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Impact and mitigation of global change on freshwater-related ecosystem services in Southern Europe

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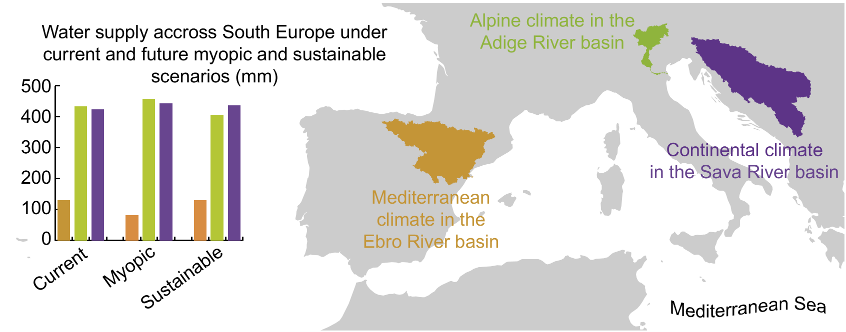
HIGHLIGHTS

- Mediterranean basins in Europe suffer great changes comparing to continental ones.
- Water supply varies from −37% to +6% depending on precipitation in studied basins.
- Sediment retention depends on precipitation, but export on agricultural practices.
- Total nitrogen production and retention, with homogeneous distribution, barely change.
- Total phosphorus production and retention increase up to +12% for the expansion of urban areas.

GRAPHICAL ABSTRACT



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ABSTRACT

Global change is severely impacting the biosphere that, through ecosystem services, sustains human well-being. Such impacts are expected to increase unless mitigation management actions are implemented. Despite the call from the scientific and political arenas for their implementation, few studies assess the effectiveness of actions on freshwater-related services. Here, by modeling water provisioning, water purification and erosion control under current and future conditions, we assess future trends of service provision with and without mitigation policies. In particular, two different storylines combine multiple climate, land use/land cover and agricultural management scenarios, and represent a pro-efficiency business as usual (myopic storyline) and a future that considers social and environmental sustainability (sustainable storyline). The mentioned services are modeled for the horizon 2050 and in three South European river basins: Ebro, Adige and Sava, which encompass the wide socio-environmental diversity of the region.

Our results indicate that Mediterranean basins (Ebro) are extremely vulnerable to global change respect Alpine (Adige) or Continental (Sava) basins, as the Ebro might experience a decrease in water availability up to 40%, whereas the decrease is of only 2–4% in the Adige or negligible in the Sava. However, Mediterranean basins are also more sensitive to the implementation of mitigation actions, which would compensate the drop in water provisioning. Results also indicate that the regulating services of water purification and erosion control will gain more relevance in the future, as both services increased between 4 and 20% in both global change scenarios as a result of the expansion of agricultural and urban areas. Overall, the impact of global change is diverse among services and across river basins in Southern Europe, with the Mediterranean basins as the most vulnerable and

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the Continental as the least. The implementation of mitigation actions can compensate the impact and therefore deserves full political attention.

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1. Introduction

From the most pristine rainforests to the intensive agricultural landscapes, all ecosystems provide services that generate socioeconomic benefits to human societies (Daily et al., 2009; MA, 2005). Many of these ecosystem services (ES) are linked to the interaction between vegetation cover and freshwater, such as water provisioning and purification or erosion control, among others. Water provisioning benefits societies through domestic, industrial and irrigation water, hydropower and other in-stream uses like fishing or kayaking (Jorda-Capdevila and Rodríguez-Labajos, 2015). Erosion control is the retention of potential soil loss and sediment moving downhill for preserving soils and avoiding reservoir siltation (Pimentel et al., 1995). Finally, water purification is the retention of total nitrogen (TN) and total phosphorus (TP) contained in freshwater, which avoids eutrophication and improves drinking water and fisheries (Smith and Schindler, 2009). Regrettably, all these services are under threat by global change (Bangash et al., 2013).

Global change arises from the acceleration of resources extraction and waste disposal, linked to the rapid population and economic growth. It is a multi-facetted environmental problem that includes changes in climate, land use/land cover (LU/LC) and environmental management practices (García-Ruiz et al., 2011; Giorgi and Lionello, 2008). These changes impair ES provision hence putting human well-being at risk (Kubiszewski et al., 2017; Runting et al., 2017). At a South-European level, the decrease of the precipitation in summer and the increase of the frequency and duration of droughts are projected to increase water scarcity (Gampe et al., 2016; Jacob et al., 2014; Lehner et al., 2006; Schröter et al., 2005). Another example of impairment in the Southern Europe is that Greece, Italy, Portugal and Spain sum 51% of the total soil lost in the EU (Panagos et al., 2015), mainly caused in croplands in steep areas and sometimes in abandoned farmland in arid areas (García-Ruiz, 2010); while future trends of erosion are irregular (Guerra et al., 2016). Meanwhile, several studies reveal that the increase of levels of nitrogen and phosphorus loads to the environment have slowed down in the last decades (Grizzetti et al., 2012; La Notte et al., 2015; Lutz et al., 2016), mainly due to the implementation of wastewater treatment plants and improved fertilizer application strategies (Lutz et al., 2016). Moreover, there are assessments at a river basin level, which show negative or uncertain future prospects, that have been performed with the correspondent scale limitations, like the low representativeness of its biogeographical region (Bangash et al., 2013; Boithias et al., 2014; Lutz et al., 2016; Sánchez-Canales et al., 2015; Vrzel and Ogrinc, 2015).

Facing these challenges that emerge from global change, a recent publication estimated that governance focused on the environment and human well-being would increase the value of the biosphere by US$31 trillion/year in the 2011–2050 period, while an ongoing focus on economic growth together with nature protection would maintain the current ecosystems' value (Kubiszewski et al., 2017). In contrast, a free-market world would maximize GDP but lead to land degradation. In this sense, the European Union is currently moving beyond the approved environmental directives (*e.g.*, the Nitrates and Water Framework Directives) towards the EU Biodiversity Strategy that aims to have the Union's biodiversity and the ES it provides protected, valued and restored by 2050 (European Commission, 2011). In a mid-term prevision, The 7th Environmental Action Programme ensures that by 2020 "land is managed sustainably in the Union and soil is adequately protected", "water stress […] is prevented or significantly reduced" and the "nutrient cycle [nitrogen and phosphorus] is managed in a more sustainable and resource-efficient way" (European Commission, 2014).

In this study, we assess the impact of global change, together with the effectiveness of mitigation strategies, on the provision of freshwater-related services in Southern Europe, which has been identified among the most vulnerable regions of the world (Schröter et al., 2005). Specifically, the impact is assessed using two storylines developed in the GLOBAQUA Project. The first is a pro-efficiency business-as-usual scenario: *myopic* storyline; and the second a scenario of socio-environmental awareness with active mitigation policies: *sustainable* storyline. The influence of these storylines for water provisioning, erosion control and water purification is assessed in the Ebro, the Adige and the Sava River basins. These basins are representative of three distinct environmental contexts in Southern Europe, namely with Mediterranean, Alpine and Continental climatic characteristics. We used the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) model (Nelson et al., 2009) to assess impact and mitigation of global change by 2050 under the previously mentioned *myopic* and *sustainable* storylines. Our hypotheses indicate that in *myopic* conditions the ES provision will generally decrease in those areas with a marked Mediterranean nature and increase in those areas where a significant expansion of urban areas is foreseen, without mitigation of the impact to the environment. For the *sustainable* storyline, we expect that mitigation practices will be able to buffer the effects of global change.

2. Materials and methods

2.1. Study area

Three river basins are analyzed in Southern Europe. The Ebro basin (87,097 km^2) in the Iberian Peninsula has a typical Mediterranean climate, though it includes from the rainy Pyrenees to the semi-desert of the Ebro depression, where intensive irrigated agriculture abounds. Spain is the country that manages the bulk of the basin, while Andorra and France also have a small part. The Adige (12,370 km^2) is in the central Southern Alps and almost entirely in Italy. Embedded in a high Alpine environment, it concentrates intensive agriculture and dense urban areas in the valleys. The Sava (96,778 km^2) is the main tributary of the Danube and its basin embrace six countries: Slovenia, Croatia, Bosnia and Herzegovina, Serbia, Montenegro and a bit of Albania. Agriculture in this basin is less intensive, but urban areas are larger. The climate there is Continental. Fig. 1 shows maps indicating the distribution of basic descriptors (altitude, annual precipitation, water bodies, land uses) under current conditions. Differences also take place in the threats of climate change, spanning severe impairment by droughts in the Ebro and increases of precipitation in the Sava (EEA, 2017; Gampe et al., 2016; Jacob et al., 2014; Vautard et al., 2014).

2.2. Development of scenarios

The development of scenarios take place in the context of the GLOBAQUA project (GLOBAQUA, 2017; Navarro-Ortega et al., 2015) and was based on two storylines developed from distinct combinations of Shared Socio-economic Pathways (SSP) and Representative Concentration Pathways (RCP) (O'Neill et al., 2014; van Vuuren et al., 2011). A storyline is a short story describing a potential future, a combination of socio-economic elements and trends. In this study, *myopic* and *sustainable* storylines are the basis for integrating climate, LU/LC, and environmental management scenarios. The data resulting from the scenario development is input for our ES models. Specifically the development of

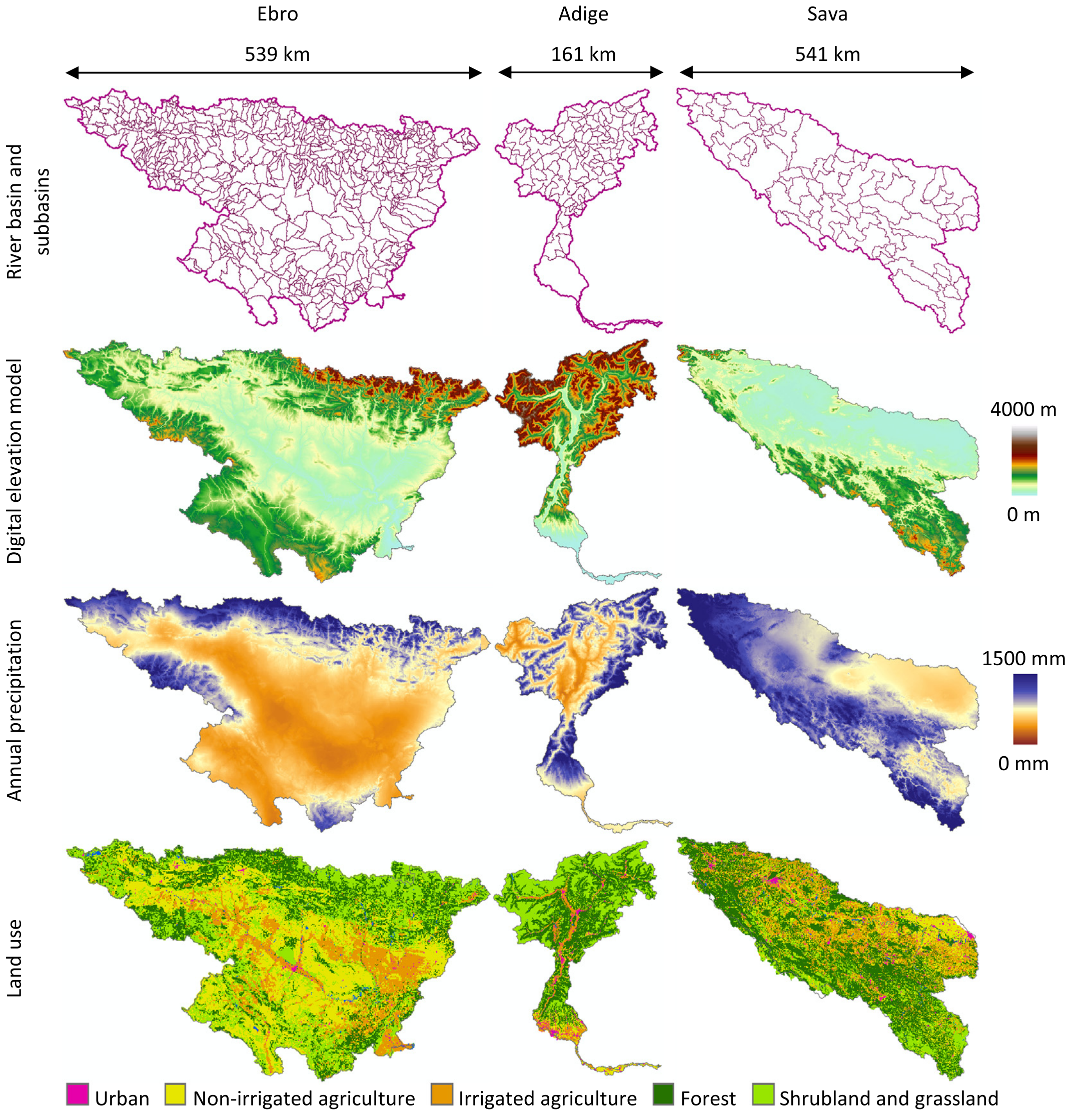


Fig. 1. Basic input data of the river basins under reference conditions.

climate and LU/LC scenarios uses data from three climate models chosen out of a model ensemble, hence results of service provision treble for each storyline and each current (1981–2010) and future (2036–2065) time (Fig. 2). The impact of global change is assessed by subtracting *myopic* to current conditions; mitigation of global change by comparing results from the current to *sustainable*. Given the three simulations for each condition, means and standard deviations are calculated and used to express average changes and their range of uncertainty, respectively.

2.2.1. Myopic versus sustainable storylines

The *myopic* storyline represents a short-termism attitude, focused on immediate return on financial investment and unrestricted use of natural resources. The *myopic* storyline relies on technologies that compensate the effect of climate change and resources depletion to boost the economic growth. The *myopic* is a business-as-usual projected towards 2050, and describes at global level the combination SSP 5 with RCP 8.5 (GLOBAQUA, 2017).

The *sustainable* storyline corresponds to the mitigation alternative scenario. The increasing effectiveness of institutions and a stronger cooperation at different levels help improving the management of local and global environmental issues over the longer term. Here non-technological measures of self-regulation are preferred in water resources management. The *sustainable* storyline prioritizes the preservation of natural capital above financial capital, and describes the combination SSP 1 with RCP 4.5 (GLOBAQUA, 2017).

2.2.2. Scenarios of global change

2.2.2.1. Scenarios of climate change. Projections for future climate are provided through the EURO-CORDEX initiative (Jacob et al., 2014). Different regional climate models (RCMs) dynamically downscale various global climate models (GCMs) under future scenarios from the different RCPs. For computational constraints, a clustering approach (Wilcke and Bärring, 2016) was applied to condense the number of GCM-RCM combinations while conserving most of the spread of the entire climate model ensemble. A selection of three GCM-RCM combinations forms the basis for the climate scenarios (Fig. 2). During the scenarios development, biases that are prone to occur at a catchment scale (Dosio, 2016; Kotlarski et al., 2014) are corrected (Yang et al., 2010) and grid resolution is transformed from 0.11° (~12 km) to 1 km (Marke, 2008).

Table 1 shows the average of precipitation, minimum and maximum air temperature, and downward radiation from the three GCM-RCM combinations for the sustainable and myopic RCPs: 4.5 and 8.5 respectively. The percent changes show the climate change signal, defined as difference of future (2036–2065) projections

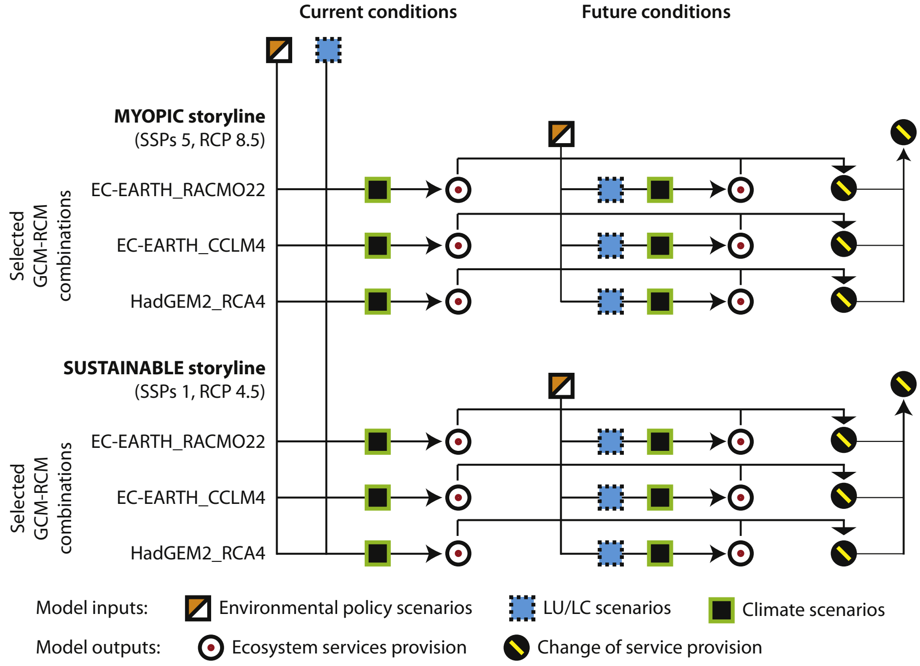


Fig. 2. Study design.

compared to current (1981–2010) conditions. For all three river basins the RCMs show a clear signal in air temperature with increases between 1.4 and 2.1 °C under both *myopic* and *sustainable* storylines. For precipitation this is not so clear, as the models show ambiguous results (Gampe et al., 2016). A slight increase in precipitation is projected in the *myopic* future over mountainous areas, possibly due to the increasing occurrence of convective events in the summer period. The projections for radiation follow the projections of precipitation – and cloud cover – inversely.

Table 1
Variation of climate variables, area of LULC, water consumption and agricultural practices under myopic and sustainable conditions.

	Ebro		Adige		Sava	
	Myop.	Sust.	Myop.	Sust.	Myop.	Sust.
Climate						
Precipitation (P)	−3.7%	−5.6%	+5.1%	−3.1%	+4.7	+2.8%
Shortwave radiation (Rs)	+0.4%	+0.5%	−1.1%	+3.1%	−0.2%	−1.6%
Maximum daily temperature (T_{max})	+2.1 °C	+1.5 °C	+2.4 °C	+1.9 °C	+2.1 °C	+1.4 °C
Minimum daily temperature (T_{min})	+1.8 °C	+1.5 °C	+2.2 °C	+1.6 °C	+2.0 °C	+1.4 °C
Evapotransporation (ETo)	+7.2%	+5.6%	+9.2%	+11.5%	+7.6%	+3.6%
Area of LULC						
Urban and industrial	+211%	+130%	+48%	+29%	+44%	+25%
Non-irrigated agriculture	−12%	−18%	−2%	+5%	+14%	+4%
Irrigated agriculture	+27%	−7%	−0%	+0%	−26%	−7%
Forest	−2%	+5%	−5%	+5%	+2%	+4%
Shrubland and grassland	−2%	+6%	+2%	−9%	−0%	−12%
Water consumption per area						
Urban and industrial	−6%	−31%	+7%	−14%	−6%	−26%
Irrigated agriculture	−6%	−31%	+7%	−14%	−6%	−26%
Total amount of water consumption						
Urban and industrial	+193%	+59%	+60%	+11%	+36%	−8%
Irrigated agriculture	+19%	−36%	+7%	−14%	−30%	−31%
Total[a]	+30%	−30%	+15%	−10%	+15%	−15%
Agricultural practices						
Cover-management factor (C)	+5%	−5%	+5%	−9%	+5%	−5%
Support practice factor (P)	+11%	−9%	+11%	−9%	+0%	−5%

[a] This is a fixed value obtained from the workshops undertaken in the GLOBAQUA Project (GLOBAQUA, 2017).

2.2.2.2. Scenarios of land use and land cover change. The LU/LC scenarios were defined from a set of socio-economic descriptors including economic growth *per capita*, population growth, and deforestation/afforestation, among many others. The expected degree of change of the descriptors was evaluated by local stakeholders and researchers in participatory workshops. Such workshops aimed to downscale climate change from global/regional to river scale level (GLOBAQUA, 2017). Results from the workshops were compared with values found in the literature and with past observed land use changes, and then transformed into quantitative estimates that explain future land use demands. These estimates are required as input for the iCLUE model (Huber García et al., 2018; Verweij et al., 2018) – new version of the Conversion of Land Use and its Effects (CLUE). The 1-km-resolution LU/LC grid maps obtained by the model were reclassified into five categories for comparisons across case studies: urban, non-irrigated agriculture, irrigated agriculture, forest, and shrubland and grassland.

The LU/LC scenarios used as input for the ES modeling show that urban and industrial areas will increase across basins and storylines, though stronger changes are expected in the *myopic* one (see Table 1). In the Ebro, the *myopic* storyline projects an intensification of agriculture, while in the *sustainable* storyline the changes towards small-scale and extensive cultivation makes both agricultural land decrease and forests and shrublands expand. The topography is a space limiting factor in the Adige, so changes are rather small for both scenarios. In this basin, in a *sustainable* future, non-irrigated agriculture grows as formerly abandoned farmlands are reactivated. In the Sava, irrigation is currently insignificant while the non-irrigated represents intensive agriculture and is expected to grow in both scenarios. There, shrublands are not considered to represent the natural vegetation, since appear when either forest is clear cut or farmland is abandoned, and decreases in the *sustainable* storyline.

2.2.2.3. Scenarios of environmental policy change: water and agricultural management practices. The same participatory workshops mentioned above facilitated information about expected change in water and agricultural management practices, which ranges from no change to a ± 25% change from current situation. Future total water consumption values were also defined in the workshops and consumption per LU/LC class is obtained from the modeling outcomes (Table 1).

Scenarios of water and agricultural management are basically explained by changes in irrigation. Such changes are caused by the expansion/reduction of irrigated agriculture and, in the *sustainable* storyline, by the improvement of water efficiency. In general, consumption increases in the *myopic* and decreases in the *sustainable* storyline, except in the Sava basin due to the expansion of intensive non-irrigated agriculture in both storylines. For urban and industrial uses, the increase in water consumption is major, especially under *myopic* conditions (up to +193% in the Ebro basin). Regarding agricultural practices, they allow an improvement of erosion control in *sustainable* conditions but the contrary in the *myopic*.

2.3. InVEST modeling tool and input data

The assessment by modeling of the previously mentioned ES is performed by means of the InVEST tool. This is a spatially explicit tool consisting of a suite of models that use biophysical and economic data and relationships to estimate biophysical levels and economic values of ES. The models run on a regular grid at an annual average time step, and results can be reported in either biophysical or monetary terms, depending on the needs and the availability of data (Daily et al., 2009). Here, only results in biophysical units are presented. The InVEST models employed in this study are: a water-yield and consumption model for water provisioning, a sediment-production and retention model for erosion control, and a nitrogen and phosphorus-production and retention model for water purification. Table 2 shows data requirements for the models, their values, units and sources. Further information about data requirements is given in Appendix A.

2.4. Calibration process

The calibration of the models was performed by comparing model predictions against observed values of water supply, sediment load, and TN and TP loads from gauging and monitoring stations spread across each basin. Model goodness-of-fit was assessed through different metrics: the slope and R^2 of the lineal regression of predicted against observed values, Nash-Sutcliffe efficiency (NSE) and Percent bias (PBIAS) (see Fig. 3 and Table 3). Values for each of the metrics – except for R^2 – correspond to the mean value obtained after the comparison for all the control points. Positive and negative values of the slope imply an overestimation and an underestimation of the predicted service provision. NSE determines the magnitude of the residual variance compared to the measured data variance (Nash and Sutcliffe, 1970) (NSE between $-\infty$ and 1) allows to accept the model if NSE > 0.50 (1 is optimal). PBIAS measures the average tendency of the simulated data to be larger or smaller than their observed counterparts (Moriasi et al., 2007). The optimal is 0.0, and we accept models with a PBIAS of ±20% for streamflow, and ±40% for sediment and nutrients, since they add the error from the water provisioning model. As the results of Table 3 illustrate, all calibration models yielded satisfactory results except the erosion control model for the Ebro basin. In this case, the size of the basin, its heterogeneity in terms of climate and geology, and the abundance of reservoirs hamper the model goodness-of-fit (see detailed explanation in Section 4).

3. Results

3.1. Ecosystem services provision under reference conditions

Water supply, as the water remaining after the subtraction of water consumption to water yield, ranges between −485 and 1601 m^3/ha year (Fig. 4). The Ebro basin shows the greatest extremes,

Table 2
Data requirements for the InVEST model, and indication of its use in the calibration process (Cal) or modified in the future scenarios (FS).

Input data	Range of values	Units	Sources	Cal	FS
Common data					
Watersheds and subwatersheds	81 (Sava)–715 (Ebro)	–	Watershed authorities		
Land use/land cover	–	–	Corine Land Cover of 1990		X
Digital elevation model (DEM)	0–3865 (Adige)	m.a.m.s.l.	CGIAR-CSI		
Threshold flow accumulation	200	cell	–		
Data for the water supply model					
Root restricting layer depth	0–2000	mm	Eusoils		
Precipitation	233 (Adige, sustainable)–4203 (Adige, myopic)	mm	Gampe et al. (2016)		X
Plaint available water content	0 (alpine areas, Adige)–20 (lowlands, Ebro and Sava)	%	Eusoils		
Evapotranspiration coefficient (Kc)	0.715 (shrubland, Adige)–1.3 (forest, Sava and Ebro)	–	InVEST User Guide	X	
Average annual reference evapotranspiration	228 (Adige, current)–1612 (Ebro, myopic)	mm	Gampe et al. (2016), and Droogers and Allen (2002)		X
Maximum root depth for vegetated land use classes	2100 (agriculture)–5200 (forest and shrubland)	mm	Eusoils	X	
Seasonally factor/Zhang factor (Z)	6 (Adige)–9 (Ebro, Sava)	–	Sánchez-Canales et al. (2012)	X	
Water demand for consumptive uses	224 (irrigated, Sava, sustainable)–9646 (urban, Ebro, myopic)	m^3/ha year	Watershed authorities		X
Data for the erosion control model					
Rainfall erosivity index (R)	315 (Adige)–88,658 (Sava)	MJ mm/ha h year	Gampe et al. (2016), and Renard and Freimund (1994)		X
Soil erodibility index (K)	0.0025 (Sava)–0.0834 (Ebro)	T ha h	Panagos et al. (2014)		
Support practice factor (P)	rf0230)	–	Sánchez-Canales et al. (2012)	X	X
Cover-management factor (C)	0.006 (urban)–0.417 (non-irrigated, Sava, myopic)	–	Sánchez-Canales et al. (2012)	X	X
Sediment retention value	5 (urban)–46 (forest, Sava)	%	Sánchez-Canales et al. (2012)	X	
Slope threshold	15	%	–	X	
Data for the water purification model					
Total nitrogen load	5000 (forest)–192,804 (urban, Adige)	g/ha year	–	X	
Vegetation filtering value for total nitrogen	0 (urban)–65 (forest, Ebro)	%	–	X	
Total phosphorus load	180 (forest, Adige and Sava)–24,742 (urban, Sava)	g/ha year	–	X	
Vegetation filtering value for total phosphorus	0 (urban)–91 (forest, Ebro and Adige)	%	–	X	

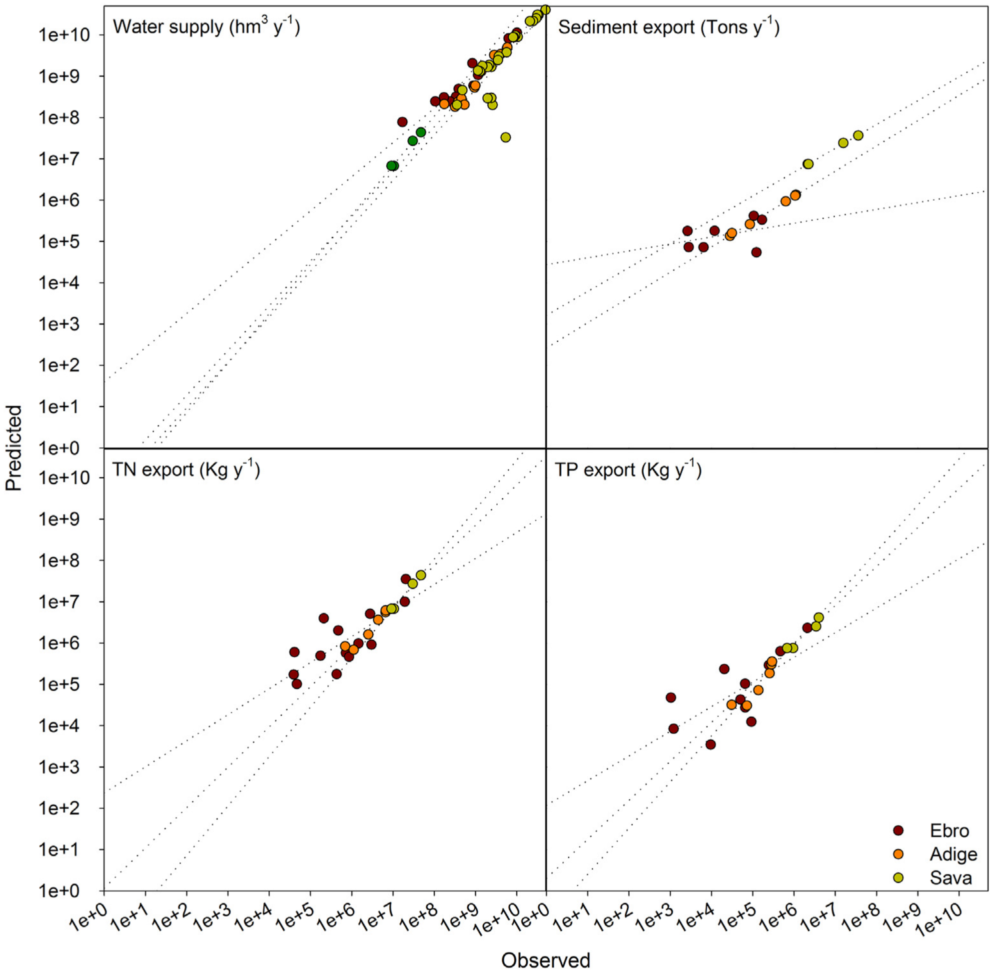


Fig. 3. Regression model of the calibration.

although the Adige also shows negative water supply values at the flat area around Bolzano. Water supply is however abundant in the mountain areas of the Ebro and Adige basins, and in a large area of the Western and Southern Sava basin (see Fig. 4).

Sediment retention ranges between 3.43 and 4249 tons/ha year. Highest values are found in small valleys at the headwaters of Gallego and Aragón tributaries (Ebro). Besides extreme values, those above 600 tons/ha year are concentrated in the high Pyrenees and the Iberian range in the Ebro basin, in the Western sub-basins of the Sava and the Eastern sub-basins of the Adige. The lowest values (below 100 tons/ha year) are found in the Po-Adige Plain, around the confluence between the Sava and the Danube Rivers, and in the Ebro depression and around its tributary Jiloca.

Regarding water purification, TN retention ranges between 0.47 and 17.66 kg/ha year, whereas TP retention ranges between 0.03 and 3.31 kg/ha year (Fig. 4). The Ebro river basin also shows the largest range of values. The maximum level of nutrient retention is located in those areas with higher levels of nutrient loads, commonly associated with highly anthropized areas. In the Adige (1.97 kg/ha year for TP and 16.08 kg/ha year for TN) and Sava (1.98 kg/ha year for TP and 14.61 kg/ha year for TN), this occurs in the flat areas around Verona (Adige) and Bihać and Belgrade (Sava) respectively.

Table 3
Results of the calibration model.

ES/basins	Control points	Slope (y)	R^2	NSE	PBIAS
Water supply					
Ebro	13	1.1675	0.9839	0.9410	−19.0241
Adige	12	0.8495	0.9742	0.9364	16.4705
Sava	25	0.8640	0.9786	0.9527	14.9943
Sediment retention					
Ebro	5	1.9784	0.2692	−5.4478	−134.6226
Adige	6	1.2552	0.9556	0.8091	−39.5001
Sava	4	1.1191	0.8231	0.8306	−35.4964
Total nitrogen retention					
Ebro	14	1.1406	0.7225	0.4912	−20.3977
Adige	6	0.8539	0.9763	0.9095	16.4932
Sava	4	0.8942	0.9888	0.9513	14.0140
Total phosphorus retention					
Ebro	11	1.1086	0.9847	0.9671	−18.6778
Adige	6	0.9739	0.8471	0.7624	8.9512
Sava	4	0.9047	0.9207	0.8966	10.1097

3.2. Impact and mitigation of global change

In the *myopic* storyline, water supply impairment will occur in almost the entire basin of the Ebro (−37%), reaching a maximum decrease of −311.63 m^3/ha year in central sub-basins. This is not only due to a decrease of the water yield, but also to the consumption growth (see Figs. 5 and 6). In the Adige and Sava, the reduction of supply is concentrated in a few sub-basins in the center and south of the basin respectively. These two basins show an increase of the supply, +6% and +4% respectively, basically caused by the raise of the water yield. This reaches a maximum of +95.67 m^3/ha year in the north-western Sava and +71.61 m^3/ha year in the Nero River sub-basin (Adige basin). Under *sustainable* conditions, the major increases occur in those sub-

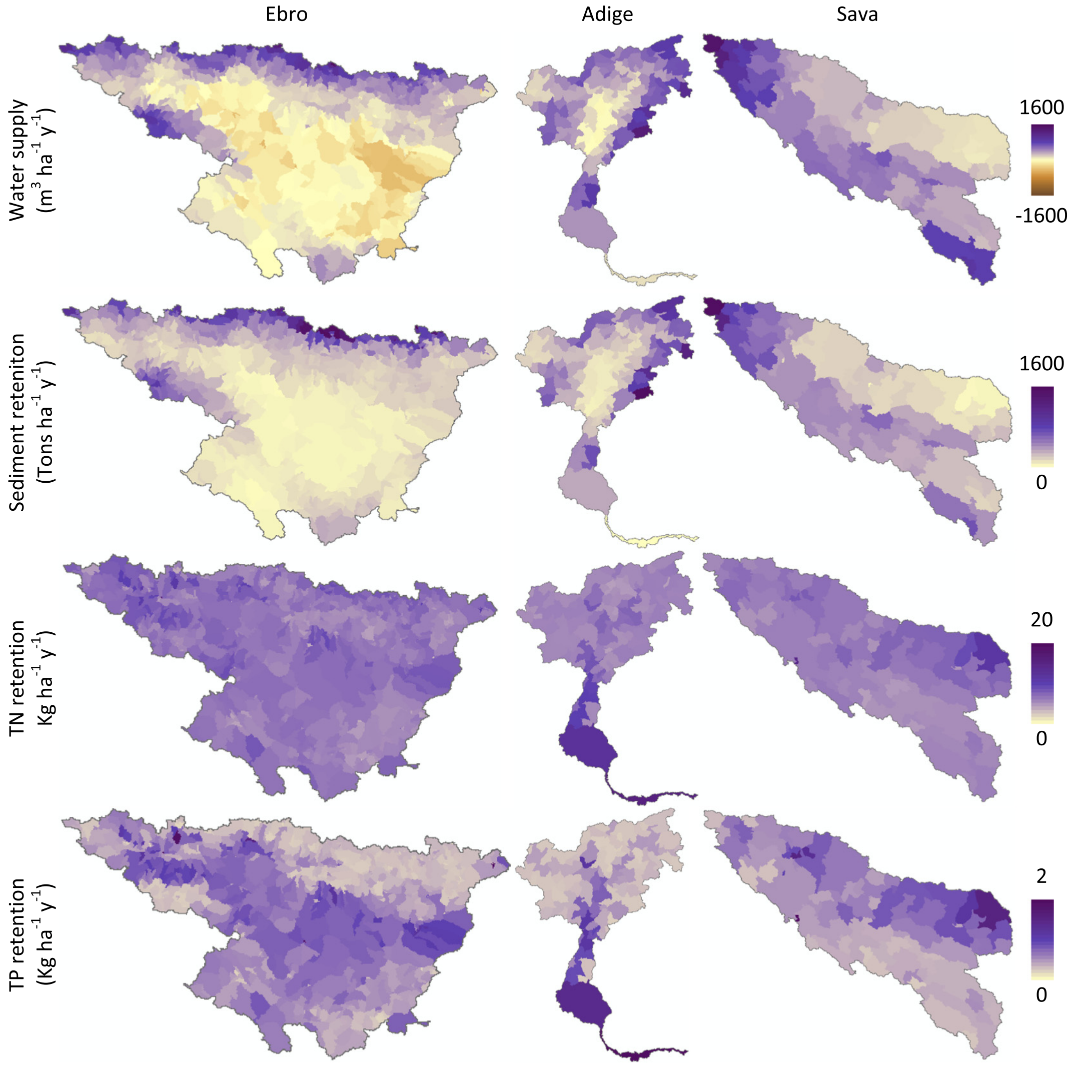


Fig. 4. Reference conditions of service provision.

basins with current lower water supply, especially in the Ebro depression, with a maximum increase of +243.01 m^3/ha year. The decreases occur in the most humid areas: Central Pyrenees (−187.059 m^3/ha year), high ranges in the Adige basin (−84.45 m^3/ha year) and Western Sava (−70.56 m^3/ha year). Particularly in the Ebro basin, the reduction of water consumption compensates the decrease of the water yield and avoids a reduction of water supply.

Regarding erosion control, the trend in sediment retention is similar to the potential soil loss (Fig. 5). In a *myopic* world, retention increases in the Adige and Sava basins +10% and +9%, respectively, because of an increase of sediment production. Retention reaches its highest value on the slopes of Monte Cristallo (+145.99 tons/ha year, Adige) and Mount Triglav (+187.76 tons/ha year, Sava). Contrarily, there is a general decrease in the Ebro basin (−8%), especially in the Pyrenees, with values down to −519.30 tons/ha. These changes are similar under *sustainable* conditions in the Sava (+4%) and Ebro (−11%) basins, with maximum changes of sediment retention of +51.18 tons/ha year in central Sava and −670.08 tons/ha year in the Gallego and Aragón headwaters, where the current values are higher. The general trend in the Adige basin is to decrease the sediment retention (−6%), as well as the sediment export (−16%).

Water purification in terms of TP retention increases in almost all cases due to a general increase of TP production. Under *myopic* conditions the growth is +9%, + 20% and +4% in the Ebro, Adige and Sava basins respectively, while in the *sustainable* storyline values are −0%, +12% and +4%. In contrast, TN retention barely changes under either *myopic* (+1% in the Ebro and Sava basins) or *sustainable* conditions (+1% in the Ebro and +1% in the Sava). The Adige basin is the exception: +7% in *myopic* and +5% in *sustainable* conditions. Nevertheless, extreme values are located in the Ebro and Sava basins. The highest values under *myopic* conditions are found in the outskirts of Bihać (Sava) and Pamplona (Ebro), with +6.56 and +5.24 kg/ha year for TN and +2.14 and 1.72 kg/ha year for TP. The city of Zaragoza (Ebro) presents the minimum values of −3.51 kg/ha for TN and −1.10 kg/ha year for TP. Under *sustainable* conditions, Zaragoza also holds the most negative change of water purification: −2.95 kg/ha year for TN and −1.13 kg/ha year for TP; while the most positive are in Miranda de Ebro: +4.37 kg/ha year for TN and +1.24 kg/ha year for TP.

Looking at all results in an integrated way (Fig. 7), we see that nitrogen barely changes after the application of mitigation practices. The same happens for all ES in the Sava basin. In the Adige basin, there is a general reduction of services provision, while in the Ebro there are clear trade-offs between water supply and the other services.

4. Discussion

4.1. Strengths and limitations of the methodology employed

We selected the InVEST tool for quantifying ES, resulting in a successful integration of climate change, LU/LC change and policy change

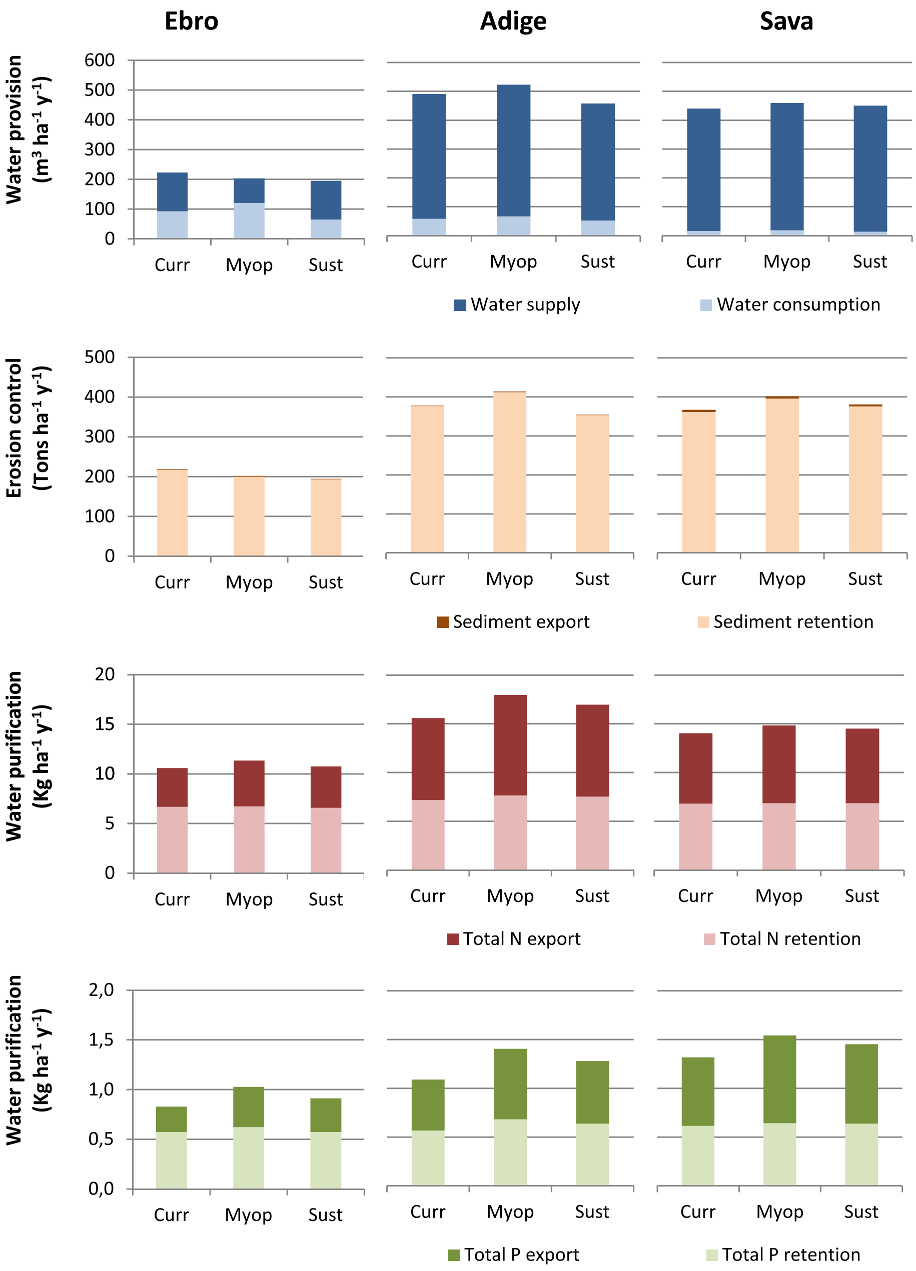


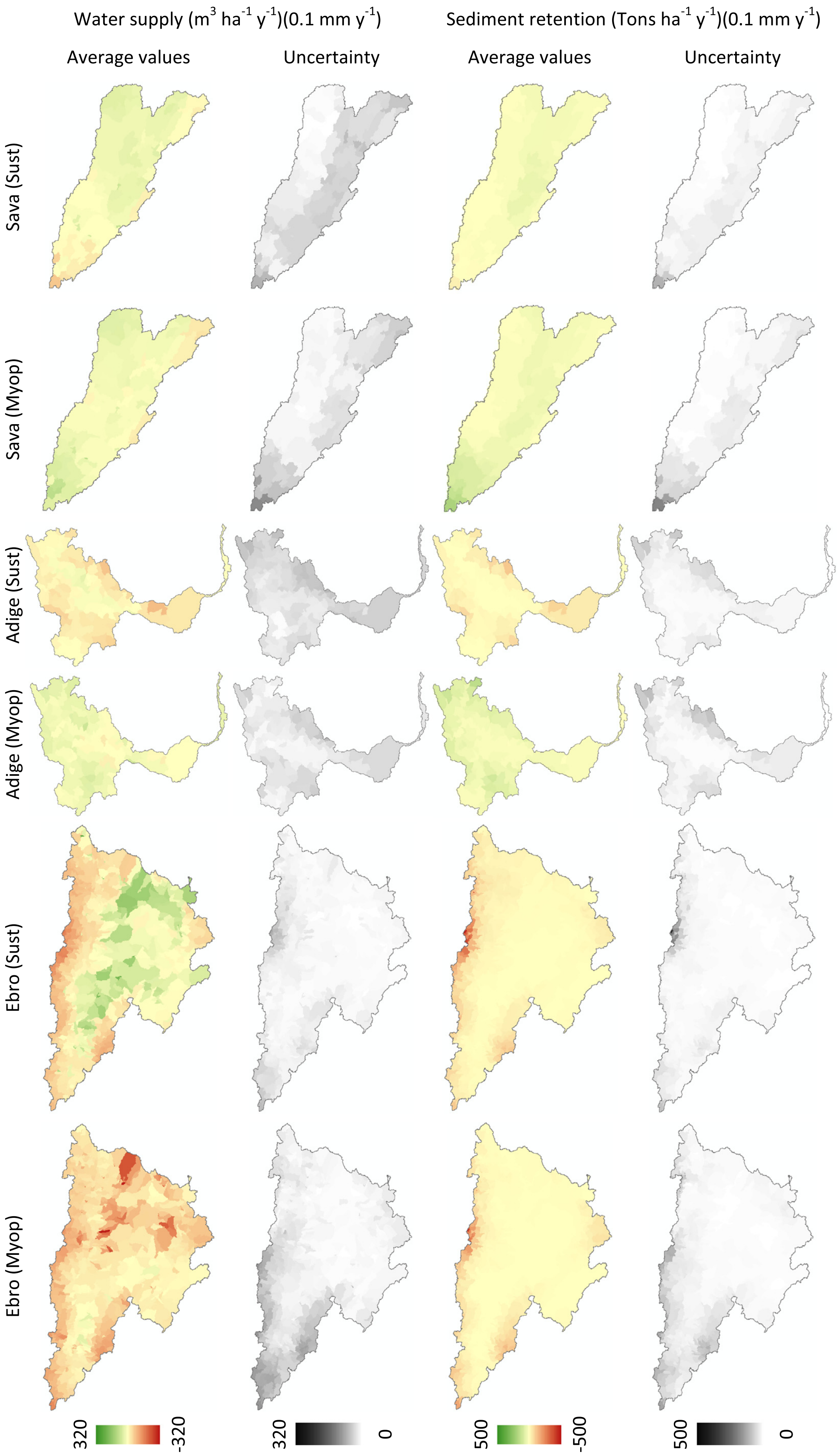
Fig. 5. Basin-scale amount of water, sediment and nutrients potentially generated, divided in exported and retained/consumed, under current, myopic and sustainable conditions.

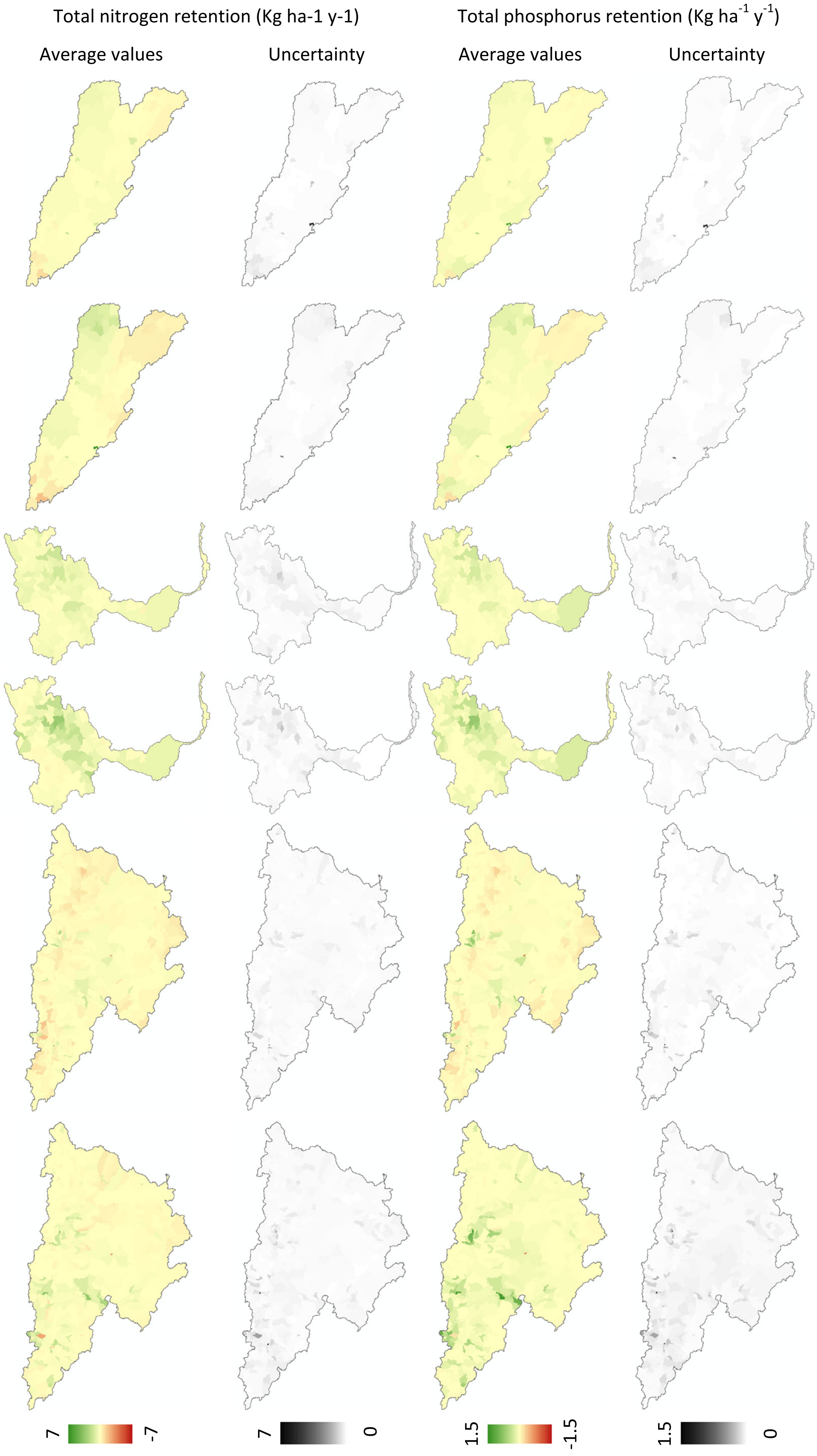
scenarios in selected river basins. However, the freshwater-related InVEST models have limitations. On the one hand, the models run at an annual time-step, and are therefore incapable of capturing the effects of shifting seasonality and extreme climate events, which are projected to increase (EEA, 2017; Harrison et al., 2015). On the other hand, these two models do not account for in-stream processes, and river networks are thus modeled as passive pipes. This simplification has little effect in sediment dynamics at an annual scale, as balances for river networks might be close to neutral. The exceptions are in those river networks with abundant reservoirs, as their effect on sediment retention is high (Vericat and Batalla, 2006). This basically impairs the erosion control model for the Ebro basin, while dams are less dominant in the Sava and Adige. The non-consideration of in-stream processes would have higher effect for nutrients, as both nitrogen and phosphorus are actively attenuated in river networks (Aguilera et al., 2015). However, we observe a good adjustment of the models after calibration (Section 2.4).

Another limitation of our approach is the relatively low number of considered services, although we believe that we can already use this set to investigate actual trade-offs between services and beneficiaries at the sub-basin and basin scale (see Fig. 7). Overall, we believe that the derived information can be utilized to support decision making towards a more inclusive governance of river basins in Southern Europe, accounting for the differences between Mediterranean, Alpine and Continental basins.

4.2. Drivers of change in ecosystem services provision

Precipitation is the main climate driving force for service provision, as water yield is the main determinant of the service water provisioning, and drives nutrient and sediment exports (Fig. 5). Water consumption also plays a major role, especially in the Ebro basin, where it contributes to 50–60% of the variation in water supply. This percentage drops to 11–22% in the Sava and Adige basins, where water consumption is much lower than water yield. Precipitation also leads to the structural impact of soil erosion, together with soil erodibility (Sánchez-Canales et al., 2015). Actually, estimated trends in precipitation are similar to


Water supply (m³ ha⁻¹ y⁻¹)(0.1 mm y⁻¹)
Sediment retention (Tons ha⁻¹ y⁻¹)(0.1 mm y⁻¹)
Average values
Uncertainty
Average values
Uncertainty
Sava (Sust)
Sava (Myop)
Adige (Sust)
Adige (Myop)
Ebro (Sust)
Ebro (Myop)
320
-320
320
0
500
-500
500
0


Total nitrogen retention (Kg ha-1 y-1)
Total phosphorus retention (Kg ha^{-1} y^{-1})
Average values
Uncertainty
Average values
Uncertainty
7
-7
7
0
1.5
-1.5
1.5
0

those in sediment production and retention. However, the small fraction of sediment exported, especially in the *sustainable* storyline, seems to be closely related to the implementation of agricultural practices, including cover-management and support practices.

Effects of LU/LC changes are more complex, since they do not exclusively depend on the expansion/reduction of certain LU/LC categories, but also on their spatial distribution and its relation to other biophysical variables (*e.g.*, climate, altitude, soil erodibility). They have an influence on vulnerability of ES and usually entail trade-offs between services and between beneficiaries (Metzger et al., 2006; Nelson et al., 2009). For instance, the expansion of rainfed agriculture at the expense of deforestation is sometimes seen as a strategy for increasing water yield (Deng et al., 2013), but it can also increase soil erosion when new croplands do not include soil protection practices. The presence or lack of agricultural practices is not as important as the expansion of urban and agricultural areas as drivers of TN and TP production and retention. This is clearer for TP, which is especially concentrated around urban areas such as Vitoria-Gasteiz (Ebro), Trento (Adige), and Zagreb (Sava). TN retention is more homogeneously distributed, presumably due to a higher relevance of diffuse sources respect TP (Grizzetti et al., 2012).

4.3. Impact and mitigation of global change – Horizon 2050

Global and regional projections of climate change foresee the decline of precipitation and increase of water consumption in Southern Europe, especially in the Mediterranean area (Alcamo et al., 2000; Harrison et al., 2015; MA, 2005; Schröter et al., 2005). Our results are fully aligned with these predictions, as precipitation and consumption changes are reflected in huge decreases in the service water provisioning in our Mediterranean basin (*i.e.* Ebro), in contrast to what observed in our Alpine and Continental river basins. This will especially occur under *myopic* conditions in those sub-basins with higher proportion of irrigated and urban land, since these two LU/LC types are expected to increase up to 27% and 211% respectively. According to our *sustainable* storyline, the mitigation actions of decreasing between 5 and 10% the irrigated land, a slowdown of the urban expansion, and an increase of about 30% of the efficiency in irrigation would maintain the same level of water supply. Oppositely, in the Continental areas of Southern Europe such as the Sava, an increase in water scarcity is not foreseen (see Fig. 5). Our results show that the increase of the precipitation and the foreseen transition towards intensive rain-fed agriculture will compensate a substantial growth of urban areas.

The increase of precipitation, especially of heavy rains in autumn and spring shown by Jacob et al. (2014) will not affect water provisioning as much as erosion control. In typical Mediterranean areas such as the Ebro basin, despite the improvement of capacity for erosion control in the last years described by Guerra et al. (2016), our estimations foresee an overall fall on the service provision, especially in the Pyrenees (Figs. 5 and 6). This is similar to what Bangash et al. (2013) reported for the Pyrenean headwaters of the Llobregat river. In the rest of the areas, our model shows that the soil loss will increase or decrease depending on whether the *myopic* or *sustainable* storyline is adopted. Revealed trends towards 2050 in Alpine and Continental areas (*i.e.* Adige and Sava), where sediment erosion and retention increase under *myopic* conditions, can be enhanced if mitigation scenarios take place. Thus, regardless of the preceding climate contexts, our results draw trends in erosion control that will vary from +10/+9% to −6/+4% due to a decrease of potential sediment erosion, mainly driven by precipitation (Fig. 7). In contrast, the sediment export will depend on the capacity of policy-makers to design and enforce regulations of soil management that supports sustainable agricultural practices such as crop rotation or terracing.

Global change effects on nutrient retention are projected to be more homogeneous throughout the study basins, and follow a similar pattern across them (Fig. 6). Thus, in all cases there will be an increase in the TN and TP retention, which is a bit higher in the case of the *myopic* scenario, due to the growth of agricultural and urban areas foreseen in both storylines. These patterns are partly in contrast to the results reported by Seitzinger et al. (2010), who estimate general decreases of TP globally. In fact, our results for TP show more pronounced differences between the *myopic* – increase up to 20% of TP loads – and *sustainable* – increase up to 12% – scenarios (Fig. 7), since TP is more linked to point-source pollution, easier to mitigate with specific policy measures. Of course, strategic plans at the European scale (European Commission, 2014, 2011) can include mitigation policies focused on the improvement of agricultural practices (*e.g.*, the development of buffer strips between croplands and water courses). These plans, together with a rational development of rural and urban areas according to our *sustainable* storyline and with some change in our socio-cultural habits (Vanham and Bidoglio, 2014), would help to foster nutrient retention of ecosystems and increase their socioeconomic value.

5. Concluding remarks

Our predictions indicate that, in Southern Europe, the impact of global change on water provisioning will vary from −37% to +6%, sediment retention from −8% to +9%, and water purification from +1 to +7% for TN and from +4 to +20% for TP. Particularly in Mediterranean areas (*i.e.* Ebro), water provisioning will tremendously decrease, worsening the water scarcity conditions. In Alpine areas (*i.e.* Adige), water provisioning is expected to increase, as well as the sediment export despite increases in the erosion control ES. In Continental areas (*i.e.* Sava), the impact of global change is less severe on all studied freshwater-related services. The implementation of mitigation actions might decrease these impacts considerably, as water provisioning will vary from −6% to +3% in respect to current conditions, sediment retention from −11% to +4%, and water purification from −1 to +5% for TN and from 0% to +12% for TP.

Overall, our findings show the precipitation as one of the main drivers of the considered services. Thus, the reduction of greenhouse gases emissions to ameliorate the effects of climate change is an indispensable measure to avoid the expected reduction of water yield in Mediterranean basins and the soil loss in Alpine areas. However, our results also show the need of restricting the expansion of urban and agricultural areas and implementing sustainable environmental management practices. Those measures would reduce the emissions of nutrients into water bodies and increase the resistance of agricultural land against erosion. Modeling ecosystem services allows predicting the effect of multiple future scenarios on human well-being. The development of integrated models through the combination of multiple strands of knowledge (*e.g.*, environmental and ecological economics) in order to assess the importance of the provision of multiple ecosystem services to the people is a challenge that still needs to be addressed in freshwater ecosystems.

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Fig. 6. Change of service provision represented by the average of the results from the three climate models, and the uncertainty as the standard deviation of these results. These maps illustrate the change in terms of water supply (m^3/ha year), sediment retention (tons/ha year), and total nitrogen and total phosphorus retention (kg/ha year) under myopic (M) and sustainable conditions (S) for our three studied river basins.

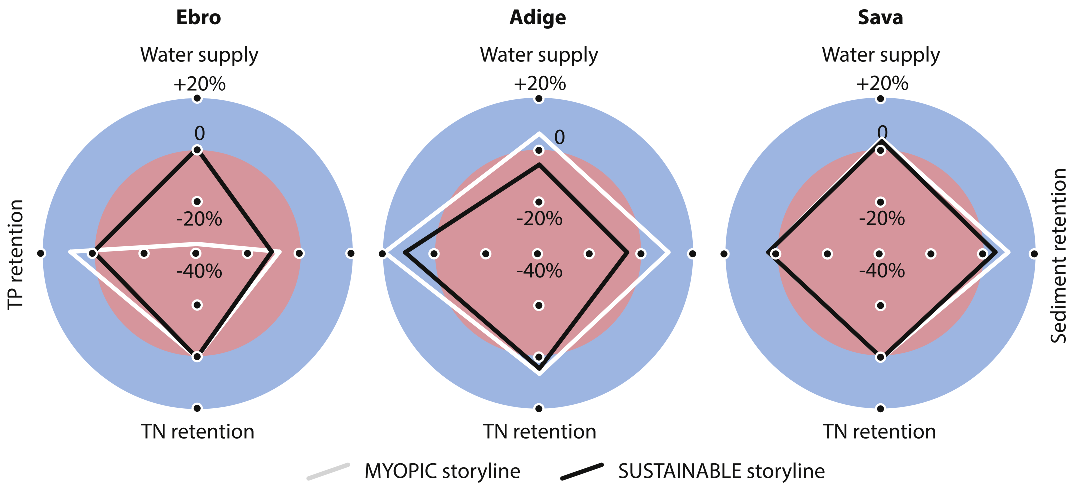

Fig. 7. Trade-offs among ecosystem services at the three studied river basins. Percentages represent the variation of service provision from current to myopic or sustainable future conditions.

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Competing interests statement

Authors have no competing interests to declare.

Appendix A. Input data for ecosystem services modeling

A.1. Input data for the water supply model

Water yield is all water generated within the basin and therefore available to humans, whereas water supply is understood as the flowing water, resulting from the balance between availability and consumption. Water supply is in fact the main outcome of our model, since water consumption is fixed in our scenarios (see Section 2.2.2) and due to the impossibility to distinguish "natural evapotranspiration" from "anthropogenic water consumption" in irrigation fields. The model has been calibrated using the water supply in current conditions, which equals to the observed data in gauging stations (see Section 2.4). Hereafter, we describe each variable and parameter used in the model. More detailed information about the water supply model can be found in the InVEST user guide, Release 2.6.0.

Root restricting layer depth

A GIS raster dataset with an average root restricting layer depth value for each cell. Root restricting layer depth is the soil depth at which root penetration is strongly inhibited because of physical or chemical characteristics. This data comes from the European Soil Portal (Eusoils).

Precipitation

A GIS raster dataset with a non-zero value for average annual precipitation for each cell. The climate models that performed precipitation data under current and future conditions are described in Section 2.2.2 and in Gampe et al. (2016).

Plant available water content

A GIS raster dataset with a plant available water content value (PAWC) for each cell. PAWC fraction is the fraction of water that can be stored in the soil profile that is available for plants' use. This data comes from the European Soil Portal (Eusoils).

Average annual reference evapotranspiration

The reference evapotranspiration (ETo) is calculated by using the equation of Droogers and Allen (2002), which only requires extraterrestrial radiation (Ra) and average temperature (T_{avg}). The equation is the following:

$$ET_0 = 0.0025 \cdot 0.408Ra \cdot (T_{avg} + 16.8) \cdot (T_{max} - T_{min})^{0.5}$$

Ra is calculated from shortwave radiation (Rs) by using the equation found in Allen et al. (1998), being kRs the adjustment coefficient, 0.16 for inland area.

$$Rs = kRs \cdot (T_{max} - T_{min})^{0.5} \cdot Ra$$

The collection of climate data that includes the annual average of daily maximum temperatures (T_{max}), annual average of daily minimum temperatures (T_{min}) and extraterrestrial radiation (Ra) is described in Section 2.2.2 and in Gampe et al. (2016).

Land use/land cover

A GIS raster dataset with thematic information with 6 different types of LULC: 1. Urban areas, 2. non-irrigated agriculture, 3. irrigated agriculture, 4. forest, 5. shrubland and grassland, and 6. water bodies. Row data was obtained from Corine Land Cover 1990 (EEA), and projected to current and future scenarios by modeling, and then reclassified to our 6 categories. More information is given in Section 2.2.2 and in Huber García et al. (2018).

Watersheds and subwatersheds

The watershed corresponds to a shapefile with a single polygon, being the Ebro, Adige and Sava River basins. Each subwatershed or sub-basin corresponds to a water body according to the management plans of the three river basins. They are represented by multiple polygons in a shapefile. The river basins are obtained by hydrological modeling, while the sub-basins are provided by the distinct watershed authorities. In the Adige River basin, some modifications had to be done because polygons did not correspond to actual sub-basins.

Maximum root depth for vegetated land use classes

This number represents the capacity of the plants of each LULC class to deep their roots into the ground. This data comes from the European Soil Portal (Eusoils) and has been adjusted during the calibration process (Section 2.4).

Plant evapotranspiration coefficient for each LULC (K_C)

K_C is a coefficient attributed to each class of LULC and represents the plant physiological characteristics to modify the reference evapotranspiration. This data comes from the European Soil Portal (Eusoils) and has been adjusted during the calibration process (Section 2.4).

Seasonality factor (Zhang factor, Z)

Zhang factor represents the seasonal distribution of precipitation. In this study, Z is taken from Sánchez-Canales et al. (2012) and adjusted during the calibration process (Section 2.4).

Water demand for consumptive uses

Water demand corresponds to the consumptive water use for each LULC class. Information for the Ebro River basin is obtained from the Ebro River Basin Management Plan 2015–2021 (CHE, 2016), for the Adige from the Piano di Gestione dei bacini idrografici delle Alpi Orientali (DIAO, 2010) and for the Sava from the Sava River Basin Management Plan (ISRBC, 2014). Trends for future scenarios were discussed and agreed in participatory workshops (Section 2.2.2).

A.2. Input data for the erosion control model

The ecosystem service erosion control was assessed as sediment retention in terrestrial ecosystems. Results are expressed as mass of sediments per unit of area, in tons·ha^{-1}. The model was calibrated using the sediment export estimates, which equals to sediment in transport (see Section 2.4).

Digital elevation model (DEM)

The DEM is a GIS raster dataset with an elevation value for each cell. The DEM used in this study is obtained from the Consortium for Spatial information (CGIAR-CSI).

Rainfall erosivity index (R)

The rainfall erosivity index (R) is a GIS raster dataset, with an erosivity index value for each cell. This variable depends on the intensity and duration of rainfall in the area of interest. Due to the lack of R maps correspondent to the study area and some evidences that demonstrate the relationship between R and annual precipitation, we have calculated R by using the equation of Renard and Freimund (1994), tested in California (USA). The equation is the following:

$$R = 0.04830 \cdot P^{1.610}, \text{ when } P<850 \text{ mm}$$
$$R = 587.8\text{–}1.219 \cdot P + 0.004105 \cdot P^2, \text{ when } P>850 \text{ mm}$$

being P the annual precipitation.

Soil erodibility index (K)

K is a GIS raster dataset, with a soil erodibility value for each cell. Soil erodibility is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. In this study, K is taken from Panagos et al. (2014) and adjusted during the calibration process (Section 2.4).

Land use/land cover

It is the same data used in the water supply model (Section A.1).

Watersheds and subwatersheds

It is the same data used in the water supply model (Section A.1).

Support practice and cover-management factors

The support practice factor P accounts for the effects of contour plowing, strip-cropping or terracing relative to straight-row farming up and down the slope. The cover-management factor C accounts for the specified crop and management relative to tilled continuous fallow. P and C factors are taken from Sánchez-Canales et al. (2015), adjusted during the calibration process (Section 2.4) and modified in the development of scenarios (Section 2.2.2).

Sediment retention value

The sediment retention value for each LULC class, as an integer percent between zero and 100. This field identifies the capacity of vegetation to retain sediment, as a percentage of the amount of sediment flowing into a cell from upslope. Values of sediment retention are taken from Sánchez-Canales et al. (2015) and adjusted during the calibration process (Section 2.4).

Threshold flow accumulation value

This is the number of upstream cells that must flow into a cell before it is considered part of a stream. With a threshold flow accumulation value of 200, the produced hydrographical maps are adjusted to those provided by the water administration.

Slope threshold

Slope threshold is an integer slope value describing landscape characteristics such as slope management practices including terracing and slope stabilization techniques. In this study, we consider that above 15% of slope farmers start to implement these practices.

A.3. Input data for the water purification model

The ecosystem service water purification was assessed as total nitrogen (TN) and total phosphorus (TP) retention in terrestrial and freshwater ecosystems. Results are expressed as mass of TN and TP retained per unit of area, in kg·ha^{-1}. The model has been calibrated using the TN and TP export estimates, which equals to TN and TP in transport (see Section 2.4).

Digital elevation model (DEM)

It is the same data used in the erosion control model (Section A.2).

Land use/land cover

It is the same data used in the water supply model (Section A.1).

Watersheds and subwatersheds

It is the same data used in the water supply model (Section A.1).

Nutrient loading for each land use

Nutrient loading is a nutrient export coefficient attributed to each LULC class, correspondent to the potential of terrestrial loading to impair water quality. Total nitrogen and phosphorus loads are obtained during the calibration process (Section 2.4).

Vegetation filtering value

This field identifies the capacity of vegetation to retain nutrient, as a percentage of the amount of nutrient flowing into a cell from upslope. Values of vegetation filtering for nitrogen and phosphorus are obtained during the calibration process (Section 2.4) and are used in nitrogen retention and phosphorus retention models separately.

Threshold flow accumulation value

It is the same data used in the erosion control model (Section A.2).

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