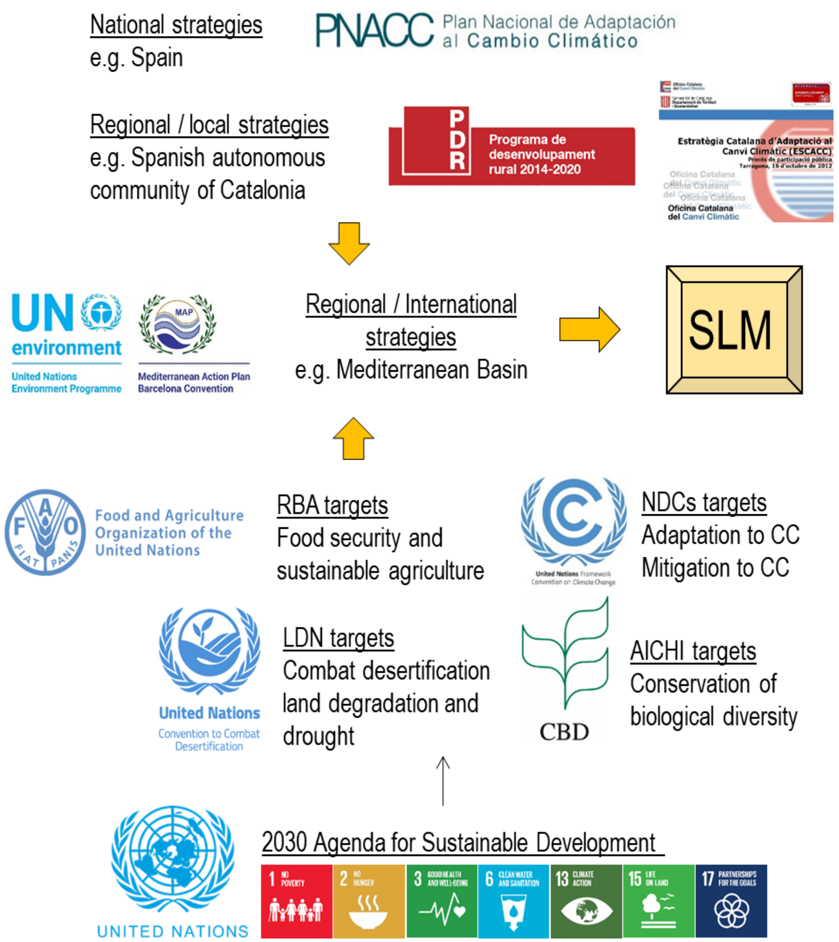


Figure 5.4. Contribution of Sustainable Land Management (SLM) to the multiple SDGs and goals of the FAO, UNFCC, UNCCD, and CBD organizations (bottom); to the objectives set by the MSSD 2016-2025 (left); and the multiple regional, national and local strategies and action plans (top). The yellow arrows indicate the best option recognized to steer SLM efforts.

change and human action such as SDG1 “no poverty”, SDG2 "zero hunger", SDG3 “good health and well-being”, and SDG15 "life of terrestrial ecosystems".

Among the different capacity-building bodies and institutions previously identified, we especially recognize the option of steering SLM actions under Objective 2 of the

MSSD 2016-2025, which states “Promoting resource management, food production and food security through sustainable forms of rural development”. The MSSD 2016-2025 addresses crucial systems disturbed by human actions from urban to rural areas (and the marine realm) with one of the focuses on climate change. This framework defines strategic directions and actions to ensure implementation and monitoring of SLM, offering offers the opportunity to overcome the above exposed barriers for SLM implementation, as it is an already existing body that coordinates the implementation of intergovernmental (top-down), national and regional (bottom-up) actions, it provides support and technical guidance to all interested parties, facilitates platforms for the civil society to participate with stakeholders, offers monitoring processes, allocates financial resources, cooperates with the scientific community for the development of analytical tools that allow forecasting and assessment of measures, and engages in civil awareness and sensitization.

5.3 Conclusions and connection

For the successful implementation of SLM actions, attention needs to be paid to the social system. With the study of CCPs, two strategies that **increase climate change awareness in rural areas**, and thus, facilitate the implementation of effective SLM, have been identified: (1) **relate climate change to direct threats** rather than prioritizing the knowledge of the science behind it, as less developed communities such as the rural ones, perceive climatic threats closer in space and time in the form of weather changes and weather events; (2) **reorient values and behaviours towards climate action through SLM implementation** as these (i.e. values and behaviours) will be understood and highly shared within the community due to its integrands’ similar strategic reasoning.

These shared values and behaviours need, however, to be supported by useful, relevant and oriented information, together with high stakeholder’s perception of the benefits of SLM practices and more deliberative and participatory approaches focusing on incorporating cultural identities, fairness, and equity. The **MSSD 2016-2025 framework** provides the means to encompass many of these aspects, emerging as **an outstanding option for steering SLM actions under its objectives**.

6. General discussion, conclusions and further research

6.1 General discussion

The region of the Mediterranean Basin represents a niche of opportunity to steer efforts towards the common sustainable goal of meliorating its impoverished water cycle while boosting climate change adaptation and mitigation capacities, steering land degradation, and further preventing the loss of the mosaic-like landscape. For this, the consideration of the ecological, social, and political framework within the region is needed and has been tackled by carrying out this interdisciplinary dissertation. It has been developed a theoretical framework that includes: (1) visions: paleoclima in Chapter 2, human–climate interactions in Chapter 3, and SLM practices in Chapter 4; (2) values: CCP in Chapter 5; (3) and voices: barriers and opportunities for SLM implementation in Chapters 4 and 5. This thesis thus, enables a science–policy platform, for policy to steer science-based key actions at the basin scale and scientists to better understand how to mainstream results in a policy-relevant language (Fig. 6.1).

Figure 6.1. Scheme of the science-policy platform of this thesis. In magenta the different chapters, in black the insights from each discipline to the other one, and in cyan the “three v” (i.e. visions, voices, values) tackled in the different chapters.

In the following lines, there is a reflection on the different methodologies used in this interdisciplinary dissertation. The provided contributions have been likewise here discussed, and while doing so, the findings are contextualized to other studies and reports to check for reliability and robustness (Figure 6.2).

Hypothesis 1 "*The hydrological system of the Mediterranean Basin has been modified by LUC practices*" has been tested to be right through the completion of Objectives 1 and 2, aimed at (1) "*differentiate between natural and anthropogenic climate variability throughout the Holocene*" and (2) "elaborate on existing knowledge about how topographic rainfall might have *been changed due to anthropogenic action*".

By working in **Objective 1** it has been discerned that while orbitally induced climate variability set the conditions for an overall dryer Basin for the past millennia, human activities further exacerbated its impoverished hydrological system (see Section 2.6).

To complete this conceptual objective, the revision of the literature on natural sciences (Chapter 2) and archaeology (Chapter 3) was conducted. The provided information is, therefore, in concordance with the latest investigations on this field (e.g. Cramer et al. 2018; IPCC, 2018; Lionello et al. 2018; Lionello et al. 2017).

This is summarized as follows. Around 4.5 kyr BP a decrease of solar insolation onsetted a generalized drying and warming of the environmental conditions in the Basin. Ever since the Mediterranean has witnessed more unstable weather patterns, a successive decline in precipitation, and a linear increase of its temperatures, reaching present-day conditions around 2.5–2 kyr BP (Fig. 2.3). The hydrological system of the Basin with its two main precipitation types (i.e. the synoptic rainfall, product of the large-scale atmospheric motion, and the topographic rainfall, caused by the local orographic convection) have consequently, been affected. In addition, human activities carried out over the centuries, further added variability to the rainfall regime of the Basin (Obj. 2). On the one hand, land use changes have resulted in soil aridification, causing fluctuations on land surface heat fluxes through the increase of albedo or the decrease in evapotranspiration rates, affecting cyclone development. On the other hand, topographic rainfall has declined as the cloud condensation level required for precipitation is not reached due to lack of inland moisture, i.e. aridification

(Fig. 2.5). In sum thus, both main precipitation types have been affected by anthropogenic actions with a consequent impoverishment of the hydrological cycle of the region.

This investigation allowed the contextualization and understanding of the base-line condition of the Basin's landscape (i.e. no mosaic-like landscape and wetter conditions), its evolution and current state (i.e. mosaic-like landscape and overall dry environment), and the near-future projected climate change (i.e. intensification of agricultural activities and risk of mosaic-like landscape together with drier climate).

Gaining an insight into the past of the Mediterranean's history is key to inform the future, as it enables both, to understand how it responded to natural climate variability and human disturbance, and to predict how it will behave given future projections.

Next, the anthropogenic share of the Basin's environmental change has been deepened by addressing **Objective 2**. It has been shown that among all agricultural activities, the one exerting a stronger impact on the Mediterranean environment, and in particular on the hydrological cycle of the Basin, is deforestation (see Section 3.5).

Conclusions on this objective were drawn after inspecting the content of a semi-structured review of scientific literature (N=23) that was used to develop a network map. First, the main descriptive LUC-environment relations were compiled and with them, the network map was constructed using the Fuzzy Cognitive Mapping (FCM) technique (Fig. 3.3). FCM, while typically applied in social sciences, here it was used to inspect on the causal relationships among the different encountered components of the Mediterranean water cycle, expanding in this way its applicability as a system mapping method. FCM allowed for a flexible integration of very disperse but related components of the water system, which were too complex to be quantified. In this manner, this technique enabled to encompass studies that used particular methodologies with different specific aims, theoretically connect all components, and draw integrated conclusions. Overall, the use of the FCM technique enabled to bridge the gap between scientific findings, expert stakeholders, and policy-makers by translating complex interactions occurring between land use changes and the environment in a synthesized and integrated way.

The revised literature described how, although limited, deforestation, depletion of plant resources and soil impoverishment were connected to a regime of sustained fires aimed at land opening already during the early-Holocene. During the mid-Holocene LUCs were related to an intensification of the land use and the exploitation of goods, further inducing aridity, biodiversity loss, and soil impoverishment. Lastly, with the onset of the late-Holocene, a transition from climate- to human-dominated landscapes occurred further aggravating the consequences of earlier practices (Table 3.1). All gathered LUC practices were classified into four categories, namely: regular fires and deforestation; farming and cropping activities; overgrazing and upstream pastoralism; hydraulic terraces and aquifers.

Next, the network map related several concepts of many disciplines, from which the following interactions were highlighted (Fig. 3.4). Deforestation decreases biomass, reducing the uptake of atmospheric CO_2 and yet, promoting the expansion of more biomass due to CO_2 availability. It also modifies the surface water balance by halting evapotranspiration, which reduces water vapour available for topographic rainfall and limits groundwater flow by eliminating wood cover deep rooting infiltration. At the same time, diminished deep rooting infiltration implies enhanced surface runoff, which causes higher aridification and further soil erosion. Besides, deforestation affects biodiversity and water quality and quantity, as the health of the ecosystems regulating the quality and the quantity of surface water, are ultimately determined by the quality and the quantity of it.

Beyond the 23 case-studies used in the semi-structured review of scientific literature, findings are in line with further case-studies evaluating the LUC−landscape relationship (Roberts et al. 2018b; Primavera et al. 2017; Clarke et al., 2016; Flohr et al. 2016; Sadori et al. 2011), meta-studies addressing the impacts of land use changes (Roberts et al. 2019; Gibson et al. 2011; Poeplau et al. 2011; Seppelt et al. 2011), empirical observations documenting a reduction of the topographic rainfall as a product of land use change (Millán et al. 2005a, 2005b), and reports and land management guidelines from the United Nations (FAO and Plan Bleu, 2018; Sanz et al., 2017).

With the completion of Objectives 1 and 2, Hypothesis 1 has been tested to be right. LUC practices, in especial deforestation, started modifying the landscape and the water cycle of the Basin already in the early-Holocene.

Hypothesis 2 "*Topographic rainfall can be naturally stimulated through SLM and this will help restoring a healthier hydrological system*" has also been disclosed to be correct through the completion of Objectives 3, 4 and 5 aimed at (3) "identify *which SLM practices can better assist in restoring topographic rainfall*", (4) "*assess the viability of adopting such practices*" and (5) "understand the social and political framework in where the research can be implemented and *extend the results into policy recommendations of effective implementation*".

To test this hypothesis, **Objectives 3 and 4** were tackled together. Furthermore, and taking into consideration results from Chapter 2, in which it was highlighted the importance of the Mediterranean's mosaic-like landscape to ensure the Basin's prosperity and food security, those SLM practices that assist preserving it, were likewise identified. Agro-forestal systems, green cover in perennial woodlands, and reforestation were the obtained SLM practices that best improved the state of water resources and the mosaic-like landscape of the Mediterranean Basin. These practices moreover, offered high opportunities for their adoption (see Section 4.4).

To complete Objectives 3 and 4, a framework that evaluated the on-ground effectiveness and implementation viability of different SLM options was developed (Fig. 4.1). All SLM practices had been previously implemented within the region and are registered by the WOCAT network. To build it, five ecological variables were defined (i.e. climate regulation; soil erosion control; biodiversity enhancement and pest/disease control; water regulation; soil quality enhancement) together with four social variables (i.e. economy and production; management and irrigation; human well-being; institutions) that encompassed multiple impacts assessed by the WOCAT (Table 4.3). Then, all similar but very specific practices were grouped, making them flexible enough to be basin-wide applicable (Table 4.2). Following this, the biophysical potential area of their implementation was examined by considering five of natural environment variables (Fig. 4.2). Lastly, the potential co-benefits and trade-offs for their implementation was inspected.

In this way, the current framework is novel in two ways. First, it allows to mainstream across the Mediterranean Basin, those successful SLM practices whose benefits go beyond the local scale of implementation, allowing policy-makers to steer coordinated efforts basin-wise. Second, it is not only based on ecological impacts, but also on geo-climatic and socio-economic ones, as these, might either highlight potential synergies overlooked otherwise or compromise the success in the implementation of SLM practices (Obj. 4).

Results showed that SLM not only has the capacity of strengthening the Basin's capacity to mitigate and adapt to climate change but also assists restoring degraded lands, stopping desertification, enhancing biodiversity and improving the state of water resources, wetlands and traditional landscapes. Among the whole array of practices (N=25) agroforestry systems, green cover in perennial woody crops, and reforestation were found to best assist in all assessed five ecological services. A different array of practices emerged when each service was evaluated separately (Table 4.5).

In particular, the mix of these three practices helps mitigating climate change by sequestering and stocking carbon, while assists in adapting to climate change by regulating the hydrological system of the Basin and promoting the multifunctionality of its landscape, among others. The hydrological cycle of the region was found to be impacted in two main ways by these practices: through increased infiltration; and through a rise of atmospheric moisture led by evapotranspiration, which decreases temperature and heat wave duration, and has the potential to enhance topographic rainfall. These practices moreover, were found to assist in promoting cultural values and traditional knowledge, increase market products, address water demand, and balance workload. Besides, according to the geo-climatic characteristics of the Basin, they offered a high potential for implementation (Table 4.6).

Because no previous work has inspected the implementation of SLM across the entire Mediterranean Basin, our results can only be compared to reports that collectively assess SLM options around the globe. The here presented findings, however, are in line with the latest UNCCD's report on SLM practices (Sanz et al. 2017), where they are classified according to the type land use in where they are implemented. That report highlights the need for practices that: control soil erosion in croplands (parity with our results: green cover in perennial woodlands); reduce deforestation in forestlands (establishment of protected forest areas; reforestation); and manage soil fertility in mixed lands (agro-forestal systems). The Voluntary Guidelines for Sustainable Soil Management, VGSSM (FAO 2017) also aligns with this dissertation's results. The VGSSM states that to minimize soil erosion deforestation or improper grassland-to-cropland conversion need to be avoided, the growing and maintenance of covering plants should be enhanced, and runoff rates and water velocity need to be reduced. To improve soil water management, the VGSSM recognizes the importance of higher efficiency in the use of irrigation water by plants, as well as reduced evaporation and percolation losses (green cover in perennial woodlands; establishment of protected forest areas; reforestation).

Lastly, **Objective 5** was addressed, from which strategies to enhance the public's perception towards climate action (bottom-up approach) and political frameworks from where to steer action (top-down approach) were identified. To the first, it has been found that relating climate change to direct threats and reorient values/behaviours are effective strategies for rural populations; whereas, for the second, it has been recognised that the Mediterranean Strategy for Sustainable Development emerges as a competent framework from where to channel SLM efforts in a basin-wide scale (see Section 5.4).

Following the methodological approach of the previous chapters, a novel framework was developed to identify the drivers of CCP (Fig. 5.1). To develop it, the FCM technique of Chapter 3 was used as follows. First, drivers of CCP were mapped by reviewing climate change influences in the literature. Then, the found terminology was homogenised and a select a set of terms, that later on were call drivers, were grouped under seven driver classes. Following this, the importance of each influence was quantified by counting the number of occurrences in the selected literature. Finally, a network map that depicted the importance of each concept was constructed. The development of this novel framework offered several advantages. First, by merging similar variables and removing restricted cases, the key drivers were exposed. Second, it combined disperse information under a single terminology, making it comparable regardless of the context of the study. Third, it offered an interdisciplinary view that is most valuable for decision- and policy-making, as this framework structured the key drivers of CCP found across disciplines in a comparable way.

Results showed that 'Changed weather' is the mechanism most frequently associated with CCP, followed by 'Collectivistic culture', 'Socio-altruistic values', and 'Self-perceived knowledge of CC' (Fig. 5.2). Importantly, the interactions between drivers of CCP were also identified and quantified, looking for the first time, the indirect paths of influence to CCP. With such an approach it was possible to unravel characteristics within a community unnoticed otherwise (Fig.5.3). The network map revealed two closely related to rural communities (bottom-up approach). On the one hand side, 'Urban community/developed nation' was negatively related to 'Personal experience and perception'. This suggests that relating climate change to direct threats and perceptions might be an effective strategy for promoting climate action in rural areas. On the other hand, people's CCPs were strongly affected by ethnographic factors, implying that reorienting values and behaviours are powerful tools to achieve climate action, more than for example, inoculating the public with information on climate change.

Because the study of CCP is generally underpinned by different methodologies, uses different criteria and terminologies, and focuses on distinct time frames and geographical locations, it is a difficult endeavour to compare our results to the literature on this topic. Nevertheless, it might be highlighted that results go in the direction of recent multi-variable studies in which authors state that the most powerful drivers of climate change perception are education, the media, shared characteristics of societies and cultures (ethnography) and personal experiences and perceptions (Capstick et al., 2015; Goldberg et al., 2019; Hornsey et al., 2016; Lee et al., 2015; Shi et al., 2016; van der Linden et al., 2019; van der Linden et al., 2017).

Subsequently, to identify available capacity-building infrastructures to steer SLM efforts and climate action towards addressing Basin-wide challenges (top-down approach), several institutional structures were revised together with barriers and opportunities of SLM implementation (Section 5.2).

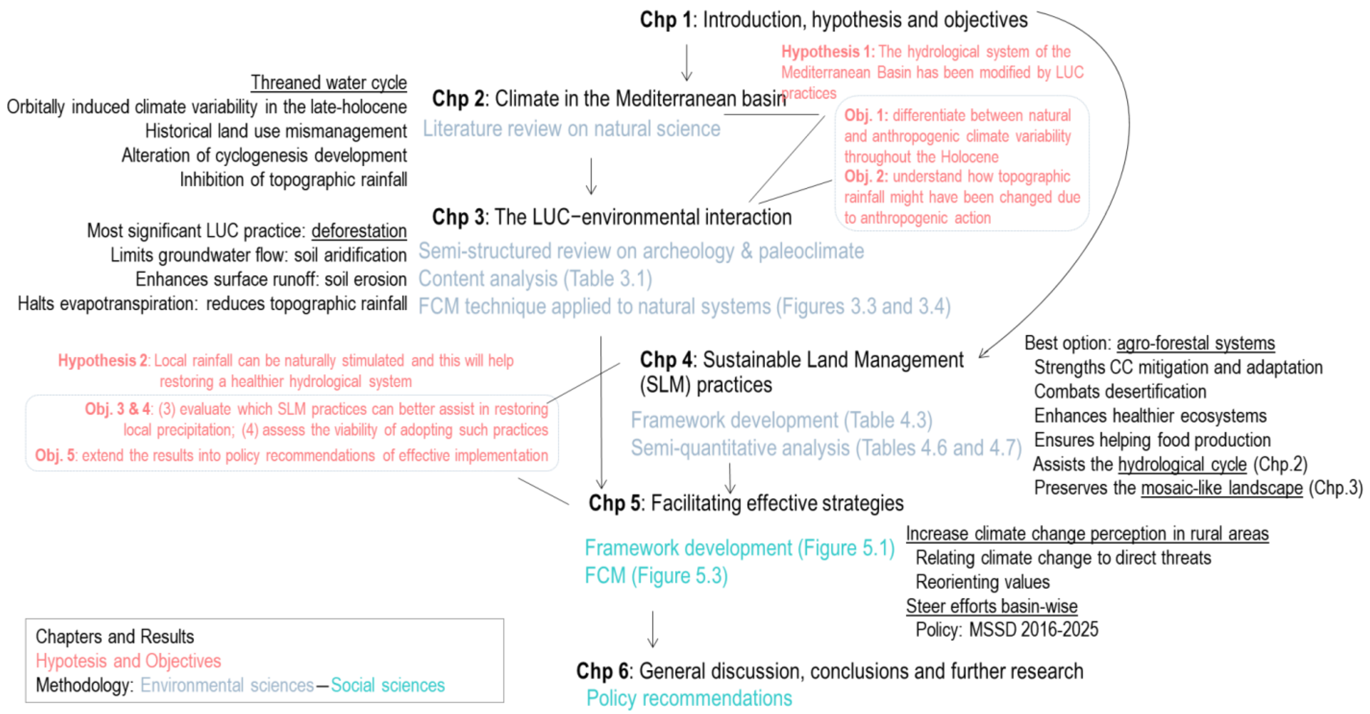
Four barriers/opportunities of SLM adoption were identified: economic; educational; institutional; monitoring, along with different available capacity-building infrastructures/systems that helped to overcome these challenges and channel opportunities. Identifying such structures was found key to ensure regional objectives that go beyond the local scale of SLM implementation and that had the potential to contribute to multiple international objectives such as the SDGs and provide practical guidance for creating an enabling environment for the selection and implementation of those (Fig. 5.4).

Marques et al. (2016) highlight FAO-LADA, EU-DESIRE, EU-PRACTICE and WOCAT as international projects/institutions to mainstream SLM. However here, the aim was to recognize institutions specific for the whole Mediterranean Basin. Priority was given to international/inter-regional structures capable of both, downscaling and upscaling efforts. The option of steering SLM actions under Objective 2 of the Mediterranean Strategy for Sustainable Development 2016-2025, which states "Promoting resource management, food production and food security through sustainable forms of rural development" was recognized as the best one to steer action in the Mediterranean Basin.

With the completion of Objectives 3 to 5, it has been concluded that Hypothesis 2 is also right. Topographic rainfall can be naturally stimulated in the rural areas through increased cover crop and extended areas of canopy (i.e. agro-forestal systems and reforestation).

The latest report of the IPCC however, states that "*In temperate regions with water deficits, the simulated change in evapotranspiration following forestation will be insignificant while the decreased surface albedo will favour surface warming*" (Jia et al., 2019). Pausas and Millán (2018) argue that beyond rural land mismanagement, coastal degradation, i.e. increased soil heating due to urbanization, vegetation loss, and disappearance of marshals and coastal lagoons, the water cycle of the Basin has been disrupted. Acting in coastal areas should be thus, parallel to acting in the rural lands since each one alone is a necessary effort, yet not sufficient to stimulate the recovery of topographic rainfall.

Figure 6.2. Schematic abstract of the thesis



6.2 Conclusions

Addressing the objectives of this dissertation required an integrated interdisciplinary approach that consolidated scientific knowledge on the environment with that from the social sciences, as landscapes are ecological−social systems. Due to its interdisciplinary, it has been possible to reach beyond deterministic climate−environment−society relationships. Similarly, the chosen approach has enabled to answer to some of the most pressing challenges of the Mediterranean region in a context-sense scenario. This highlights the need for additional transdisciplinary studies on this topic as the first conclusion of this dissertation.

It can be likewise concluded that local adaptation and mitigation actions firmly contribute to reducing climate change impacts while assisting in restoring the water cycle of the Basin. Practical steps to do so, that is, to address desertification (i.e. assist the hydrological cycle), land degradation (i.e. preserve the mosaic-like landscape) and climate change adaptation and mitigation in rural Mediterranean regions, have been achieved. These are reflected as policy recommendations (Table 6.1) of different levels, i.e. from the land use level to policy-makers.

Policy recommendations

In light of the current state of the hydrological cycle of the Mediterranean Basin, and especially, of the projected climate scenarios for the near future, the adoption of adaptation and mitigation measures to combat climate change becomes a priority. The greater efforts are placed in cities, where approximately 70% of the Mediterranean population currently lives (Plan Bleu, 2016). However, beyond cities, efforts should be recognized and incentivized in rural regions, as these, have a large capacity to effectively combat Basin-wide current and future challenges, and are key to the overall provision of food, energy and the functioning of the ecosystems. Acting in the rural areas is moreover pivotal to accomplish the overall biophysical sustainability of the Basin, it is necessary given their higher exposure to climate change, and it is effectively achievable through SLM.

SLM practices are designed and adopted at the local scale. However, the development of coordinated, coherent and consistent environmental policies for SLM actions within the Mediterranean Basin is key to ensure regional objectives that go beyond the local scale of SLM implementation. Jointly addressing local and broader regional challenges can lead to emerging synergies from which all actors and the environment can benefit. Promoting the adoption of SLM under a framework that coordinates environmental policies can steer up opportunities, achieve more significant results, and contribute to multiple regional-to-international set goals such as the SDGs.

Water availability is the limiting factor for the provision of services in the Mediterranean Basin and SLM adoption, as well as the biggest threat to climate change adaptation in the rural regions. Efforts should be directed towards win-win SLM practices that tackle locally specific challenges and help to ensure a more effective management of the Basin's hydrological budget. Attempts to decrease pressure on freshwater resources might be stewarded towards improving its management while enhancing its input. Several SLM options assist on this, from which we highlight: (i) improve irrigation efficiency through micro-irrigation systems; (ii) reduce direct soil evaporation with increased plant transpiration through reforestation and green cover in perennial woodlands; (iii) boost topographic rainfall by reforestation and stopping deforestation; (iv) enhance water use efficiency by the flora through the preservation of the mosaic-like landscape.

The cultural mosaic-like landscape of the Mediterranean Basin assists in restoring the impoverished hydrological system, combating desertification, and achieving a healthier, more productive and more diverse ecosystem. Efforts to reduce the loss of this cultural landscape might be directed towards limiting land use intensification and preserving traditional extensive systems of high cultural and productive values. The highlighted SLM options to achieve this are: (i) assist and promote cropping through vegetated earth-banked terraces practices; (ii) expand agroforestry systems.

Integrated landscape approaches (i.e. frameworks that aim at managing environmental issues) should put into value the traditional knowledge on SLM of the peoples. A way of doing that is through the establishment of cross-sectoral platforms that enable collaboration. With the joint design and implementation of SLM practices between non-state actors and policy-makers (cross-sectoral collaboration), a raise in fairness in the decision-making process is ensured, the gap existing between the different actors is bridged, social awareness on climate change is boosted, and non-state actors are empowered with knowledge and evidence-based arguments.

Table 6.1. Summary of this dissertation's integrative-regional policy recommendations, main aims, synergies and challenges.

Policy recomm	Main aim – Synergies – Challenges
Stop deforestation (Chapter 3)	**Increase available moisture necessary to induce topographic rainfall, protect and preserve biodiversity** synergies – limit surface runoff, enhance groundwater flow, prevent soil erosion, and improve soil quality by deep rooting infiltration – decrease the impacts of weather events – help regulate the micro-climate – increase C capture and storage – integrate biodiversity and autochthonous species conservation – offer natural barriers to pest spreading challenges – higher competition for arable/urban land – reduced market products, i.e. timber
Promote green cover in perennial woodlands (Chapter 4)	**Protect cropland soils from erosion** synergies – limit surface runoff and improve soil quality – decrease the impacts of weather events – increase C capture and storage – increased health of productive plants – supported by local-level capacities and land user's traditional knowledge challenges – potential water competition among vegetation
Promote agro-forestal systems (Chapter 4)	**Foster traditional Mediterranean mosaic systems (multifunctional landscapes)** synergies – limit surface runoff and improve soil quality – decrease the impacts of weather events – help regulate the micro-climate – increase C capture and storage – integrate biodiversity and autochthonous species conservation – fodder and shade to livestock – offer natural barriers to pest spreading – increase profitability through diversification of output – prevent perpetuating vulnerabilities within the Basin – improve human and environmental health – supported by local-level capacities and land user's traditional knowledge challenges – initial substantial workload

	–access to economic incentives –access to appropriate technologies/equipment –technical knowledge
Promote reforestation (Chapter 4)	**Increase available moisture necessary to induce topographic rainfall** synergies –limit surface runoff, enhance groundwater flow, prevent soil erosion, and improve soil quality by deep rooting infiltration –decrease of the impacts of weather events –help regulate the micro-climate –increase C capture and storage –integrate biodiversity and autochthonous species conservation –offer natural barriers to pest spreading –provide market products –strengthen benefits for human health challenges –potential decrease on streamflow –initial substantial workload –access to economic incentives –access to appropriate technologies/equipment –potential misconception of compensating for emitting
Relate climate change to weather changes and Reorient values and behaviours towards climate action (Chapter 5)	**Promote climate action through SLM implementation** synergies –boost social awareness on climate change –empower non-state actors with knowledge and evidence-based arguments challenges –jeopardize land users' activities aimed at meeting immediate needs but endangering the environment
Make use of existing cross-sectoral platforms that enable collaboration (Chapter 5)	**Bridge the gap existing between the different actors, i.e. land users and policy makers** synergies –put into value the traditional knowledge on SLM of the peoples –raise in fairness in the decision-making process –access to transdisciplinary arenas for knowledge exchange –prevent perpetuating vulnerabilities within the Basin challenges –possible conflict of local interests
Steer SLM efforts towards common Mediterranean goals (Chapter 5)	**Achieve more significant results in atmospheric available moisture, land quality and preservation of mosaic systems** synergies –help regulate the meso- and micro-climate –decrease the frequency of weather events

	−increase C capture and storage −integrate biodiversity and autochthonous species conservation −prevent perpetuating vulnerabilities within the Basin −contribute to multiple regional-to-international set goals −ensure regional objectives that go beyond the local scale of SLM implementation −steer up SLM associated opportunities <u>challenges</u> −jeopardize land users' activities aimed at meeting immediate needs but endangering the environment −centralized action, top-down approach

Main aim
Synergies/Challenges related to adaptation to climate change
Synergies/ Challenges related to mitigation to climate change
Synergies/ Challenges related to biodiversity enhancement
Synergies/ Challenges related to market products
Synergies/ Challenges related to human health and knowledge
Synergies/ Challenges related to institutions

6.3 Further research

The work enclosed in this dissertation can be extended into practical implementation through the launch of (a) study-case(s) in a watershed of the Mediterranean Basin. This potential study case would aim at increasing rural development while assisting the hydrological cycle and preserving the mosaic-like landscape. For this, possible portfolios of actions would be developed together with the participation of watershed stakeholders, from land-users to policy-makers. It should advocate for measures that go in the direction of implementing more participatory actions from the first involvement stage by combining information from local people, participatory assessments, field observation, and scientific findings. Completing such pilot could serve as a basis to scale up results basin-wide.

From a theoretical point of view, this dissertation can be extended in several ways. Here, we detail three possible directions.

First, the investigation on Land Use Change (LUC)−climate interaction in the Mediterranean Basin could greatly benefit from further site-based studies conducted on the coast of North Africa and the Ionian, Aegean, and Adriatic seas, for which little data exists nowadays. Moreover, if we are to engage in climate change adaptation and mitigation by looking into the past to inform anticipatory learning, it is essential to keep unfolding the quantification of such interactions, for which large uncertainties exist nowadays.

Second, in seeking to determine whether SLM adaptation strategies are effective, we need to develop a more quantifiable and yet flexible way of assessing their contribution to the different environmental indicators (e.g. CO_2, freshwater quality and quantity). There are many efforts directed towards the quantification of SLM practices in assisting to SOC storage, yet none for quantifying how the canopy and vegetation assist to the hydrological cycle by limiting direct evaporation through evapotranspiration, i.e. increased infiltration, rise of atmospheric moisture for topographic rainfall.

Third, high social perception of the climate challenges does not guarantee the effective implementation of mitigation and adaptation measures (e.g. SLM practices), although it critically determines their success. Studying how social perceptions are translated into actual action is a further research step. Many case-studies present farmer's and land user's perceptions of climate change and their adaptive strategies at the local level. However, there are no meta-studies on this issue for the Mediterranean Basin (such as van Valkengoed and Steg, 2019; Morren and Grinstein, 2016), and there are neither studies that address the perception of institutional actors and decision-makers in the process of implementing SLM practices and other adaptation measures.

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Annex

Annex-A1. Results on the performance of each SLM practice for each of the four considered scenarios (i.e. from -3 to +3)

(1) No filtering of practices and/or impacts
All selected 104 practices and all resulting 55 ecological and off-site impacts are considered

SLM practice	Climate regul.	Biodiversity […]	Soil quality	Soil erosion […]	Water regul.
1	0.33	N/A	0.20	0.83	0.50
2	3.00	N/A	2.50	2.71	0.00
3	1.20	1.50	1.00	1.00	1.50
4	1.00	N/A	1.00	1.83	1.00
5	N/A	N/A	1.00	1.00	1.00
6	0.75	1.80	2.00	2.50	1.50
7	2.00	2.50	0.50	1.80	1.67
8	1.33	1.00	3.00	2.00	0.67
9	2.00	1.00	1.00	2.50	1.00
10	1.80	3.00	3.00	3.00	1.00
11	N/A	N/A	N/A	3.00	1.67
12	2.00	1.25	2.00	0.75	0.50
13	0.75	0.00	1.50	1.67	1.50
14	1.00	N/A	N/A	1.00	1.00
15	2.50	2.33	2.00	2.00	0.67
16	0.00	N/A	N/A	1.00	N/A
17	1.50	1.00	N/A	-1.00	N/A
18	1.00	N/A	N/A	0.00	N/A
19	1.00	0.00	0.00	0.00	0.13
20	1.67	2.00	2.00	2.00	1.00
21	1.60	1.67	1.00	0.67	1.50
22	2.00	2.25	1.00	2.25	3.00
23	2.00	2.00	2.00	2.50	2.00
24	1.33	1.00	2.00	1.71	1.00
25	0.75	N/A	1.00	0.00	0.00
26	0.00	N/A	0.00	1.00	1.00
27	0.00	N/A	0.67	1.00	0.25
28	N/A	-1.00	N/A	1.33	N/A
29	1.67	1.50	2.00	2.00	1.67
30	1.00	1.00	1.00	1.33	1.00
31	2.00	N/A	2.00	2.40	0.50
32	-0.33	2.00	-2.00	-1.40	-1.20
33	3.00	1.50	0.67	0.57	0.00
34	1.00	0.50	2.00	2.43	1.50
35	1.20	0.00	0.00	0.50	0.00
36	0.50	N/A	2.00	2.20	1.00
37	N/A	N/A	N/A	3.00	1.00
38	2.33	N/A	N/A	2.00	N/A
39	0.33	0.33	0.00	0.25	1.00
40	2.00	N/A	2.00	1.00	N/A
41	3.00	N/A	N/A	2.00	N/A
42	1.00	0.75	0.67	0.33	1.00
43	N/A	1.00	N/A	1.00	N/A
44	1.00	1.50	2.00	1.25	N/A
45	0.00	-1.00	N/A	0.00	N/A
46	N/A	2.50	1.00	N/A	0.00
47	N/A	N/A	N/A	N/A	2.33
48	N/A	N/A	N/A	1.00	1.00
49	1.00	N/A	3.00	0.00	0.80

50	3.00	N/A	2.50	2.50	2.00
51	N/A	N/A	N/A	N/A	0.00
52	3.00	N/A	0.50	N/A	3.00
53	N/A	N/A	N/A	2.50	2.00
54	2.00	1.00	1.50	N/A	1.00
55	3.00	N/A	2.50	2.00	2.00
56	2.00	2.60	2.00	1.25	1.00
57	2.00	N/A	3.00	0.00	2.25
58	2.00	0.50	N/A	2.00	N/A
59	1.33	1.33	1.00	1.67	0.40
60	N/A	2.00	N/A	0.50	1.33
61	0.00	N/A	0.00	2.00	1.83
62	N/A	N/A	2.00	3.00	2.00
63	0.67	N/A	1.00	2.33	1.00
64	1.00	1.50	1.00	3.00	2.00
65	2.00	1.00	1.50	0.75	1.00
66	N/A	2.00	2.50	2.25	2.00
67	0.00	-1.00	-0.50	0.00	0.33
68	2.00	N/A	N/A	3.00	3.00
69	2.00	1.50	N/A	1.75	N/A
70	3.00	N/A	1.00	1.50	2.75
71	2.00	N/A	2.00	1.67	0.40
72	2.67	3.00	2.50	2.33	2.00
73	2.00	N/A	2.00	1.00	1.40
74	1.00	N/A	1.00	1.67	1.00
75	N/A	N/A	N/A	-2.00	2.50
76	2.33	N/A	3.00	2.50	2.50
77	2.00	N/A	N/A	2.00	N/A
78	2.00	2.33	2.00	1.75	N/A
79	-1.00	-1.00	N/A	1.00	-1.00
80	2.00	N/A	2.00	2.00	2.00
81	2.00	N/A	N/A	N/A	1.67
82	2.50	3.00	2.33	2.67	1.00
83	N/A	N/A	N/A	3.00	1.75
84	2.00	3.00	1.50	2.00	3.00
85	2.00	N/A	N/A	2.00	N/A
86	N/A	N/A	N/A	1.00	1.00
87	2.00	N/A	N/A	3.00	N/A
88	1.00	1.50	1.00	1.00	1.00
89	2.00	3.00	2.00	3.00	2.50
90	3.00	3.00	1.00	3.00	2.00
91	N/A	N/A	N/A	N/A	N/A
92	N/A	1.00	N/A	1.00	-1.00
93	1.00	1.00	1.67	1.00	1.00
94	2.00	2.25	3.00	2.75	2.33
95	N/A	N/A	0.50	2.00	1.00
96	2.00	0.00	1.67	3.00	2.00
97	1.50	1.00	N/A	2.00	2.00
98	0.86	1.00	0.33	1.20	0.00
99	1.00	N/A	N/A	N/A	N/A
100	1.80	2.00	1.25	2.40	1.40
101	N/A	N/A	N/A	N/A	N/A
102	1.00	N/A	N/A	1.50	N/A
103	0.75	0.25	1.33	1.00	0.00
104	1.80	0.75	1.40	1.67	2.38

(2) No filtering of practices and filtering of impacts
All the selected 104 practices are considered, while some ecological and off-site impacts are aggregated to avoid redundancies

SLM practice	Climate regul.	Biodiversity […]	Soil quality	Soil erosion […]	Water regul.
1	0.33	N/A	0.20	0.83	0.50
2	3.00	N/A	2.50	2.71	0.00
3	1.20	1.50	1.00	1.00	1.50
4	1.00	N/A	1.00	1.83	1.00
5	N/A	N/A	1.00	1.00	1.00
6	0.75	1.80	2.00	2.50	1.50
7	2.00	2.50	0.50	1.80	1.67
8	1.33	1.00	3.00	2.00	0.67
9	2.00	1.00	1.00	2.50	1.00
10	2.00	3.00	3.00	3.00	1.00
11	N/A	N/A	N/A	3.00	1.67
12	2.00	1.25	2.00	0.75	0.50
13	0.75	0.00	1.50	1.67	1.50
14	1.00	N/A	N/A	1.00	1.00
15	2.50	2.33	2.00	2.00	0.67
16	0.00	N/A	N/A	1.00	N/A
17	1.50	1.00	N/A	-1.00	N/A
18	1.00	N/A	N/A	0.00	N/A
19	1.00	0.00	0.00	0.00	0.13
20	1.67	2.00	2.00	2.00	1.00
21	1.50	1.67	1.00	0.67	1.50
22	2.00	2.25	1.00	2.25	3.00
23	N/A	2.00	2.00	2.50	2.00
24	1.33	1.00	2.00	1.71	1.00
25	0.75	N/A	1.00	0.00	0.00
26	0.00	N/A	0.00	1.00	1.00
27	0.00	N/A	0.67	1.00	0.25
28	N/A	-1.00	N/A	1.33	N/A
29	1.67	1.50	2.00	2.00	1.67
30	1.00	1.00	1.00	1.33	1.00
31	2.00	N/A	2.00	2.40	0.50
32	-0.33	2.00	-2.00	-1.40	-1.20
33	3.00	1.50	0.67	0.57	0.00
34	1.00	0.50	2.00	2.43	1.50
35	0.75	0.00	0.00	0.56	0.00
36	0.50	N/A	2.00	2.20	1.00
37	N/A	N/A	N/A	3.00	1.00
38	2.00	N/A	N/A	2.00	N/A
39	0.33	0.33	0.00	0.25	1.00
40	2.00	N/A	2.00	2.00	N/A
41	3.00	N/A	N/A	2.00	N/A
42	1.00	0.75	0.67	0.33	1.00
43	N/A	1.00	N/A	1.00	N/A
44	1.00	1.50	2.00	1.25	N/A
45	0.00	-1.00	N/A	0.00	N/A
46	N/A	2.50	1.00	N/A	0.00
47	N/A	N/A	N/A	N/A	2.33
48	N/A	N/A	N/A	1.00	1.00
49	1.00	N/A	3.00	0.00	0.80
50	3.00	N/A	2.50	2.50	2.00
51	N/A	N/A	N/A	N/A	0.00
52	3.00	N/A	2.00	N/A	3.00

53	N/A	N/A	N/A	2.50	2.00
54	2.00	1.00	1.50	N/A	1.00
55	3.00	N/A	2.50	2.00	2.00
56	2.00	2.60	2.00	1.25	1.00
57	2.00	N/A	3.00	0.00	2.25
58	2.00	0.50	N/A	2.00	N/A
59	1.33	1.33	1.00	1.67	0.40
60	N/A	2.00	N/A	0.50	1.33
61	0.00	N/A	0.00	2.00	1.83
62	N/A	N/A	2.00	3.00	2.00
63	0.67	N/A	1.00	2.33	1.00
64	1.00	1.50	1.00	3.00	2.00
65	2.00	1.00	1.50	0.75	1.00
66	N/A	2.00	2.00	2.25	2.00
67	0.00	-1.00	-0.50	0.00	0.33
68	2.00	N/A	N/A	3.00	3.00
69	2.00	1.50	N/A	1.75	N/A
70	3.00	N/A	1.00	1.50	2.75
71	2.00	N/A	2.00	1.67	1.00
72	2.67	3.00	2.50	2.33	2.00
73	2.00	N/A	2.00	1.00	1.40
74	1.00	N/A	1.00	1.67	1.00
75	N/A	N/A	N/A	-2.00	2.50
76	2.33	N/A	N/A	2.50	2.67
77	2.00	N/A	N/A	2.00	N/A
78	2.00	2.33	2.00	1.67	N/A
79	-1.00	-1.00	N/A	-1.00	-1.00
80	2.00	N/A	2.00	2.00	2.00
81	N/A	N/A	N/A	N/A	1.67
82	2.00	3.00	2.33	2.50	1.00
83	N/A	N/A	N/A	3.00	1.75
84	2.00	3.00	1.50	2.00	3.00
85	2.00	N/A	N/A	2.00	N/A
86	N/A	N/A	N/A	1.00	1.00
87	2.00	N/A	N/A	3.00	N/A
88	1.00	1.50	1.00	1.00	1.00
89	2.00	3.00	2.00	3.00	2.50
90	3.00	3.00	1.00	3.00	2.00
91	N/A	N/A	N/A	N/A	N/A
92	N/A	1.00	N/A	1.00	-1.00
93	1.00	1.00	1.67	1.00	1.00
94	2.00	2.25	3.00	2.75	2.33
95	N/A	N/A	0.50	2.00	1.00
96	2.00	0.00	1.00	3.00	2.00
97	1.00	1.00	N/A	2.00	2.00
98	0.75	1.00	0.33	1.03	0.00
99	N/A	N/A	N/A	N/A	N/A
100	1.67	2.00	1.25	2.34	1.40
101	N/A	N/A	N/A	N/A	N/A
102	N/A	N/A	N/A	1.50	N/A
103	0.75	0.25	1.33	1.00	0.00
104	1.80	0.75	1.40	1.67	2.38

List of aggregated impacts. In bold the renewed assessed impacts, in black the ecological impacts, and in grey the off-site impacts. N refers to the number of practices that have assessed each impact. Note that we have not combined on-site with off-site impacts.

Impact of extreme weather event (total n=12)
Hazards towards adverse events (n=4)
Flood impact (n=5)
Drought impact (n=6)
Impacts of cyclons/rain storms (n=2)
Soil loss/erosion (total n=70)
Soil loss (n=69)
Soil erosion (n=1)
Wind erosion (n=1)
Downstream flow (total n=17)
Reliable and stable stream flow in the dry season (n=16)
Runoff (n=1)
Surface water to reach downstream (n=1)
Soil cover (total n=54)
Soil cover (n=52)
Vegentation cover (n=8)
Animal diversity
(total n=27)
Animal diversity (n=26)
Soil livings (n=1)
Peast/disease control (total n=27)
Peast/disease control (n=25)
Invasive alien species(n=2)

The obtained filtered impacts are: Landslides/debris flows; Acidity; Soil surface temperature; Risk of overgrazing in the woodland; Waste; Risk of contamination of aquifers; Soil fertility; Soil accumulation; Micro-climate; Impact of extreme weather event; Impact of GHG; Natural seed multiply and supply.

(3) Filtering of practices and no filtering of impacts
All original ecological and off-site- impacts are considered. Instead, those practices that do not assist with a >1,25 to any of the five ecological variables are filtered.

SLM practice	Climate regul.	Biodiversity […]	Soil quality	Soil erosion […]	Water regul.
2	3.00	N/A	2.50	2.71	0.00
3	1.20	1.50	1.00	1.00	1.50
4	1.00	N/A	1.00	1.83	1.00
6	0.75	1.80	2.00	2.50	1.50
7	2.00	2.50	0.50	1.80	1.67
8	1.33	1.00	3.00	2.00	0.67
9	2.00	1.00	1.00	2.50	1.00
10	1.80	3.00	3.00	3.00	1.00
11	N/A	N/A	N/A	3.00	1.67
12	2.00	1.25	2.00	0.75	0.50
13	0.75	0.00	1.50	1.67	1.50
15	2.50	2.33	2.00	2.00	0.67
17	1.50	1.00	N/A	-1.00	N/A
20	1.67	2.00	2.00	2.00	1.00
21	1.60	1.67	1.00	0.67	1.50
22	2.00	2.25	1.00	2.25	3.00
23	2.00	2.00	2.00	2.50	2.00
24	1.33	1.00	2.00	1.71	1.00

28	N/A	-1.00	N/A	1.33	N/A	**65**	2.00	1.00	1.50	0.75	1.00
29	1.67	1.50	2.00	2.00	1.67	**66**	N/A	2.00	2.50	2.25	2.00
30	1.00	1.00	1.00	1.33	1.00	**68**	2.00	N/A	N/A	3.00	3.00
31	2.00	N/A	2.00	2.40	0.50	**69**	2.00	1.50	N/A	1.75	N/A
32	-0.33	2.00	-2.00	-1.40	-1.20	**70**	3.00	N/A	1.00	1.50	2.75
33	3.00	1.50	0.67	0.57	0.00	**71**	2.00	N/A	2.00	1.67	0.40
34	1.00	0.50	2.00	2.43	1.50	**72**	2.67	3.00	2.50	2.33	2.00
36	0.50	N/A	2.00	2.20	1.00	**73**	2.00	N/A	2.00	1.00	1.40
37	N/A	N/A	N/A	3.00	1.00	**74**	1.00	N/A	1.00	1.67	1.00
38	2.33	N/A	N/A	2.00	N/A	**75**	N/A	N/A	N/A	-2.00	2.50
40	2.00	N/A	2.00	1.00	N/A	**76**	2.33	N/A	3.00	2.50	2.50
41	3.00	N/A	N/A	2.00	N/A	**77**	2.00	N/A	N/A	2.00	N/A
44	1.00	1.50	2.00	1.25	N/A	**78**	2.00	2.33	2.00	1.75	N/A
46	N/A	2.50	1.00	N/A	0.00	**80**	2.00	N/A	2.00	2.00	2.00
47	N/A	N/A	N/A	N/A	2.33	**81**	2.00	N/A	N/A	N/A	1.67
49	1.00	N/A	3.00	0.00	0.80	**82**	2.50	3.00	2.33	2.67	1.00
50	3.00	N/A	2.50	2.50	2.00	**83**	N/A	N/A	N/A	3.00	1.75
52	3.00	N/A	0.50	N/A	3.00	**84**	2.00	3.00	1.50	2.00	3.00
53	N/A	N/A	N/A	2.50	2.00	**85**	2.00	N/A	N/A	2.00	N/A
54	2.00	1.00	1.50	N/A	1.00	**87**	2.00	N/A	N/A	3.00	N/A
55	3.00	N/A	2.50	2.00	2.00	**88**	1.00	1.50	1.00	1.00	1.00
56	2.00	2.60	2.00	1.25	1.00	**89**	2.00	3.00	2.00	3.00	2.50
57	2.00	N/A	3.00	0.00	2.25	**90**	3.00	3.00	1.00	3.00	2.00
58	2.00	0.50	N/A	2.00	N/A	**93**	1.00	1.00	1.67	1.00	1.00
59	1.33	1.33	1.00	1.67	0.40	**94**	2.00	2.25	3.00	2.75	2.33
60	N/A	2.00	N/A	0.50	1.33	**95**	N/A	N/A	0.50	2.00	1.00
61	0.00	N/A	0.00	2.00	1.83	**96**	2.00	0.00	1.67	3.00	2.00
62	N/A	N/A	2.00	3.00	2.00	**97**	1.50	1.00	N/A	2.00	2.00
63	0.67	N/A	1.00	2.33	1.00	**100**	1.80	2.00	1.25	2.40	1.40
64	1.00	1.50	1.00	3.00	2.00	**102**	1.00	N/A	N/A	1.50	N/A

103	0.75	0.25	1.33	1.00	0.00
104	1.80	0.75	1.40	1.67	2.38

The obtained filtered practices are: 1, 5, 14, 16, 18, 19, 25, 26, 27, 35, 39, 42, 43, 45, 48, 51, 67, 79, 86, 91, 92, 98, 99, 101

(4) Filtering of practices and of impacts

This scenario takes into account both the reduction in number of practices and the aggregation and filtering of the ecological and off-site- impacts. N refers to the number of observations in relation with the total possible for each variable

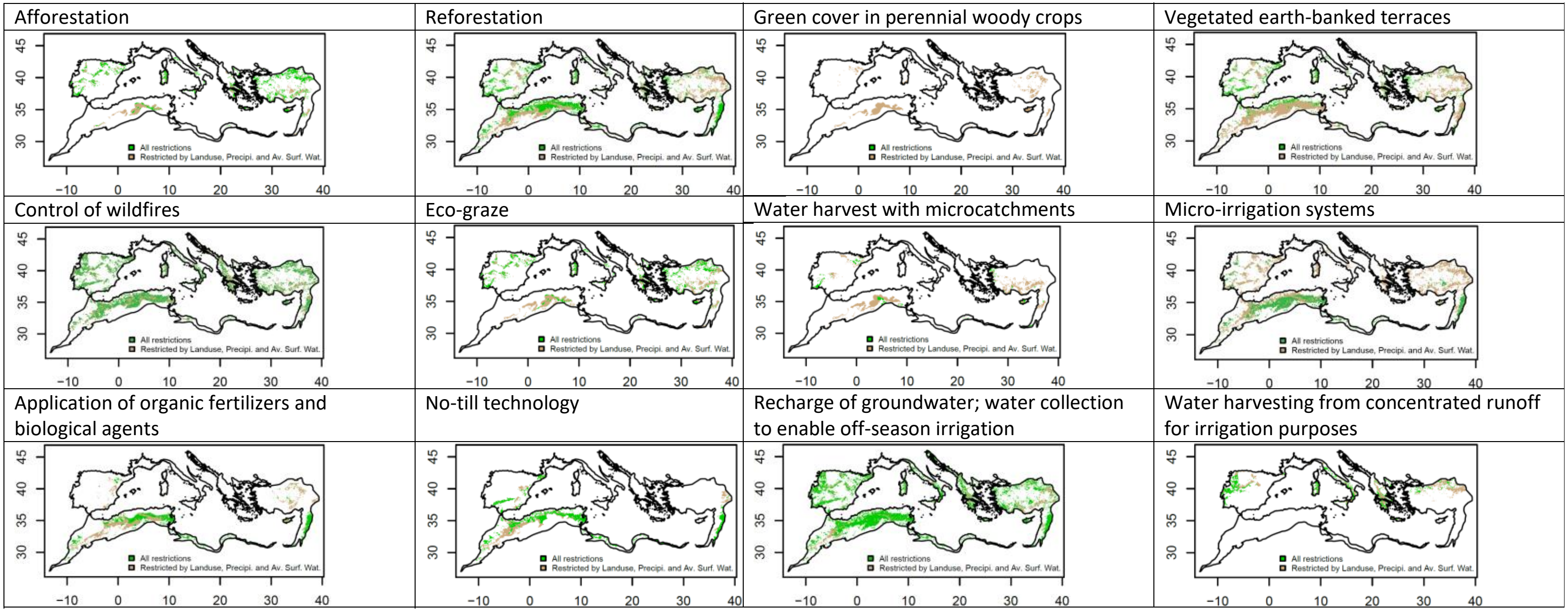
SLM practice	Clima [...]	N/6	Biodivers. [...]	N/5	Soil quality	N/5	Soil erosion	N/9	Water regulation	N/9	Average	N/34
2	3.00	*2*	N/A	*0*	2.50	*2*	2.71	*7*	0.00	*3*	2.05	*14*
3	1.20	*5*	1.50	*2*	1.00	*3*	1.00	*2*	1.50	*2*	1.24	*14*
4	1.00	*2*	N/A	*0*	1.00	*3*	1.83	*6*	1.00	*2*	1.21	*13*
6	0.75	*4*	1.80	*5*	2.00	*3*	2.50	*4*	1.50	*4*	1.71	*20*
7	2.00	*4*	2.50	*4*	0.50	*4*	1.80	*5*	1.67	*3*	1.69	*20*
8	1.33	*3*	1.00	*4*	3.00	*1*	2.00	*6*	0.67	*3*	1.60	*17*
9	2.00	*2*	1.00	*1*	1.00	*2*	2.50	*4*	1.00	*1*	1.50	*10*
10	2.00	*2*	3.00	*2*	3.00	*2*	3.00	*2*	1.00	*1*	2.40	*9*
11	N/A	*0*	N/A	*0*	N/A	*0*	3.00	*2*	1.67	*3*	2.33	*5*
12	2.00	*2*	1.25	*4*	2.00	*1*	0.75	*4*	0.50	*2*	1.30	*13*
13	0.75	*4*	0.00	*3*	1.50	*2*	1.67	*6*	1.50	*4*	1.08	*19*
15	2.50	*2*	2.33	*3*	2.00	*3*	2.00	*1*	0.67	*3*	1.90	*12*
17	1.50	*2*	1.00	*1*	N/A	*0*	-1.00	*1*	N/A	*0*	0.50	*4*
20	1.67	*3*	2.00	*3*	2.00	*1*	2.00	*3*	1.00	*3*	1.73	*13*
21	1.50	*4*	1.67	*3*	1.00	*2*	0.67	*3*	1.50	*2*	1.27	*14*
22	2.00	*2*	2.25	*4*	1.00	*3*	2.25	*4*	3.00	*1*	2.10	*14*

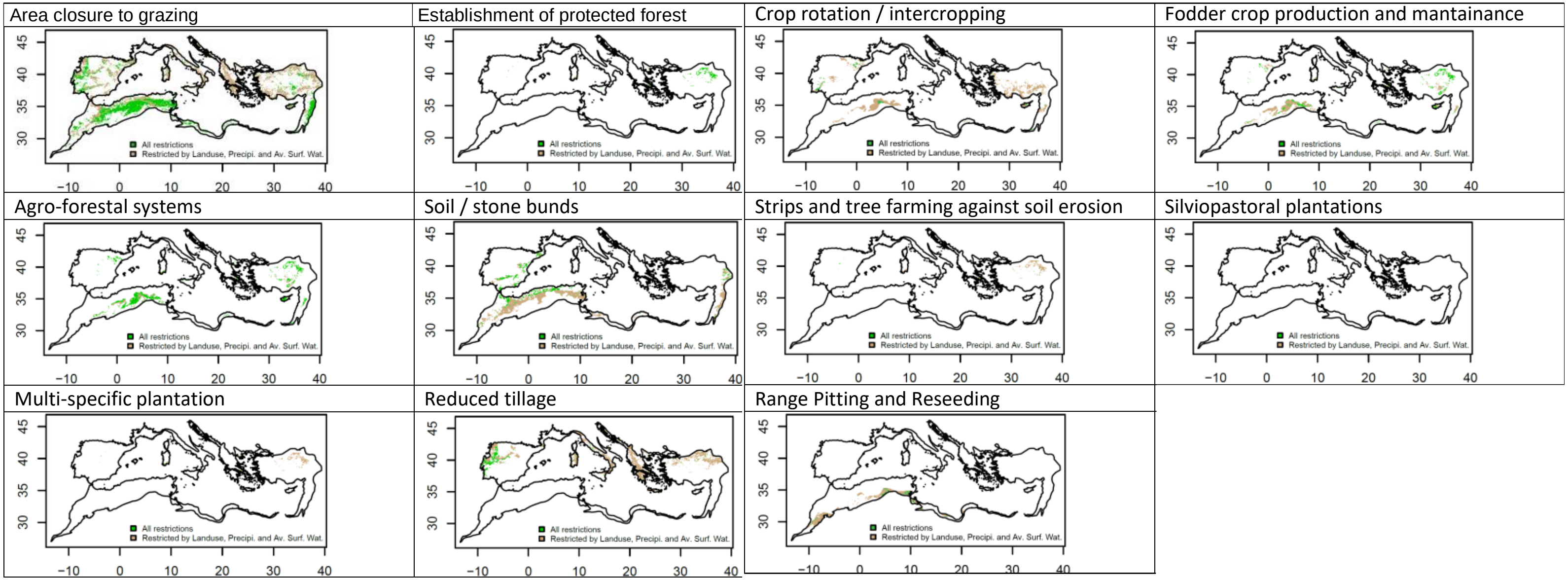
23	N/A	*0*	2.00	*2*	2.00	*2*	2.50	*2*	2.00	*1*	2.13	*7*
24	1.33	*3*	1.00	*2*	2.00	*2*	1.71	*7*	1.00	*4*	1.41	*18*
28	N/A	*0*	-1.00	*1*	N/A	*0*	1.33	*3*	N/A	*0*	0.17	*4*
29	1.67	*3*	1.50	*4*	2.00	*1*	2.00	*3*	1.67	*3*	1.77	*14*
30	1.00	*2*	1.00	*1*	1.00	*2*	1.33	*3*	1.00	*4*	1.07	*12*
31	2.00	*1*	N/A	*0*	2.00	*1*	2.40	*5*	0.50	*4*	1.73	*11*
32	-0.33	*3*	2.00	*1*	-2.00	*3*	-1.40	*6*	-1.20	*5*	-0.59	*18*
33	3.00	*1*	1.50	*4*	0.67	*3*	0.57	*7*	0.00	*3*	1.15	*18*
34	1.00	*2*	0.50	*2*	2.00	*1*	2.43	*7*	1.50	*6*	1.49	*18*
36	0.50	*2*	N/A	*0*	2.00	*2*	2.20	*5*	1.00	*2*	1.43	*11*
37	N/A	*0*	N/A	*0*	N/A	*0*	3.00	*2*	1.00	*1*	2.00	*3*
38	2.00	*2*	N/A	*0*	N/A	*0*	2.00	*2*	N/A	*0*	2.00	*4*
40	2.00	*2*	N/A	*0*	2.00	*1*	2.00	*3*	N/A	*0*	2.00	*6*
41	3.00	*1*	N/A	*0*	N/A	*0*	2.00	*2*	N/A	*0*	2.50	*3*
44	1.00	*1*	1.50	*2*	2.00	*1*	1.25	*4*	N/A	*0*	1.44	*8*
46	N/A	*0*	2.50	*2*	1.00	*1*	N/A	*0*	0.00	*1*	1.17	*4*
47	N/A	*0*	N/A	*0*	N/A	*0*	N/A	*0*	2.33	*3*	2.33	*3*
49	1.00	*1*	N/A	*0*	3.00	*2*	0.00	*1*	0.80	*5*	1.20	*9*
50	3.00	*1*	N/A	*0*	2.50	*2*	2.50	*2*	2.00	*3*	2.50	*8*
52	3.00	*1*	N/A	*0*	2.00	*1*	N/A	*0*	3.00	*2*	2.67	*4*
53	N/A	*0*	N/A	*0*	N/A	*0*	2.50	*2*	2.00	*2*	2.25	*4*
54	2.00	*2*	1.00	*1*	1.50	*2*	N/A	*0*	1.00	*1*	1.38	*6*
55	3.00	*1*	N/A	*0*	2.50	*2*	2.00	*2*	2.00	*3*	2.38	*8*
56	2.00	*2*	2.60	*5*	2.00	*1*	1.25	*4*	1.00	*1*	1.77	*13*
57	2.00	*1*	N/A	*0*	3.00	*1*	0.00	*2*	2.25	*4*	1.81	*8*
58	2.00	*3*	0.50	*2*	N/A	*0*	2.00	*5*	N/A	*0*	1.50	*10*
59	1.33	*3*	1.33	*3*	1.00	*4*	1.67	*6*	0.40	*5*	1.15	*21*
60	N/A	*0*	2.00	*1*	N/A	*0*	0.50	*4*	1.33	*3*	1.28	*8*
61	0.00	*1*	N/A	*0*	0.00	*2*	2.00	*1*	1.83	*6*	0.96	*10*
62	N/A	*0*	N/A	*0*	2.00	*1*	3.00	*1*	2.00	*1*	2.33	*3*

63	0.67	*3*	N/A	*0*	1.00	*1*	2.33	*3*	1.00	*4*	1.25	*11*
64	1.00	*1*	1.50	*4*	1.00	*2*	3.00	*2*	2.00	*1*	1.70	*10*
65	2.00	*1*	1.00	*3*	1.50	*2*	0.75	*4*	1.00	*2*	1.25	*12*
66	N/A	*0*	2.00	*3*	2.00	*1*	2.25	*4*	2.00	*1*	2.06	*9*
68	2.00	*1*	N/A	*0*	N/A	*0*	3.00	*1*	3.00	*1*	2.67	*3*
69	2.00	*3*	1.50	*2*	N/A	*0*	1.75	*4*	N/A	*0*	1.75	*9*
70	3.00	*1*	N/A	*0*	1.00	*1*	1.50	*2*	2.75	*4*	2.06	*8*
71	2.00	*1*	N/A	*0*	2.00	*1*	1.67	*3*	1.00	*4*	1.67	*9*
72	2.67	*3*	3.00	*1*	2.50	*2*	2.33	*6*	2.00	*4*	2.50	*16*
73	2.00	*1*	N/A	*0*	2.00	*1*	1.00	*1*	1.40	*5*	1.60	*8*
74	1.00	*1*	N/A	*0*	1.00	*1*	1.67	*3*	1.00	*5*	1.17	*10*
75	N/A	*0*	N/A	*0*	N/A	*0*	-2.00	*3*	2.50	*2*	0.25	*5*
76	2.33	*3*	N/A	*0*	N/A	*0*	2.50	*2*	2.67	*3*	2.50	*8*
77	2.00	*2*	N/A	*0*	N/A	*0*	2.00	*3*	N/A	*0*	2.00	*5*
78	2.00	*2*	2.33	*3*	2.00	*2*	1.67	*3*	N/A	*0*	2.00	*10*
80	2.00	*1*	N/A	*0*	2.00	*2*	2.00	*1*	2.00	*1*	2.00	*5*
81	N/A	*0*	N/A	*0*	N/A	*0*	N/A	*0*	1.67	*3*	1.67	*3*
82	2.00	*2*	3.00	*3*	2.33	*3*	2.50	*4*	1.00	*6*	2.17	*18*
83	N/A	*0*	N/A	*0*	N/A	*0*	3.00	*1*	1.75	*4*	2.38	*5*
84	2.00	*1*	3.00	*1*	1.50	*2*	2.00	*2*	3.00	*1*	2.30	*7*
85	2.00	*2*	N/A	*0*	N/A	*0*	2.00	*2*	N/A	*0*	2.00	*4*
87	2.00	*1*	N/A	*0*	N/A	*0*	3.00	*1*	N/A	*0*	2.50	*2*
88	1.00	*3*	1.50	*4*	1.00	*1*	1.00	*5*	1.00	*3*	1.10	*16*
89	2.00	*2*	3.00	*1*	2.00	*2*	3.00	*5*	2.50	*2*	2.50	*12*
90	3.00	*1*	3.00	*1*	1.00	*2*	3.00	*1*	2.00	*1*	2.40	*6*
93	1.00	*3*	1.00	*5*	1.67	*3*	1.00	*5*	1.00	*5*	1.13	*21*
94	2.00	*2*	2.25	*4*	3.00	*1*	2.75	*4*	2.33	*5*	2.47	*16*
95	N/A	*0*	N/A	*0*	0.50	*2*	2.00	*2*	1.00	*2*	1.17	*6*
96	2.00	*2*	0.00	*1*	1.00	*2*	3.00	*3*	2.00	*1*	1.60	*9*
97	1.00	*3*	1.00	*3*	N/A	*0*	2.00	*3*	2.00	*2*	1.50	*11*

100	1.67	*3*	2.00	*2*	1.25	*4*	2.34	*9*	1.40	*5*	1.73	*23*
102	N/A	*0*	N/A	*0*	N/A	*0*	1.50	*2*	N/A	*0*	1.50	*2*
103	0.75	*4*	0.25	*4*	1.33	*3*	1.00	*7*	0.00	*7*	0.67	*25*
104	1.80	*5*	0.75	*4*	1.40	*5*	1.67	*9*	2.38	*8*	1.60	*31*

Annex-A2. Map for each of the 25 practices, in where it is highlighted all regions within the basin that meet the baseline conditions in where each practice has been previously implemented





Annex-B1. List of the 35 selected studies

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Annex-B2. Assessment of the presence of a positive, negative, and/or neutral influence to CCP and to other variables for each study and identified driver. Abbreviations stand for: (SB) survey-based study (SD) social disclosure, (SA) secondary analysis, (MA) meta-analysis, (PR) peer-reviewed, (GL) grey literature, (QN) quantitative, (QL) qualitative, (+) positive interaction, (-) negative interaction, (0) neutral interaction.

Ref.	**Date of info**	**Area of study**	**Data**	**Type of study**			**(+) to CCP**	**(-) to CCP**	**(0) to CCP**	**(+) drivers**	**(-) drivers**	**(0) drivers**
Akerlof et al., 2010	2008–2009	International	4,307 questionnaires	SB	PR	QN	45, 81			45 to 81	125 to 45	
Bord et al., 1998	1997	International	1,225 questionaries	SB	PR	QN	71, 86, 81		93	125 to 93		

Brechin, 2003	1989–2002	International	24 countries	SA	PR	QN	31, 87, 51, 93, 72		71	102 to 81		71 to 72 / 51 to 93
Briggs et al., 2014	2012–2014	United Kingdom (UK)	>200 articles	SA	GL	QN	31, 32, 33, 101, 102, 103, 104			31 to 104, 84	102 to 31	
Brügger et al., 2015	–	International	–	SD	PR	QL	41, 42, 43, 44, 45, 86, 85, 81	41, 42, 43, 44, 45	41, 42, 43, 44, 45, 81, 85	85, 86 to 42, 43, 93 / 42, 43 to 86 / 41 to 93 / 41, 42, 43, 44, 45 to 81	85 to 42, 43, 93 / 42, 43 to 86	
Budescu et al., 2014	–	International	10,792 questionaries	SB	PR	QN	87, 86, 103, 71, 72, 104, 81			101, 103, 104 to 86, 87		
Capstick et al., 2015	1980–2014	International	33 studies	MA	PR	QN	51, 102, 103, 42, 44, 91, 33, 71, 87, 86, 111, 112, 114, 115	102, 112, 114, 115, 94, 81	103	102, 103 to 51, 87, 86, 81 / 51 to 42, 87, 86 / 91, 94 to 102, 103, 104, 86 / 85, 51 to 86 / 101, 102, 86 to 87, 81 / 42 to 86, 81 / 42, 44 to 85	102, 103 to 51, 87, 86, 81, 33 / 101, 102, 86 to 87 / 42 to 86, 81 / 111, 112, 114, 115 to 86	
Chan et al., 2016	–	–	–	SD	PR	QL	81, 85, 86	85		61 to 84, 86 / 85 to 86 / 86 to 81		
Chuang et al., 2016	–	China	453 survey	SB	PR	QN	85, 86			85 to 86, 93 / 86 to 85		
Clayton et al., 2015	–	–	–	SD	PR	QL	41, 42, 43, 44, 45, 85, 86, 84, 104, 51, 33, 102, 104	102, 85	71, 31, 32	111, 102, 103, 104 to 71, 72, 31, 33 / 41, 42, 43, 44, 45 to 81	102, 103, 104 to 71, 72, 31, 33	

Cook and Lewandowsky, 2016	2013	International	735 questionaries	SB	PR	QN	33, 87, 84, 94	94		33 to 87 / 51 to 33, 87 / 86 to 84 / 94 to 33	94 to 33, 84, 87 / 51 to 54	
Cook et al., 2013	1991–2011	International	11,944 studies	MA	PR	QN	33	111, 112, 114, 115			111, 112, 114, 115, 102, 103 to 33	
Doherty and Clayton, 2011	–	–	–	SD	PR	QL	41, 42, 43, 44, 45, 81, 84, 85, 86			41, 42, 43, 44, 45 to 81, 85, 86		
Franzen and Vogl, 2013	2010–2012	International	33 countries	SA	PR	QN	51, 71, 81, 85, 86, 91, 125, 72, 84		122, 123	122, 123 to 81 / 71 to 33, 81 / 51, 84 to 87, 81 / 125 to 91 / 91 to 81, 93		
Hanemann et al., 2011	2010	Spain	750 questionaries	SB	GL	QN	85	85	93	85 to 93		81, 71, 42, 86, 87 to 93
Hope and Jones, 2014	2012	United Kingdom (UK)	18 people	SB	PR	QN	86	61	61	61 to 86, 84		
Hornsey et al., 2016	–	International	25 questionaroes & 171 studies	MA	PR	QN	33, 41, 42, 51, 71, 86, 91, 112, 121, 123, 122	94, 85		85, 86, 71, 41,42 to 87 / 112 to 86/115 to 94, 94 to 115 / 86, 84 to 71	94 to 33, 71	
Howe et al., 2012	–	International	91,073 questionaries	SB	PR	QN	42			41, 42 to 87 / 122, 123 to 42		
Leas et al., 2016	2011–2016	International	Bloomberg l, Google searc	SA	PR	QN	21			21 to 101, 102, 104, 72		

			Twitter								
Lee et al., 2015	2015	International	119 countries	MA	PR	QN	71, 87, 86, 101, 85, 125, 51, 103, 104, 42, 41, 93	123, 122, 45	91	125 to 71, 72, 101, 85, 91,/ 71 to 71, 72 / 91 to 41, 42, 71, 72	125 to 41, 42, 43, 44, 45, 85 / 91 to 43, 44, 45	
Leiserowitz et al., 2013	2011	India	4,031 questionaries	SB	GL	QN	81, 87, 86, 42	86	87	125 to 71	125 to 93	125 to 86, 42, 41, 87, 81, 84
Leiserowitz, 2007	2007	International	Sur-veys	SB	GL	QN	125, 71, 45, 41, 42, 93, 87			125 to 71, 41, 43 / 81 to 41, 42, 43, 44, 45	125 to 44, 45, 43, 42, 41	125 to 87
Leviston et al., 2012	2010–2011	Australia	10,066 questionaries	SB	PR	QN	85, 86, 51			85 to 85, 84, 86, 81 / 86 to 85	85 to 84, 86, 81 / 86 to 85	
McCright et al., 2016	1998–2016	International	25 studies	SA	PR	QN	81, 86, 87, 51, 123, 71, 33, 42, 84		123, 122, 91, 61, 121, 42, 41	51 to 81, 85, 86 / 84 to 87		
Meira-Cartea et al., 2009	2008	Spain	1,200 questionaries	SB	GL	QN	71, 101, 42, 45, 93		32, 21	101, 104 , 21 to 72 / 123 to 93 / 125 to 41, 42 / 122 to 101, 93	71 to 101 / 123 to 102, 72	
Moyano et al., 2009	2001–2009	Spain	Ecobarómetro	SB	PR	QN	125, 42			42, 43 to 81		
O'Neill et al., 2015	2015	International	9 media chanel	SA	PR	QN	101, 102, 103, 104			101, 102, 103, 104 to 71, 72 / 103 to 84, 87 / 122 to 21		
Shi et al., 2016	2014	International	2,495 questionaries	SB	PR	QN	86, 85, 104, 123, 122, 71, 72		71, 72	71, 86 to 87, 81 / 86 to 42, 44, 45, 87, 81 / 104 to 71, 72		

Stern, 2016	–	Internatio nal	15 studies	S D	P R	Q L	51, 86	111, 112, 114, 115		71, 72 to 81, 84, 85 / 86 to 81, 93	111, 112, 114, 115 to 33, 51	71, 72 to 41, 42, 43, 44, 45
Sulemana et al., 2016	–	Internatio nal	Fifth Wave of the World Values Survey	S A	P R	Q N	41, 42, 43, 44, 45		91	42, 43, 44, 45, 91 to 93	125 to 41, 42, 43, 44, 45 / 94 to 93	125 to 93
Taylor et al., 2014	–	United Kingdom (UK)	44 studies	S A	P R	Q L	42, 51, 85	42, 85		81, 86 to 93 / 51 to 93 / 104, 42 to 81	42 to 81	41, 42, 87 to 93
Tjernström and Tietenberg, 2008	–	Internatio nal	<20 studies	S A	P R	Q N	71, 125, 84	91	61	71 to 41, 42, 43, 44, 45, 81 / 125 to 81, 84 / 122 to 81	33, 87 to 81	
van der Linden, 2014	2013	United Kingdom (UK)	808 questio naries	S B	P R	Q N	41, 81			41 to 81 / 86 to 81 / 81 to 86 / 71 to 86		
van der Linden, 2015	2007–2013	United Kingdom (UK)	10 studies	M A	P R	Q N	123, 51, 41, 42, 45		91, 71, 122			
Weber, 2016	2010–2015	Internatio nal	–	S D	P R	Q L	42, 122, 123			41, 42 to 93 / 81 to 87 / 87 to 81 / 41, 42, 43, 44, 45 to 81 / 81, 85 to 87, 93		

Annex-B3.

Information for Figure 5.2

Quantification of influence of drivers to CCP
(+) to CC, (-) to CC, (0) toCC
31,2,0,1
32,1,0,2
33,7,0,0
71,11,0,4
72,4,0,1
41,9,1,2
42,16,2,2
43,4,1,1
44,5,1,1
45,8,2,1
81,10,1,1
84,6,0,0
85,11,5,1
86,17,1,0
87,8,0,1
61,0,1,3
51,11,0,0
91,3,1,4
93,4,0,2
94,1,3,0
101,4,0,0
102,4,2,0
103,5,0,1
104,6,0,0
21,2,0,2
111,1,2,0
112,2,3,0
114,1,3,0
115,1,3,0
121,1,0,1
122,3,1,3
123,5,1,2
125,5,0,0

Annex-B4.

Information for Figure 5.3

Quantification between drivers
Source,Target, Weight
Positive
31,104,1
31,84,1
45,81,1
125,93,2
102,81,3
85,43,1
85,93,1
86,42,2
86,43,1
86,93,3
86,85,2
42,86,2
43,86,1
41,93,2
41,81,3
42,81,5
43,81,3
44,81,2
71,86,2
101,86,1
81,61,1
85,84,1
85,85,1
103,86,2
103,87,3
104,86,1
104,87,1
102,51,1
102,87,2
102,86,1
103,51,1
101,21,1
103,81,1
104,21,1
104,81,1
121,42,1
122,101,1
122,93,1
123,93,1
51,93,1
51,42,1
51,87,3
51,86,3
61,84,2
91,102,1
91,103,1
91,104,1
91,86,1
94,102,1
94,103,1
94,104,1
94,86,1
85,86,4
101,81,1
86,87,4
86,81,5
42,85,1
44,85,1
42,93,2
43,93,1
44,93,1

45,93,1	125,84,1	91,41,1	86,44,1	101,86,1
33,87,1	122,81,1	91,42,1	86,45,1	101,87,1
51,33,1	85,87,2	91,71,1	71,84,1	42,81,1
81,87,2	71,87,2	91,72,1	71,85,1	111,86,1
81,93,1	41,87,2	125,41,2	72,81,1	112,86,1
86,84,1	42,87,2	125,43,1	72,84,1	114,86,1
112,81,1	112,86,1	81,41,1	72,85,1	115,86,1
123,81,1	115,94,1	81,42,1	**Negative**	111,33,2
71,33,1	94,115,1	81,43,1	85,42,1	112,33,2
71,81,4	86,71,1	81,44,1	85,43,1	114,33,2
51,81,2	84,71,1	81,45,1	85,93,1	115,33,2
51,85,1	122,42,1	85,93,2	42,86,3	111,51,1
84,87,2	123,42,1	87,81,1	43,86,11	112,51,1
84,81,1	21,101,1	101,71,1	102,51,1	114,51,1
125,91,1	21,102,1	101,72,2	102,87,2	115,51,1
91,81,1	21,104,1	102,71,1	102,86,2	94,33,2
91,93,2	21,72,1	102,72,1	102,81,1	94,84,1
71,41,1	125,71,3	103,71,1	102,33,2	94,87,1
71,42,1	125,72,1	103,72,1	103,51,1	94,71,1
71,43,1	125,101,1	104,71,2	103,87,1	71,101,1
71,44,1	125,85,1	104,72,3	103,86,1	85,84,1
71,45,1	71,71,1	103,84,1	103,81,1	85,86,1
125,81,1	71,72,1	122,21,1	103,33,2	85,81,1

86,85,1	125,45,3	72,51,1	72,42,1	41,93,1
102,31,1	125,85,1	72,93,1	72,43,1	42,93,2
123,72,1	91,43,1	125,87,1	72,44,1	7193,1
123,102,1	91,44,1	125,93,1	72,45,1	81,93,1
125,93,1	91,45,1	71,41,1	125,86,1	86,93,1
94,93,1	33,81,1	71,42,1	125,42,1	87,93,2
125,41,3	87,81,1	71,43,1	125,41,1	
125,42,3	**Neutral**	71,44,1	125,87,1	
125,43,3	71,51,1	71,45,1	125,81,1	
125,44,3	71,93,1	72,41,1	125,84,1	

ID rename

Driver Class / Driver	raw id	paper id
Education and awareness of scientific work		
Consumption of scientific articles	31	1
Direct dealing with scientists	32	2
Awareness of scientific climate consensus	33	3
Self-perceived knowledge on CC	71	4
CC science literacy	72	5
Media exposure		
Media access	101	6
Volume of CC coverage	102	7
Popular media reports	103	8
Transdisciplinary communication	104	9
Online platforms	21	10
Influence of corporations		
Conservative public relations firms	111	11
Conservative elite cues	112	12
Conservative think tanks	114	13
Energy and oil sectors	115	14
Ethnography		
Emotional concern about CC	81	15
Trust	84	16
Collectivistic culture	85	17
Socio-altruistic values	86	18
Belief in anthropogenic CC	87	19
Religiosity	61	20
Liberalism supporter	51	21
Wealth		
Prosperity	91	22
Willingness to pay for CC polices	93	23
Free-market support	94	24
Personal experience and perception		
Extreme weather events	41	25
Changed weather	42	26
Loss of agricultural activity	43	27
Threatened cultures and ecosystems	44	28
Health impact	45	29
Demographics		
Non-white fraction	121	30
Young fraction	122	31
Female fraction	123	32
Urban community/developed nation	125	33