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Climate change adaptation and mitigation via targeted ecosystem service provision

Developing a sustainable land management strategy for the Segura catchment (SE Spain)

MSc thesis by Cecilia Zagaria

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Climate change adaptation and mitigation via targeted ecosystem service provision: developing a sustainable land management strategy for the Segura catchment (SE Spain)

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Abbreviations

AES- Agri-environmental Scheme
AFF- Afforestation, LULC transition
BD- Bulk Density
C- Carbon
CAP- Common Agricultural Policy
CARM- Comunidad Autónoma de la Región de Murcia (Government of the Autonomous Region of Murcia)
CC- Climate Change
CHS- Segura River Basin Authority
DEF- Deforestation, LULC transition
DEM- Digital Elevation Model
EBA- Ecosystem-based Adaptation
EBM- Ecosystem-based Mitigation
EOA- Extensification of Agriculture, LULC transition
ES- Ecosystem Service
EU- European Union
FAO- Food and Agriculture Organization
GHG- Greenhouse Gas
IPCC- Intergovernmental Panel on Climate Change
IOA- Intensification of Agriculture, LULC transition
LULC- Land Use and Land Cover
MA- Millennium Ecosystem Assessment
MARM- Ministerio de Agricultura, Alimentación y Medio Ambiente (Ministry of Environment and Rural and Marine Affairs, Spain)
PROVIA- Program of Research on Climate Change Vulnerability, Impact and Adaptation
RCP- Representative Concentration Pathway
RO- Research Objective
RTG- Green manuring and reduced tillage
SLM- Sustainable Land Management
SOM- Soil Organic Matter
SOC- Soil Organic Carbon
SWC- Soil and Water Conservation
SPS- Single Payment Scheme
SRES- Special Report on Emission Scenarios
UN- United Nations
UNCCD- United Nations Convention to Combat Desertification
UNEP- United Nations Environment Program
UNFCCC- United Nations Framework Convention on Climate Change
URB- Urbanization, LULC transition
USLE- Universal Soil Loss Equation
WMO- World Meteorological Organization

Abstract

Topical research investigating climate, land-use change and land management scenarios in the Segura catchment, SE Spain, depicts a landscape at high-risk of deserting agriculture. Land degradation in the semi-arid region of SE Spain is characterized by water shortages, high erosion rates and salinization, increasingly exacerbated by climatic changes, scarce vegetation cover and detrimental farming practices. Future climate scenarios predict increases in aridity, variability and intensity of rainfall events, leading to increasing pressure on scarce soil and water resources. This study conceptualized the impending crisis of agro-ecological systems of the Segura basin (18'800 km^2) as a crisis of ecosystem service (ES) deterioration. In light of existing land degradation drivers and future climate scenarios, the potential of Sustainable Land Management (SLM) strategies was evaluated to target three priority ESs (water provision, sediment retention and carbon sequestration) as a means to achieve climate change adaptation and mitigation. A preceding thorough process of stakeholder engagement (as part of the EU funded DESIRE project) indicated SLM technologies for potential implementation, all with a focus upon reducing soil erosion, increasing soil water holding capacity and soil organic matter content. These technologies have been tested for over four years in local experimental field plots, and have provided results on the local effects upon individual environmental parameters. Despite the growing emphasis witnessed in literature upon the context-specificity which characterizes adaptation solutions, the frequent analysis at the field scale is limited in both scope and utility. There is a need to investigate the effects of adaptive SLM solutions at wider, regional scales. Thus, this study modelled the cumulative effect of SLM technologies with InVEST, a spatial analyst tool designed for ES quantification and valuation. Additionally, the impact of historical land cover transitions on ES provision was modelled, as to ultimately develop a SLM strategy which would benefit from both local SLM technology implementation and SLM initiatives incorporating an element of land cover change. Scenario impacts upon the three selected ESs were evaluated under present and expected future climate conditions (A1B IPCC scenario storyline for 2050) using regional climate model predictions. Results are given for both the entire Segura catchment as well as for delineated sub-catchments. This study's value lies in providing relevant stakeholders with spatially explicit quantitative information upon current ecosystem service provision within the Segura, and into the considerable potential of SLM strategy implementation for building ecosystem service resilience to predicted climate change impacts. Results demonstrated respective increases of 3.25 and 0.61% for carbon storage and water yield and a decrease in sediment export of 35% following 100% adoption of reduced tillage and green manuring within fruit orchards and olive groves, compared to a 2050 climate change scenario with no SLM implementation across the Segura catchment. Results on detrimental impacts of climate change and historical land cover transitions have furthermore been used for the identification of priority areas for ES conservation of all three ESs investigated, and the potential of SLM for the safeguarding of ES provision evaluated accordingly at the sub-catchment scale. This study sheds light upon the opportunities and pitfalls of ES biophysical assessments whilst hoping to contribute towards the mainstreaming of the ESs concept in land management policy and research, familiarizing relevant stakeholders with the concept, facilitating scaling-up processes by communicating the necessity and a means to successfully achieve climate adaptation and mitigation.

Introduction

Dissatisfaction and skepticism were the defining emotional states of world leaders and interested onlookers alike reported by the media throughout the undertaking of the Rio +20 United Nations Conference on Sustainable Development (Monbiot 2012; Watts and Ford 2012). What these reports failed to sufficiently communicate, however, is what Luc Gnacadja, former Executive Secretary of the United Nations Convention to Combat Desertification (UNCCD), has claimed to be the beginning of a critical paradigm shift in the way land degradation is being perceived and managed (UNCCD, 2012). In its final outcome document, leaders acknowledged the importance land management strategies hold within climate adaptation and mitigation solutions, the protection of soil resources vital for food security, and thus for our future economic and social welfare. It was agreed that current farming practices cannot continue in their unsustainability, as global estimates project quasi two-fold increases in food, water and energy demands by 2030, all requiring further land inputs (UNCCD, 2012). A sense of disquieting urgency accompanied this newly acquainted consciousness; *this* - they thought- *is a last call for action towards a land degradation-neutral world.*

Land degradation in the Segura catchment of southeastern Spain is characterized by high erosion rates and salinization, partly driven by a warming climate (García-Ruiz, 2010). Recent Land Use and Land Cover (LULC) transitions in the region are witnessing trends of agricultural abandonment occurring alongside intensification, forest fragmentation, forest fires and marked tourist developments, presenting additional pressures to the land and exacerbating existing degradation concerns (Symeonakis, Calvo-Cases, and Arnau-Rosalen 2007; Nainggolan et al. 2013). A continuation of these trends alongside climate change predictions could ultimately result in the complete disappearance of the agricultural landscape within the majority of the Segura (Calatrava, Barbera, & Castillo, 2011). It is mandatory to build resilience and adaptation amongst local agro-ecosystems threatened by such degradation processes.

The current passivity of local agricultural land owners, having shown general disinterest in changing their production methods, and thus the adoption of erosion prevention techniques (unless they present very low costs), cannot continue to persist (Hein, 2007). Soil and water conservation (SWC) structures once prevalent throughout the dependent landscape are not witnessing their necessary maintenance. Where still present, terraces and earth dams are paradoxically turning into major sediment sources (Bellin, van Wesemael, Meerkerk, Vanacker, & Barbera, 2009). Effective action and associated decision-making in land management can successfully stem via stakeholder participation and enhanced social learning (Reed, 2008). These concepts are embedded within Sustainable Land Management (SLM) theory, encouraging empowerment, transparency, the understanding of local perceptions and the promotion of local solutions for more sustainable agricultural practices and technologies. The potential of SLM in the Segura has been investigated and proven effective at the local, plot scale by numerous, often European Union (EU) funded, research projects and initiatives. Yet, dissemination and spontaneous uptake of SLM practices remains low and almost strictly dependent upon EU selected and subsidized sustainable agricultural practices, at times unsuitable as a result of mismatches of scale between supranational governance and vastly heterogeneous farming communities.

Research must strive to quantify the impacts of trending LULC transitions and potential SLM practices upon agro-ecological systems at regional or catchment scales as to aid EU, national and regional authorities who have thus far been unable to establish a coherent and unified SLM policy agenda, and continue to dismiss soil conservation as a priority. An overarching SLM strategy needs to be developed, able to address degradation concerns and with equal potential for successful communication, outreach and ultimate dissemination of practices at the regional level. This study conceptualizes the crisis of agro-ecological systems of the Segura as a crisis of ecosystem service (ES) deterioration, and thus proposes the quantification of priority ESs as the methodological underpinning. Global recognition of the underlying innovation and potential ES valuation holds for the conservation of natural resources is increasingly being witnessed, particularly within European political agendas in consideration of climate adaptation and mitigation concerns (Maes et al., 2012).

The effects of selected SLM practices and recent LULC transitions can thus be evaluated against their ability to safeguard priority ES provision, addressing both climate adaptation and mitigation needs. In a time of last calls for action towards a land-degradation neutral world, this research hopes to shed further light into the benefits and trade-offs associated with SLM strategy development in Mediterranean agro-ecological systems prone to increased degradation, ecosystem-based approaches to climate adaptation and mitigation and the opportunities and pitfalls of ES biophysical assessments. At last, and at best, this research exemplifies an attempt to simplify the extraordinary complexity of environmental systems; the many limitations associated with such methodologies should not eclipse the value which lies in their unique power as highly transposable and communicative tools.

Background

Biophysical aspects and socio-economic context

The Segura catchment (18’800 km^2), situated within south-eastern Spain (**Figure 1**), represents the case study area of this research. The Segura River is the most important water source for agriculture in the autonomous community of Murcia. The region has a semi-arid climate, receiving between 300 and 700 mm of rainfall per year and with annual potential evapotranspiration ranging between 800-1300 mm (Hein 2007; Llamas 2007). Soils are mostly poor, shallow and with low fertility and organic matter, characterized by marl and limestone lithologies (López-Bermúdez 1990; Romero Diaz, Lopez Bermudez, and Cabezas 1992). The region’s Mediterranean climate has nonetheless encouraged the development of agricultural activities covering 565’143 ha, characterized by a heterogeneous sector comprised of both rain-fed agriculture, often situated on steeper slopes, and irrigated agriculture (188’543 ha) (Alcon, Martin-Ortega, Pedrero, Alarcon, & de Miguel, 2013). The more traditional agro-ecosystems are increasingly threatened due to low profitability and socio-economic changes; however, elements of traditional farming techniques are still present (Martínez-Fernández, Esteve-Selma, & Calvo-Sendín, 2000). Cereal crops, notably barley and wheat represent the main herbaceous annual dryland crops cultivated in the region. Their production is currently undergoing decline and is dependent upon EU subsidies. Irrigated crops grown include lettuce, cabbage, artichokes, broccoli, tomatoes, peppers, melons and grapes. Almond and olive orchards, formerly largely the dominant type of agriculture in the region, are increasingly losing production to irrigated horticulture; yet remain important, particularly with regards to almond production (Hein, 2007). Furthermore, grape cultivation, pig farming and organic agriculture are nowadays being introduced despite them requiring further scarce inputs (Nainggolan et al., 2013). Alongside cultivations, sheep and goat herding is also common within shrubland areas, yet is undergoing constant decline (Hein, 2007).

Studies undertaken in the Guadalentin catchment (Nainggolan et al. 2013), a tributary of the Segura, have described a human environment characterized by small-scale land users, with cropland area ranging 5-100 ha per household, commonly privately owned. Between 1960 and 1999, a 378% decrease of smallholders (of approximately 1 ha) occurred throughout the region of Murcia, whereas the occurrence of larger plots witnessed an increase of 346% (Bellin et al., 2009). Annual population growth within the catchment area is below 0.5%, reflecting general trends of migration to urban centers and coastal cities often resulting in agricultural land abandonment and loss of rural vitality (Bellin et al., 2009). The majority of farmers are over 50 years of age, with unlikely prospects of willing successors to continue practicing agriculture. Furthermore, the majorities of farmers are cooperative members, and base their financial and managerial decision-making to the cooperative. However, following the country’s financial crisis and severe unemployment rates, younger farmers are returning to agriculture and farming (Kosmas & Valsamis, 2001). Reliance upon secondary occupations and off-farm income is evident and contributes to over 50% of income, regardless of degree of mechanization and market-orientation of farming system. Most farming systems are mechanized and demonstrate commercial orientation (Schwilch, Hessel, & Verzandvoort, 2012).

Water use is regulated via a permit system, controlled by the Segura river basin water authority (CHS) (Schwilch et al., 2012). Water scarcity prevails and water resources are continuing to witness depletion (Zimmer, 2010) as the Segura has been identified as the catchment with the lowest water resources at the national level following a history of overexploitation, and ranking third as the catchment with highest water stress in Europe (Romero Diaz and Belmonte Serrato 2002; Alarcon and Egea 2005; Alcon et al. 2013). With an average annual precipitation of 312 mm and average annual temperatures reaching 15.2ºC, the catchment presents a water deficit of over 500mm per annum (Caravaca Ballester et al. 2005). Highly variable and insufficient water inputs hinder viability of agriculture in the region by lowering yields and limiting crop varieties. Insufficient rainfall has furthermore resulted in low vegetation cover and low biodiversity (Schwilch et al., 2012).

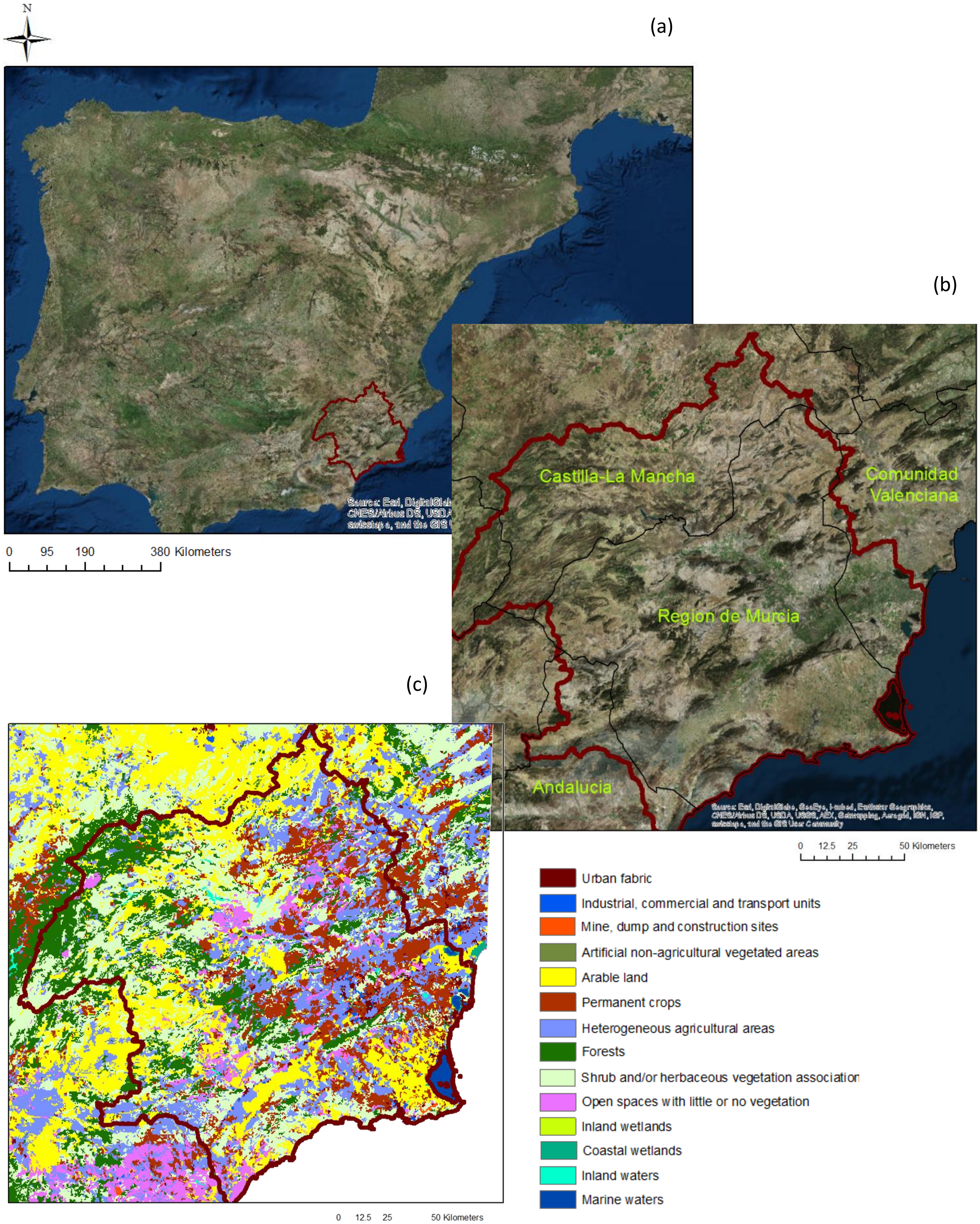

Figure 1- (a) Location of the Segura catchment with respect to the Iberian Peninsula, (b) Segura catchment boundaries within relevant autonomous communities of Spain and (c) LULC map of the Segura catchment based on CORINE level 2 nomenclature

Land degradation and management

Soil erosion is the main form of land degradation in the area and the region has higher than average erosion rates, often representing amongst the most severe cases of land degradation in Europe (Boix-Fayos et al. 2005; Hein 2007; Calatrava, Barbera, and Castillo 2011). Multiple studies have been undertaken in the catchment with the aim of identifying both natural and anthropogenic causes of land degradation, partly included within **Table 1.** What is apparent is the exacerbation of the regional soil's natural inclination towards erosion and degradation by anthropogenic land management practices. In addition to the tabulated factors, erosion also induces off-site problems, particularly severe when considering flooding and siltation of reservoirs. Past cropping systems heavily reliant upon SWC structures are witnessing reform following a desire to increase mechanizations. Step terraces and stone bunds within cultivated fields have undergone a steady decline of over 25% between 1956 and 2005 in the region of Murcia alone, as they present impediments to mechanization and occupy potential arable land (Bellin et al., 2009)

Table 1- Types and causes of land degradation in the Segura catchment

Type of Land Degradation	Driver(s) of Land Degradation	Supporting Literature
Soil erosion	-Widespread deforestation in 19th century, exposing soils to rainfall -Erosive land management practices (e.g. intensive tillage) -Agricultural land abandonment -Semi-arid climate -Conversion of land to irrigated, resulting in removal of topsoil layer -Marginal implementation of soil conservation structures -Past agricultural policies affecting land management practices directly and indirectly via income support mechanisms	Hein (2007) Calatrava, Barbera, and Castillo (2011)
Crusting	-Vulnerable soils of loamy to sandy-loamy texture prone to crusting	Hein (2007)
Gulley formation	-Erosive land management practices -Vulnerable soils	Schwilch, Hessel, and Verzandvoort (2012)
Loss of landscape diversity	-Rural depopulation, resulting in land abandonment and halted maintenance of soil conservation structures	Calatrava, Barbera, and Castillo (2011)
Salinization	-Overexploitation of deep aquifers	Calatrava, Barbera, and Castillo (2011)
Nitrate pollution	-Intensive fertilizer and pesticide use; resulted in nitrate pollution in catchment waters and soil nutrient imbalances	Calatrava, Barbera, and Castillo (2011)
Decline in Soil Organic Matter (SOM) content	-Farming practices, including weeding and intensive tillage	Calatrava, Barbera, and Castillo (2011)

Climate change

IPCC and climate change scenarios

The Intergovernmental Panel on Climate Change (IPCC) was born through collaboration between the United Nations Environment Program (UNEP) and the World Meteorological Organization (WMO) in 1988, representing the organization charged at an international level with the assessment of climate change (IPCC, n.d.). In 2000, the IPCC published the Special Report on Emission Scenarios (SRES), and thus provided a series of alternatives for our 2100 future, as well as creating a tool for assessing the impacts of driving forces upon greenhouse gas emissions (GHG) and the associated consequences upon the biosphere (Nakicenovic & Swart, 2000). These scenarios are of particular importance in modeling studies aiming to investigate both adaptation and resilience to climate change, both of which should be considered in the identification of suitable SLM strategies (Nakicenovic & Swart, 2000).

The scientific communities argued new scenarios were needed for more accurate climate change modeling and assessment (van Vuuren et al., 2011). Thus, Representative Concentration Pathways (RCPs) were developed and adopted by the IPCC fifth Assessment report, currently undergoing public release (van Vuuren et al., 2011). They vary from previous

SRES as their development was derived from a variety of models and thus with differing assumptions; each pathway represents a different level of radiative forcing, with a stronger focus upon LULC changes incorporated within storyline development than previously (van Vuuren et al., 2011). This research will however utilize ENSEMBLE regional models based upon the 2000 SRES predictions, due to the novelty of RCPs and lack of readily available future regional climate data based on RCP outputs.

The SRES are subdivided within four "families"; each of which gives different emphasis upon a particular driving force in terms of economic development, demographic changes, GHG emissions and uptake of technological innovations. Furthermore, the scenarios consider varying degrees of convergence or divergence between nations in sharing of knowledge and solutions, as outlined in **Table 2**.

Table 2- IPCC outlined SRES families and associated CO_2 emissions and temperature increases (Nakicenovic and Swart 2000; Ipcc 2007). Note: A1 range results from variety of green technologies available for uptake

Scenario Family	**Key driving concepts**	**Global CO_2 emission (GtC/yr)**	**Best estimate temperature increase (^{o}C) in 2090-99 from 1980-99 levels**
A1	*Rapid economic growth, decline in population growth following mid-century, rapid uptake of new technologies, convergence of nations over global solutions and per capita income*	5-29	2.4-4
A2	*Heterogeneous and regionally-oriented development, slow economic growth and uptake of technological innovations*	29	3.4
B1	*Uptake of green technologies, convergence of nations over global solutions, decline in population growth following mind-century, economic development emphasis upon service and information sectors*	5	1.8
B2	*Global divergence of nations, increasing global population and emphasis upon local solutions and development*	13	2.4

Each scenario envisages a temperature increase by 2100 with respect to 1980-99 levels, the repercussions of which are uncertain, particularly with regards to magnitude and frequency, yet can be predicted. An increase in frequency of droughts, flash floods and heat waves is *very likely* to occur. Of *high confidence* is the likelihood of river runoff and water availability to diminish amongst current arid and semi-arid regions by mid-century. Such climatic changes are expected to occur within the Mediterranean region, furthermore increasing the risk of soil erosion, waterlogging of soils and damage to crops, increasingly threatening farming livelihoods within the region (Ipcc 2007).

Implications of climate change for SE Spain and the Segura catchment

Projected increases in water scarcity for the Mediterranean, resulting from higher average temperatures and more frequent droughts, will occur in parallel with increases in water demand for irrigation purposes, placing additional pressures on local environmental sustainability (Iglesias, Garrote, Flores, & Moneo, 2007). Sumner et al. (2003) concluded Murcia will face the most significant changes in annual precipitation within the whole of Mediterranean Spain, witnessing a 10% decrease in annual precipitation by 2080 with respect to 1990 levels, most perceivable throughout the Spring months (Moreno et al., 2005). In addition, their results indicated a high degree of uncertainty for the magnitude of change in annual precipitation for the region, suggesting the eventuality of precipitation values to be even lower, or at the very least more variable. Maximum temperature change for Murcia by 2100, published by the Spanish National Meteorological Institute, provide estimates higher than global averages, suggesting values ranging between 4-11^{o} across IPCC scenarios (AEMET, n.d.).

Such trends for future annual precipitation rates need to be considered alongside projections of increases in temperature and of interval period between rainfall events (Lavee, Imeson, & Sarah, 1998). Furthermore, there are implications associated with projected increases in frequency of high temperature and rainfall anomalies and extremes (Moreno et al., 2005). Higher temperatures are likely to induce a reduction in soil water content, limiting plant growth and thus biomass inputs to soil. A reduction in soil organic matter will further impoverish aggregate stability and, consequently, soil permeability. What ensues is a positive feedback loop fuelling soil crusting and desertification. The necessary soil fertility vital to agriculture and semi-natural ecosystems cannot be expected in the future of the region unless action is taken. Furthermore, increased frequency of intense rainfall events is likely to induce flooding. Moreno et al. (2005) predict a 2% increase in surface runoff and 1.7% increase in soil erosion with every 1% increase in annual rainfall.

Spain's agricultural sector is particularly vulnerable, and will suffer from increases in inter-annual variability and occurrence of extreme events as a result of its already too often unsuitable soils and terrain (Iglesias, Rosenzweig, & Pereira, 2000). This will affect the 6% of the Spanish working population employed in agriculture, affecting over 10% of total EU farmers (ADAGIO, 2006). The country's rural population, like the ones of the other Mediterranean countries, is likely to suffer profound structural changes as a result, unless effective adaptive measures are taken in turn also in consideration of the affected EU food supply chain. The influence of agriculture upon employment and the local economy is of furthermore importance in the region of Murcia, expected to witness a continuation in trends of rural depopulation and land abandonment.

Adaptation alongside mitigation

Adaptation is an intrinsic feature of unmanaged natural systems, and has long been defined as both reactive and autonomous (Smith and Pilifosova 2001). In light of present climate change impacts and forthcoming scenarios, society's uncritical reliance upon ecosystems' inherent ability to adapt to changing climatic conditions is a notion we can no longer afford to support. In the context of re-conceptualizing hydrological engineering for water-scarce environments, Milly et al. (2008) have entitled their article "Stationarity is dead", and proceed to elaborate that it cannot be "revived". The alteration of present ecosystems' functions, compositions and distributions, due to climatic changes, upon which our socio-economic reality depends, is, however, unquestionable if not downright factual. Despite mitigation action, further warming is a likely possibility under current commitment efforts (Milly et al. 2008). Climate change mitigation is a goal whose pursuit must imperatively be continued; yet, the impossibility of stationarity-revival, emphasized by Milly et al. (2008), calls for the exploration of adaptation strategies.

Adaptation has, until recently, not only been disregarded by policy-makers and the scientific community favoring mitigation solutions, it has also been predominantly framed within a mindset of "historical fidelity" (Stein et al., 2013). Thus, adaptation solutions have been designed to enhance resistance and resilience to climate change impacts, rather than incorporating the third dimension of adaptive transformation strategies. Depending on the magnitude of climate change, currently uncertain and dependent upon future socio-economic developments outlined within the SRES pathways, the maintenance of a status quo may not result in the best outcome, or may altogether not be an option.

Conceptualizing the adaptation strategy

Adaptation in the context of climate change is defined by Smith and Pilifosova (2001) as the adjustment of "*ecological, social or economic systems in response to actual or expected climatic stimuli and their effects or impacts. It refers to changes in processes, practices and structure to moderate potential damages or to benefit from opportunities associated with climate change*". This definition aids in the conceptualization of the adaptation strategy this research focuses upon through the introduction of relevant key elements associated with climate change adaptation; notably: the trans-disciplinary nature of such strategies, their analysis and reliance upon expected climate change and impact scenarios, and perspectives of opportunity.

Challenges currently remain in the understanding and conceptualization of adaptation, and the framing of potential strategies. Smith and Pilifosova (2001) state current efforts placed upon enhancing adaptive capacities to be insufficient and poorly understood. More specifically, they denounce the scientific community and current decision-makers for dismissing close evaluation of adaptive strategies and policies currently in process of implementation. The biggest limitation is often declared to be within current adaptive strategies' limited ability to incorporate and account for increased variability and occurrence of extreme events.

As a result of the influence both socio-economic and environmental realities exert on the effectiveness of adaptation strategies, implemented strategies, despite facing global challenges and unlike most mitigation solutions, are often both local and autonomous (Smith and Pilifosova 2001; Pijnappels and Dietl 2013) This realization has been reflected and witnessed throughout the past decade amongst international organization's climate change adaptation guideline documents increasingly shifting the focus of vulnerability, impact and adaptation solutions upon sectorial or regional approaches (Hinkel, van Vuuren, Nicholls, & Klein, 2013).

Improvements in the field of adaptation can be undertaken throughout the analysis of past successful adaptation strategies undertaken in other contexts facing the same challenges; this is considered by many not only as a valuable process, but also as a necessary one. The consultation and dissemination of adaptation success stories provides the inspirational drive needed to push adaptation into the priority agendas of both public and private entities, as well as inspiring and building motivational willpower amongst individuals. Its strategic descriptions and project outcomes render it a tangible, achievable pursuit, often otherwise dismissed as far too distant a concept, in terms of both its meaning and time scale (Pijnappels and Dietl 2013). As such, designed adaptation solutions will be part of a creative process, inspired by existing traditional practices, which often indirectly build resilience and thus climate change adaptation, as well as by the collective efforts, knowledge and practices of a global community. For this reason, numerous databases and knowledge sources created with the purpose of systematically collecting data of climate change adaptation case studies are being developed at all scales, most often funded by public institutions, desirably facilitating scaling-up processes (Gomes, Venturini, & Mojaisky, 2012).

In this study, adjustments undertaken via adaptation strategies are within a specific "system-of-interest" (Smith and Pilifosova 2001): an agro-ecosystem, and thus represent a complex context which is both ecological and socio-economic in nature. For an adaptation strategy to be successful, both elements must be considered within the strategy's delineation and implementation. However, the scope of this study is limited to the investigation of the effects of physical "adjustments" of the agro-ecological system (although these imply a change in farming practices and thus socio-economic adjustments too). What must furthermore be emphasized is that adaptation strategies can be seen as opportunities to not only safeguard the remains of a past desirable system, but also as strategies which can alter or introduce new elements and thus induce a beneficial "re-birth" or system transformation which allows inherent dynamism to pursue. In addition, climate change adaptation strategies also need to be framed within an ES perspective.

At an international level, the UNFCCC has defined "adaptation" as one of its core focus themes for action (UNFCCC, n.d.); it is thus placing efforts on the development of a database of Ecosystem-based Adaptations (EBA) and Ecosystem-based Mitigation (EBM) case studies (Doswald & Osti, 2011). EBAs utilize ESs as an integral part of their adaptive strategy; they represent the "physical" adjustments mentioned within Smith and Pilifosova (2001) climate change adaptation definition. Thus, EBAs currently most appropriately frame the type of adaptation strategy this research will investigate, as SLM options are examples of EBA approaches.

Smith and Pilifosova (2001) provide a listing under which climate change adaptation strategies may be categorized, and in light of which solutions relative to the case study area may be found, including behavioral, research and educational approaches, amongst others. Due to the nature of this study, involving the spatial assessment of the effects of climate change adaptation strategies, the strategies will tend to focus upon structural and/or technological prevention, as they are furthermore in line with the nature of SLM. Thus, the adaptation strategies chosen will by definition represent “precautionary” or “anticipatory” adaptations, hopefully diminishing the detrimental costs associated with the alternative emergency adaptation (Smith and Pilifosova 2001). Such strategies may also imply changes in land use or location.

Ecosystem Services (ESs)

Conceptualization and historical developments

“We use nature because it is valuable. We abuse it because it is free”
– Pavan Sukhdev, lead author of TEEB

“Ultimately nature is priceless. But it is not valueless.”
– Simon Milne MBE, Chief Executive, Scottish Wildlife Trust

“We can’t manage what we don’t measure”
–World Forum on Natural Capital, Edinburgh 2013

Figure 2- Value of the ES concept in natural resource management illustrated by quotations

Public mainstreaming of the ESs concept was initiated with the release of the Millennium Ecosystem assessment (MA) in 2003. The MA presents a framework whereby ESs, defined as beneficial services in the form of resources and processes provided by the environment for human well-being, are categorized as supporting, cultural, provisioning or regulating ESs (Gómez-Baggethun, de Groot, Lomas, & Montes, 2010). From an initial core focus upon biodiversity assessments, the ESs concept now represents a core area of ecological research investigating an expansive spectrum of services (Daily, 1997). Several quantification methodologies have been developed over the years; all established upon a different classification and conceptual framing of what constitutes an ES. The definition provided by the MA was deliberately loosely formulated as to allow for subjectivity of differences by which a population understands and appreciates the services nature provides (Costanza, 2008). Others have argued the definition provided by the MA is misleading as a result of issues in double-counting, in consideration of supporting services, and of furthermore not distinguishing between which services comprise a process, and which represent an end (Costanza 2008). Another school of thought suggests differentiation is better termed through the analysis of intermediate (supporting services under the MA) and final services, as the end .goal is ultimately human well-being and all ESs represent a means to this (Costanza, 2008). These ongoing debates have emphasized the complexity behind ecosystem functioning analysis. Furthermore, the controversies and contradictions may be interpreted as a reflection of the diversity of uses behind such classification methods. Costanza (2008) concludes “pluralism of typologies” is a beneficial reality which will result in multiple classification theories useful for respective differing purposes, and separates a large part of existing classification systems as either within a spatial characteristics or an excludability/rivalry approach.

The ES concept is nowadays an established tool for the economic communication of our human dependence upon nature and its resources, as a result of developed valuation mechanisms which place a monetary value upon the services, increasingly implemented within payment mechanisms such as Payment for Ecosystem Service schemes and Markets for Ecosystem Services (Gómez-Baggethun et al., 2010). The World Forum on Natural Capital held its first ever meeting in Edinburgh, late 2013, establishing one of the first global debate platforms for governments and business leaders to discuss the role natural capital and what it should play within corporate decision-making (Forum on Natural Capital). Natural capital accounting comprises a form of ES quantification and valuation, redefined for the business sector by presenting natural capital as a life-sustaining “asset stock” rather than via the concept of service provision. This distinction has often incorrectly led to the misconception of natural capital accounting further fueling the exploitation of our natural resources, when in fact the opposite is true. ES valuation and natural capital accounting are both stressing the same vital concept: the survival of our valuable, global ecosystem necessitates quantification. Its sustainable management calls for its measurement, and failure to do so will induce ecological, economic and social deterioration (Spencer, 2013).

The Natural Capital Project began in 2006 as a result of collaborative efforts between Stanford University, The Nature Conservancy and the World Wildlife Fund (Tallis et al., 2010). The InVEST tool (Integrated Valuation of Environmental Services and Tradeoffs) is one of the outcomes of this project, and represents one of several existing spatially explicit tools able to assess changes in ES provision under differing user-defined scenarios in both biophysical and monetary terms. Such tools have high potential for utilization within policy decision-making processes, through the possibility of modeling the impacts of various land management alternatives. Furthermore, this tool is able to provide an assessment across a broad geographical and temporal scale in contrast to previous assessments (Nelson et al., 2009). This allows for a wider understanding of the trade-offs and synergies associated with ES provision.

There is widespread acknowledgement that despite a guaranteed provision of several ESs by agro-ecological systems, agricultural activities may provide disservices, including habitat destruction, depletion of water sources and pollution of soil resources through intensive fertilizer usage, amongst others (see **Figure 3**) (Bennett and Balvanera 2007; Swinton et al. 2007). Furthermore, chosen agricultural practices may influence ES provision away from the farm level. The presence of trade-offs between ESs within an agricultural system is what drives the need for the exploration of feedback mechanisms and quantification. It is necessary to identify what the most desirable provision of ESs is, and thus what land management practices guarantee such provision.

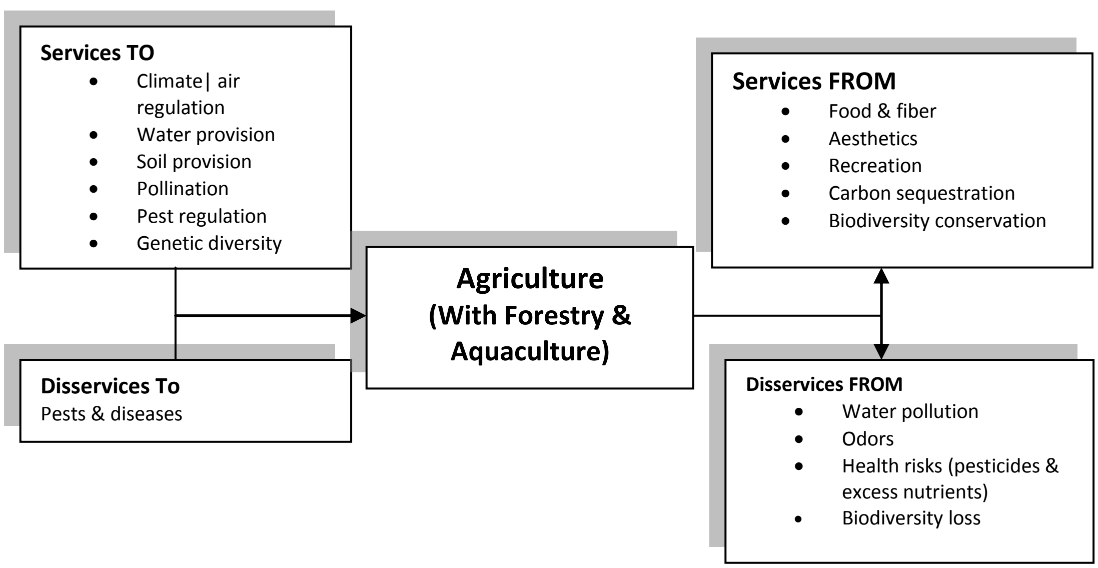

Figure 3- Exchange of ESs within cultivated systems, emphasizing existence of trade-offs and need for valuation and decision-making, from Swinton et al. (2007)

ES provision at a global scale is increasingly threatened by unprecedented ecosystem change, in part driven by climate change and continuous expansion and intensification of cropland (Muller, 2006). When looking at additive effects, what is likely to ensue from such climatic alterations and consequential changes in soil biophysical parameters is a switch in species ranges, phenology and biome distribution, with direct implications upon vital ESs including nutrient cycling and those associated with primary production (Grimm et al., 2013). It is imperative to try and increase understanding of climate change impacts upon individual ES provision, and of how induced stresses will interact and furthermore lead to interactions and trade-offs between ES provision (Staudt et al., 2013). Response initiatives by the Food and Agriculture

Organization (FAO) of the United Nations (UN) include concepts centered upon education, active adaptive management, development of technologies and ES valuation (Muller, 2006); concepts which equally comprise the core of SLM theory.

Healthy ecosystems are complex and dynamic; they represent systems able to withstand or adapt to change through the maintenance of "ecological coherence"(Lucius et al., 2011). Via land degradation, the ability of ecosystems to adapt is gradually lost, and with it the provision of vital ESs. This research will focus on SLM adaptive strategies able to safeguard provision of ESs (under MA definition) via enhancing the adaptive capacity of ecosystems at the wider, regional scale. It will furthermore place specific emphasis on what have been identified as *priority* ESs, notably water provision, enhanced carbon sequestration and sediment retention, and associated synergies and trade-offs, as they present significant challenges for the future of agricultural systems of the Segura.

ESs in the Segura catchment

Priority ES 1: Water provision

Under climate change scenarios, ES provision within European agricultural systems is predicted to decline (Schröter et al., 2005). In the context of agriculture in the Segura catchment, a region characterized by water scarcity, salinization and nitrogen pollution, the most critical ES to safeguard is undoubtedly water provision. Spanish natural water sources are expected to decline between 5 and 14% by 2030, amongst which the Segura is mentioned as a hotspot for severe resource decrease (Moreno et al., 2005). Water provision is furthermore critical as it limits the few potential increases in ES provision which may arise as a result of feedbacks from climate change impacts. Notably, increases in crop yield and primary production which would be expected under the "fertilizer effect" associated with higher atmospheric carbon concentrations is likely to be inhibited by water scarcity.

Priority ES 2: Sediment retention

Sediment retention maintains soil fertility and is thus crucial for ecosystem productivity. Furthermore, negative off-site impacts associated with flooding and siltation of water courses, harbors and reservoirs are dependent upon sediment retention. Sediment retention and soil fertility are both likely to decline under climate change, as forest fire frequency increases, desertification spreads and salinization problems are exacerbated. Scenarios predict an 80% increase in the EU's agricultural soil's susceptibility to erosion by 2050 (Klik, Hardan, & Nachtnebel, 2011). As previously outlined land degradation in the Segura catchment is a critical and increasingly significant process driven by both anthropogenic and natural factors.

Priority ES 3: Carbon sequestration

Soils represent the largest terrestrial C pool and so play a crucial role in the global carbon budget. Land degradation processes are detrimental to soil properties, and entail a decline in soil carbon content. The influence of agro-ecological systems on climate regulation is of critical importance, particularly with regards to CO_2 emissions and their potential to reduce them via carbon sequestration in soils and woody biomass. Increasing temperatures are expected to result in soil carbon losses, with every degree increase in temperature inducing a 6-7% loss in organic carbon amongst Spanish soils (Moreno et al. 2005; Schröter et al. 2005). In addition, further carbon losses can be indirectly expected by changes in land use induced by climate change (Moreno et al., 2005). Alterations in soil properties and climate regime by definition alter the terrestrial ecosystem and thus its associated plant and animal biodiversity. Climate change is likely to induce a reduction in genetic diversity and ultimately structural simplification, allowing a more dramatic spread of invasive species and pests (Moreno et al., 2005).

Sustainable Land Management (SLM)

Terminology

Variations within relevant SLM terminology were found throughout the literature research to identify and select suitable SLM solutions. This research adopted the following definitions of relevant SLM and soil conservation terms, outlined below for clarification:

- *Ecosystem-Based Approaches to Adaptation* (EBA) - Approaches utilizing the ESs concept and associated biodiversity conservation solutions as adaptation strategies to climate change (Doswald & Osti, 2011).
- *SLM Technologies* - WOCAT definition adopted in this research refers to the physical *practices* implemented in the field to control land degradation and enhance productivity. They may be one or more of agronomic, vegetative, structural or management technology measures (Schwilch et al., 2012).
- *SLM Technology Groups* - WOCAT defines nine different SLM technology groups which cluster similar technologies together and are commonly understood amongst rural development stakeholders. The nine SLM technologies groups are (Liniger & Critchley, 2007).
    1. Conservation agriculture
    2. Manuring/composting
    3. Vegetative strips/cover
    4. Agroforestry
    5. Water harvesting
    6. Gulley control
    7. Terracing
    8. Grazing land management
    9. Other
- *Soil and Water Conservation* (SWC) - WOCAT definition referring to field activities which aim to control land degradation and enhance productivity. In this study, SWC technologies are utilized as a synonym to SLM technologies (or practices) which involve the implementation of structures or management techniques and do not define a change in LULC (Liniger & Critchley, 2007).
- *SLM Approaches* - WOCAT definition adopted in this research refers to the overall approach by which SLM technologies are implemented and promoted on ground. It involves all participants, inputs and means and technical, scientific and practical know-how (Schwilch et al., 2012).
- *SLM Strategies* - Research-specific term to define the identified SLM technologies, practices and approaches for potential effective implementation in the catchment. Furthermore, this definition has extended the term to also include deliberate LULC changes and transitions for enhanced sustainability purposes.

SLM as a strategy for climate change adaptation via targeted ES provision

(Schwilch, Bachmann, & Liniger, 2009) define SLM as a land management strategy that "involves soil, water and vegetation adequately supporting land-based production systems for current and future generations", and is based upon concepts of agricultural productivity, security, conservation of natural resources, economic viability and social acceptance. SLM technologies have been researched and documented extensively; what is only recently being stressed is the necessity of stakeholder participation and analysis of local contexts to find the most effective solutions (Schwilch et al., 2009). Twenty years after its initial conceptualization, SLM is increasingly being valued for its ability to better suit local solutions (Schwilch et al., 2012).

SLM practices are increasingly being used in regional climate change mitigation and adaptation action plans, particularly within contexts of increasing aridity and desertification of the land, advocated by several development organizations including the World Bank and FAO (The World Bank 2008; Almagro et al. 2013; Stringer et al. 2013). Changing land management strategies profoundly affects our environment and provision of ESs. Land degradation, almost by definition, induces a loss in ES provision, particularly so within cultivated landscapes and for regulating ESs, emphasizing priority areas for action (Schwilch et al., 2012). Examples include direct and indirect effects upon net radiation, partitioning of precipitation and the altering vegetation cover and soil properties. Farming practices, including contour tilling or ridging, directly influence sediment retention within soils. Similarly, rotation periods, afforestation, establishment of grass strips or planting of perennials all have the ability to enhance carbon sequestration within woody biomass and soil, thus simultaneously guaranteeing ES provision and climate change mitigation. Water provision can be safeguarded by implementation of water conservation structures, and soil management techniques aimed at increasing infiltration and soil water retention (Mendoza et al., 2011). In some cases, implementing SLM strategies may simultaneously bring about a reduction in some ESs due to the existence of trade-offs when aiming to exploit land resources for production whilst also attempting conservation.

Soil and water conservation (SWC) structures and SLM strategies exist, yet their dissemination is limited and dependent upon a standardized methodology able to enhance capacity-building and thus scaling-up of success stories (Liniger & Critchley, 2007). SLM adoption remains a relatively novel and rarely implemented concept in semi-arid European regions; assessments of benefits at both local and regional scales are missing (Almagro et al., 2013). The EU DESIRE project was undertaken with the aim of identifying, implementing and evaluating SLM strategies that could use and conserve areas at risk of desertification, with the Segura as one of its many case study areas (DESIRE 2007). Importantly, the project involved stakeholder participation to induce social learning throughout the process, as to result in co-production of knowledge. The undertaken stakeholder discussion aimed at the identification of land degradation problems and existing solutions in the region was followed up by talks and research into the understanding what SLM technologies would be effective within the region. Finally, solutions were selected for test implementation (Schwilch et al., 2012). These results provide the basis for SLM testing within this study.

Policy and decision-making

Supranational to regional level decision-making

Spain adopted its National Climate Change Adaptation Plan of the European Climate Adaptation Platform in 2006. The plan has thus far initiated two working programs based upon developing regionalized climate change scenarios and impact and vulnerability assessments for priority sectors. Furthermore, it is aiming to develop mitigation and adaptation strategies in close collaboration with stakeholders and policy-makers at both the national and regional level (EEA, n.d.). Coordination of decision-making at multiple governance levels has thus far been proven challenging; shared perspectives at the national and regional level are often contested amongst local municipalities (Vargas-Amelin & Pindado, 2013).

In light of climate change scenarios of decreased precipitation in Spain, of particular concern in the southeastern coast, decision-making throughout the past decade has witnessed gradual decentralization and a shift in prioritization of regional interests. This has encouraged the development of multiple regional assessment and place-based approaches to resource management and climate adaptation (Hinkel et al. 2013; Vargas-Amelin and Pindado 2013).

Land management and soil conservation-specific policies

An understanding of the current policy context is necessary if SLM strategies are to be implemented effectively. Land degradation has long been acknowledged in Spain, particularly so within the southern regions, yet effective action and research did not begin until after the 1950s. Currently, a National Research and Development Plan is in place with the aim of targeting causes of soil erosion and desertification, funded by both National and European mechanisms (DESIRE 2007b). Agricultural practices in Spain are under the influence of the EU's Common Agricultural Policy (CAP) since the country's entry into the Union in 1986 (Rojo Serrano, 2004). According to Calatrava, Barbera, and Castillo (2011), it is the EU that is currently playing the most significant role in promoting soil conservation in the policy realm, rather than Spanish national laws or regional acts. However, in collaboration with EU policy, the Spanish Ministry of Environment and Rural and Marine Affair (MARM) and the regional government of Murcia (CARM) are charged with translating the CAP's framework into national and regional policy, thus ultimately implementing agricultural law (Calatrava et al., 2011). The complex nature of regional, national and supranational governance characterizing soil conservation and agricultural management policy pose significant bureaucratic challenges, often resulting in unsuccessful coordination and financing hindering desirable outcomes of existing policies.

The CAP's current two-pillar structure offers aid to farmers via both income support policy and rural development policy, establishing both a compliance approach alongside offering voluntary measures. The importance of these measures in the context of land degradation differs between rainfed and irrigated agriculture (**Table 3**).

Table 3- Most important policies of the EU's CAP influencing soil conservation in the Guadalentin Basin for rainfed and irrigated agricultural systems respectively (Calatrava et al., 2011)

	Policy description	Soil conservation measures
Rainfed Agriculture		
1. Single Payment Scheme (SPS)	Under Pillar I: Direct Support Provision of basic income support to farmers, no longer coupled to production. Must meet cross-compliance conditions, including Good Agricultural and Environmental Conditions designed to prevent soil erosion and include soil conservation measures. (EC, 2009)	-Sow as soon as possible as to prevent exposure of bare soils -Limited tillage on steep slopes -Regular maintenance of soil conservation structures (Calatrava et al., 2011)
2. Code of Good Farming Practice	Under Pillar II: Rural Development Must comply to be eligible for other Rural Development measures. Provides baseline environmental standards to be met for agricultural production; mostly relates to soil and water pollution (DARDI, 2008) (Calatrava et al., 2011)	-Traditional crop rotations -Efficient water use -Limited fertilizer and pesticide use -Contour tillage -No burning of stubble fields (Rojo Serrano, 2004) (Calatrava et al., 2011)
3. Agri-environmental Scheme (AES)	Under Pillar II Support to voluntary measures aimed at environmental protection (Calatrava et al., 2011)	-Erosion control -Regular maintenance of soil conservation structures -Establishment of vegetation strips (Calatrava et al., 2011)
Irrigated Agriculture		
1. AES a. Organic Agriculture	Provides compensation payment for each organically produced crop (payment amount differs according to crop) (Calatrava et al., 2011)	-Strict requirements for authorized chemical inputs -Crop rotation -Extensification of livestock (JRC-EC, 2009).
b. Integrated Production	Technical rules aimed at minimizing pesticide and fertilizer use via adoption of Integrated Pest Management techniques (Randall & James, 2012); excludes extensive herbaceous crops (Calatrava et al., 2011)	-Strict requirements for authorized chemical products -Prioritization of traditional and biological pest control methods (Calatrava et al., 2011)

The Single Payment Scheme (SPS) has been identified as fundamental for the persistence of rainfed farming households of the Guadalentin catchment often struggling to make above marginal profit. Despite the SPS's important role in promoting soil conservation measures in both rainfed and irrigated contexts, its success is limited due to poor regional adaptation of a scheme designed at supranational level. AES's under Pillar II have shown greater flexibility in adapting EU agricultural policies to heterogeneous local contexts, and thus represent a preferred option by agricultural stakeholders in the region (Calatrava et al., 2011). However, funding for the AES is limited, and negotiations for the financing of the reformed 2014-2020 CAP support mechanisms are suggesting further cuts to all Pillar II Rural Development objectives (Kolling, 2013). Dacian Ciolos, current Commissioner for Agriculture and Rural Development, is stressing the importance of a reformed, simplified CAP (EC, n.d.), yet cutting spending of Rural Development objectives could hinder one of the most important European support mechanisms implemented currently allowing action against desertification (Rojo Serrano, 2004).

Whether as a result of impending reform or not, the role of the CAP in supporting agricultural livelihoods and soil resources undoubtedly will face significant changes. Drawbacks of adoption of voluntary measures identified by Calatrava, Barbera, and Castillo (2011) relate to low financial incentives, insufficient technical extension services and complexity of the bureaucratic system. Furthermore, design and implementation of agricultural policies should aim to increase stakeholder involvement and consideration, particularly with regards to farmer cooperatives and agricultural organizations. The evaluation component of implemented measures should also be given further importance, particularly with regards to impacts towards more social and economic domains. More efforts should be geared towards education on land degradation and conservation options. Studies have identified a high degree of variability amongst what farmers perceive land degradation to be; solutions should take the subjective nature of the process into account (Calatrava et al., 2011)

Research aim and objectives

The aim of this thesis is to explore and quantify the effect of identified and selected SLM practices and historical LULC transitions upon priority ES provision; notably, carbon storage and sequestration, water provision and sediment retention. These will be investigated under past, present and future climate scenarios at the catchment and sub-catchment scales, in order to develop a SLM strategy comprising elements of both or either SLM practices and LULC changes for effective climate adaptation and mitigation in the Segura catchment, based upon targeted ES provision. This research primarily used of the spatially explicit InVEST model, via the investigation of the following Research Objectives (ROs):

RO1- To identify SLM practices able to foster priority ES provision and allow adaptation to climate change in the Segura catchment

RO2- To quantify and assess the impact of climate change on priority ES provision at two different catchment scales

RO3- To quantify and assess the impact of historical LULC changes upon ES provision at two different catchment scales, in comparison with SLM practice implementation

RO4- To quantify and assess the impact of selected SLM practices upon guaranteeing present and future priority ES provision at two different catchment scales, in light of climatic changes

Research framework

This research begins with the perception of land degradation problems within agro-ecological systems of the Segura catchment as problems of ES deterioration. Notably, there is underprovision and lack of conservation of increasingly scarce water and soil resources, exacerbated by a decreasing vegetation stock with further implications for carbon sequestration. Fostering ES provision to safeguard the agro-ecological landscape's biophysical and socio-economic reality of the Segura can only be done in consideration of climate change predictions of further ES deterioration. In other words, there is a direct link between fostering ES provision, and climate adaptation and mitigation. As such, a strategy which is focused upon priority ES provision will furthermore implement sustainable measures which will by definition implement a climate adaptation mechanism, and may potentially further incorporate a mitigation component via implementing carbon storage and sequestration mechanisms. The concepts of SLM, ES provision and climate adaptation and mitigation have been previously introduced and discussed within their respective sub-chapters. This chapter aims to incorporate them within the scope, objectives and methodological sections of this specific research, furthermore illustrated within **Figure 4**.

Figure 3 shows a linear process via which a SLM strategy will be developed for climate adaptation and mitigation, by means of targeting the provision of priority ESs. Methodologically speaking, this implies an initial step which aims to identify suitable SLM practices, addressing RO1, followed by ES quantification modeling with the InVEST tool to assess the impacts of climate change and increased ES provision by both LULC cover changes and local SLM practice implementation, addressing ROs 2-4. This will generate as a final outcome a SLM strategy based upon which combination of SLM practices and deliberate LULC changes is able to best guarantee ES provision, in consideration of existing ES synergies and trade-offs.

Underlying assumptions of research

This study and its constructed research framework are founded upon several defining assumptions. The priority ESs chosen for investigation throughout this study were also selected based on the availability of input data for their respective InVEST models. Despite existing literature supporting the notion that they represent priority ESs for conservation within the case study area, they do not represent an exhaustive list. Their selection should furthermore be taken in consideration of subjectivity associated with ES research; perceptions of what defines an ES and of their importance are relative issues, and thus dependent upon whom is contemplating. A second fundamental assumption is the framing of ES quantification as the means to achieving climate adaptation and mitigation. Once again, despite the significant body of literature founded upon ecosystem-based approaches to adaptation supporting this methodology, this study does not imply or aim to prove its superiority with regards to other methodological frameworks, but merely aims at quantifying its potential benefits.

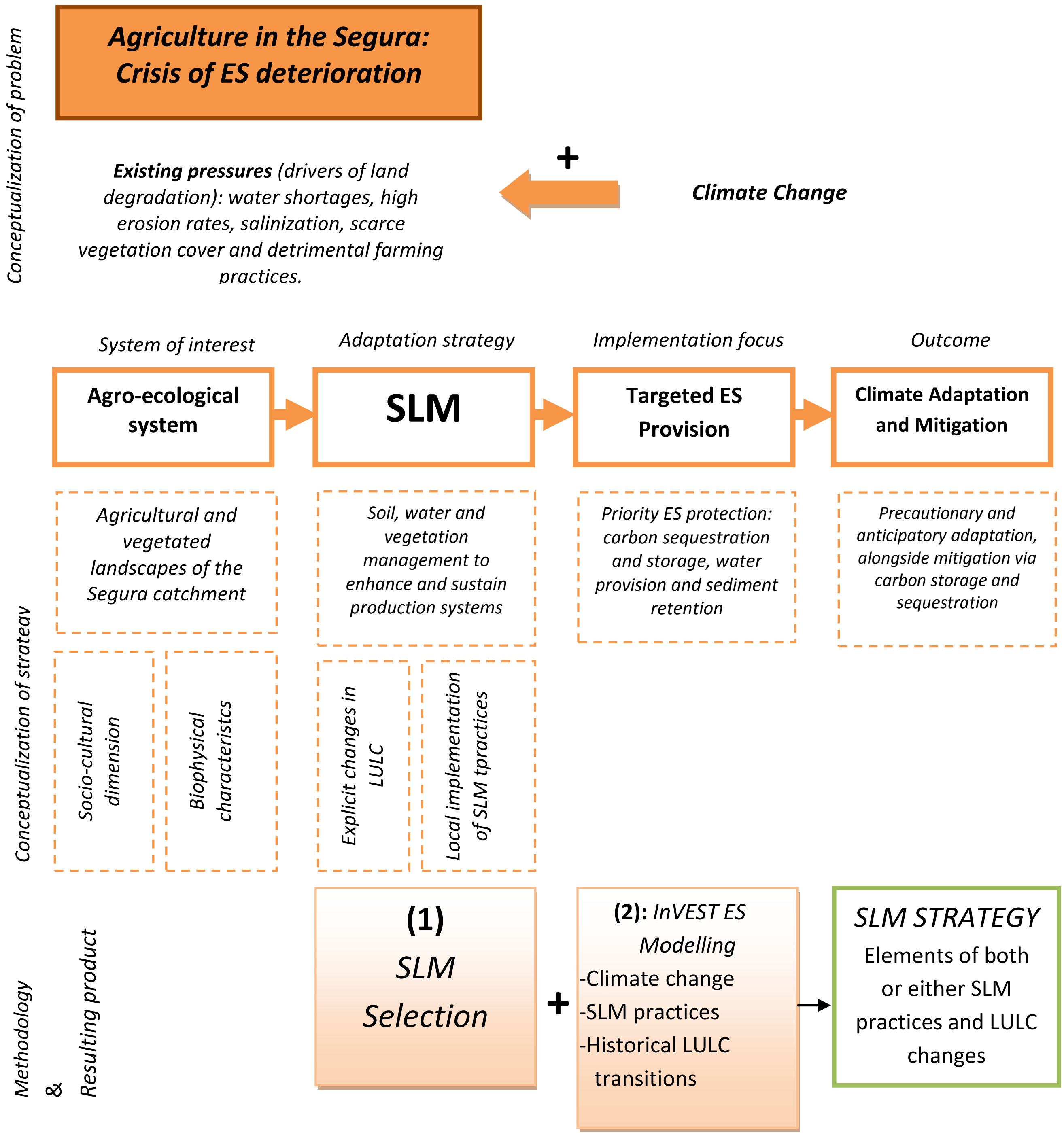

Figure 4- Research framework illustrating conceptualization of study by means of problem statement, adaptation strategy and methodology towards final product

Methodology

Initially, a listing of identified SLM practices able to guarantee adaptation to climate change via the provision of ESs for application in the Segura catchment was developed. Subsequently, a spatial analysis assessment of the impacts of climate change, historical LULC changes and SLM practice implementation upon priority ES provision (notably carbon sequestration, sediment retention and water provision) at two scales was undertaken through the use of the InVEST model; a regional catchment scale for the whole of the Segura, and a smaller scale focusing upon the Taibilla sub-catchment. This allowed for the development of SLM strategy based on a comparison of SLM practices and deliberate LULC changes able to best provide priority ESs. These outcomes were achieved via the completion of the following, outlined methodological steps:

Identification of SLM practices

For an SLM practice to be identified as effective for the Segura catchment in this particular study, it must guarantee adaptation to climate change via protection of priority ES provision. The initial methodological approach was thus *a literature review with the aim of listing all SLM practices relevant to the area. Following such identification, SLM practices able to maximize water provision, sediment retention and carbon sequestration (deemed to be priority ESs) were selected for further research.* This literature review was undertaken in consultation of:

- WOCAT SLM Technology Database
- Outcomes of the DESIRE stakeholder workshop on stakeholder selection and adoption of SLM technologies in the Guadalentin
- The United Nations Framework Convention on Climate Change (UNFCCC) Local Coping Strategies Case Study Database on ecosystem based approaches to adaptation
- Scientific literature review on potential and traditional soil conservation measures of southeastern Spain and the wider Mediterranean

WOCAT Technology Database

The WOCAT database documents SLM technology options for the prevention, mitigation/reduction and/or rehabilitation of global degraded drylands, and was chosen as a starting point for the identification of relevant SLM strategies (Schwilch et al., 2012). WOCAT SLM Technologies are present within the database as local case studies; their "common name" and use is thus at times very site-specific. SLM technology identification within the WOCAT Technology Database was undertaken as follows:

- The only limiting factors initially considered for the selection of SLM technologies in the database were climate regime and rainfall; the initial step involved restricting natural environment to a *semi-arid* climatic regime with *250-500* mm of average annual rainfall, being the climate and rainfall of the Segura catchment.
- All soil fertilities were considered despite the catchment being characterized by low fertility. This was decided as the aim of this study is to guarantee priority ES provision which might be underprovided even amongst terrains where soil is successfully being maintained, or is uncharacteristically naturally, fertile.
- Similarly, all types of soil degradation addressed by technologies (soil erosion by water; soil erosion by wind; chemical soil deterioration; physical soil deterioration; biological degradation; water degradation) are deemed to be relevant as such to the case study catchment area and were thus all explored. As previously mentioned and illustrated in **Table 1**, erosion by wind and water is the predominant form of land degradation in the area, thus categorized respectively. According to the WOCAT Categorization System and in accordance with FAO (1999), chemical soil deterioration includes fertility decline, acidification, soil pollution, salinization and alkalinisation, also occurring within the Segura catchment. Physical soil deterioration processes of relevance mostly relate to soil crusting. Biological degradation generally refers to reduction in quantity of vegetation and associated

biodiversity, relevant in a region subject to frequent forest fires and a study investigating impacts upon carbon sequestration. SLM measures targeting water degradation were also considered as water quantity is deemed a priority ES to safeguard in the semi-arid Segura catchment.

- Of the many SLM technologies presented following a search only restricted by climate regime and rainfall, many were discarded for further consideration in this research based on:
    i. Technologies representing solutions non-applicable to the bio-physical conditions of this research's study site
    ii. Present within a human environment very different from the socio-economic reality present in this research's study site
    iii. Involving flora and fauna not relevant and non-adaptable to this research's study site's environmental conditions
    iv. Assessing land degradation issues not relevant or of no priority within this research's study site and scope (particularly with regards to chemical and biological degradation problems addressed)
    v. Lack of detail and necessary information within technology description
    vi. Technologies which are already widely adopted within this research's study site
- The remaining SLM technologies were listed, alongside their respective WOCAT code indicating country of implementation, relevant to identify which SLM technologies have already been implemented within the study site and thus have a higher degree of relevance and increased likelihood of success. They were furthermore allocated according to their relevant WOCAT SLM technology group (see **Table 10**).

UNFCCC Local Coping Strategies: Case studies

The UNFCCC has defined "adaptation" as one of its core focus themes for action. Amongst its frameworks and programs, the UNFCCC has furthermore developed the Database on Local Coping Strategies with the aim of providing a platform whereby information regarding case studies of successful adaptation strategies and technologies can be shared. The database does not include any case studies undertaken within Spain; there is a stronger focus upon strategies being implemented within developing countries in comparison to WOCAT. However, case studies whereby useful insight and innovation could be derived for adaptation to this research's study area were noted and selected as follows:

- Relevant Hazard was defined as *drought/aridity* and impact was selected as *land degradation*, as they are the most relevant to the study's context. Strategy and region were left undefined.
- Of the case studies presented by the restricted database search, some were not considered for further investigation as a result of:
    i. Representation of case study solutions non-applicable to the bio-physical conditions of this research's study site
    ii. Present within a human environment very different from the socio-economic reality present in this research's study site
    iii. Involving flora and fauna not relevant and non-adaptable to this research's study site's environmental conditions
- The remaining case studies were listed in **Table 10** and assigned to a WOCAT SLM technology group based upon their description.

The InVEST tool

This research was undertaken via the utilization of the InVEST (Integrated Valuation of Environmental Services and Tradeoffs) tool (Nelson et al., 2009). This spatially-explicit tool is able to quantify changes in provision of multiple ESs both in biophysical and monetary terms. It utilizes LULC maps and biophysical input data parameters which may be altered; in this case according to the SLM technology implemented and future climate change datasets. A description of InVEST methodology regarding the assessment of the priority ESs is outlined below. In each case, only the biophysical component of the model was run, excluding the optional valuation component. All model outputs are given on an annual basis.

InVEST models used

1. **Carbon Storage and Sequestration: Climate Regulation Model**: this InVEST model utilizes input data regarding four carbon pools: aboveground biomass, belowground biomass, soil organic carbon and dead organic carbon stored in the landscape. All pool inputs are given in Mg of elemental carbon per ha of each LULC layer. For the model to run, at least one of the carbon pools must have input data. The model then assigns each raster cell a LULC layer type and gives it a value corresponding to the sum of the carbon pools input data, thus giving an output of total stored carbon per grid cell, also in Mg. The model may furthermore calculate sequestration if an optional, future LULC layer is introduced. In this case, the net change in carbon storage within each grid cell is calculated by the model. (Sharp et al., 2014)

2. **Water Yield: Reservoir Hydropower Production Model**: this InVEST model is subdivided into three components aiming to quantify water yield, water scarcity and hydropower production and valuation. These models run and give outputs on a sub-watershed level, rather than for the whole catchment. For the scope of this research and due to data limitations, only the water yield model was run and translated into the ES of water provision. The estimation of water yield is essentially based upon the calculation of precipitation minus total evapotranspiration losses. The model then assumes that all remainder water that does not evaporate reaches the outlet point of the sub-watershed; differentiations between different types of flows (sub-surface, surface or base flow) are not made. Final outputs are then given as the sum and mean of the water within each sub-watershed.

   The model utilizes annual average outputs rather than daily precipitation data. It utilizes the Budyko curve developed by Zhang et al. (2004) to determine water yield, based on annual actual evapotranspiration and annual precipitation per pixel of a specific LULC type. The calculation of annual actual evapotranspiration is based upon the computation of the Budyko Dryness index, requiring a raster grid of potential evapotranspiration and an estimated crop coefficient factor given per LULC layer, and a non-physical parameter characterizing natural climatic-soil properties based upon a seasonality factor, plant available water content and root restricting soil depth. The outline of formulas and steps taken for the computation of the water yield model can be found in the Online InVEST User Guide (available at: http://ncp-dev.stanford.edu/~dataportal/invest-releases/documentation/current_release/). A listing of model inputs and outputs, in their required format and units is outlined in **Table 4**. (Sharp et al., 2014)

3. **Sediment Retention: Avoided Dredging and Water Purification Model**: the model is able to calculate average annual soil loss, sediment export and sediment retained per grid cell at the sub-watershed level. It works by estimating soil loss through the Universal Soil Loss Equation (USLE) (see **Equation 1**), whose inputs are all required with the exception of LS which is calculated from the DEM and a set flow accumulation threshold value, by the model itself. Potential soil loss is then calculated via the RKLS, which provides a bare soil estimate of erosion. Sediment retention is thus initially calculated by subtracting the USLE from the RKLS on a pixel basis, estimating the ability of vegetation to prevent erosion. To account for sediment retained by vegetation cover upstream of each cell, the model furthermore accounts for a sediment retention efficiency input per LULC layer. Sediment export is then computed as the sum of all

sediment loads that reach their respective sub-watershed outlets. Furthermore, reservoir information, notably the dead volume, is required as a model input to consider the benefit the ES provides in terms of avoided sedimentation. The outline of the remaining formulas and steps taken for the computation of the sediment retention model can be found in the Online InVEST User Guide (available at: http://ncp-dev.stanford.edu/~dataportal/invest-releases/documentation/current_release/). (Sharp et al., 2014)

Equation 1- USLE (Wischmeier & Smith, 1978)

$$USLE_X = R_X * K_X * LS_X * C_X * P_X$$

Where,

$USLE_x$ = Sediment originating from parcel x

R_x = Rainfall erosivity

K_x = Soil erodibility

LS_x = Soil slope-length index

C_x = Ground cover variable

P_x = Management factor

Sediment retention is thus calculated as the sum of sediment coming from upslope, from which sediment export from cell is subtracted and avoided erosion (calculated as RKLS * (1 – CP)) added.

Table 4- Priority ESs and respective InVEST model data requirements and resulting outputs (The Natural Capital Project, 2012)

InVEST model and tool	ES quantified	Model requirements	Outputs
Carbon Storage and Sequestration: Climate Regulation Tool: Carbon Biophysical	Carbon storage and sequestration	- Past/present/future LULC - Carbon pool per LULC, at least one of: aboveground, belowground, soil organic carbon and dead organic carbon (Mg/ha)	- Total carbon stored (within one or both of present and future LULCs) (Mg/pixel) - Carbon sequestered (Mg/pixel)
Water Yield: Reservoir Hydropower Production Tool: Water Yield	Water provision	- LULC - Watersheds - Soil depth (mm) - Maximum root depth per LULC (mm) - Average annual precipitation (mm) - Average annual reference evapotranspiration (mm) - Plant available water content (AWC) (fraction) - Plant evapotranspiration coefficient per LULC - Seasonality factor	- Estimated actual evapotranspiration fraction of precipitation per pixel - Estimated actual evapotranspiration per pixel (mm) - Estimated water yield per pixel (mm) - Mean precipitation per pixel per watershed (mm) - Mean potential evapotranspiration per pixel per watershed - Mean actual evapotranspiration per pixel per watershed (mm) - Mean water yield per pixel per watershed - Volume of water yield per watershed (m^3) - Volume of water yield in watershed per hectare (m^3)
Sediment Retention: Avoided Dredging and Water Purification Tool: Soil Loss	Sediment retention	- Digital Elevation Model (DEM) - LULC - Watersheds - USLE rainfall erosivity factor (R) (MJ MM ha^{-1} yr^{-1}) - USLE soil erodibility factor (K) (Mg H MJ^{-1} mm^{-1}) - USLE crop management factor (C) per LULC - USLE support practice factor (P) per LULC - Sediment retention efficiency (%) per LULC - Slope threshold (%) - Threshold flow accumulation - Allowed annual sediment loading of reservoirs (tons) - Dead volume of reservoirs (m^3) - Remaining designed lifetime of reservoirs	- Mean potential soil loss per watershed (tons/ha) - Total potential soil loss per watershed (tons/watershed) - Sediment export (tons/watershed) - Mean sediment export (tons/ha) - Mean sediment retained (tons/watershed) - Mean sediment retained (tons/ha) - Total sediment retained (tons/watershed)

Input data

Preparation of input layers and analysis of outputs were all undertaken via the use of ArcGIS 10.1. The coordinate system used was ETRS89/UTM zone 30N. All input raster files for models investigating the whole of the Segura catchment were run at a resolution of 100 m. All input raster files for the Taibilla catchment were run at a resolution of 30 m. The input data preparation outlined below presents the layers as they were prepared pre-calibration, unless otherwise stated. Similarly, the data inputs hereby presented are generally for the present "baseline" scenario, with present climate data and no SLM implementation, unless otherwise stated.

LULC and sub-watersheds layers were required for more than one model; the methodology involved in their acquisition is as follows:

- *Segura LULC*- LULC maps were obtained from the CORINE Land Cover Program; datasets for the years 1990, 2000 represent historical data, whereas 2006 data was used as the present LULC baseline scenario. The finest of the three different levels of nomenclature of CORINE was used in this study. Not all of the 44 LULC classes were present within the delineated area of study; the relevant classes are outlined within the **Results** chapter.

Taibilla LULC- For the Taibilla sub-catchment, LULC maps for the years 1956, 1987 and 2000 used were derived from digital aerial photographs (Boix-Fayos, Barberá, López-Bermúdez, & Castillo, 2007). The classes were translated to CORINE level 3 nomenclatures for comparison and to facilitate the use of LULC based input tables used within the different InVEST models.

- *Sub-watersheds*- The sub-watersheds map was generated using the Watershed tool in Arc Hydro extension for ArcGIS software. A reservoir map of the Segura catchment was used to identify the points which represented watershed outlets, resulting in a Segura watershed layer containing 30 sub-catchments (**Figure 5**).

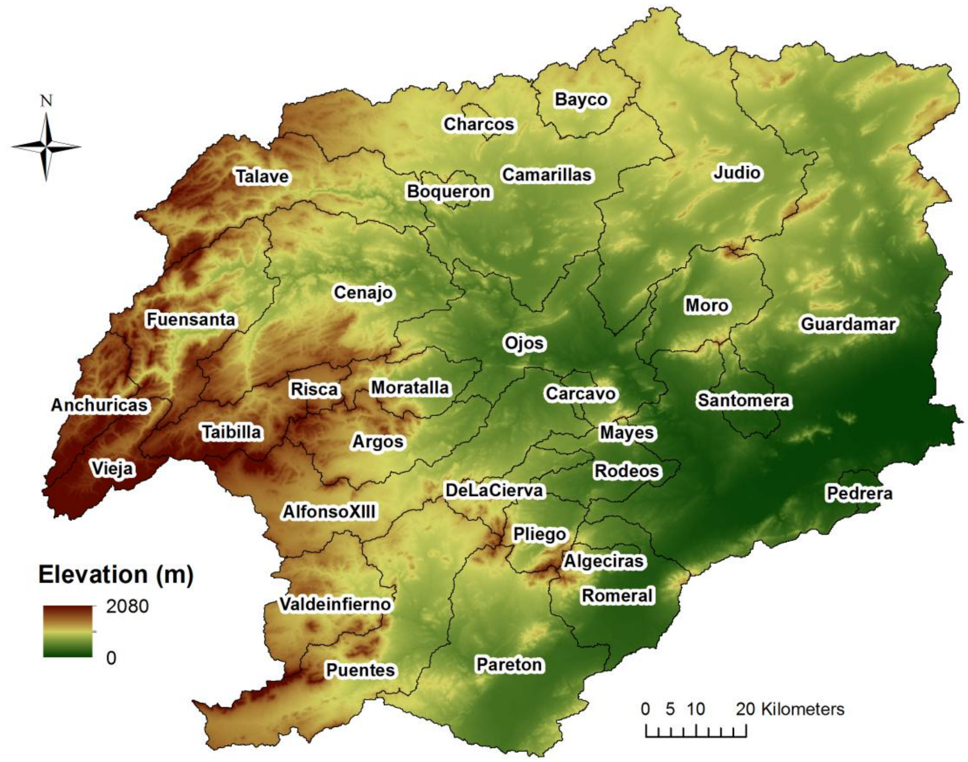

Figure 5- Sub-watersheds of the Segura and elevation in catchment

1. **Carbon Storage and Sequestration: Climate Regulation Model**

- *Above and below-ground biomass*- Despite these two pools being separate inputs within the InVEST carbon storage and sequestration model, available data considered both above and below ground biomass (stem, branches, foliage and roots) carbon densities averaged per Mg per ha of each CORINE LULC level 3 class combined. Muñoz-Rojas et al. (2011) derived stock values from literature and applied them to the region of Andalusia, SE Spain. In this research, the same values per LULC were used, with the exception of carbon stock values for the *Moors and Heathlands* layer, for which no data was available in Muñoz-Rojas et al. (2011) and was thus given the same value suggested for other bushland layers, notably *Sclerophyllous Vegetation* and *Transitional woodland-shrub layers*.
- *SOC*- SOC for the region of Murcia, covering the majority of the catchment, was calculated using modeled SOC data from the LUCDEME project. For the remainder of the catchment, SOC was calculated from organic matter derived from the "Topsoil Organic Carbon for Europe" project of the EC's Joint Research Centre European Soil Portal- Soil Data and Information Systems (EUSoils, n.d.). The Kriging Interpolation method was used to downscale the raster resolution from 1 km to 100 m. These values were subsequently passed from percentages

to Mg/ha as required by the InVEST model. The first 20cm of SOC were made from the OM layer by calculating bulk density of soil through the Pedotransfer methodology, whereby Bulk Density (BD) is established according to **Equation 2**.

Equation 2- Bulk density

$$BD = 1.72 - 0.294 * (\%OC)^{0.5}$$

Bulk density was then divided by five, to obtain the top 20 cm from the top 1 m of soil, and then converted from percentage to hectares. Average values were then calculated for 20-60cm depths and 60-100 cm depth, obtaining SOC content from relationships between depth and land use class established by Albaladejo et al. (2012). The three values for the different depths were subsequently summed to give a single raster layer of SOC in Mg/ha. This was overlaid with the LULC maps to give a mean value of SOC per LULC class.

Final value for total carbon stocks per individual LULC class is outlined in **Table 5**, furthermore delineating the respective percentage contribution of SOC to the total carbon stock.

Table 5- Ranking of LULC classes per total C stock in Mg C/ha, alongside respective contribution of SOC to the total C stock (%)

	LULC code	LULC class	Total C stock (Mg C/ha)	Contribution of SOC pool to total C stock (%)
1	312	*Coniferous forest*	148.9	60
2	313	*Mixed forest*	137.8	70
3	311	*Broad-leaved forest*	118.8	76
4	324	*Transitional woodland-shrub*	96.6	81
5	323	*Sclerophyllous vegetation*	93.3	81
6	322	*Moors and heathland*	81.9	78
7	333	*Sparsely vegetated areas*	80.1	98
8	223	*Olive groves*	76	72
9	222	*Fruit trees and berry plantations*	75.9	72
10	243	*Land principally occupied by agriculture, with significant areas of natural vegetation*	75.5	85
11	213	*Rice fields*	74.3	93
12	332	*Bare rocks*	72.8	100
13	221	*Vineyards*	71.7	71
14	244	*Agro-forestry*	70.4	89
15	321	*Natural grasslands*	70.1	96
16	334	*Burnt areas*	68	100
17	131	*Mineral extraction sites*	66.4	100
18	242	*Complex cultivation patterns*	66	82
19	142	*Sport and leisure facilities*	65.5	91
20	211	*Non-irrigated arable land*	64.1	92
21	331	*Beaches, dunes, sands*	61.5	100
22	241	*Annual crops associated with permanent crops*	61.5	79
23	212	*Permanently irrigated land*	60.6	92
24	112	*Discontinuous urban fabric*	60.2	95
25	124	*Airports*	58.4	98
26	133	*Construction sites*	57.1	100
27	132	*Dump sites*	51.6	100
28	421	*Salt marshes*	31.5	48
29	411	*Inland marshes*	17.2	0
30	141	*Green urban areas*	7.5	20

Note: *Continuous urban fabric (111), industrial or commercial units (121), road and rail networks and associated land (122), salines (422), water courses (511), water bodies (512) and coastal lagoons (521)* do not contribute to the total C stock as no carbon was deemed to be stored within the pools considered for these LULC layers. These layers were thus excluded from the ranking.

2. **Water Yield: Reservoir Hydropower Production Model**

- *Soil depth*-Soil depth was derived from a combination of point data from the LUCDEME project profiles and MAGNA geological maps for the Murcia region, and from random points of the MAGNA and SEISnet projects for the remainder of the Segura catchment (MAGRAMA-LUCDEME; SEISnet); data sources for the different parts of the catchment are illustrated in **Figure 6**.

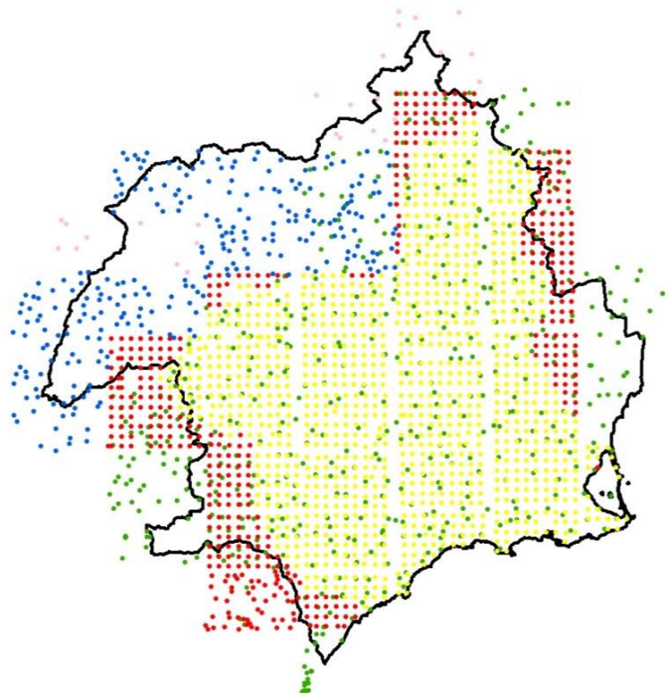

Figure 6- Data sources for estimation of soil depth, where:

- **Green: LUCDEME profile data; values were averaged for each soil class.**
- **Yellow: Arable land LUCDEME profile data; values were obtained by intersection with LUCDEME soil profile data layer.**
- **Red: Arable land LUCDEME intersected with MAGNA project data for points where intersection with the LUCDEME profile data was not possible. For this area, soil depth was calculated from percentage area coverage by LUCDEME soil class for the lithology MAGNA classes. This allowed for the identification of the predominant soil classes, for which depth values were given in reclassification.**
- **Blue: Random points from MAGNA data; using the Create Random Points function of the Feature Class, Data Management Toolbox on ArcMap, following intersection with the MAGNA lithology map to obtain lithological class.**
- **Pink: Random points from SEISnet data; also derived from the Create Random Points function but without previous intersection with both LUCDEME or MAGNA layers, and instead utilized data from SEISnet.**

Interpolation process followed via Kriging in ArcGIS to obtain a raster layer at a 100 m resolution.

- *Maximum root depth per LULC*- Values of maximum root depth per LULC were adapted from research by de Vente et al. (2007) in the Taibilla catchment. In this study, forested layers were found to have a constant yearly maximum root depth at 2 m; for remaining vegetated layers monthly root depth was determined as a function of the layer's vegetation Leaf Area Index (LAI), and then averaged. Values for CORINE layers not included in the de Vente et al. (2007) study were taken from literature findings.
- *Average annual precipitation*-
    - *Present: 1970-2000*: Methodology adopted from de Vente et al. (2008), using average monthly precipitation data derived from monitoring stations of the national meteorological institute for the period 1971-2000 at a resolution of 1 km for the whole Segura catchment.

- *Past: 1950-1970*: Past climate data for the Taibilla catchment was derived from historical data from an on-site monitoring station. The percentage change in precipitation was calculated between the 1950-1970 mean and the 1971-2000 mean, and was applied to the raster file of present annual rainfall.
- *Future: 2041-2050*: Future precipitation data was derived from ENSEMBLE STREAM 2 regional model prediction system for seasonal forecast based on global and regional models developed in Europe. Notably, the CRCM4.2.3 model was used under the IPCC SRES A1B climate change scenario storyline. This scenario is part of the A1 storyline, with a technological emphasis upon a balance between fossil and non fossil energy sources (IPCC, 2007).

- *Average annual reference evapotranspiration-*
  - *Present: 1970-2000*: Methodology adopted from de Vente et al. (2008), using average monthly potential evapotranspiration data derived from monitoring stations of the national meteorological institute for the period 1971-2000 at a resolution of 1 km.
  - *Past: 1950-1970*: Derived from monthly maximum and minimum temperatures for Spain between 1950 and 1970 obtained from (Herrera et al., 2012). Annual reference evapotranspiration was calculated via the Hargreaves equation (**Equation 3).**

Equation 3- Hargreaves equation

$$ET_0 = 0{,}0023 * (T_{med} + 17{,}78) * R_0 * (T_{max} - T_{min})^{0{,}5}$$

Where
ET_0 = daily potential evapotranspiration, mm/day
T_{med} = average daily temperature, °C
R_0 = extraterrestrial solar radiation, mm/day (see **Table 6**)
T_{max} = maximum daily temperature
T_{min} = minimum daily temperature

Extraterrestrial solar radiation was obtained from average radiation data per latitude (38°) corresponding to the Segura catchment, and respective month (**Table 6**). Radiation estimates are expressed in MJ/m^2/day; however values needed for the equation are necessary in evaporated water in mm/day, thus multiplying the radiation value by a conversion factor of 0.408.

Table 6- Average extraterrestrial solar radiation data, as input for the calculation of the Hargreaves equation

R0_lat38 (MJ/m^2/day)	Month	mm/day
16,2	January	6,6096
21,5	February	8,772
28,1	March	11,4648
35,2	April	14,3616
39,9	May	16,2792
41,8	June	17,0544
40,8	July	16,6464
37	August	15,096
30,7	September	12,5256
23,6	October	9,6288
17,5	November	7,14
14,8	December	6,0384

Potential evapotranspiration was calculated on a monthly basis, taking values for maximum and minimum temperatures throughout the period 1950-1970 and from this obtaining the mean temperature. Average monthly evapotranspiration was calculated over the period to then achieve a monthly sum.

- *Future: 2041-2050*: Future evapotranspiration data was derived from ENSEMBLE STREAM 2 regional model prediction system for seasonal forecast based on global and regional models developed in Europe. Notably the CRCM4.2.3 model was used under the IPCC SRES A1B climate change scenario storyline.

- *Available Water Content (AWC)* - The calculation of AWC was based upon soil texture data. The USDA textural triangle was used to identify the percentages of clay, silt and sand required for each of the 12 main soil textural classes. The three soil textural layers were derived from the EU LUCAS (Land Use/Cover Area frame statistical Survey) project, and combined into a single layer with an attribute table defining the texture percentage component of each of the 12 layers. Plant AWC was derived from tabular information estimating AWC in in/ft per each of the 12 soil texture classes as outlined in **Table 7** (ITC, 1997); each soil textural class was thus given its corresponding AWC value after converting ft/in to a factor as required by InVEST.

Table 7- Estimated AWC (ft/in) per soil texture class (ITC, 1997)

Soil texture class	AWC (ft/in)
Clay	1.8
Clay loam	2.4
Silty clay	1.9
Silty clay loam	2.4
Loam	2.0
Silt loam	2.4
Silt	2.0
Sandy clay	1.9
Sandy clay loam	1.8
Sandy loam	1.5
Loamy sand	0.9
Sand	0.3

- *Plant evapotranspiration coefficient (Kc) per LULC*- Kc values were derived following the InVEST Online User's Manual, which refers directly to values represented in FAO Kc tables. Recommended FAO equations were used to calculate the Kc factor for layers representing areas of natural vegetation, and thus not present within the FAO crop tables.
- *Seasonality factor*- The InVEST Online User's Manual defines the seasonality factor (Z) as a factor between 0 and 10 defining the rainfall seasonality in the area of study; whereby a value close to 0 would define strong seasonality with peak rainfall in summer months, and a value close to 10 would define strong seasonality with winter peaks. (Sumner et al., 2003) define rainfall seasonality in the region of Murcia as marked, with a long dry season in summer and autumn peak in precipitation. For this reason, and following calibration, the Z factor was set to a value of 9.

3. **Sediment Retention: Avoided Dredging and Water Purification Model**:

- *Digital Elevation Model (DEM)*-
- *USLE R factor*- From de Vente et al. (2008), using equation by Renard and Freimund (1994) based on average monthly precipitation data derived from monitoring stations of the national meteorological institute for the period 1971-2000 at a resolution of 1 km. The same equation was used to calculate erosivity with precipitation information for the periods 1950-1970 and 2041-2050 for their respective scenarios.

- *USLE K factor*-Similarly to OM, the K factor was downloaded from the EC's Joint Research Centre European Soil Portal- Soil Data and Information Systems. Downscaling to 100 m took place using the Natural Neighbor Interpolation method.
- *USLE C factor per LULC*- Values for the C factor were taken from de Vente et al. (2009), assigned per CORINE land cover class from estimates of erosion studies undertaken by the Spanish Ministry of the Environment, and for remaining natural vegetation layers by guidelines under Dissmeyer and Foster (1980).
- *USLE P factor per LULC*- The erosion control factor was set to a value of 1 for all vegetated layers in the present "baseline" scenario, as no information is available for the spatial distribution of soil erosion prevention measures (de Vente et al. 2009), and the research assumes low present adoption of such measures in the area based on literature findings.
- *Sediment retention efficiency per LULC*- Values for sediment retention efficiency were calculated by taking the average sediment transport capacity value per lad use class used in the WatemSedem model applied to 14 sub-catchments of the Segura catchment (de Vente et al. 2009).
- *Slope threshold*- Value represents the slope limit above which slope management practices are no longer practiced and no cultivation takes place. This value was set to the recommended standard of 75%, as no information is available for more accurate representation. Model calibration showed this value had no impact upon outcomes.
- *Threshold flow accumulation*- Value represents the number of upstream cells from each point which are considered to be part of a stream. Following calibration, this value was set to 250 for the Segura catchment run, based on the input resolution 100 m. For the Taibilla catchment model running at a 30 m resolution, the threshold flow accumulation value was set to 75. The Taibilla catchment model runs were calibrated independently for this factor.
- *Allowed annual sediment loading*- Calculated from the annual volume decrease allowance, derived from remaining designed lifetime and dead volume values of reservoirs. Volumetric answer was subsequently converted to tonnes of sediment.
- *Dead volume of reservoirs*- No information is publicly available regarding reservoir dead volume in the catchment. It was thus assumed at 10% of the reservoirs initial or current capacity, depending on data availability from the Segura's Hydrological Confederation's online reservoir database. If the reservoir is no longer listed as useful for irrigation or drinking water, but remains solely for flood protection purposes, the dead volume was increased to 90% of the reservoirs initial or current capacity (Confederacion Hidrografica del Segura, 2014).
- *Remaining designed lifetime of reservoirs*- Reservoir construction date was retrieved from the Segura's Hydrological Confederation's online reservoir database. As no information on reservoir lifetime is available, it was assumed all reservoirs have a designed lifetime of 100 years, and was calculated in consideration of 2006 as the present "baseline" scenario. Valdeinferno and Pareton reservoirs exceed the 100 year lifetime assumption, yet they remain in use for flood protection purposes. Their remainder lifetime was thus calculated from annual allowed sediment loading and current capacity values.

InVEST scenario modeling

- *The present baseline scenario*: The present scenario was run by placing inputs as outlined in the *Input data* sub-chapter. This corresponds to the 2006 LULC layer for the Segura catchment, and the 2000 LULC layer for the Taibilla sub-catchment. Both scenarios used the same climate data covering the period 1971-2000. Results for each ecosystem service were reported and analyzed as shown in the respective chapters.
- *Historical LULC changes*: For both the Segura and Taibilla catchments, two historical model runs were made to furthermore compare with the present scenario. For the Segura, historical LULC layers correspond to 1990 and 2000, and utilize the same climate data as the present scenario. For the Taibilla catchment, historical LULC layers date 1956 and 1987; past climate data is only available for the 1956 layer, as 1987 falls within the same climate

data as the present scenario. Thus, for the year 1987 model output changed as a result of differences in LULC class distribution and frequencies, in turn affecting inputs directly based upon LULC classes.

In addition to comparing the outputs directly generated by the three ES models, the LULC transitions which occur between the three years were calculated and categorized into the LULC transition trends outlined in **Table 8** adapting methodology from Muñoz-Rojas et al. (2011). Categorization of LULC changes into transition trends such as urbanization, agricultural intensification or extensification, and afforestation or deforestation of the land will be used to compare the effect of such LULC transitions with SLM implementation.

Table 8- Classification of LULC transitions (Muñoz-Rojas et al., 2011)

LULC transition: Trend	Past LULC (CORINE level 3 codes)	Future LULC (CORINE level 3 codes)
Urbanization (URB)	Agricultural areas (211-244), areas of natural vegetation (311-335), wetlands (411-423) and water bodies (511-523)	Urbanized and industrialized layers (111-142)
Intensification of agriculture (IOA)	Scrublands, herbaceous vegetation and sparsely vegetated land (321-335)	Agricultural areas (211-244)
Extensification of agriculture (EOA)	Arable land and permanent crops (211-223)	Pastures and heterogeneous agricultural areas comprising non-productive areas of natural vegetation (231-244)
Afforestation (AFF)	Agricultural areas (211-244), open spaces with sparse vegetation cover (331-335) and inland wetlands (411-412)	Forested and scrubland and herbaceous vegetation (311-324)
Deforestation (DEF)	Forested (311-313)	Agricultural areas (211-244) and scrublands, herbaceous vegetation and sparsely vegetated land (321-335)

Note: refer to appendix for CORINE nomenclature conversion to code classification system

- *Climate change impacts*: Climate change impacts were evaluated upon present LULC distribution; information regarding future LULCs can be made based on extrapolation from historical LULC transitions and future predictions, however spatially explicit future LULC maps of the region are not readily available, and their derivation is outside the scope of this research. Thus, as outlined within the *Input data* sub-chapter, the inputs changed for the climate change scenarios were limited to climate inputs (annual rainfall and annual potential evapotranspiration), and the rainfall erosivity factor of the USLE equation. As the carbon sequestration model does not take into account any climate variability, only sediment retention and water provision were quantified under climate change impact for both the Segura and Taibilla catchments.
- *Carbon sequestration:* The InVEST Carbon Storage and Sequestration Model used for past, present and SLM scenario analysis determines the respective carbon storage, or carbon stock, at the watershed or sub-watershed level for the Segura. Occurred carbon *sequestration* is only considered by the model through the subtraction of past LULC maps from present ones. However, this only calculates sequestration if a LULC transition has occurred, and does not consider annual changes which have occurred in carbon stocks as a result of sequestration within the four pools over time. This concept is relevant for all present LULC classes, but particularly for those which did not undergo transitions in the delineated time frames and are therefore assigned a sequestration value of zero by the InVEST model.

  To account for this, yearly carbon uptake rates from Almagro et al. (2010) were used to calculate sequestration for LULC layers which did not undergo transitions. Almagro et al. (2010) estimated annual net primary productivity from above and belowground biomass for forested, abandoned agricultural fields and rain-fed olive grove LULCs of a Spanish Mediterranean ecosystem at rates of 648, 541 and 324 g/C/m^2 per year respectively.

Changes in SOC were assumed by Almagro et al. (2010), and subsequently this study, to be at near steady-state and thus of near negligible amounts. Other studies from the region, notably by Liski, Perruchoud, and Karjalainen (2002), further suggest the local low and declining importance of soils as carbon sinks.

All vegetated CORINE LULC classes were assigned a value of annual net primary productivity based on the aforementioned Almagro et al. (2010) findings. *Olive groves*, *Vineyards* and *Fruit trees and berry plantations* were all assigned the value of 324 g/C/mg^2 per year as given by Almagro et al. (2010) for the rain-fed olive groves. The Almagro et al. (2010) annual carbon uptake value for forests was used for all CORINE forested layers, whereas the value for abandoned agricultural fields was assigned to *Sclerophyllous vegetation* and *Transitional woodland-shrub* layers. It was assumed that if *Natural grasslands* and *Sparsely vegetated areas* did not undergo transitions between past and present datasets, they did not undergo major changes in biomass and were thus also assumed to have reached a steady state. *Annual crops associated with permanent crops* and *Land principally occupied by agriculture, with significant areas of natural vegetation* layers were both assigned a value equivalent to half the uptake amount of rain-fed olive groves, based on CORINE nomenclature descriptions of the layers. Following the same methodology, *Complex cultivation patterns* were assigned a value based on 10% of the rain-fed olive groves rate and 10% forest rates. *Agro-forestry* layers were assigned 20% of the forest rate value.

Per LULC land areas were calculated for "no-change" cases where no LULC transitions had occurred between 1990 and 2006, alongside cases which had not undergone LULC transitions between 2000 and 2006, but were under a different LULC in 1990, and cases of new LULCs in the year 2006 which were under a different use in both 2000 and 1990. The year 1990 was assumed to be a starting "year zero", as no LULC data is available for previous years for the Segura. It was assumed that LULC transitions occurred mid-way through the transition periods; in other words, annual net primary productivity rates for no-change cases between 2000 and 2006, under a different LULC in 1990, were multiplied by 11.5 years, and 2006 cases which were different in both 2000 and 1990 had rates multiplied by 3 years. LULCs which remained the same throughout the whole time period (1990-2006) had rates multiplied by a value of 16 years.

- *SLM implementation:* The selected SLM practices for implementation in the Segura are green manuring and reduced tillage (RTG) (following selection process outlined in **Results**). Impact of SLM implementation upon carbon storage and sequestration was modeled under present climate conditions, as the effect of climate change upon this ES cannot be quantified by the model and the scope of this assessment lies within mitigation, rather than adaptation efforts. Effect of SLM implementation upon sediment retention and water provision is modeled under future climate predictions, to evaluate its scope as an adaptation and resilience building strategy via comparison with the climate change scenario runs where no SLM implementation is included.

Model input parameters were altered based on Almagro et al. (2013), whose study evaluated the impact of SLM technologies in two rainfed agroecosystems within the Segura catchment. Research undertaken by Almagro et al. (2013) was tested in organic rainfed almond plots; these were translated to the *fruit trees and berry plantations* and *olive groves* CORINE LULC class layers throughout this study's modeling work. The effect of SLM implementation was thus not further evaluated at the finer Taibilla scale as the present LULC data for this sub-catchment did not include either of the two LULCs translated from Almagro et al. (2013) for SLM implementation. Green manure (GM), a mix of barley or common oat and vetch (Vicia sativa) was used only in combination with reduced tillage (RT), comprising a tillage reduction from 3-5 times a year as practiced under conventional tillage, to 2 times a year in spring and autumn. Thus, both SLM practices were modeled in combination as RTG; this was supported by literature studies furthermore confirming their widespread application in combination (Bescansa et al. 2006; Mekonnen et al. 2014). The effect of implementation of SLM practices upon ES provision across the Segura was evaluated at different adoption levels (10, 50, 80 and 100%) within the aforementioned LULC classes. The computation of different levels of adoption was undertaken via the Subset Features tool within the Geostatistical Analyst tools on ArcMap 10.1 as to select different adoption levels of *parcels*, as opposed to pixels. The different adoption levels are thus not indicating the percentage of land area within the LULC class, despite being representative of the different amounts.

Table 9 provides a summary of the InVEST model parameter alterations which were undertaken for modeling of the effects of SLM implementation for climate mitigation and adaptation.

Table 9- InVEST input parameter alterations undertaken under SLM implementation, based on experimental data reported in Almagro et al. (2013)
*represents the reduction in erosion reported in Almagro et al. (2013) from which an increase in sediment retention efficiency was calculated

SLM practice	InVEST model	Input parameter	Change from conventional (%)	CORINE LULC affected
Reduced Tillage and Green Manure (RTG)	*Carbon storage and sequestration*	Carbon pool	SOC- ***+ 47.5%***	*Fruit trees and berry plantations; Olive groves*
	Water Provision	AWC	***+ 8.3%***	*Fruit trees and berry plantations; Olive groves*
	Sediment retention	Sediment retention efficiency	***-66.0%****	*Fruit trees and berry plantations; Olive groves*

Model calibration

Calibration was based upon the present scenario modeled results for ES provision; indicators were used for each of the ESs investigated, as follows.

- *Carbon storage*

No calibration was made for modeled carbon storage values as no studies have been undertaken for the same carbon pools investigated in the area or for the whole of the Segura Catchment.

- *Water provision*

Calibration of water yield values generated by the InVEST model was based upon the comparison of modeled and observed values for sub-catchments with a higher likelihood of accuracy. These were the sub-catchments with an upstream location and low density of agricultural land, under the assumption of limiting influences from irrigation withdrawals which are not included by the water yield model; notably, the Anchuricas, La Vieja, Argos, Alfonso XIII, La Cierva and Valdeinferno reservoirs. Water yield averages were calculated between 1971 and 2000 (reflecting the climate data years included in the present scenario model run), from observed data obtained from CHS hydrological statistics open-sources. These were compared with modeled values via the Nash-Sutcliffe model efficiency coefficient (**Equation** 4). The coefficient values closest to 1 represent a more efficient model; negative values indicate the observed data mean is a better predictor than the model value. Calibration involved initially increasing the Kc input values by 10% to increase AET as the model primarily overestimates water yield. Following an analysis of the LULC layers characterizing the sub-watersheds analyzed for the model efficiency coefficient, individual Kc values per LULC layer were altered, either further increased by 10% or returned to original values.

Equation 4- Nash-Sutcliffe model efficiency coefficient (de Vente et al. 2008)

$$ME = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - O_{mean})^2}$$

Whereby:

O_i = Observed value
P_i = Predicted value
O_{mean} = Mean observed value

- *Sediment retention*

Sediment retention was also calibrated through the use of the Nash-Sutcliffe model efficiency coefficient (**Equation 1**). Observed area-specific sediment yield (SSY) values for the Talave, Fuensanta, Taibilla, Anchuricas, Cenajo, Camarillas, Argos, Alfonso XII, Valdeinferno, Puentes and De La Cierva reservoirs were available from de Vente et al. 2008 and thus provided the basis of comparison for calibration of sediment export model output values in $t/km^2/yr$. The model was calibrated by altering the flow accumulation factor and sediment retention efficiency values originating from transport capacity values obtained from the WatemSedem model for the Segura catchment, as outlined in the Methodology. Sediment retention values were increased for all agricultural and natural vegetation layers by 10% and all water layers (with the exception of water courses) were increased to 100% sediment retention efficiency. Values were then homogenized according to the LULC CORINE class code 1 and 2 for simplification purposes.

Results

SLM practices for climate change adaptation and mitigation via ES provision for the Segura catchment

The identified SLM practices for InVEST modeling are a result of the analysis of scientific journal articles and existing SLM databases and case studies, as outlined in the **Methodology**. Several *points of note* are stipulated below:

- Successful adaptation to climate change can only be achieved if efforts and action arise from a comprehensive variety of sources and sectors, thus combining policy, infrastructural and technical strategies. Adaptation to land degradation and increasing aridity is ultimately undertaken by land managers. Designation of suitable SLM technologies should thus be taken as part of a wider strategy which further aims at capacity-building and stakeholder participation. For this reason, outcomes of the DESIRE stakeholder workshop undertaken within the region have been taken into greater consideration in the final delineation of SLM practices than from the other investigated sources.
- SLM practices selected within this study are aimed primarily at climate adaptation. Yet, these should be taken in consideration of synergy with mitigation technologies for the eventual incorporation of such mechanisms within adaptive strategies, specifically in the context of climate mitigation via carbon sequestration and storage.

Findings from the WOCAT Technology Database and UNFCCC Database on Local Coping Strategies are listed in **Table 10** alongside the WOCAT SLM technology group name if relevant. In addition, a second column heading "SLM Technology Cluster" was developed to re-group/re-name findings from both databases into a common SLM technology name more suitable than case-specific database headings.

Table 10- Relevant WOCAT technologies and case studies from the UNFCCC Database on Local Coping Strategies for potential implementation in the Segura basin, listed alongside corresponding SLM Technology Cluster name

WOCAT SLM Technology Group	SLM Technology Cluster	Case studies in supporting literature (relevant WOCAT technology code, if applicable)
AGROFORESTRY	*Afforestation and revegetation*	1. Tradition forest establishment in semi-arid land (T_TAN008en) 2. Planting forest on mountain slopes using moisture accumulating trenches (CACILM) (T_TUM003en) 3. Revegetation and re-seeding (T_RSA037en) 4. Assisted natural regeneration of degraded land (T_BRK003EN) 5. Growing Acacia albida in Burkina Faso (UNFCCC)
	Agroforestry	1. Afforestation for rehabilitation of degraded irrigated croplands (CACILM)-under high salinity (T_UZB004en)
	Tree and shrub plantations as windbreaks	1. Shelterbelts for farmland in sandy areas (T_CHN048en) 2. Woven wood fences (T_TUR05en)
CONSERVATION AGRICULTURE	*Soil-protective tillage and sowing*	1. The ridge sowing technology (CACILM) (T_KYR002en) 2. Reduced contour tillage of cereals in semi-arid environment (T_SPA001EN) 3. Soil-protective minimal technology of the tillage and sowing (T_KAZ006en) 4. Growing cereals by using minimum tillage (CACILM) (T_KYR003en)
	Erosion control throughout production	1. Controlling of soil erosion during crop production: contour, mulching and intercropping (T_RSA052en) 2. Improving water efficiency in Mudzi and Gwanda, Zimbabwe (UNFCCC)
	Strip farming	1. Strip farming (T_TUR002en)
GRAZING LAND MANAGEMENT	*Grazing land management and monitoring*	1. Rotational grazing (T_RSA100en) 2. Night corralling (T_NIG023en) 3. Communal grazing management (T_RSA041en) 4. Fodder crop production (T_TUR004en) 5. Monitoring the conditions of pastures (CACILM) (T_KYR007en) 6. Community-based rangeland management in Sudan (UNFCCC)
GULLEY CONTROL	*Gulley rehabilitation*	1. Gulley rehabilitation (T_KEN024en) 2. Gulley control by plantation of Atriplex (T_MOR15en) 3. Gulley healing using trash lines (T_TAN010en) 4. Check dams from stem cuttings (T_NIC004en)
MANURING/ COMPOSTING	*In-situ composting*	1. In-situ compost cultivation or "pattern farming" (T_TAN007en)
	Organic mulching	1. Organic mulch under almond trees (T_SPA002en) 2. Ecological production of almonds and olives using green manure (T_SPA005en) 3. Two chamber farm yard manure/Water Hyacinth compost preparation in Bangladesh (UNFCCC) 4. Mulching in Burkina Faso (UNFCCC)
	Vermicomposting	1. Vermicomposting in Rajasthan, India (UNFCCC)
TERRACING	*Terraces*	1. Terrace (T_CHN050en) 2. Afforestation and hillside terracing (T_ERI002en) 3. Konso bench terrace (T_ETH036en) 4. Rehabilitation of ancient terraces (T_PER001en) 5. Vegetated earth-banked terraces (T_SPA02en) 6. Bench terraces covered with small stones (T_YEM001en)
	Stone faced bunds	1. Stone faced soil bund of Tigray (T_ETH014en) 2. Stone faced trench bund (T_ETH015en)
VEGETATIVE STRIPS/COVER	*Vegetative strips/cover*	1. Cover crops in organic vineyard (T_SPA007en) 2. Vineyard with natural grass cover in an arid alpine zone (T_SWI546en)
WATER HARVESTING	*Drip irrigation*	1. Application of water by drip irrigation (T_GRE002en) 2. Drip irrigation (T_RUS01en)
	Rainwater harvesting	1. Roof rainwater harvesting system (T_BOT004en)
	Runoff harvesting	1. Water harvesting from concentrated runoff for irrigation purposes (T_SPA004en) 2. Vallerani system (T_BRK011en) 3. Water-spreading weirs for the development of degraded dry river valleys (T_CHA001en) 4. Water harvesting in Illela District, Niger (UNFCCC) 5. Tassa planting pits in Niger (UNFCCC)
	Below-ground piping	1. A woolen water retention bed installed under the roots of a tree integrated by a pipe feed (T_TAJ398en) 2. Low-pressure irrigation system "Californian" (T_SEN002en)

DESIRE stakeholder workshop in Guadalentin basin

Stakeholder workshops undertaken under the DESIRE project in 2008 involved the participation of local farmers, scientists and decision-makers towards the identification of best options for SLM in the Guadalentin catchment. It was decided that the main objectives of implemented SLM technologies in the catchment should be to address problems of soil erosion, low fertility and water loss; thus in line and confirming priority ESs of this research. Twenty potential solutions were identified by the present stakeholders, those identified as most desirable via a voting mechanism are:

- Minimum and/or correct tillage
- Integration of agricultural and ecological systems-mosaic landscape
- Liquid manure, to biogas and fertilizer
- Terraces and vegetation strips
- Shift to ecological agriculture/high quality products

In addition, preferred measures were re-defined or changed to best suit local conditions and for field-testing and ranked as the following:

1. Green manure in an ecological almond orchard
2. Reduced tillage in cereal and almond fields
3. Traditional water harvesting (*boquera*)
4. Straw mulch under almonds

Ranking of preference was given by stakeholders following the outcomes of field experimentations. There was a marked desire from participants to maintain traditional SLM practices, notably the *boquera* water harvesting technique. Straw mulch was deemed unsuccessful as it did not result in higher soil moisture content in comparison to control plots, and required expensive inputs. It was however noted that another mulch type could be utilized and potentially result in increased productivity. In conclusion, farmers preferred options which either resulted in yield increases or required very inexpensive implementation.

Literature review: existing SLM technologies and experimental findings in Mediterranean agro-ecological systems

- ***Grazing land management***: mobile agro-pastoralism, despite having witnessed marked decreases, remains relatively common in Mediterranean Spain. It involves a sheep rearing and cereal-fallow production system (Correal, Robledo, Rios, & Rivera, 2006). The fallow period begins in autumn, allowing for spontaneous germination of fallen grains and development of encroaching vegetation with the rains, regenerating fertility within poor soils. Sheep feed on fallen grains, weeds and stubbles remaining post cereal harvesting. The traditional agro-pastoral system is versatile and thus adaptable to climatic changes. Planned grazing has resulted in a sustainable system whereby pressure upon land is controlled (and thus limited) and animal efficiency maximized. Furthermore, planned grazing had aided in taming the spread of forest fires and has allowed for the development of unique steppe landscape and associated biodiversity in *dehesas* and *montados* (Correal et al. 2006; Manzano Baena and Casas 2010).
- ***Step terraces***: used particularly within rainfed almond orchards. Currently, no stones are used to support these structures. Ploughing occurs on terraces. There has been a 27% decrease in the presence of step terraces within the region of Murcia between 1956 and 2005, mostly occurring as part of the abandonment of the whole agricultural terrain. Implementation and maintenance of terraces has also declined as farmers believe these structures hinder mechanization opportunities (Bellin et al., 2009).
- ***Check dams***: mostly for cereals, built across thalwegs and perpendicular to the slope gradient within the concavities of the landscape. Currently, no stones are used to support these structures. There has been a

28% decrease in the presence of check dams within the region of Murcia between 1956 and 2005, mostly occurring as part of the agricultural abandonment occurring in the region. Like terraces, implementation and maintenance of check dams has decline as they are perceived by farmers to hinder mechanization opportunities and reduce the amount of potentially productive land (Bellin et al., 2009).

- ***Composting and mycorrhizal inoculation***: experiments in southeastern Spain by (Caravaca Ballester et al. 2005) utilizing composted municipal residue and mycorrhizal inoculation with *Glomus intraradices* aimed to optimize soil biological and physical parameters for increased fertility and revegetation of degraded land with local shrub species, notably *Olea europacea subsp. Sylvestris, Pistacia lentiscus L., Retama sphaerocarpa L., Boissier and Rhamnus lyocides L*. Results demonstrated successful vegetation growth under both treatments, particularly for composting, but also synergistically. According to Calatrava, Barbera, and Castillo (2011), compost from urban waste is becoming increasingly common in the Guadalentin, although it remains expensive; most widespread use of exogenous organic matter is seen through manure inputs.
- ***Revegetation***: revegetation experiments undertaken within the Segura catchment by Martinez-Fernandez et al. (1995) demonstrated high survival rates for *Anthyllis citysoides, Stipa tenacissima, Ephedera fragilis, Pinus halapensis, and Olea europaea*.
- ***Drip irrigation with fertilizer injection (fertirrigacion)*****:** drip irrigation is already common throughout the majority of the basin. There is potential to increase use of advanced drip irrigation systems able to simultaneously inject fertilizers within soils of broccoli and lettuce cultivations and apricots and lemons amongst orchards. Egea and Alarcon (2004) demonstrate potential for expansion from the current 60% of agricultural land area utilizing advanced irrigation technologies.
- ***Contour tillage, reduced tillage, no tillage***: minority option mostly implemented within rainfed systems of the Guadalentin (Calatrava et al., 2011). Field visits by Hein (2007) confirm contour tillage is only applied at a modest scale.
- ***Organic agriculture***: increasingly being implemented in the Guadalentin under subsidization from EU, particularly for less profitable crops or crops which require very low conversion costs (Calatrava et al., 2011).
- ***Gulley control***: studies undertaken in the Puentes catchments showed gulley control measures as one of the most adopted SLM practices amongst local farmers. These measures involve checking the gulley as to divert runoff, prevent further deepening and erosion within the gully and allow for stabilization and subsequent revegetation (Hein, 2007).
- ***Undersowing***: undersowing and intercropping are not common practices within the investigated region, primarily because they are seen as additional pressures upon already scarce water resources by local experts and stakeholders. Studies have furthermore indicated grass strips to be a more effective and culturally accepted measure to undersowing (Calatrava et al., 2011).
- ***Grass strips***: involve vegetation trapping sediment either on- or off-site from the agricultural field, in the form of vegetative buffers, contour strips or at specified vertical intervals within the agricultural plot. Concentrated runoff is spread and flow rate reduced, encouraging deposition of sediment (Mekonnen et al., 2014). According to Calatrava, Barbera, and Castillo (2011), vegetated strips, despite their infrequent implementation, are considered a very promising and effective soil erosion prevention measure for the Segura region. Vegetation type selected plays a determining role in impact and success of implemented measure. Martínez Raya, Durán Zuazo, and Francia Martínez (2006) tested the effect of vegetated strips at vertical intervals within almond orchards in southeastern Spain, concluding thyme as a very effective species for reducing soil loss.

In addition, the following literature findings should furthermore be considered for the selection of SLM practices for implementation:

- Farmers prefer implementation of SLM technologies which are inexpensive and result in significant yield increases (Calatrava et al., 2011). Thus, subsidization of certain measures

- Farmers are unlikely to implement SLM technologies which present only very long term benefits or have a long payback period (Hein, 2007).
- Application of grass strips and undersown crops is scarce and limited (Calatrava et al., 2011).
- No tillage is not practiced (SOCO, nd.).

SLM strategies selected for InVEST modeling

Because of limitations associated with InVEST model characteristics, the following SLM technology clusters were discarded as options for modeling: gulley rehabilitation, stone faced bunds, terraces, drip irrigation and water harvesting techniques including rainwater harvesting, runoff harvesting and below-ground piping. Furthermore, terraces and drip irrigation are already widespread throughout the research area, thus running a present scenario whereby the region would be presented as free from such SLM practices would be incorrect. Furthermore grazing land management was excluded as pastures and grazing levels in the region are negligible. In addition, SLM Technology Clusters which are by definition multi-purpose, notably organic agriculture and erosion control throughout production were excluded as they would not show the individual effect of each SLM technology upon ES provision. Afforestation and agro-forestry were also excluded as SLM clusters as they represent direct LULC changes. The literature review and site-specific SOCO and DESIRE studies shed light on preferences and techniques to date not practiced within the catchment. Based on such results and complexity, strip farming, in-situ composting, vermicomposting and undersowing were discarded from modeling work in favor of green manuring techniques and reduced tillage. These two technologies are listed in **Table 11** and thus represent the final SLM practices selected for quantification for potential implementation for climate adaptation and mitigation in the Segura.

Table 11: SLM technologies selected for InVEST modeling

	SLM strategy	SLM Technology Cluster	WOCAT SLM Technology Group
1	*Green manure*	Organic mulching	MANURING/COMPOSTING
2	*Reduced tillage*	Soil-protective tillage and sowing	CONSERVATION AGRICULTURE

InVEST modeling for priority ESs

Results of calibration of present ES provision

- *Carbon storage*

Despite calibration of the InVEST Carbon Storage and Sequestration model not being possible, comparisons were made between modeled results and data from available scientific literature. Global studies of carbon stocks within smaller catchments suggest similar average values per hectare, adding support to the modeled outcomes (**Table 19**); few studies report measured and modeled carbon stock values at the wider, regional scale. Shrestha and Singh (2008) investigated soil and vegetation carbon stocks in the Pokhare mountainous watershed of Nepal. Their results demonstrate an average carbon stock of 78.7 Mg C/ha, in line with the average results generated by the InVEST model for the Segura catchment of 85.72 Mg C/ha. Muñoz-Rojas et al. (2011) suggest a total vegetation carbon stock, covering both belowground and aboveground biomass, of 156.08 Tg in 2007 for the region of Andalusia, with an area of 87’000 km^2. Nevertheless, the limited value of comparison amongst different regions and watersheds should be noted, as carbon stocks are highly dynamic and dependent upon numerous factors, as is further elaborated within the discussion. Sharma and Rai (2007), show variability in mean carbon density from 46 Mg/ha to 669 Mg/ha within the Indian Mamlay watershed, depending on the LULC layers investigated.

Table 12- Total and average per hectare carbon stock values per catchment. Note-, pools refer to: A= aboveground biomass, B= belowground biomass

Total C (Mg C)	Total land area ha (km2)	Average (Mg C/ha)	Reference
149 859 663 (2006)	*1 748 430 (17 484)*	*85.71*	*InVEST modeled Segura catchment results (pools A, B, SOC)*
835 642	10 600 (106) (Hawaii)	78.8	(Goldstein et al., 2012) (pools A, B)
59 815	503 (5.03) (Nepal)	118.9	Shrestha and Singh (2008) (pool SOC)

- *Water provision*

Calibration was undertaken until a final, most optimal, value of 0.45 for R^2, and 0.47 for model efficiency (**Figure 13**).

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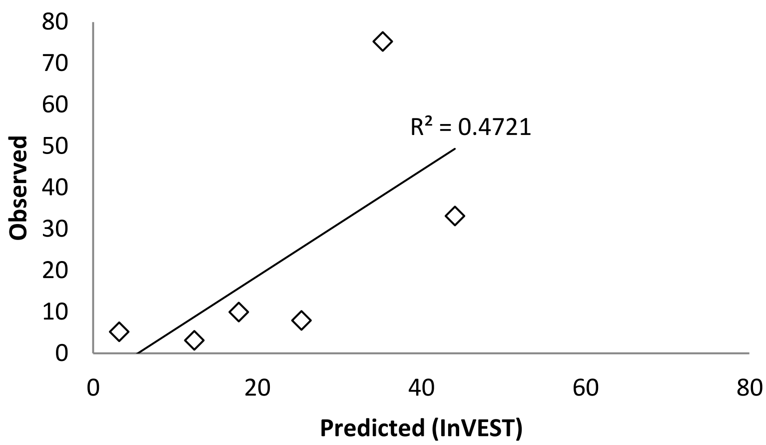


Figure 7- R^2 values for water yield (Mm^3) from predicted InVEST model results and observed water yield data average 1971-2000

- *Sediment retention*

Sediment retention also calibrated through the use of the Nash-Sutcliffe model efficiency coefficient (**Equation 4**) gave a final model efficiency coefficient value of 0.45 yielding an R^2 value of 0.59 (**Figure 14**).

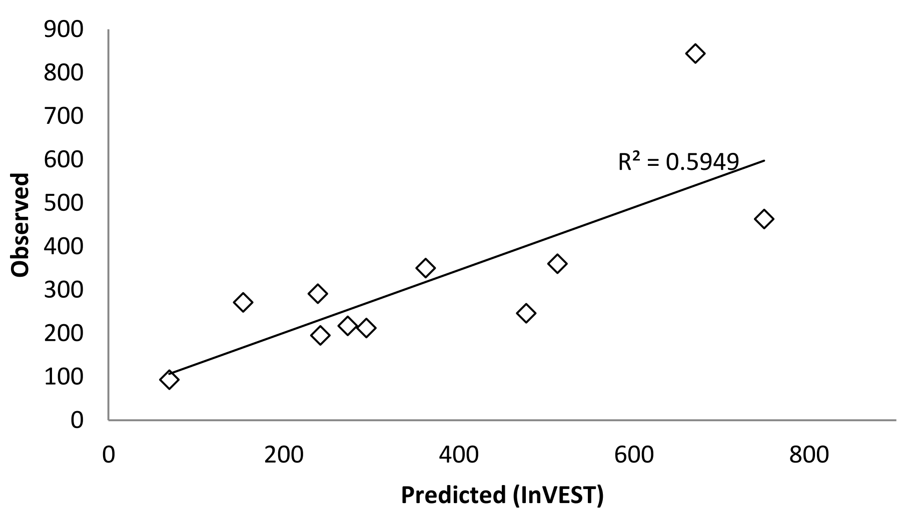


Figure 8- R^2 values for sediment export (t) from predicted InVEST model results and observed SSY values

Current ES provision in the Segura and Taibilla catchments

- *Carbon storage*

The total carbon stock of the Segura catchment in 2006 stored in belowground and aboveground biomass and SOC is estimated by the model at 152 x 10^6 Mg of C. Coniferous forest contributed to over 25% of the carbon stock, followed by sclerophyllous vegetation and complex cultivation patterns in order of significance in contribution to the carbon stock (**Table 12**). Complex cultivation patterns and non-irrigated arable land represent two land cover layers which are agricultural rather than forested or naturally vegetated areas, yet contribute considerably to the total carbon stock. Results demonstrate upstream catchments of Anchuricas, Talave, Fuensanta, La Vieja and Taibilla provide greatest values for average C stock; lowest values were found in sub-watersheds situated downstream (**Figure 7**, **Table 13**).

Table 13- LULC layers ranked in order of simulated contribution to total C stock for the Segura (% and total values in Mg of C)

	LULC layer	Contribution to total C stock (%)	Total C stock (Mg C)
1	*Coniferous forest*	27	40.4 x 10^6
2	*Sclerophyllous vegetation*	15	23.0 x 10^6
3	*Complex cultivation patterns*	11	16.6 x 10^6
4	*Transitional woodland-shrub*	11	16.1 x 10^6
5	*Non-irrigated arable land*	9	13.8 x 10^6

Table 14- Simulated average C stock (Mg C/ha) for top and bottom-five ranking sub-watersheds, compared with ranking value of respective sub-watershed for total C stock, per annum

Sub-watershed	Average C stock (Mg C/ha)	Ranking per average C stock	Ranking per total C stock
Anchuricas	124	1	17
Talave	117	2	5
Fuensanta	110	3	9
La Vieja	108	4	16
Taibilla	106	5	14
Judio	78	26	3
Guardamar	77	27	1
Bayco	76	28	21
La Pedrera	72	29	27
Santomera	71	30	23

The total carbon stock for the Taibilla catchment in the year 2000 was simulated to be 3.39 x 10^6 Mg C. The main contributing LULC layers are outlined in **Table 14**. Coniferous forest contributed to over half of the total sub-watershed stock. The remainder five top most contributing land cover layers are the same as for the whole of the Segura, with the exception of natural grasslands contributing to approximately 10% of total C stock for the Taibilla, not present within the Segura ranking, and complex cultivation patterns on the contrary contributing to approximately 11% of total C stock for the Segura but not present within the Taibilla ranking. For the Taibilla, non-irrigated arable land represents the only agricultural layer within the ranking contributing to total carbon stock.

Table 15- LULC layers ranked in order of contribution to total C stock for the Taibilla (percentage and total values of Mg of C)

	LULC layer	Contribution to total C stock (%)	Total C stock (Mg C)
1	*Coniferous forest*	53	1.80 x 10^6
2	*Transitional woodland-shrub*	17	560 x 10^3
3	*Natural grasslands*	10	325 x 10^3
4	*Sclerophyllous vegetation*	9	293 x 10^3
5	*Non-irrigated arable land*	8	257 x 10^3

Figure 7 illustrates the geographical distribution of carbon throughout the sub-watershed, in terms of hotspots of highest concentration of Mg of C per ha from belowground, aboveground and SOC. Carbon storage distribution throughout the area is heterogeneous, reflecting a fragmented landscape of coniferous forest and agricultural areas. **Figure 8** illustrates the same concepts for the Taibilla sub-watershed at a finer resolution.

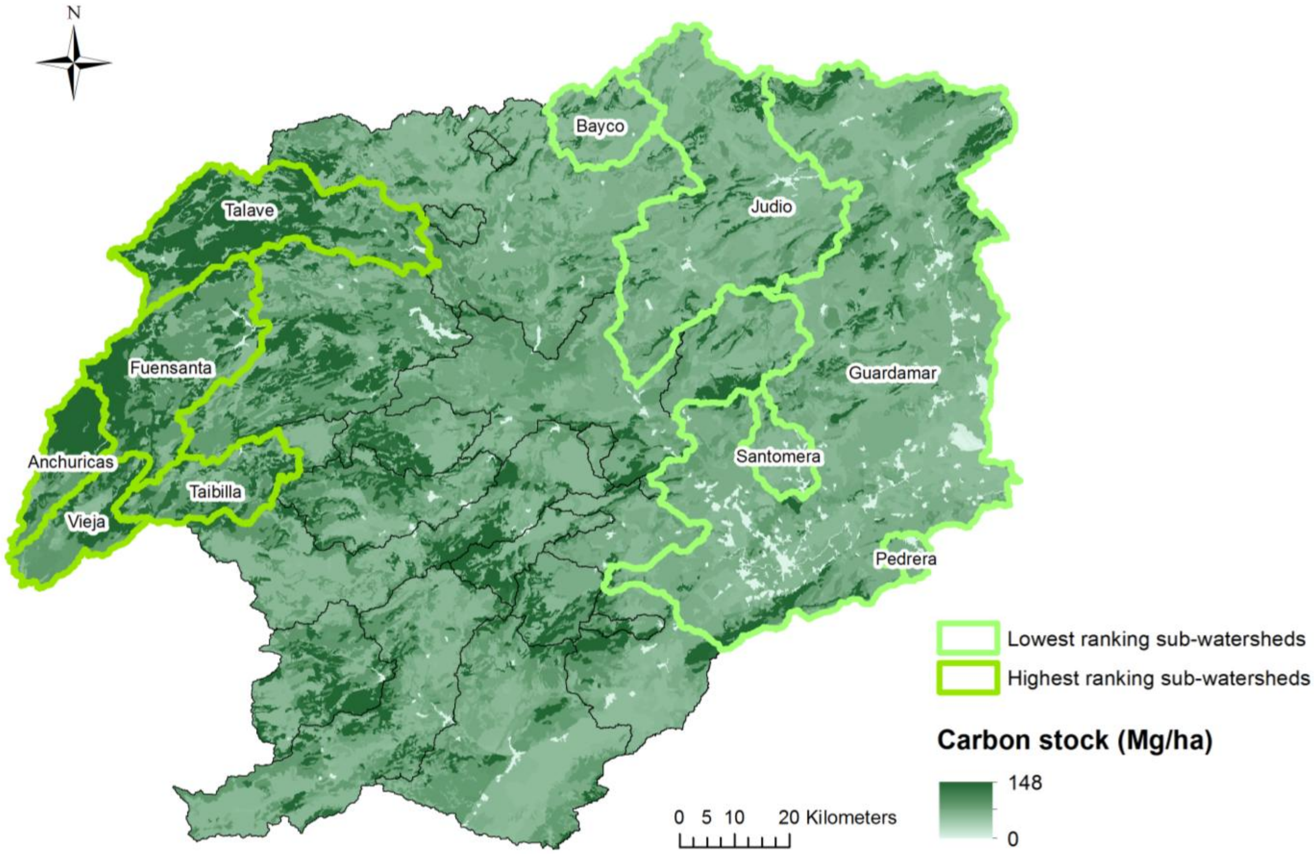


Figure 9- Carbon stock distribution in the Segura catchment and respective delineated highest and lowest scoring sub-watersheds ranked by average carbon stock for the year 2006 [3]

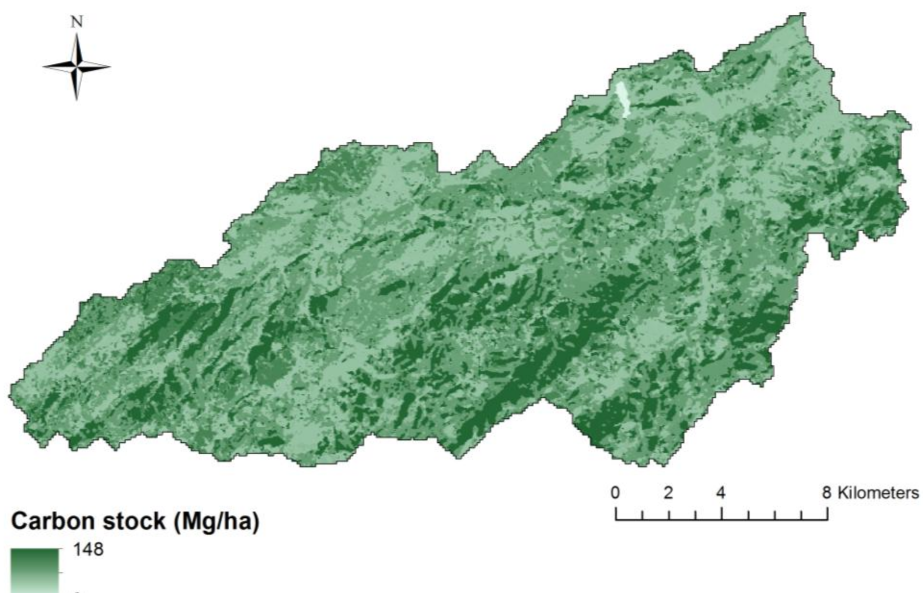


Figure 10- Average carbon stock distribution in the Taibilla sub-watershed in 2000

➢ *Water provision*

Total water yield of the Segura catchment in 2006 was simulated to be 560 Mm^3. In the Taibilla, the water yield had a value of 33 Mm^3 in 2000 and held the seventh highest total per sub-watershed throughout the whole of the Segura in 2006 (**Table 15, Figure 9**). Highest water yield averages per hectare are found upstream, reaching a maximum of 160 m^3 per hectare in La Vieja. Lowest values are for Roderos and Carcavos, with an average of approximately 11 and 6 m^3 of water per hectare respectively. Per hectare and total water yield rankings per sub-watershed fit similar trends.

Table 16- Average water yield (m^3/ha) for top and bottom-five ranking sub-watersheds of the Segura in 2006, compared with ranking value of respective sub-watershed for total water yield

Sub-watershed	Average water yield (m^3/ha)	Ranking per average water yield	Ranking per total water yield
La Vieja	160	1	3
Anchuricas	149	2	4
Taibilla	97	3	7
Fuensanta	74	4	2
Risca	64	5	17
Romeral	13	26	16
Mayes	11	27	30
Pliego	11	28	24
Rodeos	11	29	23
Carcavo	6	30	29

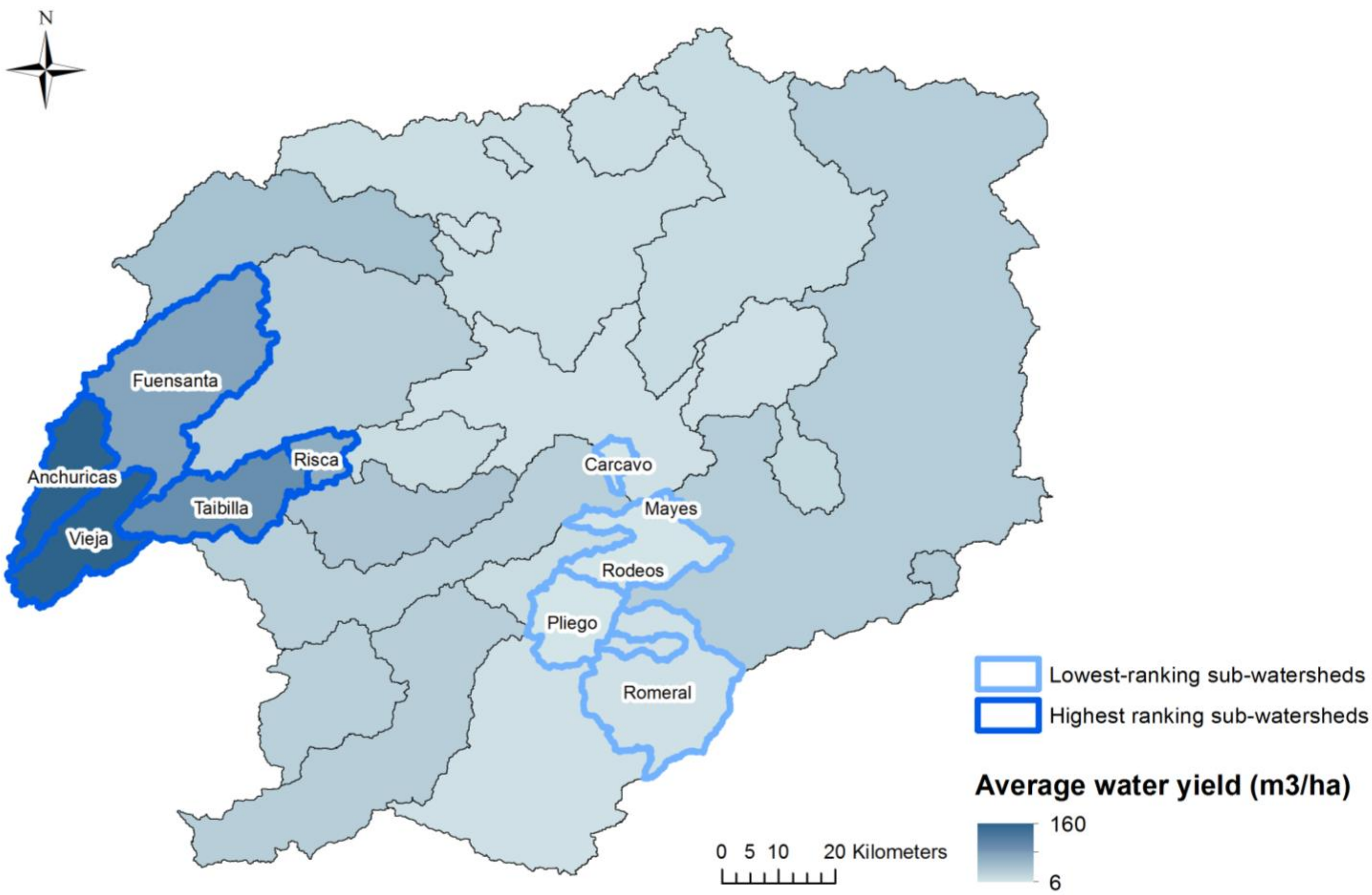


Figure 11- Average water yield values per sub-watershed throughout the whole of the Segura catchment and respective highest and lowest ranking sub-watersheds ranked by average water yield provision in 2006

➢ *Sediment retention*

Total simulated sediment retention and export for the Segura and the Taibilla in 2006 and 2000 respectively are shown in **Table 16**. Sub-watersheds with highest average sediment retention are also the sub-watersheds with highest values for average sediment export (**Table 17**; **Table 18**). Sub-watersheds with lowest values for average sediment retention and export, retaining an estimated lowest of approximately 1.69 x 10^3 t/ha and exporting a lowest of 0.4 t/ha respectively, are more geographically dispersed within the Segura catchment (**Figure 10**; **Figure 11**). The sub-catchments of Pedrera, Camarillas and Bayco however represent regions with lowest yearly values of average sediment retention yet also lowest average sediment export rates.

Table 17- Sediment export and sediment retained in the Segura watershed and Taibilla sub-watershed in 2006 and 2000 respectively

	Segura (2006)	Taibilla (2000)
Sediment export (t)	3.48 x 10^6	199 x 10^3
Sediment retained (t)	284 x 10^9	1.16 x 10^9

Table 18- Average sediment retention (t/ha) for top and bottom-five ranking sub-watersheds, compared with ranking value of respective sub-watershed for total sediment retention

Sub-watershed	Average sediment retention (t/ha)	Ranking per average sediment retention	Ranking per total sediment retention
Anchuricas	2.44 x 10^6	1	2
La Vieja	1.64 x 10^6	2	3
Fuensanta	934 x 10^3	3	1
Taibilla	703 x 10^3	4	5
Talave	385 x 10^3	5	4
Boqueron	7.25 x 10^3	26	28
Camarillas	5.45 x 10^3	27	20
Charcos	4.74 x 10^3	28	30
Pedrera	2.64 x 10^3	29	29
Bayco	1.69 x 10^3	30	27

Table 19- Average sediment export (t/ha) for top and bottom-five ranking sub-watersheds, compared with ranking value of respective sub-watershed for total sediment export

Sub-watershed	Average sediment export (t/ha)	Ranking per average sediment export	Ranking per total sediment export
La Vieja	10.5	1	5
Taibilla	7.5	2	7
Fuensanta	6.7	3	1
Risca	5.7	4	17
Anchuricas	5.1	5	10
Camarillas	0.7	26	11
Romeral	0.6	27	20
Bayco	0.5	28	23
Judio	0.5	29	15
Pedrera	0.4	30	30

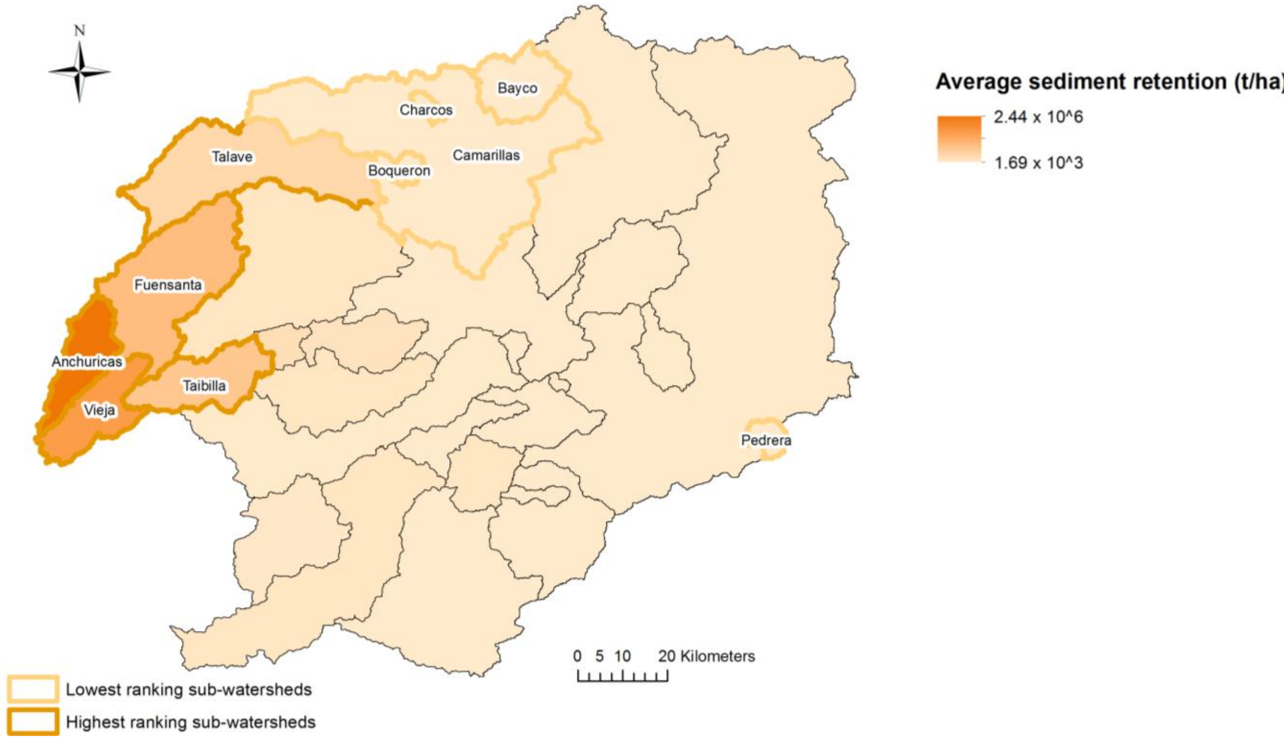


Figure 12- Average sediment retention values per sub-watershed for the whole of the Segura catchment and respective highest and lowest ranking sub-watersheds ranked by average sediment retention values in 2006

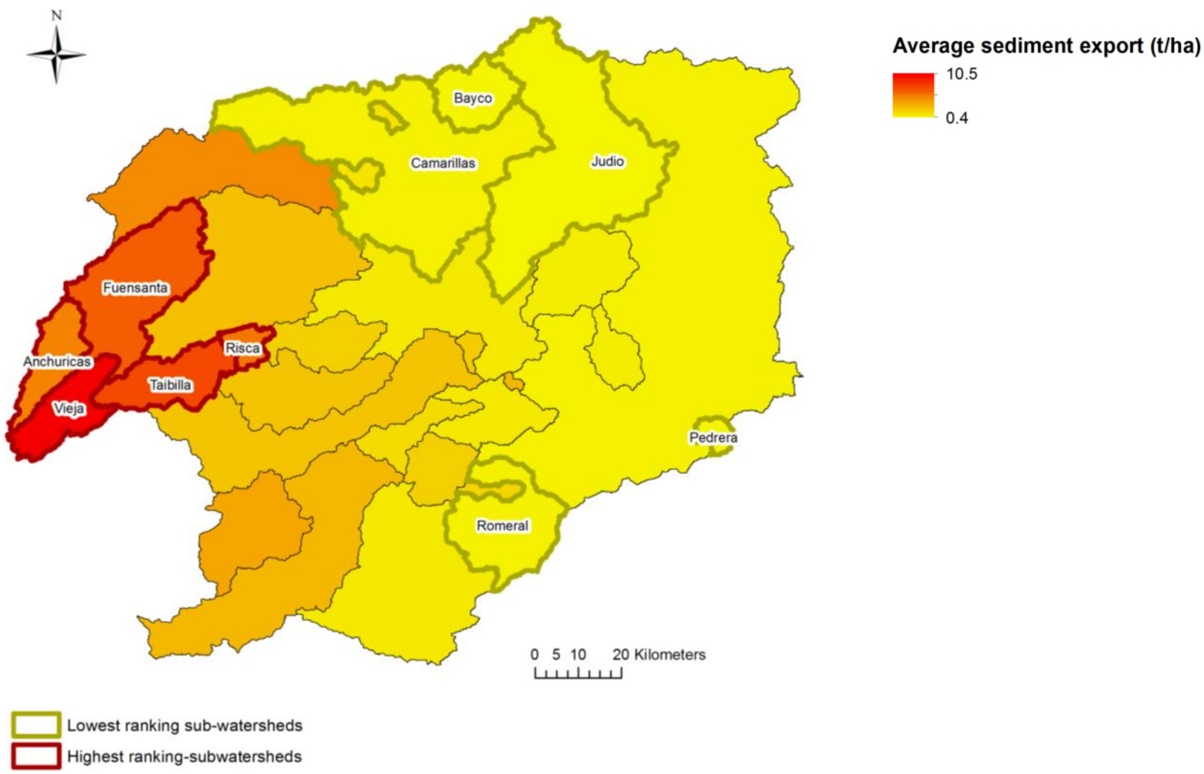
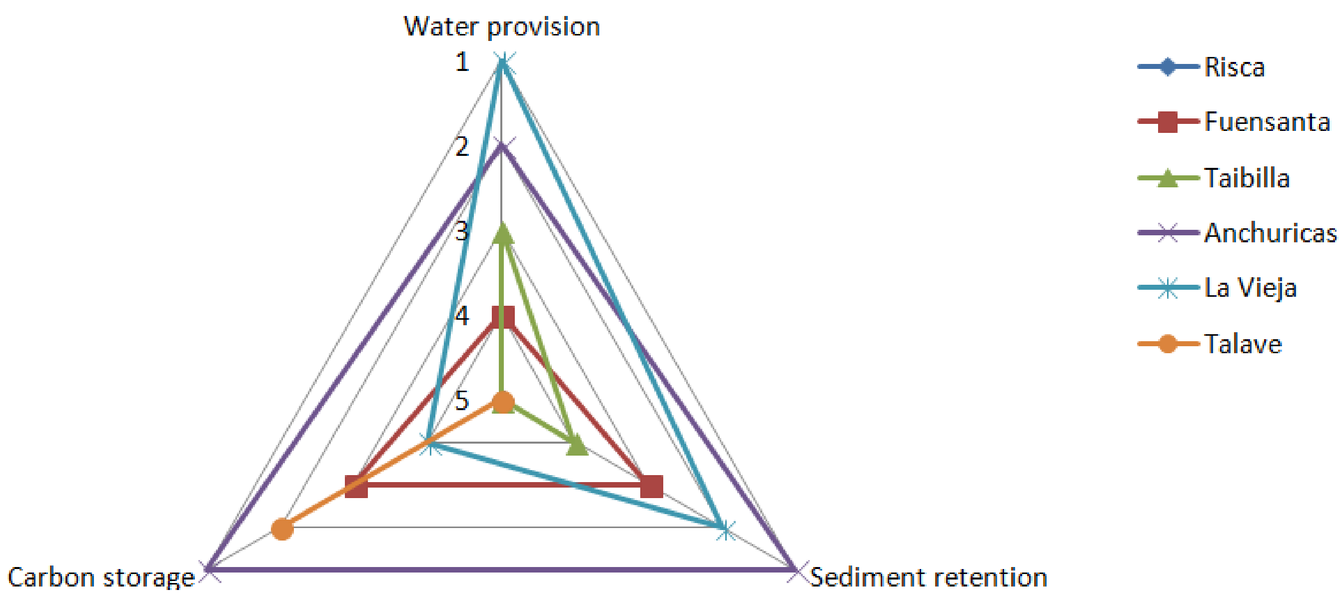


Figure 13- Average sediment export values per sub-watershed for the whole of the Segura catchment and respective highest and lowest ranking sub-watersheds ranked by average sediment export in 2006

Trade-offs and synergies within present ES provision

Highest provision of the three ESs investigated on an average per hectare basis was localized within upland (upstream) sub-watersheds. Rankings made of the top five sub-watersheds where highest average per hectare provision occurs for each of the three ES investigated demonstrated six of the thirty sub-watersheds of the Segura catchment as the main providers of ESs in the Segura, notably the Risca, Fuensanta, Taibilla, Anchuricas, La Vieja and Talave sub-watersheds. **Figure 12** aims to illustrate the synergies and trade-offs amongst the ESs provided by these six highest ranking sub-catchments by mapping the rankings on a radar diagram. The area size of the triangle within the radar diagram reflects the ranking position of the sub-watershed in terms of provision of each of the three ESs investigated. The bigger the area, the more significant is the sub-watershed for overall ES provision in the Segura. Furthermore, the more equilateral triangles suggest the existence of synergy, as opposed to trade-off, between the provisions of the three ESs. In light of this, the Fuensanta and Anchuricas sub-watersheds demonstrate greatest synergy for ES provision. The La Vieja and Taibilla sub-catchments show the lowest synergy in ES provision; both have greater contribution to water provision in comparison to lower sediment retention, and even lower contribution to carbon storage. The Talave and Risca sub-catchments are both limited to the top-provision of one or two of the three ESs, and are thus by definition not demonstrating synergy. Lowest values are more dispersed; in terms of geographical location, few share boundaries or overlaps between ESs poorly provided. The ecological functions and mechanisms underpinning ES provisions are dynamic and not representative of linear relationships. The statements made with regards to synergies and trade-offs are thus based on numerous assumptions, and can be at best be interpreted as broad indications; the discussion of the results chapter will aim to further explore these assumptions and shed light on the problematic.



	Water provision	Sediment retention	Carbon storage
Risca	5	-	-
Fuensanta	4	3	3
Taibilla	3	4	5
Anchuricas	2	1	1
La Vieja	1	2	4
Talave	-	5	2

Figure 14- Top-five ES provisioning sub-watersheds and extent of contribution to each ES by ranking position; illustration of contributions to ES provisions, synergies and trade-offs.

Effects of historical LULC changes on ES provision in the Segura catchment, 1990-2006

Comparing present scenario (2006) values of ES provision for the Segura catchment with ES provision according to 1990 and 2000 LULC data provides an indication of the effects of recent LULC transition trends on ES provision in the region. Both sediment retention and sediment export results from the sediment model are shown. Because of limitations and uncertainties associated with the sediment retention model component (refer to Discussion), these results will place greater focus upon the export results. The most significant changes were witnessed with regards to the provision of sediment; the least affected was carbon stock followed by water yield. Positive trends are witnessed for water yield, increase by 3.3% between 1990 and 2006, and sediment export, decreasing by over 20%. Carbon stock, however, decreased by 1.7% (**Table 20**; **Table 21**Table 21). In the case of sediment export, the most significant changes occurred between 1990 and 2000; for both water yield and carbon stock changes, LULC transitions occurred between 2000 and 2006 resulted in the most significant changes to their provision.

Table 20- Past (1990, 2000) and present (2006) total ES provision in the Segura catchment per ES investigated, further including sediment export

	Water yield (Mm3)	Sediment export (t)	Sediment retention (t)	Carbon stock (Mg C)
1990	542	4.40×10^6	528×10^9	152×10^6
2000	547	3.50×10^6	285×10^9	153×10^6
2006	560	3.48×10^6	285×10^9	150×10^6

Table 21- % Change between present (2006), 2000 and 1990 values for the three ESs investigated in the Segura catchment, furthermore including sediment export

	% Change water yield	% Change sediment export	% Change sediment retention	% Change carbon stock
1990 - 2000	+ 0.8	- 20.6	- 46.1	+ 0.1
2000 - 2006	+ 2.4	- 0.4	+ 0.1	- 1.6
1990 - 2006	***+ 3.3***	***- 20.9***	***- 46.1***	***- 1.7***

The prevailing LULC classes in the Segura catchment in 1990 were classified as arable and permanent crops, covering 35% of the area, followed by pastures and heterogeneous agricultural areas which comprised approximately 22% of the area (**Figure 15**). Both land classes, alongside forested land, witnessed decreases by 2006 at the expense of increases in urbanized and industrialized layers and scrubland and herbaceous vegetation. Sparsely vegetated land remained at 5% of area coverage throughout the time frame investigated.

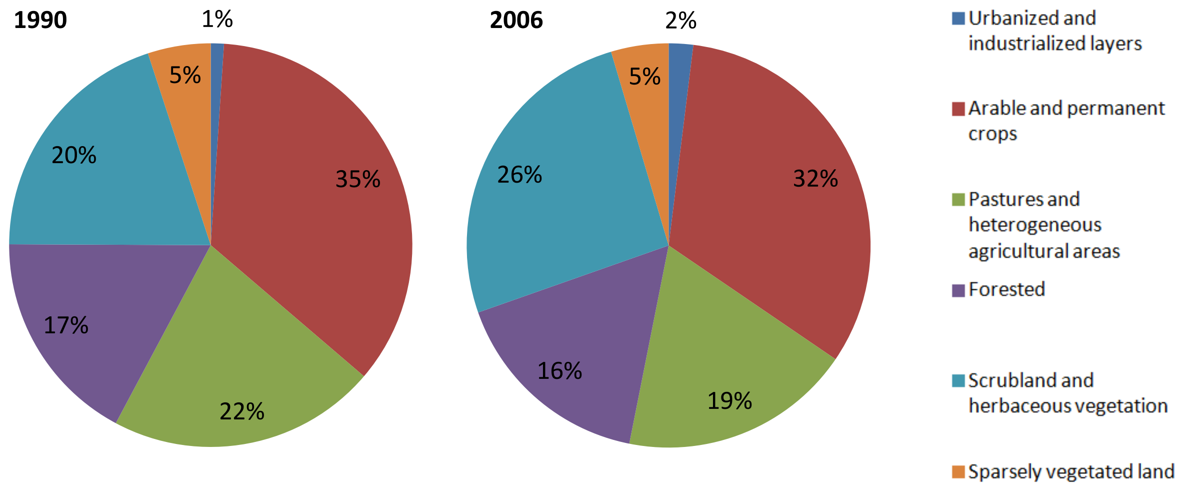


Figure 15- LULC distribution in the Segura catchment in 1990 and 2006

Transitions were classified as cases of urbanization, intensification of agriculture, extensification of agriculture, afforestation and deforestation as outlined in the methodology. The most prominent trend throughout the set time frame was afforestation, occurring over approximately 1'879 km^2, followed by the extensification of agriculture occurring over 1'019 km^2 (**Figure 16**). Deforestation occurred over 963 km^2, just over half the amount of afforestation.

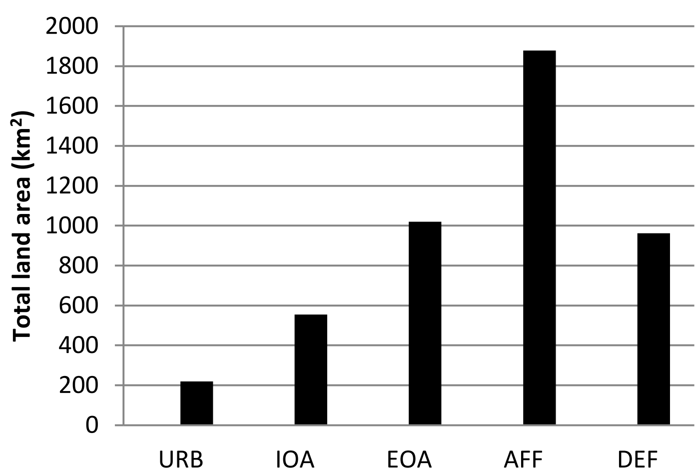
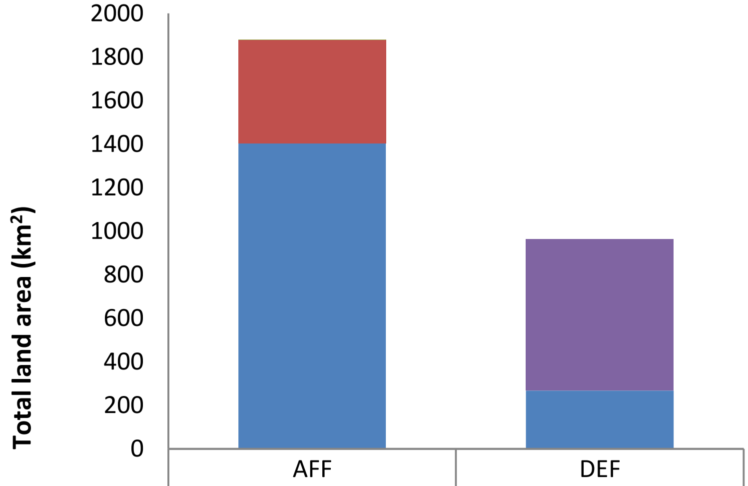


Figure 16-Total land area of LULC transition cases in the Segura catchment between 1990 and 2006

Results indicated a decrease in carbon stock between 1990 and 2006 despite transitions indicating afforestation occurring on a much wider scale than deforestation; this discrepancy is dependent upon the LULC which transformed to forested covers, or vice-versa. Cases of urbanization stemmed in 82% of cases from agricultural areas and the remaining 18% from areas of natural vegetation. **Figure 17** illustrates the original LULC layers which transitioned to forests under afforestation, and the LULC layers which transitioned from forests to other layers under deforestation. Afforested layers in 2006 originated in 74.7% of cases from 1990 agricultural areas, and the remainder from open spaces with sparse vegetation in 1990. Forested layers in 1990 which did not remain forested in 2006 transitioned in 72.3% of cases to scrubland, herbaceous vegetation and sparsely vegetated land, and in the remainder of cases to agricultural areas.



	AFF	DEF
Scrubland, herbaceous vegetation and sparsely vegetated land	0	696
Inland wetlands	0	0
Open spaces with sparse vegeation	475	0
Agricultural areas	1404	267

Figure 17- Originating and transitioned LULC layers for respective afforestation and deforestation transitions in the Segura catchment, 1990-2006

Investigating the spatial distribution of changes in the provision of ESs following LULC changes in the catchment allows for increased understanding of the existing correlations with specific LULC transitions and for the identification of priority sub-catchments for action in fostering ES provision. Because the input values of the carbon stock model are all given per LULC class, the spatial distributional changes in carbon stock since 1990 directly reflect the LULC transitions which have occurred at the watershed and sub-watershed scale.

- *Carbon storage*

Figure 18 illustrates 10 of the 30 of sub-catchments of the Segura have witnessed a decrease in their annual average carbon stocks in 2006 when compared to their 1990 stock following LULC transitions and consequently delineating regions of ES decline and thus priority areas for action. Highest decreases occurred within the sub-watersheds of Fuensanta, Valdeinferno and Moratalla and Ojos sub-catchments, both in terms of absolute values and as percentage decreases. Fuensanta, Valdeinferno and Moratalla present respective average carbon stock values 5.71, 3.78 and 3.17 Mg C/ha lower than in 1990. Highest absolute increases in annual per hectare carbon stock values were witnessed in the Pliego, Algeciras and De La Cierva sub-catchments, where the 2006 per hectare annual values were respectively of 31.1, 24.2 and 23.9 Mg C/ha higher than in 1990. For the Pliego catchment, this represents a 44% increase in average water yield, considerably higher than the 4.96% highest average decrease witnessed in the Fuensanta sub-catchment (**Table 22**). Absolute values and percentage changes for the sub-watersheds which have witnessed a decreased carbon stock suggest similar rankings.

Table 22-Percentage increase in average carbon stock between 1990 and 2006 per top five sub-watersheds ranked by highest % increase

	Sub-watershed	Percentage increase
1	*Pliego*	44.43
2	*Algeciras*	31.59
3	*De La Cierva*	30.36
4	*Romeral*	12.51
5	*Boqueron*	8.54

As previously noted, because the InVEST Carbon Storage and Sequestration model is based solely upon LULC-based inputs, the changes are a direct reflection of the LULC transitions which have occurred and thus of high- or low-carbon density LULC layers. It can therefore logically be assumed that the catchments having witnessed an increased carbon stock, particularly Pliego, Algeciras and De La Cierva, have undergone net LULC transitions of afforestation and/or extensification of agriculture. The opposite holds true for the catchments having witnessed decreases in carbon stock. It should furthermore be noted that 9 sub-watersheds have both an absolute and relative (%) value of carbon stock increase and decrease of $^{+}/_{-}1$ (**Figure 18**); in light of coarseness of data we can assume these sub-watersheds have maintained their existing 1990 carbon stock.

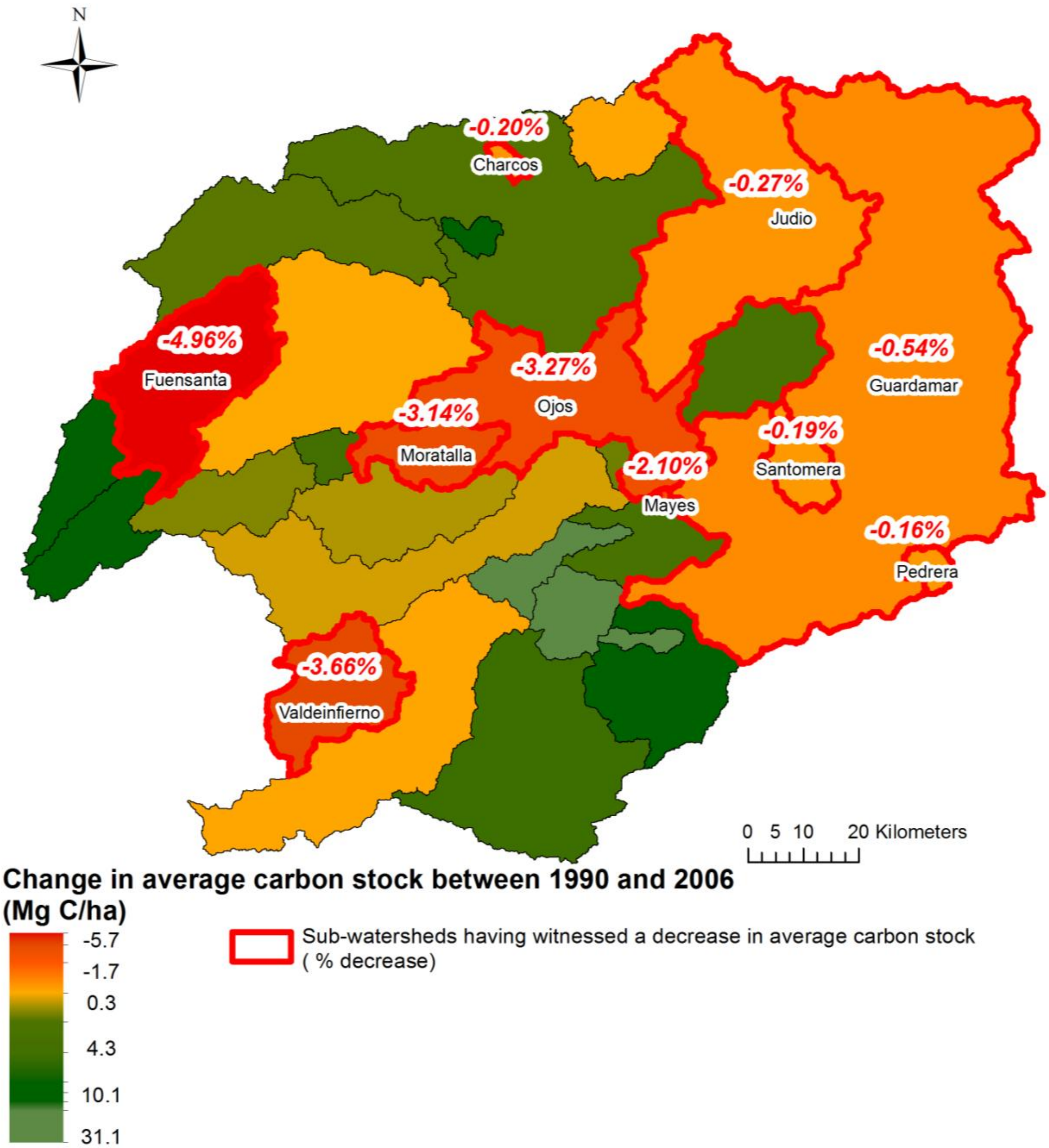


Figure 18- Average per hectare change in carbon stock (Mg of C) per sub-watershed of the Segura between 1990 and 2006, alongside percentage change in sub-watersheds having witnessed a decrease in average carbon stock

➢ *Water provision*

The Segura has witnessed a net increase in water yield due to LULC transitions between 1990 and 2006 at the catchment scale. However, this trend was not witnessed within each of the sub-catchments. The upland catchments providing the highest average water yield values in 2006 are for the large part also the sub-catchments which witnessed decreases in water yield levels since 1990, as illustrated in **Figure 19**. Highest absolute decrease in water provision between 1990 and 2006 was of 41.3 m^3/ha, representing a 21% decline from 1990 levels, occurring within the La Vieja sub-catchment. Biggest increases of 8.7 and 6.8 m^3/ha (38% and 21%) respectively occurred in the Guardarmar and Argos sub-catchments. The analysis of the LULC transitions between 1990 and 2006 within the La Vieja and Argos sub-catchments (chosen instead of Guardarmar as a result of inclusion within calibration and higher likelihood of accuracy in values), outlined in **Table 23**, indicates afforestation and deforestation as the most significant transitions, with negligible LULC changes towards extensification of agriculture and urbanization. Whereas in the La Vieja catchment, afforestation and deforestation changes have occurred at similar scales (40% and 36% of overall change), in the Argos catchment afforestation occurred over 14% more of the catchment area than deforestation. Furthermore, the Argos catchment had more significant instances of urbanization and lower cases of extensification of agriculture.

Table 23- Comparison of LULC transitions occurred between 1990 and 2006 in the La Vieja and Argos sub-watersheds, respectively representing the catchments which witnessed highest decrease and increase in the provision of per hectare average water yield in absolute terms within the Segura. Total land area which has undergone change (km^2), percentage of total land which has undergone change and percentage of total catchment area are stated.

	La Vieja			*Argos*		
	Total land area (km^2)	**% of change**	**% of catchment land area**	**Total land area (km^2)**	**% of change**	**% of catchment land area**
URB	-	-	-	6.9	7.7	1.5
IOA	10.8	14.8	3.9	12.9	14.3	2.9
EOA	6.8	9.4	2.5	3.3	3.6	0.7
AFF	28.9	39.8	10.5	40.2	44.3	8.9
DEF	26.1	36.0	9.5	27.4	30.2	6.1

In consideration of percentage changes, the highest increase and decrease in the provision of average water yield occur within different sub-watersheds (**Figure 19**; **Table 25**). The top five ranking highest percentage increases in average water yield are outlined in **Table 24**, the highest estimated at 87% occurring within the Mayes sub-catchment. Analysis of LULC changes for the Mayes catchment shows it was subject to significant deforestation, occurring over 20% of total catchment area. Opposite trends are witnessed in the Boqueron catchment, having witnessed approximately a 70% decrease in average water yield provision as a result of extensive afforestation having occurred on over 90% of all catchment land area (**Table 25**).

Table 24- Percentage increase in average water yield between 1990 and 2006 per top five sub-watersheds ranked by highest % increase

	Sub-watershed	**Percentage increase**
1	*Mayes*	87.17
2	*Ojos*	41.06
3	*Guardamar*	37.66
4	*Pareton*	28.79
5	*Algeciras*	22.39

Table 25- Comparison of LULC transitions occurred between 1990 and 2006 in the Boqueron and Mayes sub-watersheds, respectively representing the catchments which witnessed highest percentage decrease and increase in the provision of per hectare average water yield in the Segura. Total land area which has undergone change (km^2), percentage of total land which has undergone change and percentage of total catchment area are stated.

	Boqueron			*Mayes*		
	Total land area (km^2)	**% of change**	**% of catchment land area**	**Total land area (km^2)**	**% of change**	**% of catchment land area**
URB	0.3	0.5	0.5	0	0	0
IOA	7.5	13.0	14.4	0.5	9.4	3.6
EOA	-	-	-	0.2	3.2	1.2
AFF	48.2	83.2	93.2	1.7	34.0	13.1
DEF	1.9	3.3	3.7	2.7	53.3	20.5

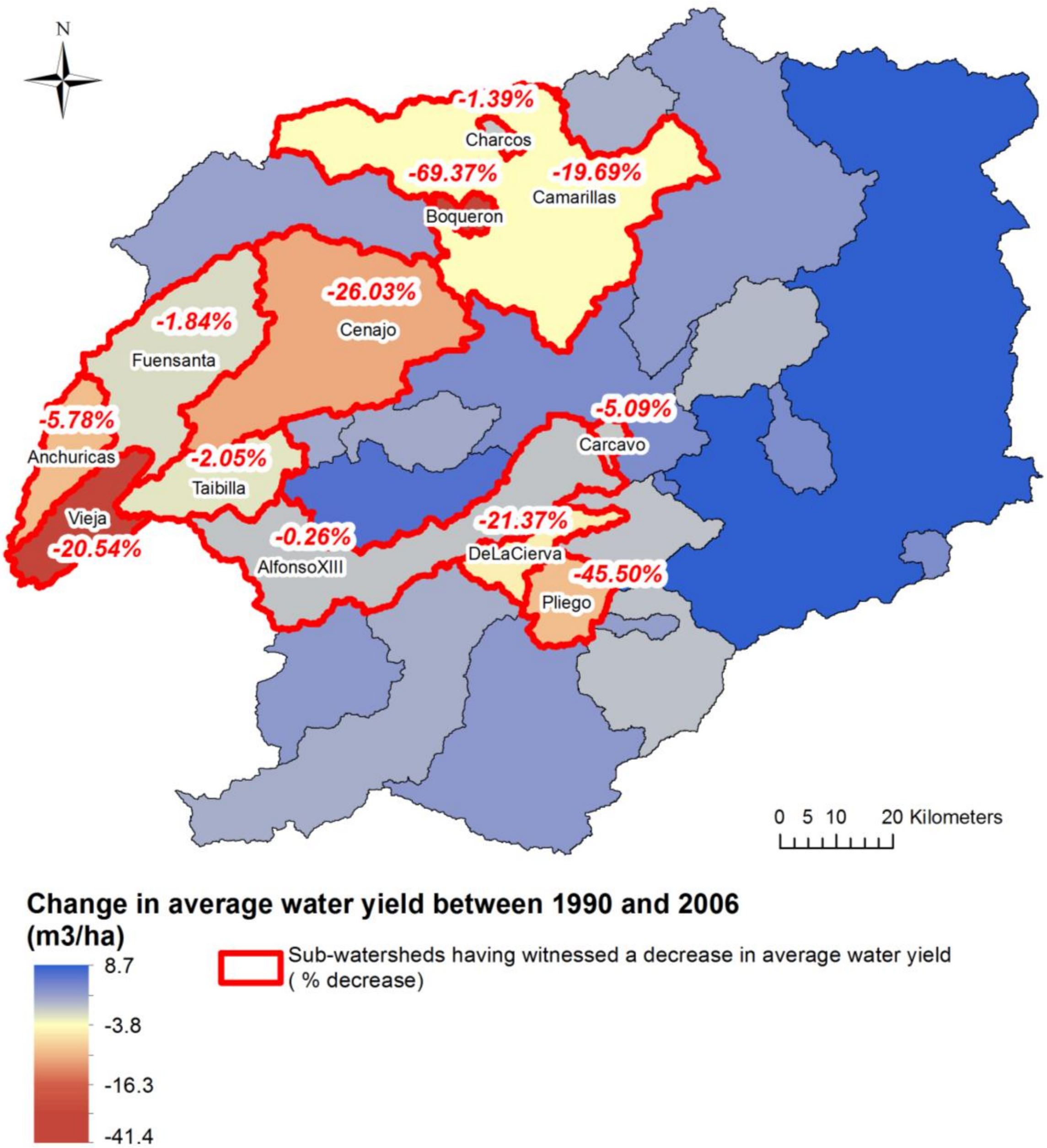


Figure 19- Change in average per hectare water yield provision (m^3) per sub-watershed of the Segura between 1990 and 2006

➢ *Sediment retention*

Per hectare sediment retention witnessed a decrease in all of the Segura's sub-catchments between 1990 and 2006 as a result of LULC transitions. Highest decrease in absolute terms was witnessed in the Anchuricas sub-catchment, whereas lowest occurred in the Boqueron with an estimated 64 t/ha (**Figure 20**). **Table 26**Table 26 outlines the LULC transitions which have taken place in these two sub-catchments. This analysis shows over 93% of the Boqueron catchment land area has witnessed afforestation between 1990 and 2006; this figure is reduced to 12.5% for the Anchuricas catchment, despite remaining the most important LULC transition. Highest decreases in absolute values for the provision of this ES mostly occurred within upland catchments, but also within De La Cierva and Pliego more southerly located.

Table 26- Comparison of LULC transitions occurred between 1990 and 2006 in the Anchuricas and Boqueron sub-watersheds, respectively representing the catchments which witnessed highest and lowest decreases in the provision of per hectare average sediment retention in absolute terms within the Segura. Total land area which has undergone change (km^2), percentage of total land which has undergone change and percentage of total catchment area are stated.

	Anchuricas			*Boqueron*		
	Total land area (km^2)	**% of change**	**% of catchment land area**	**Total land area (km^2)**	**% of change**	**% of catchment land area**
URB	-	-	-	0.3	0.5	0.5
IOA	2.6	4.8	1.1	7.5	13.0	14.4
EOA	1.3	2.3	0.5	-	-	-
AFF	29.6	54.0	12.5	48.2	83.2	93.2
DEF	2.1	38.9	0.9	1.9	3.3	3.7

Catchments having witnessed lowest percentage decreases match catchments having witnessed lowest decreases in absolute values. Outlined in **Table 27**, the top-five lowest percentage decrease sub-watersheds hold v alues ranging from -1 to -15%, also lowest within the Boqueron. With the exception of the Pliego catchment, watersheds which have witnessed highest percentage decreases do not occur within the same catchments which witnessed highest decreases in absolute values, and are clustered south of the Segura (**Figure 20**).Furthermore, values for percentage decrease are considerably high, the top-five ranking sub-waterhseds holding values above 73%, highest within the De La Cierva subwatershed. Analysis of LULC transitions within this subwatershed (**Table 28**), suggest afforestation to be the prevalent transition occurred in De La Cierva, affecting 50% of catchment area, as opposed to the 93% occurred within Boqueron.

Table 27- Percentage decrease in average sediment retention between 1990 and 2006 per top five sub-watersheds ranked by lowest % decrease

	Sub-watershed	**Percentage decrease**
1	*Boqueron*	-0.93
2	*Guardamar*	-9.20
3	*Pedrera*	-11.07
4	*Ojos*	-11.41
5	*Bayco*	-14.84

Table 28- Comparison of LULC transitions occurred between 1990 and 2006 in the De La Cierva and Boqueron sub-watersheds, respectively representing the catchments which witnessed highest and lowest percentage decrease in the provision of per hectare average sediment retention in the Segura. Total land area which has undergone change (km^2), percentage of total land which has undergone change and percentage of total catchment area are stated.

	De La Cierva			*Boqueron*		
	Total land area (km^2)	**% of change**	**% of catchment land area**	**Total land area (km^2)**	**% of change**	**% of catchment land area**
URB	1.0	0.9	0.6	0.3	0.5	0.5
IOA	0.8	0.7	0.5	7.5	13.0	14.4
EOA	10.0	8.9	5.7	-	-	-
AFF	90.1	80.6	51.8	48.2	83.2	93.2
DEF	9.9	8.8	5.7	1.9	3.3	3.7

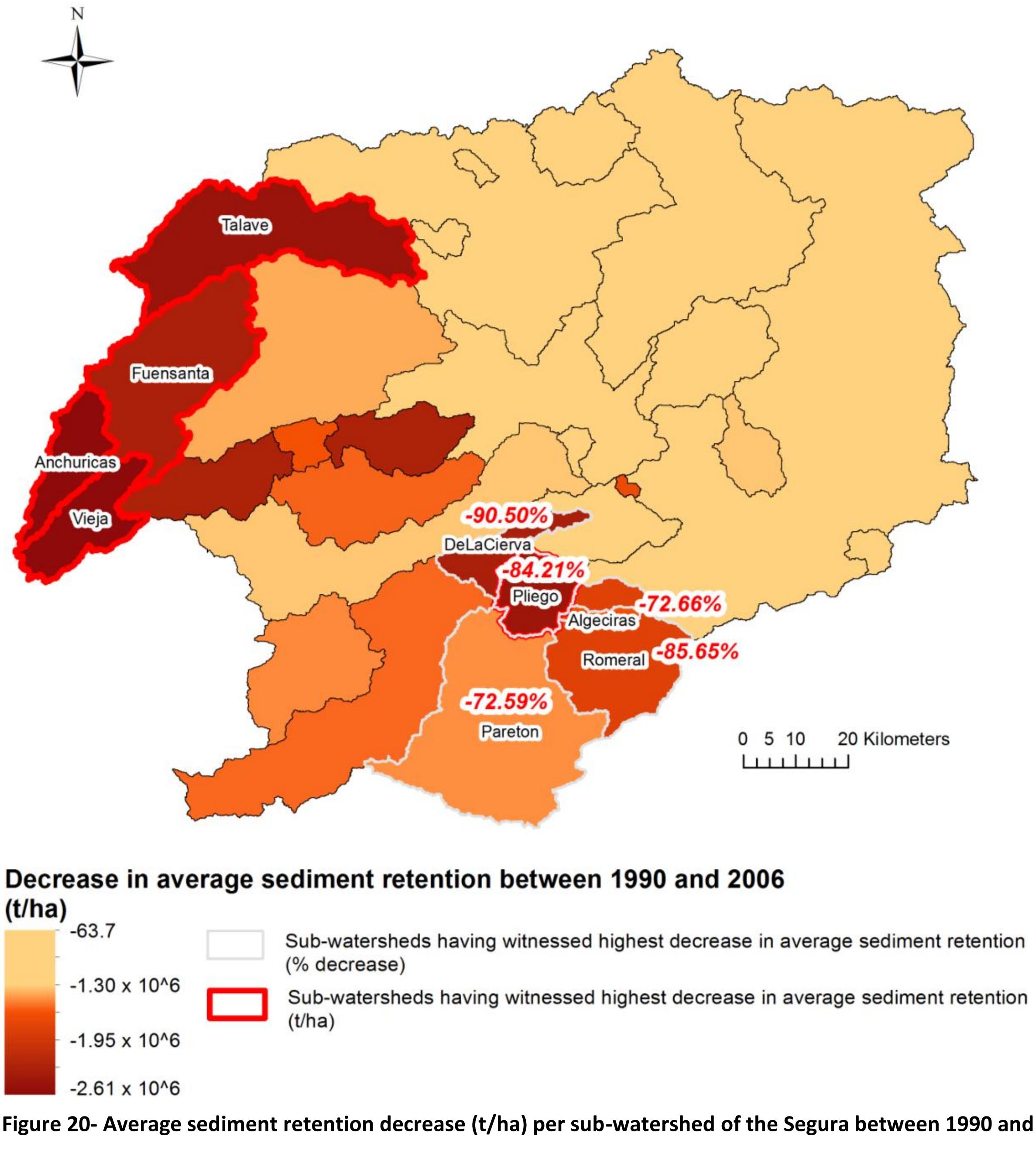


Figure 20- Average sediment retention decrease (t/ha) per sub-watershed of the Segura between 1990 and 2006

➢ *Sediment export*

Per hectare sediment export witnessed a net decrease between 1990 and 2006 throughout the Segura catchment as a result of LULC transitions; this trend is thus witnssed in the majority of the sub-catchments with the exception of the La Vieja, Risca, Talave, Judio and Charcos sub-catchments (**Figure 21**). The increases in average export rates were largely smaller than the decreases witnessed by the majority. Highest increase in per hectare sediment export occurred within the Talave by 0.5 t; highest decrease, on the other hand, was witnessed within the Anchuricas sub-catchment with an average decrease in sediment export of 5.98 t per hectare between 1990 and 2006.

Analysis of LULC transitions between 1990 and 2006 for the catchments which witnessed highest decrease and highest increase in per hectare sediment export in absolute values suggest similar trends between the two (**Table 29**). Afforestation has been the main LULC transition for both catchments (over 50% of all LULC transitions), followed by deforestation and with considerably less cases of urbanization, intensification and extensification of agriculture (less than 10% of all LULC transitions for both catchments). However, when considering the percentage of total catchment area which has undergone specific transitions, deforestation is largely more noteworthy in the Talave than in the Anchuricas catchment, where 7.2% of total catchment area witnessed deforestation between 1990 and 2006 in comparison to 0.90% in Anchuricas.

Table 29- Comparison of LULC transitions occurred between 1990 and 2006 in the Talave and Anchuricas sub-watersheds, respectively representing the catchments which witnessed highest increase and decrease in per hectare average sediment export in the Segura. Total land area which has undergone change (km^2), percentage of total land which has undergone change and percentage of total catchment area are stated.

	Talave			*Anchuricas*		
	Total land area (km^2)	**% of change**	**% of catchment land area**	**Total land area (km^2)**	**% of change**	**% of catchment land area**
URB	0.4	0.2	0.1	-	-	-
IOA	17.1	8.9	2.2	2.6	4.8	1.1
EOA	11.9	6.2	1.6	1.3	2.3	0.5
AFF	107.5	56.1	14.1	29.7	54.0	12.5
DEF	54.7	28.6	7.2	2.1	38.9	0.9

Analysis of percentage increases and decreases provides additional insight into the effects of LULC changes upon distribution of average sediment export rates. Highest percentage decreases for the top-five ranking sub-watersheds all had values above 50%, highest within the Romeral catchment with an estimated decrease of -79% (**Table 30**). LULC changes occurred in the Romeral show afforestation to be the most important transition, having occurred over 26% of the total catchment area, followed by extensification of agriculture over 10% of the catchment area (**Table 31**). On the other hand, highest percentage increase in sediment export occurred within the Talave, as for absolute values, characterized by a higher proportion of deforestation and more considerable intensification of agriculture over extensification rates (**Table 31**Table 31).

Table 30- Percentage decrease in average sediment export between 1990 and 2006 per top five sub-watersheds ranked by highest % decrease

	Sub-watershed	**Percentage decrease**
1	*Romeral*	-79.17
2	*Pliego*	-73.12
3	*De La Cierva*	-68.07
4	*Anchuricas*	-53.07
5	*Pareton*	-50.37

Table 31- Comparison of LULC transitions occurred between 1990 and 2006 in the Romeral and Talave sub-watersheds, respectively representing the catchments which witnessed highest percentage decrease and increase in per hectare sediment export in the Segura. Total land area which has undergone change (km^2), percentage of total land which has undergone change and percentage of total catchment area are stated.

	Romeral			*Talave*		
	Total land area (km^2)	**% of change**	**% of catchment land area**	**Total land area (km^2)**	**% of change**	**% of catchment land area**
URB	6.8	3.2	1.4	0.4	0.2	0.1
IOA	9.9	4.7	2.0	17.1	8.9	2.2
EOA	48.5	22.8	9.8	11.9	6.2	1.6
AFF	128.5	60.6	25.9	107.5	56.1	14.1
DEF	18.6	8.8	3.7	54.7	28.6	7.2

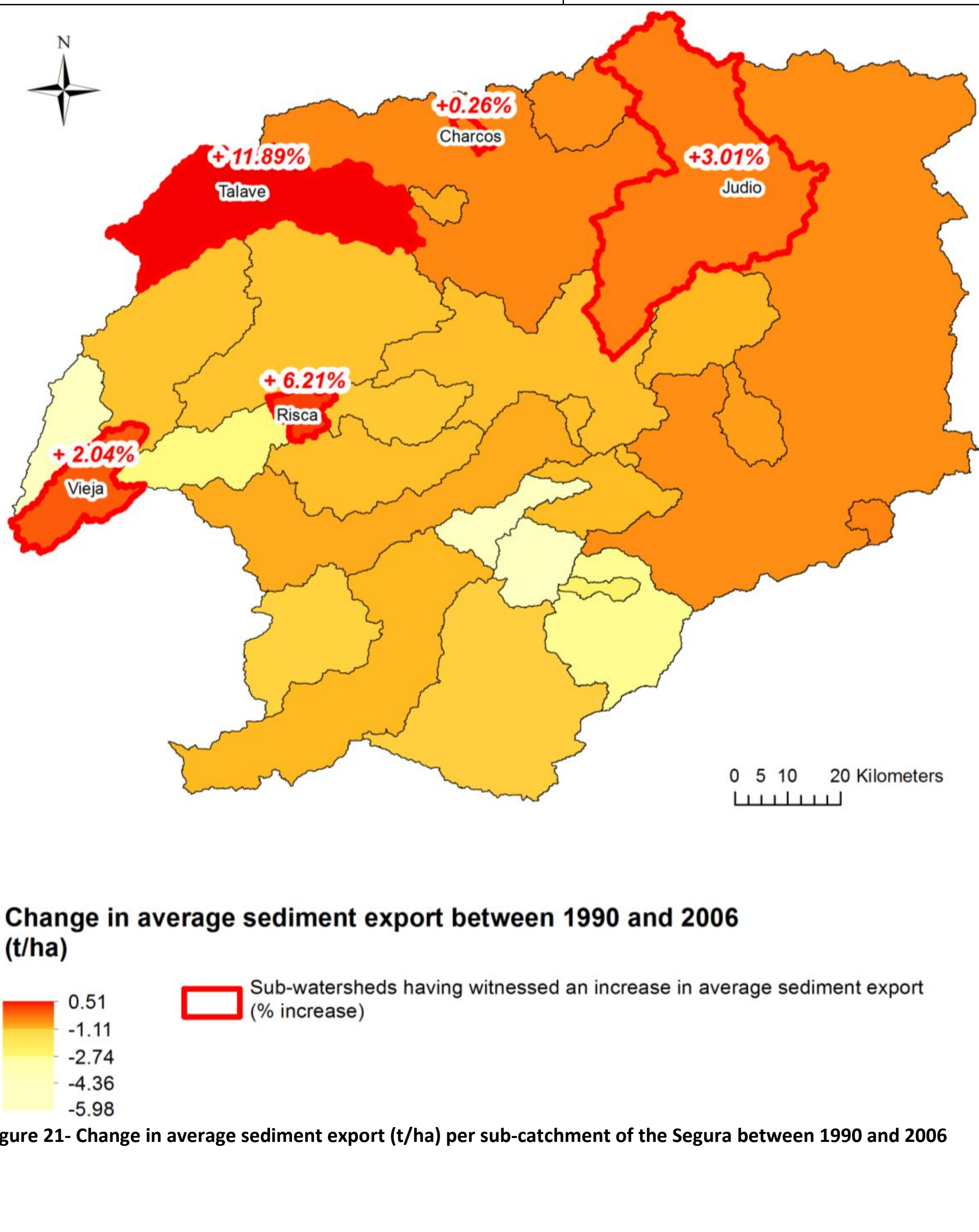


Figure 21- Change in average sediment export (t/ha) per sub-catchment of the Segura between 1990 and 2006

Effects of historical LULC changes and past climatic changes on ES provision in the Taibilla sub-catchment, 1956-2000

Analysis of changes in ES provision between 1956 and 2000 in the Taibilla sub-catchment, investigated at a finer resolution, gives an indication of the effects of LULC transitions on ES provision within an upstream sub-catchment of the Segura. Furthermore, historical precipitation and reference evapotranspiration data used allows for the quantification of differences in the provision of water as a result of historical changes in LULC transitions in comparison to precipitation changes. Decreases in ES provision between 1956 and 2000 were witnessed for water yield; however carbon stock witnessed an increase of 10.5% and sediment export a decrease in 54% (**Table 32**; **Table 33**). In the case of sediment export and carbon stock, the biggest proportion of change occurs within the 1987 and 2000 time frame. However, it should be noted that trends reversed when considering the 1956 and 1987 time period and 1987 to 2000 time frame for carbon stock. Carbon stock witnessed little, negative change in 1987 compared with 1956 levels, however the majority of change occurred in the 1987-2000 time frame whereby the stock of carbon increased by over 10%.

When investigating differences in impact from historical LULC changes and past climatic changes in consideration of water yield, it can be noted that climate has a much stronger impact upon water provision than LULC changes (**Table 33**). Historical precipitation records show a 19.5% higher average than was witnessed for the 1970-2000 period (**Table 34**). Similarly, average PET taken from historical data was of 1116 mm compared with an average of 1104 in the 1987-2000 average utilized for present and 1987 scenarios. The model running on present climate data, and thus altering only as a result of LULC transitions which have occurred, shows a decrease of 8.4% in water provision throughout the 1956-2000 time frame, mostly occurred since 1987. However, incorporating respective historical climate averages demonstrates a decrease of over 40% in water provision in the same time frame.

Table 32- Past (1956, 1987) and present (2000) total ES provision in the Taibilla catchment per ES investigated, further including sediment export. InVEST water provision model was run twice with two sets of climate data; one adjusted for the 1950-1980 period, the other under the same climate as the 1987-2000 dataset, represented as *LULC and climate* and *LULC only* respectively.

	Water yield (Mm3)		Sediment export (t)	Sediment retention (t)	Carbon stock (Mg C)
	LULC only	*LULC and climate*	*LULC only*	*LULC only*	*LULC only*
1956	36.0	56.7	432 $\times 10^3$	1.67 $\times 10^9$	3.08 $\times 10^6$
1987	35.8		401 $\times 10^3$	2.36 $\times 10^9$	3.06 $\times 10^6$
2000	33.0		199 $\times 10^3$	1.16 $\times 10^9$	3.39 $\times 10^6$

Table 33- % Change between present (2000), 1987 and 1956 values for the three ESs investigated in the Taibilla catchment, further including sediment export. InVEST water provision model was run with two sets of climate data; one adjusted for the 1950-1980 period, the other under the same climate as the 1987-2000 dataset, represented *as LULC and climate* and *LULC only* respectively.

	% Change water yield		% Change sediment export	% Change sediment retention	% Change carbon stock
	LULC only	*LULC and climate*	*LULC only*	*LULC only*	*LULC only*
1956 - 1987	- 0.5	- 40.3	- 7.1	+ 41.5	- 0.8
1987 - 2000	-8.0		- 50.5	- 50.8	+ 11.0
1956 - 2000	***- 8.4***	***- 41.8***	***- 54.0***	***- 30.4***	***+ 10.2***

Table 34- Comparison of results from modeling of water provision derived with the utilization of historical climate data (averaging from 1956-1970) and present scenario climate data (averaging 1970-2000 period) for the Taibilla catchment.

Climate data	Average precipitation (mm)	Average PET (mm)	Average AET (mm)	Average water yield (m^3)
Historical mean	840	1116	659	179
Equal to 1987 and 2000 (present) scenario	703	1104	587	114

Because the LULC classification system was different for the year 1956, with a more limited set of classes, analysis of LULC transitions which have occurred have been based upon comparison of 1987 and 2000 LULC datasets. **Table 35** indicates the most important LULC transition to have occurred in the Taibilla in the delineated time frame to be afforestation, affecting 21.6% of catchment land area and comprising over 47% of all transitions. There were no cases of urbanization and extensification of agriculture; whereas both intensification and deforestation occurred throughout the catchment.

Table 35- Comparison of LULC transitions occurred between 1987 and 2000 in the Taibilla sub-catchment

	Taibilla		
	Total land area (km^2)	**% of change**	**% of catchment land area**
URB	-	-	-
IOA	25.5	17.8	8.1
EOA	-	-	-
AFF	68.4	47.7	21.6
DEF	49.7	34.6	15.7

ES provision in 2050 under IPCC A1B scenario in the Segura and Taibilla catchments

Under the A1B IPCC scenario, average precipitation is expected to decrease by an average of 30% across the Segura by 2050, while PET is expected to increase by an average of 0.2% across the Segura (**Table 36**). This has severe repercussions upon the ESs of water yield and sediment export; expected to respectively decline by approximately 61 and 63% across the Segura in 2050 as a result of climatic changes (**Table 37**Table 37).

Table 36- Average precipitation and PET under the modeled A1B climate change scenario and percentage change in comparison to modeled results from present (2006) scenario for the Segura catchment

	A1B climate change scenario	**% change from present scenario**
Average precipitation (mm)	302	- 30.0
Average PET (mm)	1438	+ 0.2

Table 37- Total ES provision in the Segura catchment for water provision and sediment retention and further including sediment export under the A1B climate change scenario; total values and percentage change in relation to the present (2006) scenario results

	Water yield (Mm^3)	**Sediment export (t)**	**Sediment retention (t)**
A1B climate change scenario	216	1.29×10^6	21.9×10^9
% change from present scenario	- 61.4	- 62.9	- 92.3

Expected percentage change values for precipitation and PET are considerably higher across the Taibilla when compared to results for the whole of the Segura, resulting in more significant impacts upon ES provision. Climate change data suggests a decrease in precipitation of over 56% and an increase in PET of over 20% (**Table 38**). As a result, both water yield and sediment export are modeled to decrease by 95 and 79% respectively (**Table 39**). The analysis of ES provision at the sub-catchment scale for the remaining watersheds at the coarser scale was furthermore investigated, shedding light on the distributed effects for both water provision and sediment production.

Table 38- Average precipitation and PET under the modeled A1B climate change scenario and percentage change in comparison to modeled results from present (2006) scenario for the Taibilla sub-catchment

	A1B climate change scenario	**% change from present scenario**
Average precipitation (mm)	311	- 55.8
Average PET (mm)	1330	+ 20.5

Table 39- Total ES provision in the Taibilla sub-catchment for water provision and sediment retention and further including sediment export under the A1B climate change scenario; further includes percentage change in relation to the present (2006) scenario results

	Water yield (Mm^3)	Sediment export (t)	Sediment retention (t)
A1B climate change scenario	1.61	42.7 x 10^3	40.4 x 10^6
% change from present scenario	- 95.1	- 78.5	- 96.5

- *Water provision*

All sub-catchments, with the exception of La Pedrera, are predicted to witness a decrease in average water yield per hectare between 2006 and 2050. Absolute decrease is expected to be highest in the La Vieja catchment with a decrease value of -152 m^3/ha; followed by Anchuricas and Taibilla. As illustrated in **Figure 22**, upstream catchments will witness highest decreases in average water yield, in comparison to downstream catchments where change will in absolute values be minimal. Analysis of impact of climate change upon present values in relative (percentage) terms suggests similar distribution of impact amongst the sub-catchments than results given in absolute values. Highest decreases will be present within the upstream catchments of Taibilla, La Vieja and Anchuricas, all witnessing average water yield decreases of over 90% when compared to 2006 levels. Lowest decreases occur within the Guardamar, Romeral and Santomera sub-watersheds by respective values of -9, -14 and -29%. La Pedrera will be the only catchment to witness an increase in average water yield of levels 158% higher than at present.

- *Sediment retention*

All sub-catchments will witness a decrease in average sediment retention per hectare by 2050 under the modeled A1B climate change scenario (**Figure 23**). Decrease in average sediment retention in absolute terms is highest in the Anchuricas catchment, followed by La Vieja and Fuensanta, both also upstream catchments. Lowest decrease will occur in the Pedrera catchment, followed by the neighboring Bayco and Charcos catchments. Percentage changes yield very similar results, and values of percentage decrease are high for almost all sub-catchments; with the exception of La Pedrera, the remaining watersheds of the Segura are all expected to witness a decline in average sediment retention of over 62% under climate change.

- *Sediment export*

The sub-catchments where highest decreases in average export occur are also within the uplands; notably La Vieja, Taibilla and Fuensanta (**Figure 24**). Lowest decrease in average sediment export are predicted to occur within the Pedrera, Judio and Romeral sub-catchments, situated in the lower stretches of the catchment. Percentage decreases are not as high as numbers yielded by the model for sediment retention. All sub-catchments with the exception of La Pedrera are modeled to witness a decrease in average sediment export values under climate change of at least 35%; in 14 of the 30 sub-catchment the percentage decrease value is above 50%, once more occurring predominantly within upstream catchments.

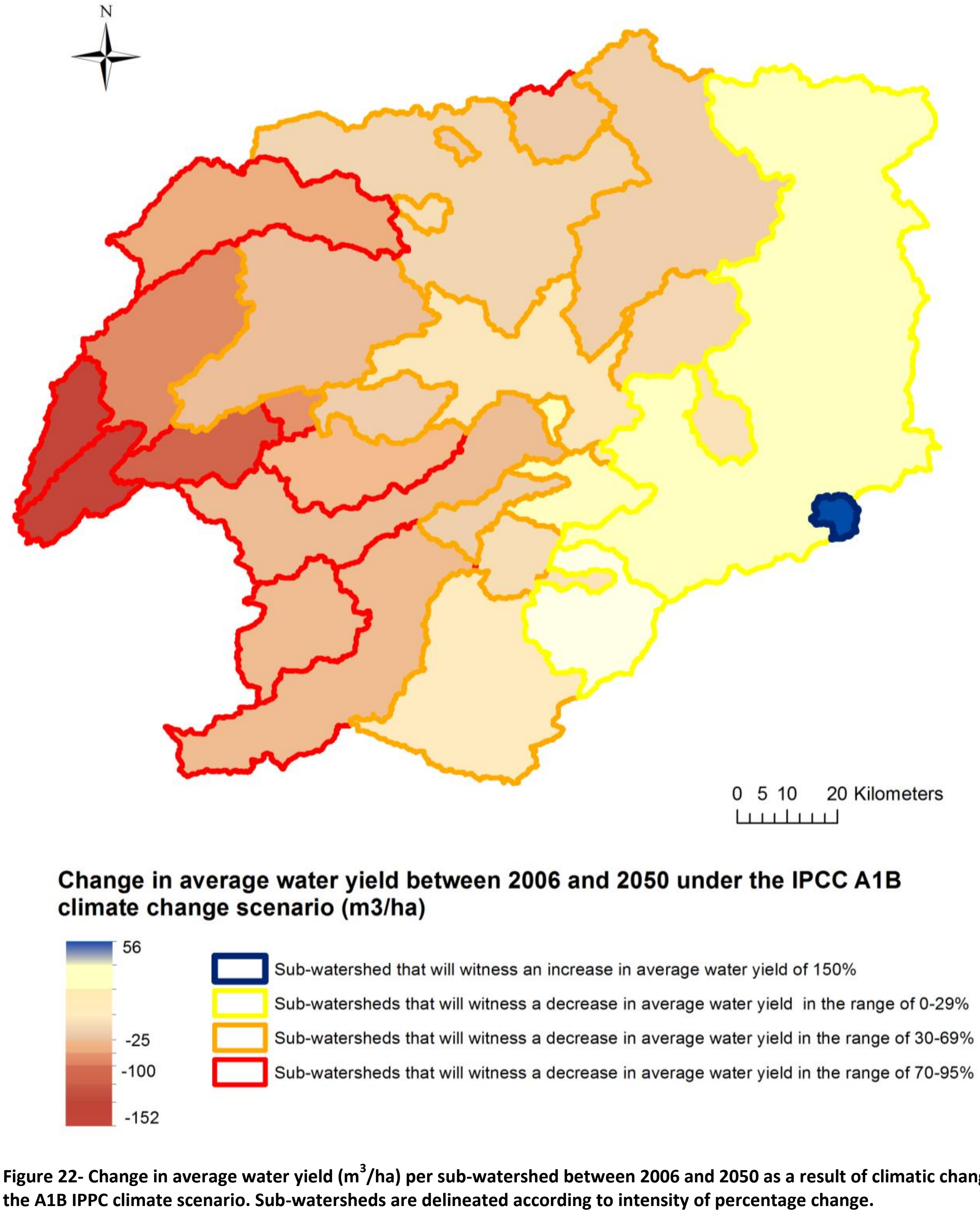


Figure 22- Change in average water yield (m^3/ha) per sub-watershed between 2006 and 2050 as a result of climatic changes under the A1B IPPC climate scenario. Sub-watersheds are delineated according to intensity of percentage change.

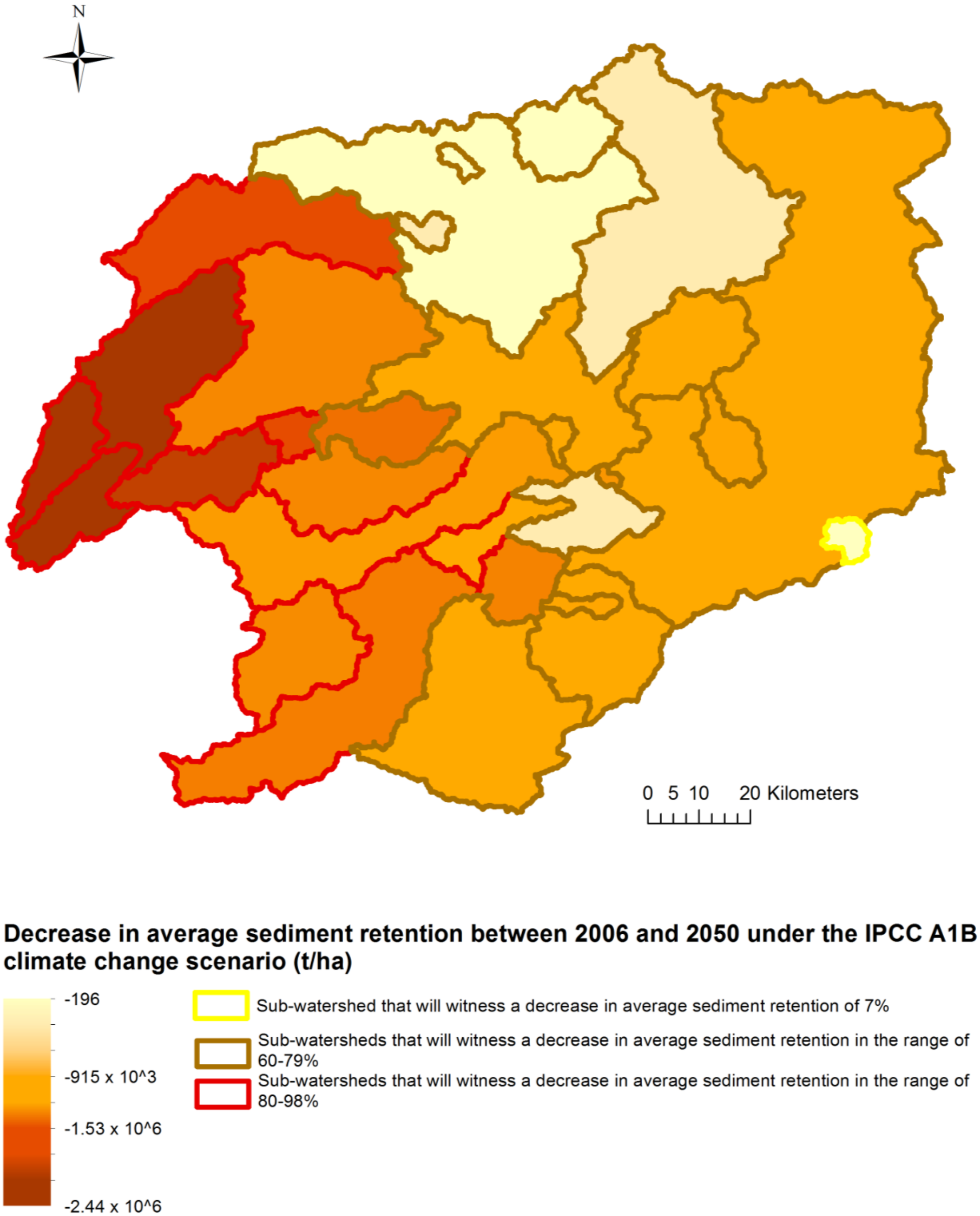


Figure 23- Decrease in average sediment retention (t/ha) per sub-watershed between 2006 and 2050 as a result of climatic changes under the A1B IPPC climate scenario. Sub-watersheds are delineated according to intensity of percentage decrease.

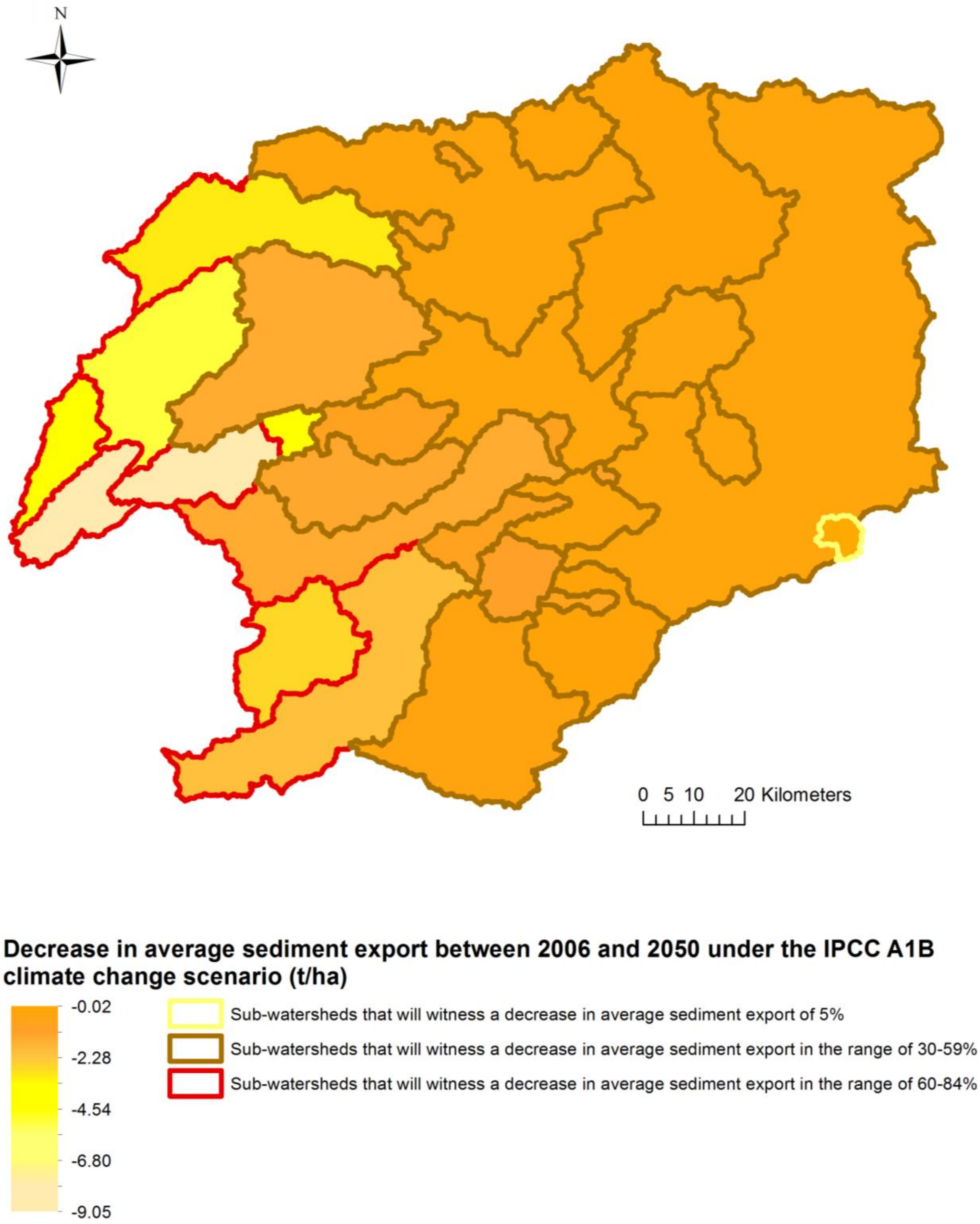


Figure 24-- Decrease in average sediment export (t/ha) per sub-watershed between 2006 and 2050 as a result of climatic changes under the A1B IPPC climate scenario. Sub-watersheds are delineated according to intensity of percentage decrease.

Carbon sequestration in scenario analysis

Accounting for carbon sequestration occurred within layers which did not undergo LULC transitions in the time periods investigated adds an additional 91.8 x 10^6 Mg C to the total carbon stock of 2006. Highest increases are witnessed in *Coniferous forest* and *Vineyard* layers, with respective percentage increases of 92.2 and 85.6 (**Table 40**). Lowest increases as a result of incorporating annual sequestration occurred for *Agro-forestry* and *Complex cultivation patterns* layers. Including sequestration rates furthermore alters the ranking of most contributing LULCs to carbon stock in 2006 (**Table 41**). *Fruit trees and berry plantations*, in light of carbon sequestration rates, have played a more considerable role in the present carbon stock than *non-irrigated land*, as otherwise considered by the InVEST model alone.

Table 40- Adjusted values for present scenario (2006) carbon stock accounting for annual carbon sequestration rates of LULCs which did not undergo transitions throughout and between the 1990 and 2006 time periods

Vegetated LULC layers	InVEST present C stock (Mg C)	Additional C from annual sequestration rates (Mg C)	% increase
Coniferous forest	40.4 x 10^6	37.2 x 10^6	92.2
Vineyards	5. 87 x 10^6	5.03 x 10^6	85.6
Sclerophyllous vegetation	23.0 x 10^6	19.5 x 10^6	84.6
Transitional woodland-shrub	16.1 x 10^6	13.2 x 10^6	81.8
Broadleaf forest	385 x 10^3	289 x 10^3	75.1
Mixed forest	1.78 x 10^6	1.28 x 10^6	72.0
Fruit trees and berry plantations	13.2 x 10^6	7.85 x 10^6	59.6
Olive groves	1.22 x 10^6	689 x 10^3	56.4
Annual crops associated with permanent crops	26.2 x 10^3	12.5 x 10^3	47.6
Land principally occupied by agriculture, with significant areas of natural vegetation	5.47 x 10^6	2.11 x 10^6	38.6
Complex cultivation patterns	16.6 x 10^6	4.66 x 10^6	28.1
Agro-forestry	4.44 x 10^3	984	22.2

Table 41- LULC layers ranked in order of contribution to total C stock for the Segura present scenario (2006), when calculated by InVEST only and when accounting for annual sequestration rates in biomass

	Present C stock (InVEST)	Present C stock adjusted for sequestration
1.	*Coniferous forest*	*Coniferous forest*
2.	*Sclerophyllous vegetation*	*Sclerophyllous vegetation*
3.	*Complex cultivation patterns*	*Transitional woodland-shrub*
4.	*Transitional woodland-shrub*	*Complex cultivation patterns*
5.	*Non-irrigated arable land*	*Fruit trees and berry plantations*

These results are a reflection of both the varying annual net primary productivity rates of the various vegetated LULC layers, but also of the amount of land area of each LULC class which did or did not undergo transitions within the investigated time period. **Table 42** sheds light upon which proportion of present vegetated LULC classes have remained under the same use since 1990, or have undergone a transition. The LULC layers in which over half of the land area has remained under the same use since 1990 represent both naturally vegetated and cultivated covers; comprising both *coniferous forests*, *vineyards*, *land principally occupied by agriculture, with significant areas of natural vegetation* and *annual crops associated with permanent crops*.

Table 42- Vegetated LULC layers ranked according to percentage of land which did not undergo a LULC transition between 1990 and 2006 from LULC respective total land area in 2006

	Vegetated LULC layers	% of "no-change" from total area
1	*Coniferous forest*	72
2	*Vineyards*	70
3	*Land principally occupied by agriculture, with significant areas of natural vegetation*	59
4	*Annual crops associated with permanent crops*	54
5	*Complex cultivation patterns*	47
6	*Transitional woodland-shrub*	44
7	*Sclerophyllous vegetation*	43
8	*Mixed forest*	38
9	*Broadleaf forest*	30
10	*Fruit trees and berry plantations*	26
11	*Olive groves*	24
12	*Agro-forestry*	0

ES provision under SLM implementation for climate mitigation and adaptation

Results show SLM implementation leads to an increase in ES provision across the Segura in light of the detrimental climate change impacts predicted (**Table 43**). Most beneficial outcomes are witnessed for sediment export, demonstrating a predicted decrease value of -35%. Water yield and carbon stock both show positive increases in ES provision in the order of 0.3 - 3.2%; highest for 100% adoption for carbon stock, and for 10% adoption for water yield.

Table 43- Total ES provision in the Segura under SLM implementation at 10 and 100% levels of adoption; total values and percentage change in relation to the A1B climate change scenario are shown for water yield and sediment retention and export. Values for carbon stock are compared to the present (2006) scenario.

	Adoption within LULCs (%)	Water yield (Mm^3)	Sediment export (t)	Sediment retention (t)	Carbon stock (Mg C)
SLM implementation scenario	10	221	931×10^3	14.6×10^9	494×10^3
	100	218	843×10^3	14.7×10^9	4.94×10^6
% change from CC scenario or present scenario	10	**2.15**	**- 28.05**	**- 33.62**	**0.32**
	100	**0.61**	**- 34.87**	**- 32.96**	**3.25**

- *Mitigation by reduced tillage and green manure: Carbon storage and sequestration*

Results show a direct increase in carbon storage with increasing levels of implementation of RTG, with a highest increase of 3.25% at 100% adoption witnessed across the Segura catchment, representing an added value of 4.94×10^6 Mg C to the present scenario (**Table 44**). The LULC classes within which SLM implementation was modeled witnessed more considerable increases in total Mg C in the range of 3-34% respective of minimum and maximum level of adoption modeled.

Table 44- Increase in carbon storage from present scenario following SLM implementation at different levels of adoption within the whole of the Segura and delineated LULC classes (*Fruit trees and berry plantations* and *Olive groves*); values states as both absolutes (Mg C) and percentages.

Adoption within LULCs (%)	*% Increase in carbon storage per total land area*			*Increase in cabon storage (Mg C)*
	Fruit trees and berry plantations	*Olive groves*	Segura catchment	Segura catchment
10	**3.44**	**3.44**	**0.32**	**494×10^3**
50	**17.18**	**17.19**	**1.62**	**2.47×10^6**
80	**27.49**	**27.50**	**2.60**	**3.96×10^6**
100	**34.36**	**34.38**	**3.25**	**4.94×10^6**

These increases occur within the sub-watersheds containing LULC classes of *Fruit trees and berry plantations* and *Olive groves* for which SLM implementation was modeled. For carbon storage, the sub-watersheds with highest density and amount of cover of the aforementioned LULC classes will show highest increases in the provision of the ES (**Table 45; Figure 25**). Notably, highest total increases will occur within the catchments of Guardamar and Ojos; largest per hectare increases will occur within La Pedrera and Pliego.

Table 45- Cover of delineated LULCs for SLM implementation (*Fruit trees and berry plantations* and *Olive groves*) per top-five ranking watersheds; values stated as both absolutes (ha) and percentages. Note: the sub-watersheds of Anchuricas and Charcos do not include either of the two LULC classes.

	Sub-wathershed	Total area cover (ha)	Sub-watershed	Density (%)
1	Guardamar	76’421	La Pedrera	50
2	Ojos	14’447	Pliego	33
3	Camarillas	13’269	Rodeos	28
4	Pareton	8’836	Carcavo	22
5	Romeral	7’875	Guardamar	19

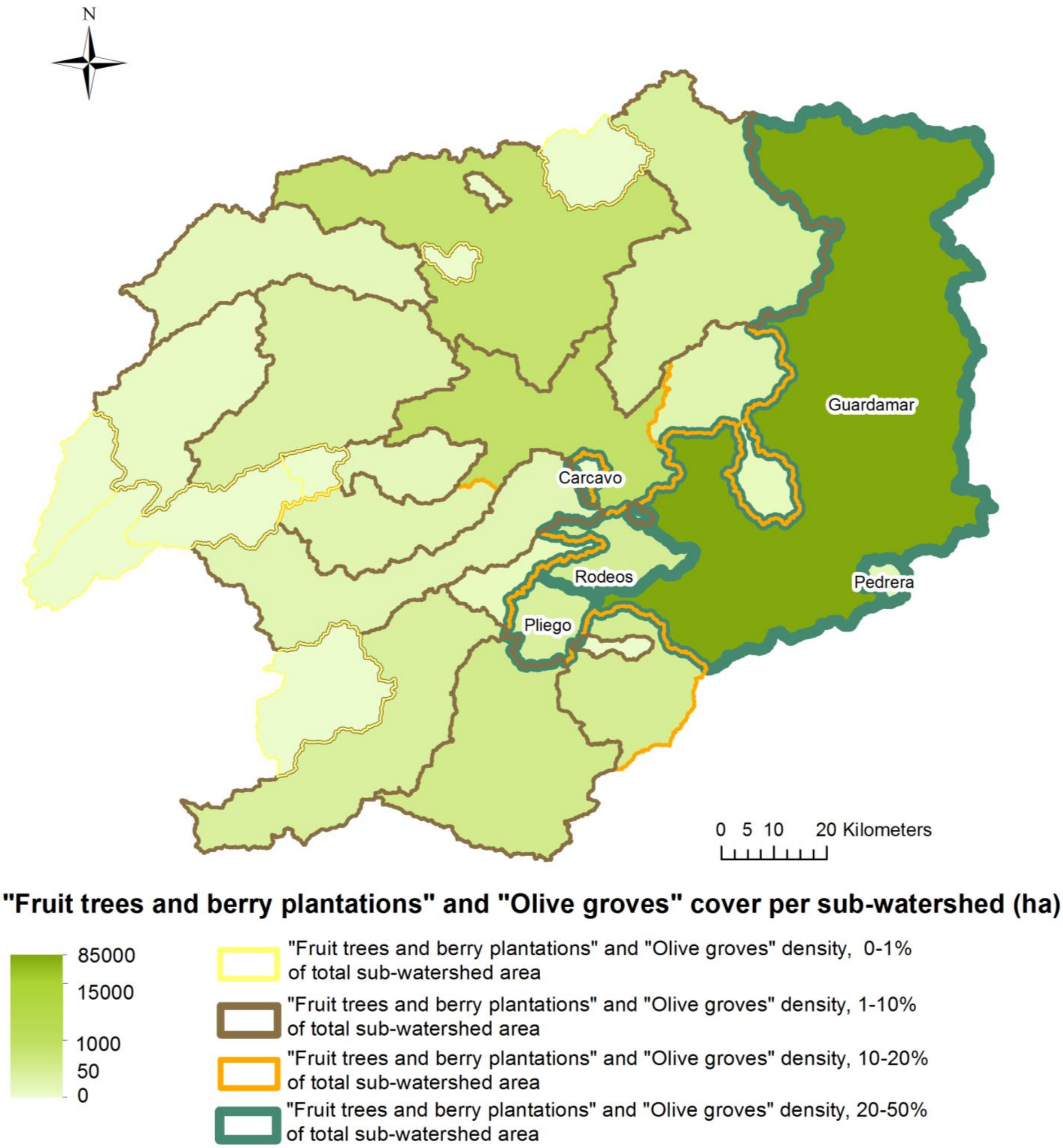


Figure 25- Distribution of delineated LULCs for SLM implementation (*Fruit trees and berry plantations* and *Olive groves*) per sub-watershed; values stated as both absolutes (ha) and percentages. Note: the sub-watersheds of Anchuricas and Charcos do not include either of the two LULC classes.

- *Adaptation by reduced tillage and green manure: Water provision*

Implementation of RTG within the Segura results in an increase in total water yield with respect to levels predicted under the climate change scenario for all levels of adoption (**Table 46**). Results further indicate highest increases in water yield are achieved under the minimal adoption level investigated of 10%; the remainder adoption levels suggest a negative correlation between water provision and increasing level of adoption. Highest increase under the 10% adoption is of 2.15% from the climate change scenario, representing a total water yield of 221 Mm^3.

Table 46- Increase in water yield from climate change scenario following SLM implementation at different levels of adoption within the whole of the Segura catchment; values stated as both absolutes (Mg C) and percentages.

Water yield under RTG implementation in 2050 across the Segura catchment		
Adoption within LULCs (%)	Increase from CC scenario (%)	Total water yield (Mm^3)
10	**2.15**	**221**
50	**0.82**	**218**
80	**0.67**	**218**
100	**0.61**	**218**

Analysis of modeled outcomes at the sub-watershed level sheds further insight into changes in water provision following the modeled implementation of RTG. Under both 10 and 100% adoption, highest percentage increases in average water yield are witnessed within the Risca and Charcos sub-catchments, situated upstream, yielding slightly lower values under 100% adoption than under 10%, both estimating above a 10% increase in water yield for the Risca sub-catchment (**Table 47; Figure 26**). Under the 10% adoption scenario, these two sub-catchments are followed in the ranking of highest increases in water yield by Pliego, Carcavo and La Pedrera catchments, representing the catchments which ranked highest for density of the LULC classes within which SLM practices were implemented/modeled, showing estimated increases in average water yield ranging between 5 and 10%. Under the 100% adoption scenario, the same sub-watersheds of Pliego and La Pedrera second last and last, respectively demonstrating decreases in the average provision of water yield of -3.09 and -3.22%. **Figure 27** further illustrates sub-watersheds witnessing highest and lowest rankings under 100% adoption in relation to elevation of the Segura. The sub-watersheds estimated to undergo decreases in average water yield under 100% adoption are situated downstream, within the lower plains of the Segura.

Table 47- Top and bottom-five ranking sub-watersheds, ranked by highest percentage change in average water yield from the 2050 climate change scenario following the implementation of SLM practices at 10% and 100% adoption levels. If present, the sub-watersheds with highest density of LULCs within which SLM was implemented are emphasized with their respective ranking, as shown in Table 44.

% Change in average water yield under RTG implementation in 2050 per sub-watershed ranked by 10% and 100% adoption of SLM					
	Ranking	**10% adoption**		**Ranking**	**100% adoption**
Risca	1	11.12	*Risca*	1	10.94
Charcos	2	9.46	*Charcos*	2	9.46
Pliego (2)	3	7.52	*Alfonso XIII*	3	5.41
Carcavo (4)	4	7.51	*Boqueron*	4	4.77
La Pedrera (1)	5	6.39	*Valdeinfierno*	5	4.67
Romeral	26	1.54	*Santomera*	26	0.10
Guardamar (5)	27	1.38	***Rodeos (3)***	27	-0.15
Fuensanta	28	1.37	***Guardamar (5)***	28	-0.22
Algeciras	29	0.88	***Pliego (2)***	29	-3.09
Santomera	30	0.77	***La Pedrera (1)***	30	-3.22

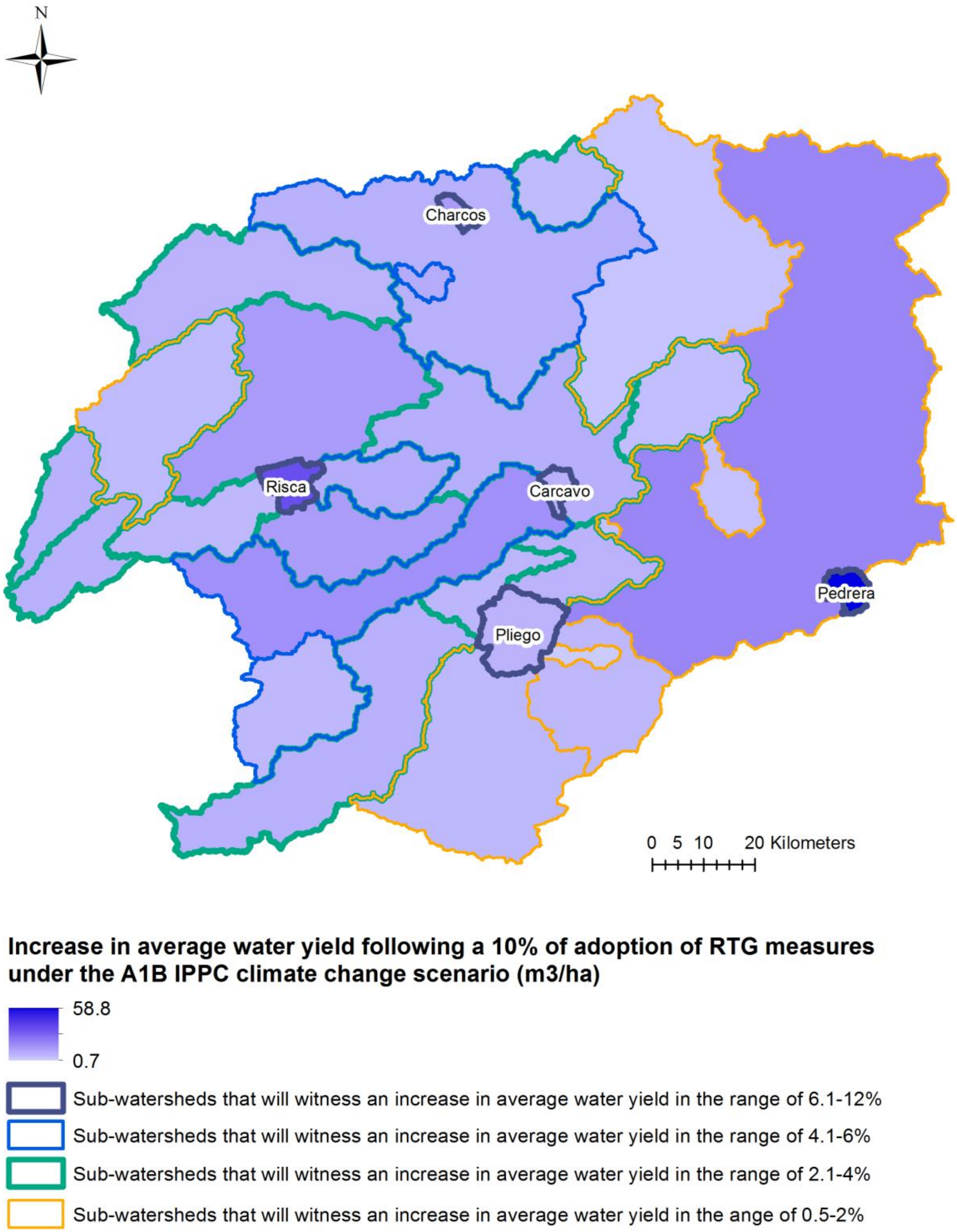


Figure 26- Increase in average water yield per sub-watershed following a 10% adoption of RTG measures from average water yield values under the A1B IPPC climate change scenario without SLM implementation. Percentage increase range is stated alongside absolute difference values.

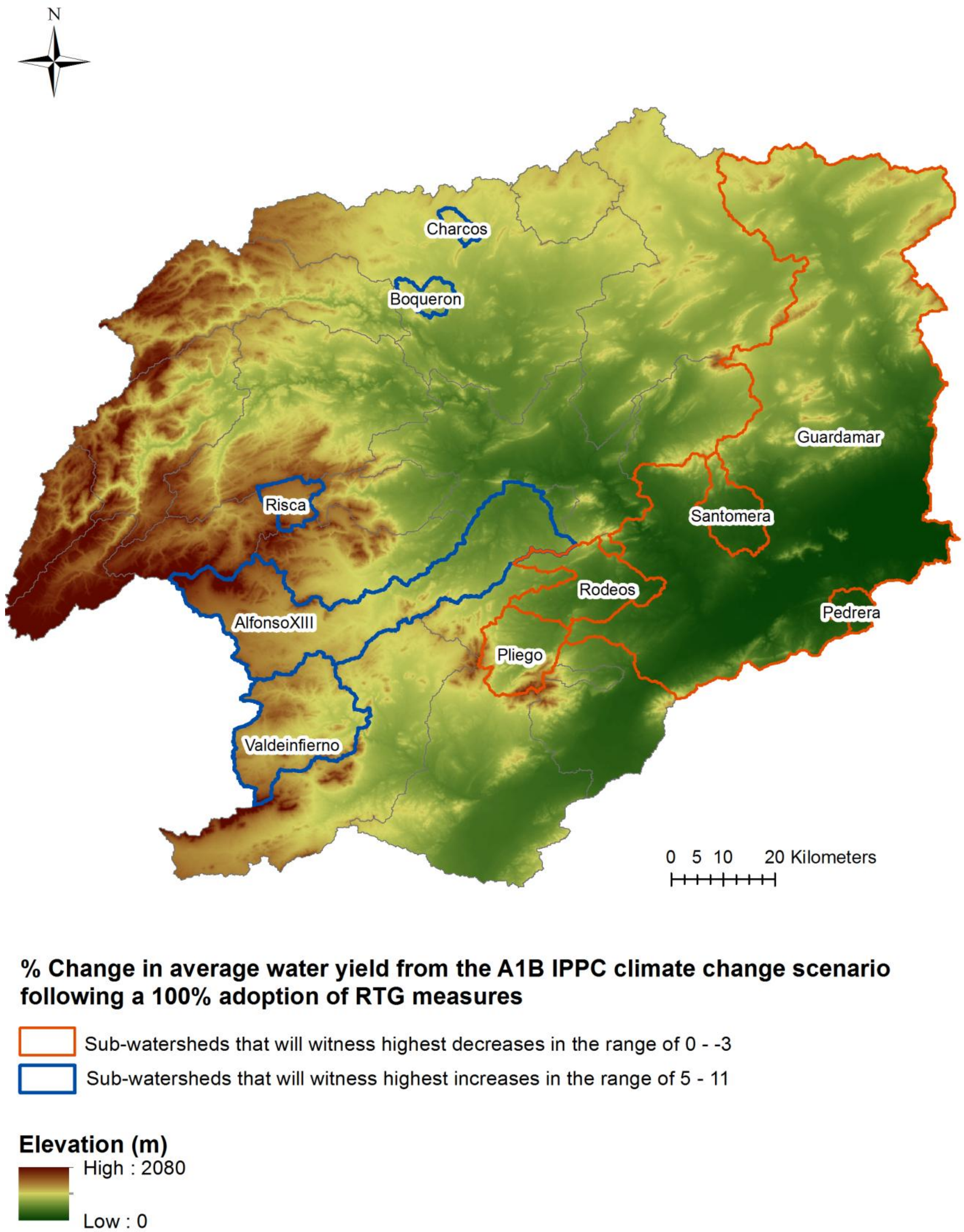


Figure 27- Percentage change in average water yield from the A1B IPPC climate change scenario following 100% adoption of RTG measures. Percentage value range stated for top-5 sub-watersheds witnessing highest decreases and highest increases in percentage change.

- *Adaptation by reduced tillage and green manure: Sediment retention and export*

Results predict a decrease in sediment retention following the implementation of RTG within the Segura. There is little variation across the different levels of adoption, ranging from 32.57% under 80% adoption and 33.62% under 10% adoption. Values of percentage change for sediment export suggest an inverse trend and relationship to sediment retention values (**Table 48**, **Table 49**). Percentage change in export increases with level of adoption from 28% (10% adoption) to 35% (100% adoption).

Table 47- Decrease in sediment retention from climate change scenario following SLM implementation at different levels of adoption within the whole of the Segura catchment; values states as both absolutes (Mg C) and percentages.

Sediment retention under RTGM implementation across the Segura		
Adoption within LULCs (%)	Decrease from CC scenario (%)	Total sediment retention (t)
10	**33.29**	**14.6×10^9**
50	**33.29**	**14.6×10^9**
80	**33.29**	**14.6×10^9**
100	**33.29**	**14.6×10^9**

Table 48- Decrease in sediment export from climate change scenario following SLM implementation at different levels of adoption within the whole of the Segura catchment; values stated as both absolutes (Mg C) and percentages.

Sediment export under RTGM implementation across the Segura		
Adoption within LULCs (%)	Decrease from CC scenario (%)	Total sediment export (t)
10	**27.79**	**934×10^3**
50	**32.19**	**877×10^3**
80	**34.19**	**852×10^3**
100	**35.09**	**839×10^3**

Analysis at the sub-watershed level (**Table 50; Figure 28**) demonstrates the breadth of change within sediment retention and export results. Sediment retention only witnessed an increase following implementation of RTG in the catchments of La Pedrera and De La Cierva of 49 and 6% respectively. The remaining catchments all witnessed a decrease in ES provision above 50% from climate change predictions for the catchments of Argos, Fuensanta and Anchuricas. La Pedrera represents the only catchment with high density of LULC classes for which SLM was modeled with a predicted increase in sediment retention following RTG implementation. Export values decreased for all sub-catchments, ranging from 5 to 56%, highest within upstream catchments.

Table 50- Top and bottom-ranking sub-watersheds ranked by highest percentage increase in ES provision assessed by average sediment retention and export from the 2050 climate change scenario following the implementation of SLM practices at the 100% adoption level. If present, the sub-watersheds with highest density of LULCs within which SLM was implemented are emphasized with their respective ranking, as shown in Table 44.

% Change in average sediment retention and sediment export under RTG implementation in 2050 per sub-watershed ranked by ES provision at 100% adoption of SLM					
RETENTION	**Ranking**	**100% adoption**	**EXPORT**	**Ranking**	**100% adoption**
De La Cierva	1	49	*Fuensanta*	1	-56
La Pedrera (1)	2	6	*La Vieja*	2	-50
Moratalla	3	-4	*Talave*	3	-49
Carcavo (4)	4	-7	*Risca*	4	-43
Algeciras	5	-11	*Camarillas*	5	-42
Mayes	26	-44	*Mayes*	26	-15
Santomera	27	-47	***Carcavo (4)***	27	-11
Argos	28	-50	*Moro*	28	-11
Fuensanta	29	-51	*Santomera*	29	-6
Anchuricas	30	-61	*De La Cierva*	30	-5

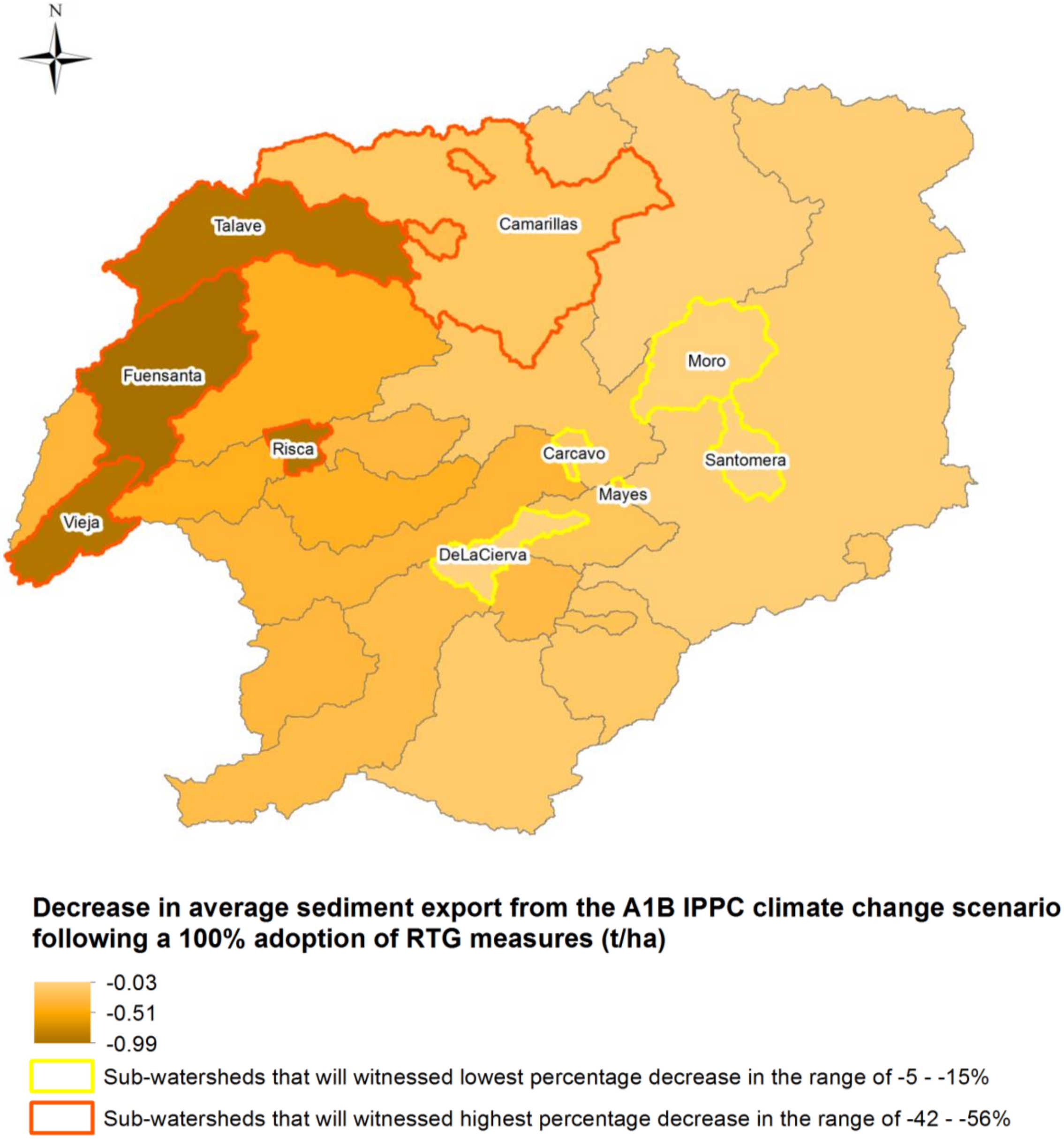


Figure 28- Decrease in average sediment export per sub-watershed following a 100% adoption of RTG measures from average sediment export values under the A1B IPPC climate change scenario. Percentage value range is stated for top-5 sub-watersheds witnessing highest and lowest decreases in percentage change.

Discussion

Analysis and relevance of results

In their delineation of guidelines for the mainstreaming of ES concepts in EU policy, Maes et al. (2013) begin with stressing the necessity of "spatially explicit data and models", as ES conservation calls for spatial identification (Eigenbrod et al., 2010). The newfound ability to visualize and quantify spatial information regarding multiple ES provision at a given temporal and spatial scale which has come with the development of multiple decision-support models and tools (Bagstad, Semmens, Waage, & Winthrop, 2013) has profoundly empowered and changed the face of natural resource management and communication. The analysis of trade-offs associated with policies affecting ecosystems and natural resources is facilitated within both decision-making and implementation phases by ES spatial modeling (Maes et al., 2013), rendering ultimate resolutions more "effective, efficient and defensible" (Nelson et al., 2009). This study has demonstrated the potential of the InVEST tool for achieving these purposes via quantifying and illustrating the spatial distribution of priority ESs at two different catchment scales, and providing an analysis of its utility within land management decision-making regarding the quantification of the multiple impacts of stakeholder selected SLM measures on priority ESs.

The importance of the baseline scenario

Model calibration for the water provision and sediment retention models yielded R^2 and Model Efficiency values of 0.5 or above. Given the relative simplicity of the tools, these values ascertain InVEST may be successful in delivering this primary and fundamental quantitative, spatial information. Results illustrate trade-offs amongst ESs and shed light upon the existing disparities between the sub-catchments of the Segura. Greatest ES provision, measured on an average per hectare basis, was found in the uplands of the Segura. The sub-watersheds of Anchuricas, Fuensanta, La Vieja and Taibilla were all amongst the top-five highest ranking for all of the investigated priority ESs. Sub-watersheds demonstrating lowest current ES provision were primarily situated at lower altitudes. For carbon stock, the highest ranking sub-watersheds were located on the West of the Segura catchment. For water provision, the southern catchments of Pliego, Romeral, Rodeos, Mayes and Carcavo demonstrated lowest provision. Analysis of ES provision within the highest ranking sub-watersheds suggest the Anchuricas and Fuensanta sub-watersheds as illustrative of ES synergy, whereas the sub-watersheds of La Vieja and Taibilla show greatest water provision, at the sake of lower sediment retention provision, and even lower carbon stocks, perhaps suggesting the occurrence of trade-offs.

Identifying priority regions for adaptation and mitigation action

Spatial identification of ES provision further allows for the localization of climate change impacts, as to identify priority areas of concern for targeting by climate change adaptation and mitigation strategies. Climate change is predicted to have an overall considerably high and adverse effect on priority ES provision within the Segura catchment. Scenarios run for 2050 under regional climate data indicate a 30% average decrease in precipitation alongside a 0.2% increase in PET across the catchment, leading to a modeled decline in water yield of 61%. **Figures 29-32** aim to provide a summary of past and predicted detrimental impacts from climate change and LULC transitions upon priority ES provision in the Segura at the catchment scale, shown in relation to the present scenario. Areas of concern, calling for ES conservation action, can be identified from both overall complexities or in light of a specific driver, be it climatic or LULC change. It should be reminded that the carbon model does not include climatic variables; thus from the data investigated within this study, areas of concern for carbon storage can only be identified in consideration of past trends in deforestation and afforestation from LULC transitions, and of sub-watersheds currently witnessing lowest stocks. **Figure 29** illustrates sub-catchments showing lowest carbon stocks in 2006 match those which have experienced carbon stock decline since 1990, with the exception of the Bayco catchment. These down-stream situated catchments may thus be considered areas of concern if local, current trends of deforestation or intensification of agriculture are to continue. The implications of continuation of current trends in LULC transitions for the sub-catchments of Fuensanta and Valdeinferno should be further taken into consideration, as they represent upstream catchments with highest current values in carbon stock, with potential for future sequestration. These findings are of topical importance as investigations of Mediterranean agro-ecological systems have thus far primarily focused upon provision at the plot level, limited for managerial scopes (Padilla et al. 2010; Scharlemann et al. 2014).

Identified priority sub-catchments for water yield provision, illustrated in **Figure 30**, suggest higher concurrence of drivers of deterioration within upstream sub-catchments. Climate change is predicted to induce considerable changes in water quantity and distribution within the Segura. As illustrated within the results, all sub-watersheds of the Segura will witness a decrease in average water yield by 2050 with the exception of La Pedrera. Thus, arguably, the Segura in itself should be considered as a whole, as a region of priority concern for climate adaptation and mitigation in light of such widespread decreases in water provision. Nonetheless, regional distinctions can be made for sub-watersheds based on magnitude of predicted climatic changes and current, potentially on-going trends of LULC transitions inducing reductions in water provision. Sub-watersheds witnessing lowest water yield values in 2006 are not predicted to be the lowest providers by 2050. With the exception of Carcavo and Pliego, decreases in average water yield as a result of climate change will be higher for the catchments of Charcos, Moro and Valdeinferno, absent from the ranking of lowest providers in 2006. Spatially merging and illustrating information from both the effects of LULC transitions and climate change shows these two drivers of change induce detrimental effects largely within the same regions, primarily within upstream catchments. Furthermore, it shows that sub-catchments currently providing highest average water yield have witnessed marked decreases as a result of LULC transitions and are predicted to witness further pressures under climate change demonstrating highest average decreases amongst the catchments of the Segura. This is extremely worrying since the upland watersheds play a fundamental role in provision of freshwater to the region of Murcia for irrigation and drink water purposes.

Priority areas for action in consideration of safeguarding sediment retention must be achieved via the analysis of results for both retention and export estimates (**Figure 31**, **Figure 32**). As for water yield, detrimental impacts for sediment retention associated with land cover and climatic changes both occur within upstream catchments. This does not occur when spatially analyzing effects for sediment exports; whereby no sub-catchment witnesses an increase in average export rates as a result of recent land cover transitions within sub-catchments which are predicted to demonstrate lowest decreases in export under future climate data. All sub-watersheds are predicted to witness a decrease in both export and sediment retention under the climate change scenario. For sediment retention, as for water yield, regions of concern for future ES provision may also be identified within upstream, higher elevation areas under pressure from both climate and land use changes.

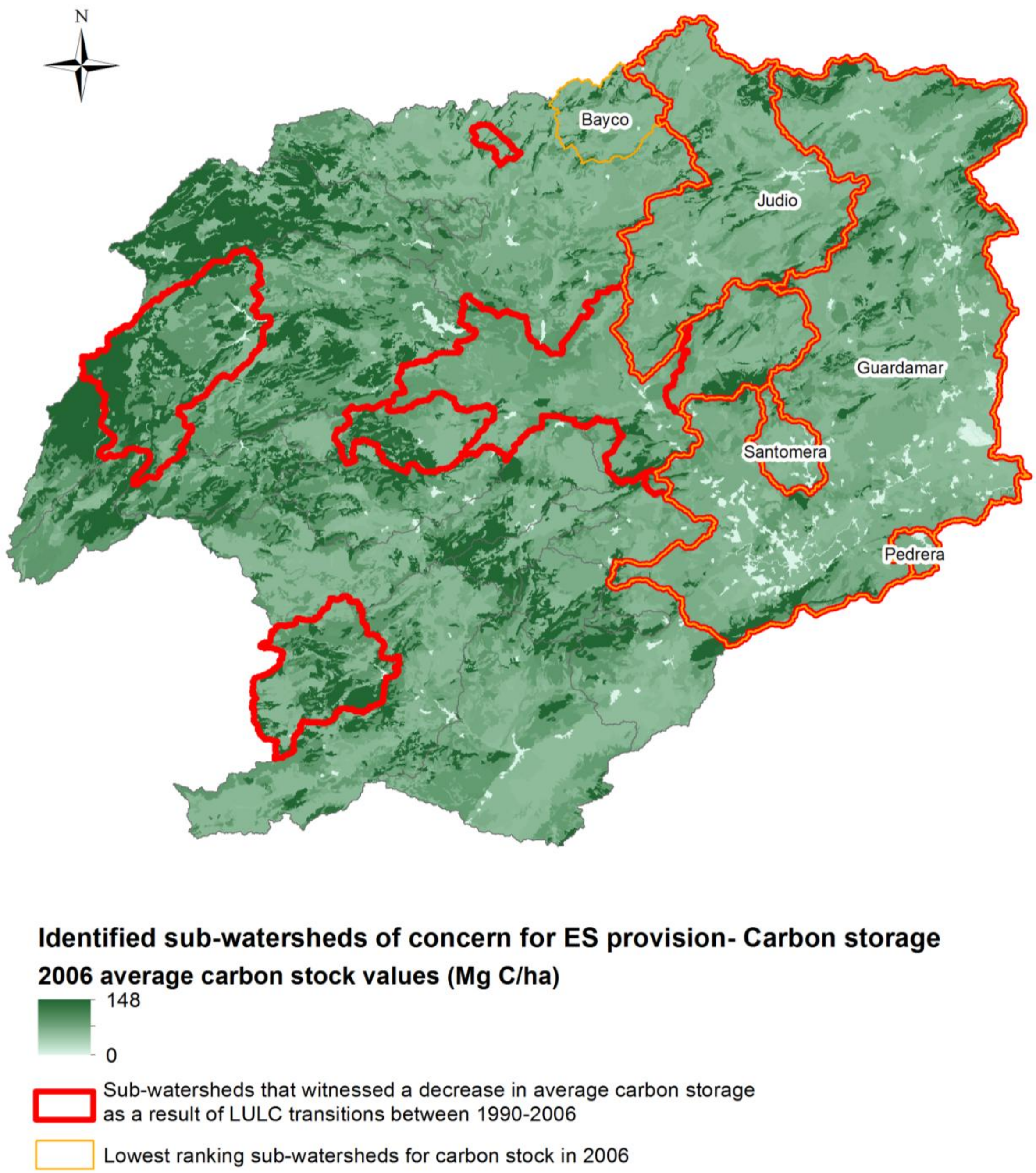


Figure 29- Sub-watersheds of concern for carbon storage provision, identified as lowest-ranking providers in 2006 and sub-watersheds having witnessed a decline in carbon stock as a result of LULC transitions between 1990 and 2006

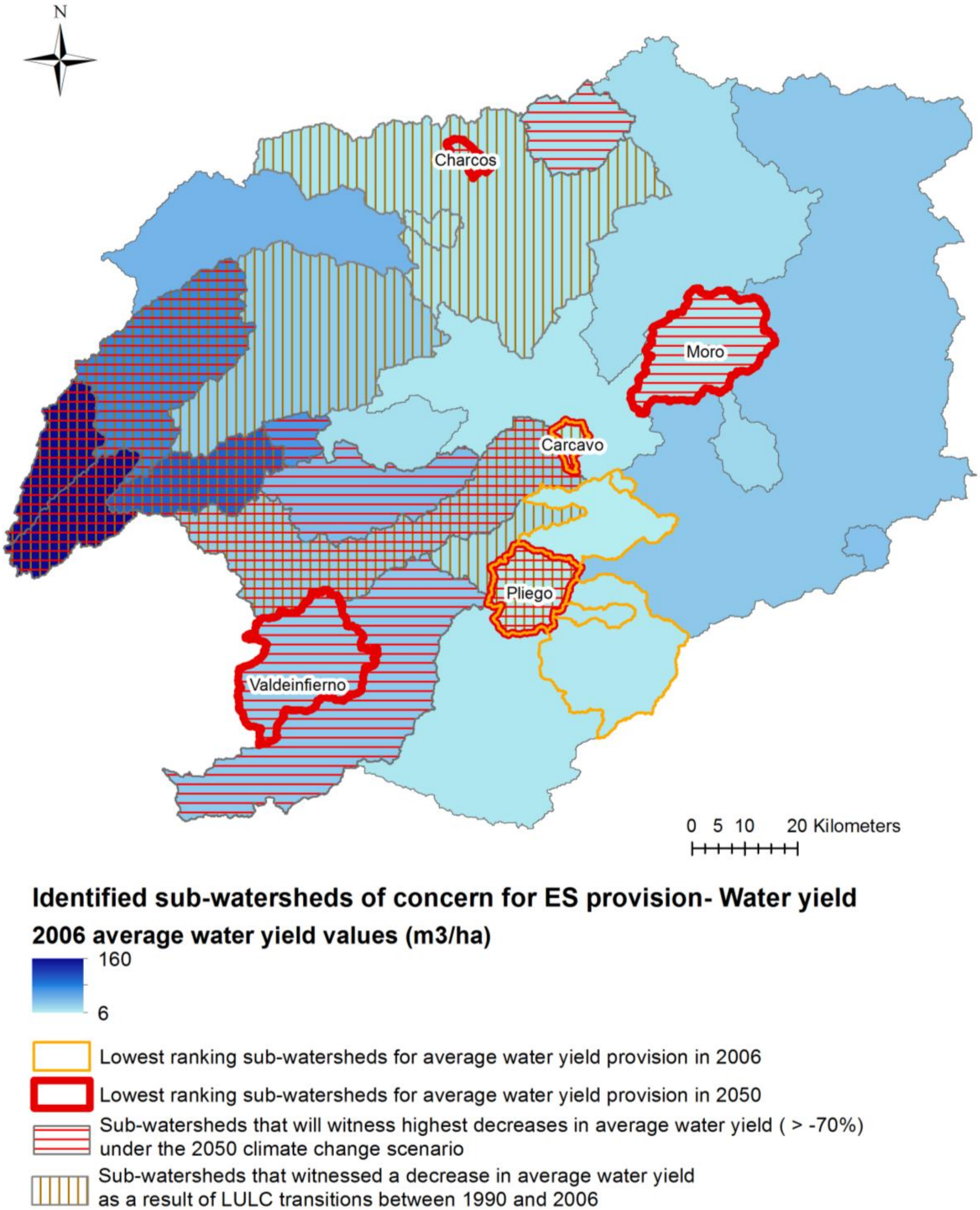


Figure 30- Sub-watersheds of concern for water provision, identified as lowest-ranking providers in 2006 or 2050, or sub-watersheds having witnessed highest decreases in water yield as a result of LULC transitions between 1990 and 2006, or sub-watersheds that are predicted highest decreases in water yield under the 2050 climate change scenario.

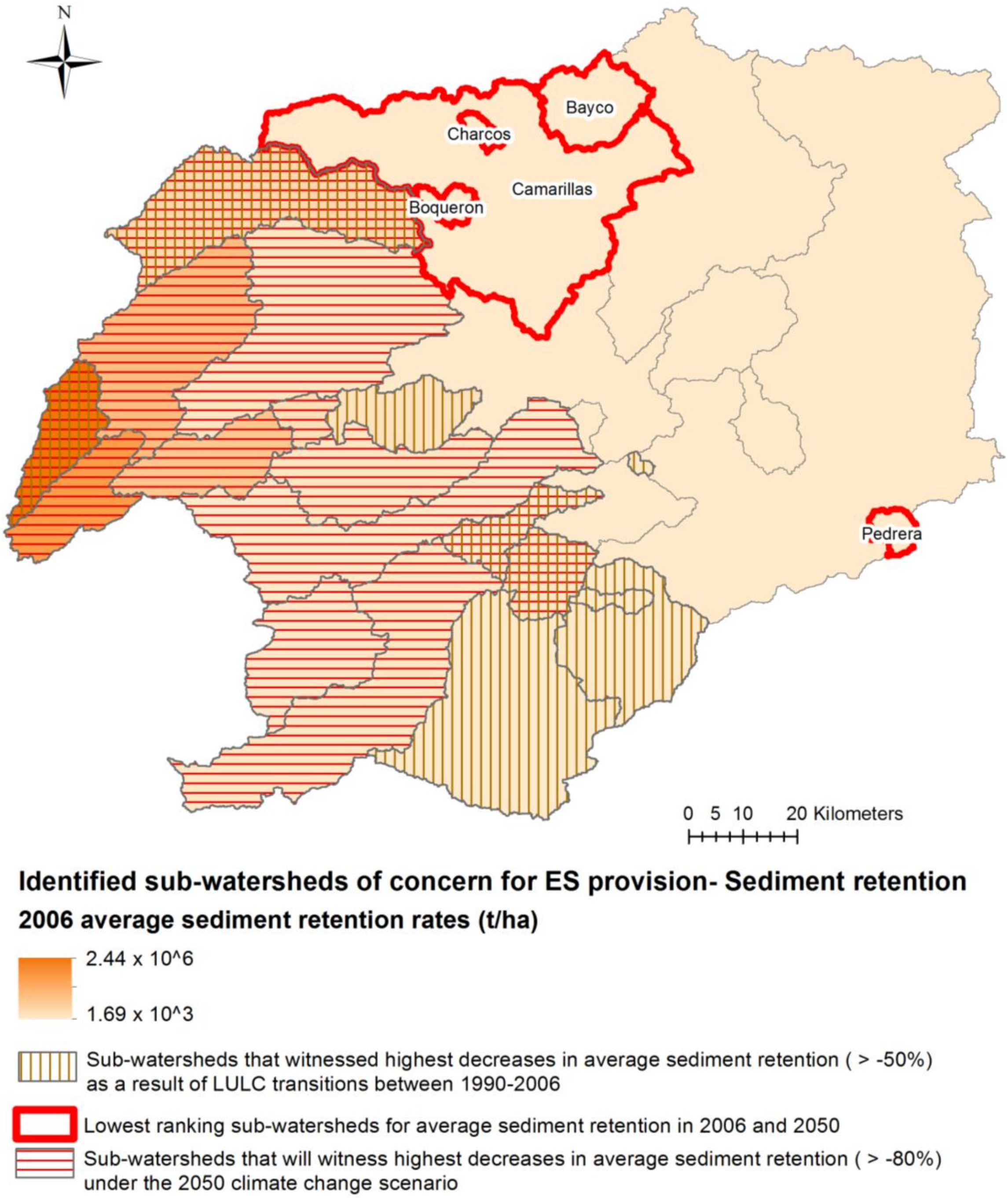


Figure 31- Sub-watersheds of concern for sediment retention identified as lowest-ranking providers in 2006 and 2050, or sub-watersheds having witnessed highest decreases in sediment retention as a result of LULC transitions between 1990 and 2006, or sub-watersheds that are predicted highest decreases in sediment retention under the 2050 climate change scenario.

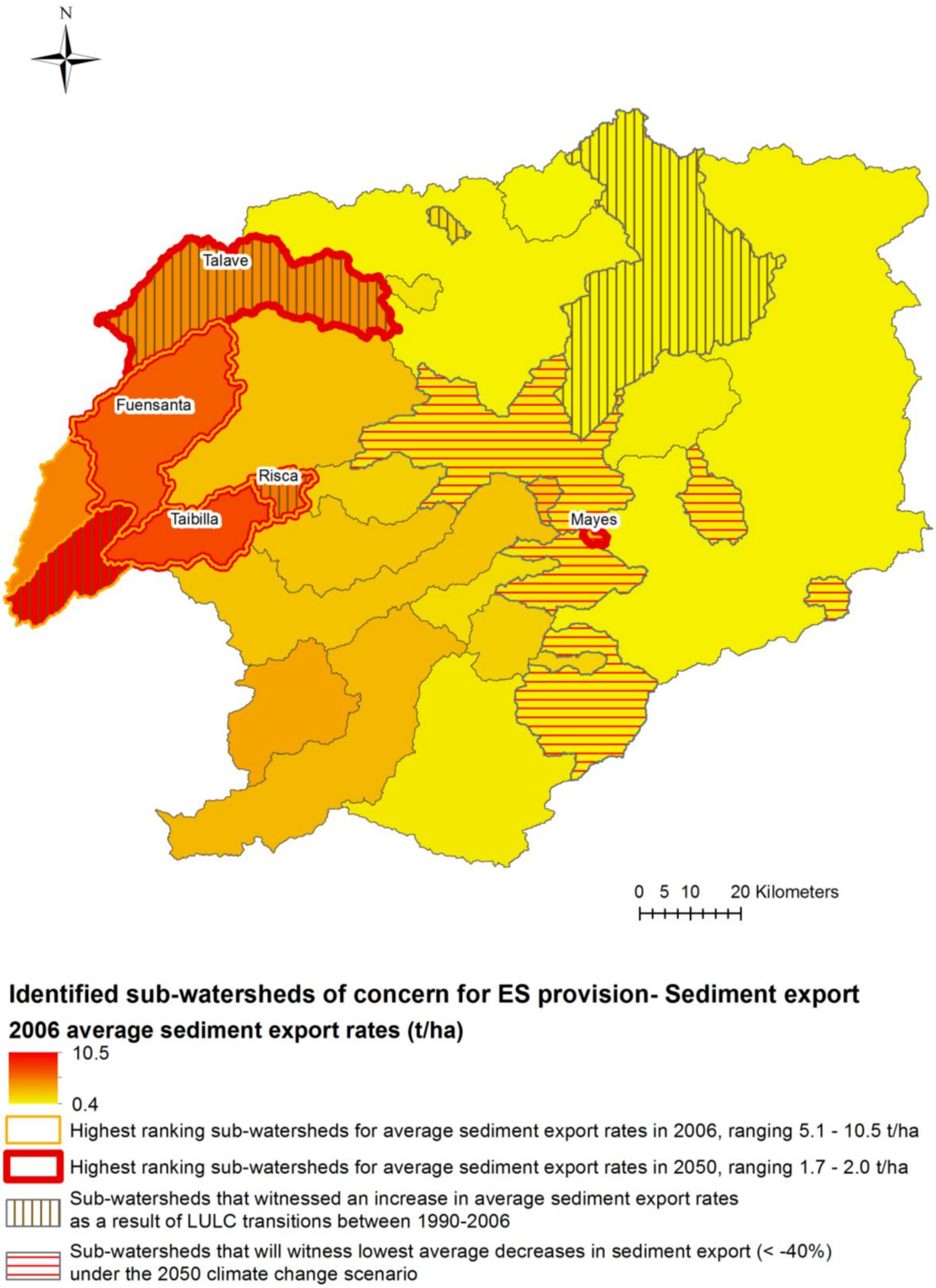


Figure 32- Sub-watersheds of concern from sediment export, identified as highest-ranking providers in 2006 or 2050, or sub-watersheds having witnessed an increase in sediment export as a result of LULC transitions between 1990 and 2006, or sub-watersheds that are predicted lowest decreases in sediment export under the 2050 climate change scenario.

Figures 29-32 shed light on the sub-catchments of concern determined from the analysis of current and past spatial ES distribution and the influences of LULC transitions and climatic changes individually for each of the three priority ESs. It is of further importance to compare the distribution of areas of concern between the three ESs investigated, prior to the ultimate delineation of priority areas for action. **Table 49** represents the methodological matrix used for scoring the sub-watersheds on the degree of "priority" for intervention on ES conservation. An equal weighing was given to each of the following statement parameters, whereby a value of 1 was attributed if the statement held true for each of the sub-catchments, thus determining a higher likelihood of ES deterioration, and calling for intervention:

1. Decrease in ES from historical LULC transitions
2. Decrease in ES provision under climate change scenario
3. Lowest-5 ranking sub-watersheds for ES provision in 2006
4. Lowest-5 ranking sub-watersheds for ES provision in 2050

For the analysis of sediment export, the statements were re-formulated as opposites, as a decrease and low ranking in sediment export would be beneficial for ES provision regarding sediment retention. In the case of statement parameters (1) and (2) being true for every sub-watershed of the Segura, a further value of 1 was attributed to the sub-watersheds which witnessed highest percentage decreases (or increases for sediment export) and were thus present within the highest percentile band considered.

Table 49- Scoring of sub-watersheds of the Segura for the identification of priority intervention areas for ES conservation.

	WATER YIELD	CARBON STOCK	SEDIMENT EXPORT	SEDIMENT RETENTION
*Decrease from historical LULC transitions **	1	1	0	1
*Decrease under climate change scenario **	1	1	0	1
Lowest-5 ranking sub-watersheds in 2006	1	1	0	1
Lowest-5 ranking sub-watersheds in 2050	1	1	0	1
*Increase fromhistorical LULC transitions **	0	0	1	0
*Increase under climate change scenario **	0	0	1	0
Highest-5 ranking sub-watersheds in 2006	0	0	1	0
Highest-5 ranking sub-watersheds in 2050	0	0	1	0

*** In the case of decreases or increases in ES provision under climate change scenario and from historical LULC transitions occurring within every sub-watershed investigated, a further value of 1 was attributed to the sub-watersheds which witnessed highest % decreases or increases, and were thus present within the highest percentile band considered and illustrated within Figures 29-31.**

The results from filling and mapping the matrix in **Table 49** are illustrated in **Figure 33**; aiding comparison and identification of priority areas to target and safeguard ES provision of all three priority ESs. From the modeled data, the downstream sub-catchments suggest lowest need for intervention for the safeguarding of sediment retention and water yield; these however represent the areas which have been witnessing highest trends of decrease in carbon stock resulting in lowest average values. Water yield and sediment retention values are lowest for downstream catchments, yet their status is not seen to be worsening under climatic and LULC transition changes. The sub-catchments of Fuensanta and Valdeinferno represent highest present average values of C stock, but have witnessed decreases as a result of deforestation and intensification of agriculture. Because of their upstream location, the wider implications for sedimentation of reservoirs via enhanced erosion and effect upon water provision should be considered, and perhaps prioritized for intervention over downstream catchments. Priority scoring for water yield and sediment retention/export shows greater potential for simultaneous, targeted action on ES conservation. Highest priority is given to upstream sub-catchments; Taibilla, Anchuricas, Fuensanta and La Vieja are of medium high importance for priority conservation for both ESs in question. Synergy is also found for the Pliego catchment, of highest priority for enhancing sediment retention. Trade-off between potential water provision and sediment retention seems to be present within the Talave and Risca sub-catchments, both of highest priority for safeguarding water provision but of low priority with regards to sediment retention. Can RTG measures successfully foster ES provision within the identified priority sub-catchments for ES conservation action? Which SLM measures are best promoted in which sub-watersheds?

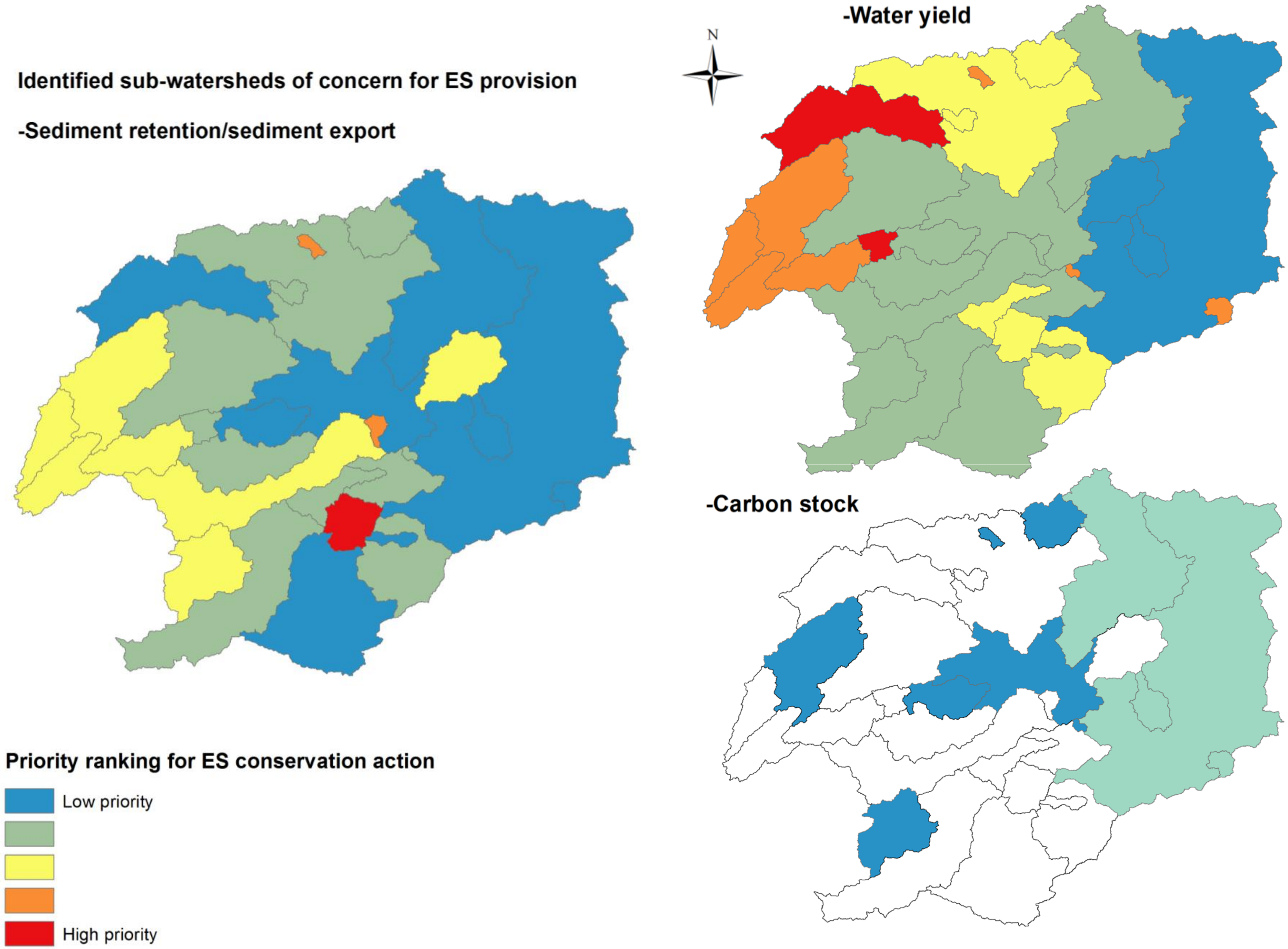


Figure 33-Scoring of priority for action on ES conservation for sub-watersheds across the Segura, based on the implications of current and future provision values, effect of past LULC transitions and predicted climate change impacts.

Potential of local SLM practice implementation vs. LULC transitions

This research was conducted on the premise of the potential of SLM practices for fostering priority ES provision within the Segura; and the value of this approach for climate adaptation and mitigation. In light of the identified priority sub-catchments for ES conservation action (**Figure 33**) the potential of the investigated implementation of RTG measures was evaluated. Results demonstrate high suitability of RTG implementation for enhancing carbon stocks. High priority sub-catchments for conservation of carbon stocks represent catchments whereby a higher proportion of the land is dedicated to agriculture and non-forested layers; primarily situated downstream of the Segura. RTG measures thus have a high potential to increase carbon stocks within these agricultural settings (see **Table 44**), ultimately resulting in a 3.25% increase in C storage at the Segura watershed level at 100% adoption. However, in light of declining carbon stocks as a result of deforestation occurring in some of the upstream sub-catchments, the scope of RTG implementation is limited when compared to the potential of LULC transitions, having resulted in a maximum 44% increase in average carbon stock in a 16 year time span within the Pliego sub-watershed. Especially reforestation on agricultural land is expected to be most effective for carbon sequestration due to the deeper soil profiles and higher potential for C sequestration (Albaladejo et al., 2012). The sub-watersheds of Fuensanta, Valdeinferno, Moratalla, Mayes, Ojos and Charcos, currently witnessing a decline in carbon stocks following trends of deforestation and/or intensification of agriculture and with limited potential for RTG implementation within the investigated LULC classes, are therefore calling for afforestation or extensification measures for safeguarding their carbon stocks and contributing to higher C sequestration rates.

Sub-watersheds of high priority for ensuring water provision are, unlike those identified for carbon storage, situated upstream of the Segura. There is potential for the implementation of RTG measures in safeguarding water provision throughout all of the catchment. Close fit is found for the sub-watersheds of Risca, Charcos and Pliego as high priority sub-catchments with highest increases in average sub-watershed water yield following RTG implementation of 6-12%. It should be noted that percentage increases in average water yield induced by historical LULC transitions resulted in considerably higher rates (87% and 41% increases in the Mayes and Ojos catchments respectively). It is furthermore important to consider both the local environmental conditions and optimal adoption percentage of RTG in order to achieve an optimal impact on an increase in water yield. Higher AWC under SLM has shown potential for both increasing and decreasing water yield by affecting evapotranspiration rates. The higher evapotranspiration rates witnessed under 100% adoption may however induce lower crop stress, thus increasing crop yields, calling for further detailed investigation.

Similarly, sediment retention high priority sub-catchments are situated primarily upstream and central catchments of Pliego, Carcavo and Charcos. There is scope in implementing RTG throughout the Segura as decreases in sediment export were witnessed within all of the catchments. The highest decreases in sediment export following SLM implementation within high priority sub-catchments were witnessed for Charcos, Fuensanta and La Vieja. Discrepancies between high priority sub-catchments and potential of RTG implementation are present for the Carcavo and Moro sub-catchments, whereby decreases in sediment export following implementation are simulated at their lowest between 5 and 15%. Percentage decrease values compared as a result of SLM practice implementation and LULC transitions yield similar results and both demonstrate high potential; afforestation between 1990 and 2006 in the Romeral catchment resulting in a 79% decrease in sediment export.

Contextualizing the SLM strategy

There is scope for a SLM strategy in the Segura to benefit from both local SLM practice implementation and explicit LULC transitions; the weighing given to either of these two separate approaches cannot however be determined solely by the outcomes of this research. Local SLM practice implementation, particularly with regards to low-cost measures like RTG, would initially appear to be a more feasible and applicable approach than implementing a wide scale LULC change. Yet, local SLM practice implementation is often highly dependent upon a voluntary uptake by farmers. If adoption rates have thus far suggested limited spontaneous uptake and up-scaling of SLM practices, then, arguably, efforts are best placed upon policy changes which could directly influence LULC transitions. Policy-makers thus need to resort to a variety of policy instruments, whilst taking into account the high potential of education and training initiatives identified within the region (Cocklin, Mautner, and Dibden 2007; Stringer et al. 2014).

The outcome maps produced by this research lack context and furthermore raise issues in need of further explorations and calling for a review in the methodological approaches utilized. The research demonstrates bias in suggesting that sub-watersheds currently yielding lowest provision in ESs are *under*-providing, as this is dependent upon a varying demand for ESs. This study did not investigate whether there is a match or mismatch between ES demand and supply, or whether the sub-watersheds investigated are under a state of equilibrium. Exploring this would in turn raise further questions of perspective, as ESs represent benefits which are subjectively perceived by different stakeholders. Are the priorities of the local community the same as those of regional policy-makers? Can the conservation of individual ESs be deemed of equal priority?

Concerns with used methodology

Concerns with used methodology relate to the conceptualization of the research, the limitations of the InVEST tools and the reliability of input data utilized.

- The ESs and SLM practices modeled do not represent an exhaustive list. In light of climate change results suggesting drastic decreases in water yield by 2050, SLM measures focusing upon a more efficient water use should be prioritized for further investigation. The incorporation of more ESs will furthermore allow for a more comprehensive understanding of ES trade-offs.
- This study arguably did not sufficiently integrate feedback mechanisms, synergies and trade-offs. For example, SLM practices that tackle water provision, either vegetative or structural, will in turn increase SOM and carbon stocks, but also sediment retention (Scharlemann et al., 2014). This synergy between multiple ES delivery by SLM implementation was poorly illustrated by SLM practice modeled outcomes, whereas was generally stronger for LULC transitions and climate change scenarios. Climate change will deliver feedbacks which call for more integrated modeling; notably, ES scenario modeling within the Segura should capture the implications of increased drought and land degradation, strongly affecting ecosystem respiration and thus carbon sequestration rates (Pereira et al. 2007; Scharlemann et al. 2014).
- The limitations of the InVEST model are in part characteristic of many ES biophysical models in their attempts at simplifying the complexity of socio-ecological systems. Perhaps the greatest limitation of the InVEST model in light of forecasts of increased intensity of rainfall events for the Segura under climate change, is the model delivery of outputs (reflecting input requirements) at the annual scale, thus not allowing for the consideration of flooding as a threat for ES provision (Scharlemann et al., 2014). Furthermore, the model's scope for managerial purposes is limited as it does not differentiate between groundwater sources crucial to water management in the Segura (Domingo et al., 2011). With regards to the carbon storage and sequestration model, InVEST is limited in its inability to incorporate a climatic dimension within its quantification of carbon storage and sequestration. SOC rates are correlated to precipitation and temperature variables, whose predicted changes under climate change are expected to reduce the potential of Spanish soils as C sinks (Doblas-Miranda et al., 2013). The results thus provide information regarding carbon stocks under different modeled scenarios; yet are misleading in the consideration of sequestration of carbon and thus climate change mitigation potential. In attempting to calculate sequestration rates not accounted for by the InVEST model, further limitations were acknowledged regarding assumptions of steady-state and the establishment of a baseline "year-zero" scenario. The model thus provides limited in consideration of varying temporal scales, as it furthermore does not take into account feedback mechanisms which occur within the carbon pool as ecosystems develop; for example, biomass expansion would result in more litter inputs and transfer of carbon from biomass to soil and atmosphere (Liski et al., 2002). According to Almagro et al. (2010) the SOC pool of agro-ecological systems reaches a steady-state 50 years into the same land management, yet rates are highly dynamic and dependent upon

external factors (Martens, Reedy, & Lewis, 2004). Powlson, Whitmore, and Goulding (2011) discuss the misconceptions of achieving climate change mitigation via the implementation of SLM practices. Mitigation occurs if a net transfer of C from the atmosphere to the land is witnessed, however this is not necessarily reflected by increases in SOC and furthermore limits the scope of comparing carbon stocks across catchments. Whereby a LULC transitions from non-forested to forested layers will inevitably result in increased C uptake and thus mitigation, C transfers following local SLM practice implementation are not so clear-cut. Green manuring will add C to the soil, yet this would only constitute a mitigation potential in consideration of the alternative fate of the residue. Reduced tillage, on the other hand, slows down decomposition rates thus resulting in sequestration (Powlson et al., 2011).

- Although we tried to obtain and combine most accurate and detailed available data for the different input data sources, we obtained input data in part from secondary sources, inevitably leading to uncertainties in modelled outcomes. The CORINE LULC datasets used are not detailed representations of the highly fragmented mosaic landscape, particularly limiting in consideration of SLM practice modelling. Calibration was undertaken in consideration of only a select group of catchments with available data, potentially yielding inaccurate results. More importantly, the regional future climate data used calls for exploration of downscaling techniques to reach more accurate representations, as current resolution has averaged rainfall throughout the catchment and does not account for differences in climatic variables between the upstream and downstream catchments. This is particularly relevant for the R factor, also based on mean annual rainfall and thus not accounting changes in rainfall seasonality or rainfall intensity. According to Sánchez-Canales et al. (2012), the InVEST water yield model is "highly contingent" upon input climatic variables of precipitation and potential evapotranspiration. Sensitivity analysis undertaken by Hoyer and Chang (2014) agree the water yield outcomes are strongly driven primarily by precipitation inputs.

Recommendations for further research

This research served an exploratory purpose for the development of a climate change adaptation and mitigation SLM strategy based upon ES biophysical modeling with the use of the InVEST tool. It investigated the effects of LULC transitions, climate change, scale and SLM practice implementation upon ES provision in the Segura catchment. The research has demonstrated each of these variables has high potential for further investigation on its own, so that efforts can be placed upon improving the quality of the respective inputs and implementing a more comprehensive and integrated approach. Particular emphasis can be given to not only identifying the most appropriate SLM technologies, but to also determine their most efficient location within the catchment (Mekonnen et al., 2014).

Furthermore, there is scope in bringing both the process and outcomes of this strategy and scenario exploratory research within a participatory context. Prevention technologies (adaptation and mitigation SLM practices) can and should be implemented within wider adaptation strategies involving educational and behavioral dimensions. Closer stakeholder collaboration and community involvement will improve likelihood of success via the identification of current, sometimes cultural, practices, whilst ensuring a bottom-up approach to climate change adaptation (Smit & Wandel, 2006). In addition, this will aid in the mainstreaming of the ES concept, still poorly incorporated within local natural resource management decision-making processes, and in need of communication to land managers (Daily, 1997). Research by (Smith & Sullivan, 2014) investigated perceptions of the ES concept by different stakeholder groups, and found that despite farmers not being familiar with the terminology, they found the concept of individual ESs to be easily understood, and could relate this understanding to past experiences witnessed in their management of the land. They furthermore highly valued ESs and found them to be "mostly manageable", strengthening the standpoint for the incorporation of natural capital concepts within natural resource management.

For example, the investigation of the effects of LULC transitions, shown to induce considerable impact s upon ES provision, could be complemented by a participatory approach involving stakeholder defined scenarios delineating future viable regional LULC transitions. Nainggolan et al. (2013) shed light upon the future competing trajectories of LULC changes within semi-arid Mediterranean agro-ecological systems, primarily based upon the continuation of current trends of afforestation, agricultural land abandonment and intensification of agriculture. This is relevant for the utilization of this tool and research approach for policy-makers, with implications for reforestation and agricultural subsidies. Of additional insight for decision-makers would be investigating a monetary valuation within the identified ESs.

Concluding thoughts

Results reveal climate change will strongly inhibit priority ecosystem service (ES) provision in the Segura catchment, calling for intervention mechanisms and tools able to assess and facilitate decision-makers via an exploratory scenario approach. Sustainable land management (SLM) measures implementing reduced tillage and green manuring (RTG) have demonstrated their potential in fostering priority ES provision. Future research is needed to investigate additional SLM practices, and to identify the most optimal implementation sites and adoption levels for fostering ES provision at the sub-catchment and catchment scales. Future policy directions aiming to safeguard ES provision via SLM should furthermore consider the potential of LULC transitions, and need to assess likelihood of SLM implementation by relevant stakeholders. Decision-makers are thus faced with two missions, on the one hand to place resources upon establishing spontaneous SLM adoption amongst agricultural land owners, and on the other to drive policies towards explicit land use and land cover (LULC) transitions. There is scope for developing a stakeholder informed SLM strategy including LULC transitions for the explicit, informed purpose of scenario modeling. This will establish a contextualized setting, and thus permit to answer questions on which ESs are of higher priority for conservation, and highlight where priorities differ amongst invested stakeholders. The existing limitations of this modeling approach should be communicated to all stakeholders, to ensure transparency and trust in both process and outputs.

InVEST proves a useful tool for ES quantification at multiple scales, and can be of high value to provide input of information to a participatory process. This study demonstrates the value of a regional scale assessment, yet simultaneously sheds light on the necessity of investigation at the smaller, sub-catchment scale for a more comprehensive and integrated analysis of ES tradeoffs. Despite more research being needed into downscaling the available regional climate prediction models for rainfall erosivity factors, integrating inter-annual variability, the strength of this research lies within demonstrating the value of an exploratory approach and in utilizing readily available, and thus transposable and communicative information. Unlike the majority of ES mapping literature, this study investigated LULC, climate and SLM practices as independent variables (Hoyer & Chang, 2014), offering unprecedented insight into the responses of ESs at the regional level.

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Appendix

CORINE Land Cover nomenclature conversion to Land Cover Classification system- The CORINE Land Cover is a vector map with a scale of 1:100 000, a minimum cartographic unit (MCU) of 25 ha and a geometric accuracy better than 100m. It maps homogeneous landscape patterns, i.e. more than 75% of the pattern has the characteristics of a given class from the nomenclature. This nomenclature is a 3-level hierarchical classification system and has 44 classes at the third and most detailed level (Table 1). In order to deal with areas smaller than 25ha a set of generalisation rules were defined.

Table 1- CORINE Land Cover (CLC) nomenclature

http://www.igeo.pt/gdr/pdf/CLC2006_nomenclature_addendum.pdf

Level 1	Level 2	Level 3
1 Artificial surfaces	11 Urban fabric	111 Continuous urban fabric 112 Discontinuous urban fabric
	12 Industrial, commercial and transport units	121 Industrial or commercial units 122 Road and rail networks and associated land 123 Port areas 124 Airports
	13 Mine, dump and construction sites	131 Mineral extraction sites 132 Dump sites 133 Construction sites
	14 Artificial, non-agricultural vegetated areas	141 Green urban areas 142 Sport and leisure facilities
2 Agricultural areas	21 Arable land	211 Non-irrigated arable land 212 Permanently irrigated land 213 Rice fields
	22 Permanent crops	221 Vineyards 222 Fruit trees and berry plantations 223 Olive groves
	23 Pastures	231 Pastures
	24 Heterogeneous agricultural areas	241 Annual crops associated with permanent crops 242 Complex cultivation patterns 243 Land principally occupied by agriculture, with significant areas of natural vegetation 244 Agro-forestry areas
3 Forest and semi natural areas	31 Forests	311 Broad-leaved forest 312 Coniferous forest 313 Mixed forest
	32 Scrub and/or herbaceous vegetation associations	321 Natural grasslands 322 Moors and heathland 323 Sclerophyllous vegetation 324 Transitional woodland-shrub
	33 Open spaces with little or no vegetation	331 Beaches, dunes, sands 332 Bare rocks 333 Sparsely vegetated areas 334 Burnt areas 335 Glaciers and perpetual snow
4 Wetlands	41 Inland wetlands	411 Inland marshes 412 Peat bogs
	42 Maritime wetlands	421 Salt marshes 422 Salines 423 Intertidal flats
5 Water bodies	51 Inland waters	511 Water courses 512 Water bodies
	52 Marine waters	521 Coastal lagoons 522 Estuaries 523 Sea and ocean