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ORIGINAL ARTICLE

Ecosystem services and biodiversity conservation under forestation scenarios: options to improve management in the Vez watershed, NW Portugal

Claudia Carvalho-Santos[1,2] · Rita Sousa-Silva[3] · João Gonçalves[1] · João Pradinho Honrado[1]

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Abstract Ensuring forest protection and the delivery of forest ecosystem services is a central aim of the European Union's biodiversity strategy for 2020. Therefore, accurate modelling and mapping of ecosystem services as well as of biodiversity conservation value is an important asset in support of spatial planning and policy implementation. The objectives of this study were to analyse the provision of the multiple ecosystem services under two forestation scenarios (eucalyptus/pine vs. oak) at the watershed scale and to evaluate their possible trade-offs with the biodiversity conservation value. The Vez watershed, in northwest Portugal, was used as case study area, in which soil and water assessment tool (SWAT) was applied to simulate the provision of hydrological services, biomass and carbon storage services. Biodiversity conservation value was based on nature protection regimes and on expert judgement applied to a land cover map. Results indicated large provision of ecosystem services in the high and low mountain sub-basins. The overall performance for water quantity and timing is better under the shrubland and oak forest scenarios, when compared to the eucalyptus/pine forest scenario, which perform better for flood regulation and erosion control services, especially in the low mountain sub-basin. The current shrubland dominated cover also shows good performance for the control of soil erosion. The oak scenario is the one with less trade-offs between forest services and biodiversity conservation. Results highlight SWAT as an effective tool for modelling and mapping ecosystem services generated at the watershed scale, thereby contributing to improve the options for land management.

Keywords Biodiversity conservation value · Ecosystem services · Forestation scenarios · SWAT · Vez watershed

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✉ Claudia Carvalho-Santos
claudiasantos.malta@gmail.com; c.carvalho.santos@ua.pt

1 Departamento de Biologia, Faculdade de Ciências and CIBIO/InBIO - Centro de Investigação em Biodiversidade e Recursos Genéticos, Universidade do Porto, Campus Agrário Vairão, 4485-661 Vairão, Vila do Conde, Portugal

2 CESAM and Department of Environment and Planning, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal

3 Division of Forest, Nature and Landscape, Department of Earth and Environmental Sciences, KU Leuven (University of Leuven), Celestijnenlaan 200E, Box 2411, 3001 Leuven, Belgium

Introduction

Watersheds are considered primary units for ecosystem services management and planning (Panagopoulos et al. 2011; Cook and Spray 2012; Boithias et al. 2014). Forests are often used as a management strategy to improve ecosystem services provision in many watershed around the world (Quintero et al. 2009; Lele 2009; Onaindia et al. 2013). Financial mechanisms are supporting several forestation actions, either by forest subsidies under agri-environmental schemes (for instance in Europe) or by payments for ecosystem services, mainly applied in tropical countries with successful results on carbon sequestration and water services (Hein et al. 2013).

Furthermore, ensuring forest protection and the delivery of forest ecosystem services is one of the aims inscribed in the EU Biodiversity Strategy to 2020 (EU 2011). However, land cover and land use changes pose major challenges to water resources management and the provision of hydrological services (Kepner et al. 2012; Geneletti 2013). Therefore, understanding the processes behind forest ecosystem services provision as well as their trade-offs with biodiversity conservation is a useful asset to support spatial planning and land management. In addition, several studies have shown that mapping ecosystem services can be highly useful for informing land use and management decisions on trade-offs and win–win situations between ecosystem services (Chan et al. 2006; Egoh et al. 2008; Nelson et al. 2009; Egoh et al. 2009).

Beyond the traditional source of timber and pulp, forests have long been known for providing other services for human well-being, such as carbon sequestration and hydrological services (e.g. water supply and water damage mitigation) (Shvidenko et al. 2005; Brauman et al. 2007; Carvalho-Santos et al. 2014). Although the overall balance of forests on services provision is generally positive, their influence on the hydrological processes is complex and often site specific, requiring daily rainfall-runoff modelling for an accurate evaluation (Calder 2002; Malmer et al. 2010; Crossman et al. 2013). This is particularly important regarding the magnitude of decreasing the total annual water yield in the watershed (Bosch and Hewlett 1982; Brown et al. 2005). In fact, forest plantations are encouraged for carbon sequestration strategies; however, the environmental consequences of forestation are often not fully considered, for instance, on the reduction in annual streamflow (Jackson 2005) and, in some cases, on the reduction in biodiversity (Pawson et al. 2013). Also the natural reforestation that is happening in some mountains around the world resulted from agricultural abandonment may change the traditional pattern of biodiversity and landscape values (Sitzia et al. 2010).

After acknowledging the role of forests on hydrological services provision in a given watershed, further analysis can be performed to evaluate the provision of other services (Logsdon and Chaubey 2013). Soil and water assessment tool (SWAT) is a hydrological modelling tool applied worldwide for evaluating the hydrological regime in a watershed (Arnold et al. 1998). Ultimately, the SWAT outputs can also be used to model the provision of other non-hydrological services, such as carbon sequestration and timber production (Logsdon and Chaubey 2013). In addition, different planning or management options affecting landscape composition and configuration may induce trade-offs between the provision of multiple ecosystem services and biodiversity conservation (Chisholm 2010; Villamagna et al. 2013; Wang and Fu 2013). In this context, modelling and mapping those trade-offs is an important step forward in order to create sustainable options for forest management (Ninan and Inoue 2013; Wang and Fu 2013; Onaindia et al. 2013).

The purpose of this study is to map the provision of multiple ecosystem services at the watershed level, using SWAT as the primary modelling tool, and to evaluate their possible trade-offs with biodiversity conservation based on habitat value and protection regimes. Two distinct forestation scenarios of common tree species in the region were compared to the present condition dominated by shrubland. One scenario is eucalypts/pine, representing a further expansion of two evergreen tree species that are widely planted for pulp or timber in the region. The other scenario is European oak, representing deciduous forests dominated by native tree species. These forestation scenarios do not consider management regimes.

The watershed level of analysis is particularly interesting here, because it constitutes the base unit where all the processes operate, namely the flow of water (Savenije and Van der Zaag 2008). The research was developed following a four-stage workflow. In a first stage, the modelling and mapping of the ecosystem services and biodiversity conservation was developed. Subsequently, the spatial distribution of the ecosystem services and biodiversity conservation value was analysed under the forestation scenarios previously described. Then, a correlation analysis was performed to assess the spatial conflicts or synergies between the provision of ecosystem services and biodiversity conservation. Finally, the results were analysed and discussed in a governance framework, particularly to support land management options for improving the decision-making processes for ecosystem services provision and biodiversity protection.

Materials and methods

Study area

The selected study area was the watershed of river Vez, a medium-sized watershed (252 km^2) located in the Soajo and Peneda mountains, northwest Portugal (Fig. 1). The Vez is one of the main tributaries of river Lima, a major river in northwest Iberian Peninsula. Annual precipitation in the watershed varies from 1000 mm/year in lowlands up to 3000 mm/year in highlands (wet years), mainly concentrated in the autumn and winter months (October–March). Topography is complex with elevation ranging from 30 to 1400 m and slopes above 25 %, shaping 58 % of the watershed. Granites and locally schist characterize the regional geology, with five major soil types occurring in the watershed: Humic Regosols (67 %) and Leptosols (9 %) prevail in highlands; Dystric Antrosols (22 %), Fluvisols (1 %) and Urban (0.56 %) in lowlands.

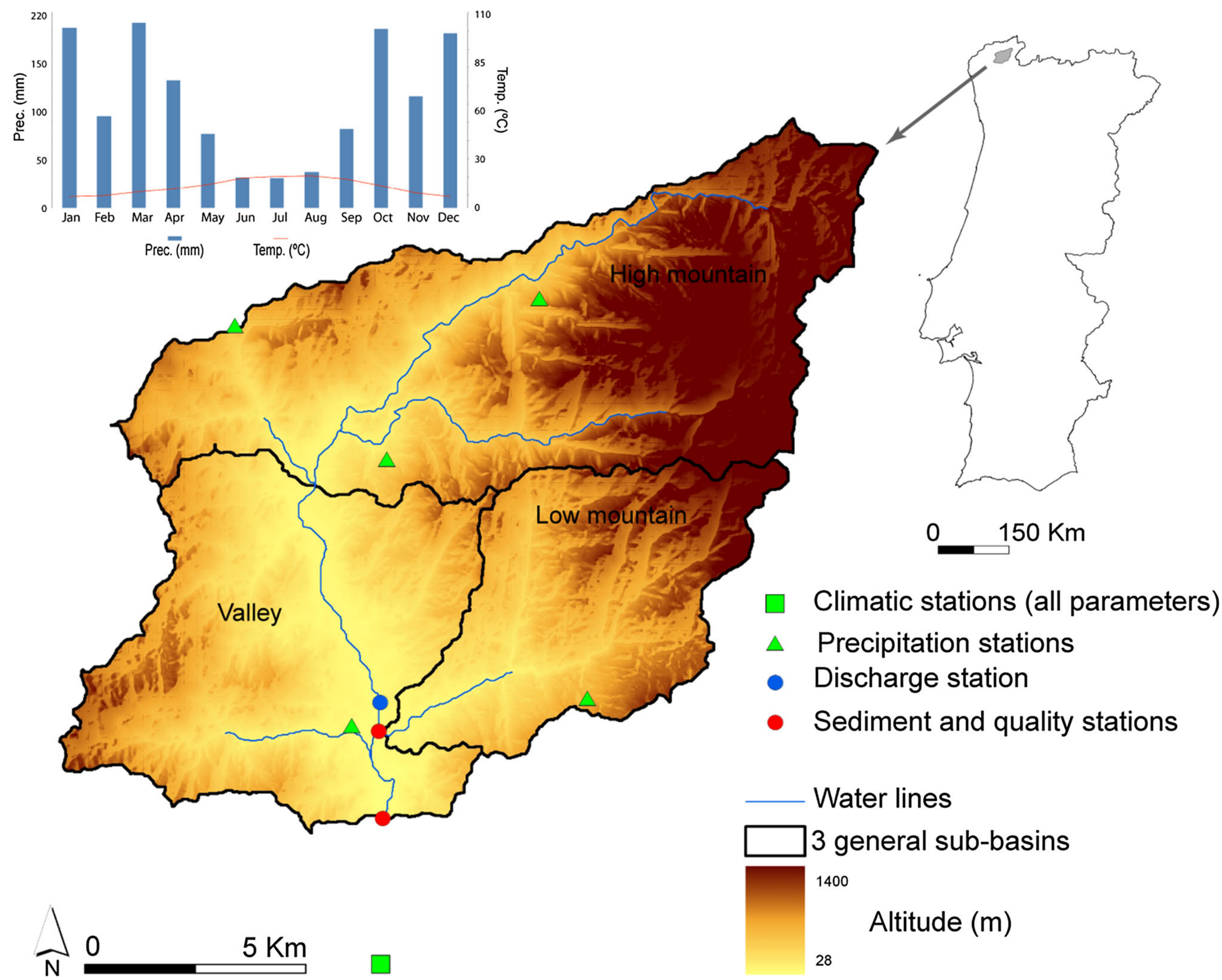


Fig. 1 Study area, Vez watershed, with the location of observed data stations used to set up SWAT model, the range of altitude and a climate plot for monthly precipitation and temperature (yearly average values 1999–2008)

Regarding land cover/use, open areas of bare rock and heath occupy the top of the mountains, shrubland with scattered woodland areas occupies the highlands, and agricultural land associated with forest areas of European oak (*Quercus robur*), Maritime pine (*Pinus pinaster*) and Eucalypts *(Eucalyptus globulus)* is common in lowlands (Fig. 2a). Approximately one-third of the watershed (the mountainous areas and the river Vez itself) is included in the EU Natura 2000 network (EC 2000), and the upper part of the watershed is further included in the Peneda-Gerês National Park (Fig. 2b). These areas are very important for biodiversity conservation, with the presence of some charismatic species such as the Iberian wolf (*Canis lupus signatus*), Roe deer (*Capreolus capreolus*) and several birds of prey. Phytogeographically the region represents the southwest limit of the Eurosiberian (Atlantic) region, with sub-Mediterranean deciduous oak forests as the potential vegetation type (Costa et al. 1998; Capelo et al. 2007).

Recently, there is a plan for construction of a mini-dam in the upper part of the watershed, which has been followed by protests from the inhabitants and nature organizations that want to preserve the landscape and biodiversity values of Vez watershed.

Assessment of ecosystem services provision

Hydrological services

Hydrological services encompass the benefits for people involving water in the ecosystems (Brauman et al. 2007). Following the conceptualization used in a previous study (Carvalho-Santos et al. 2014), hydrological services are: (a) the provision of water supply, in the dimensions of

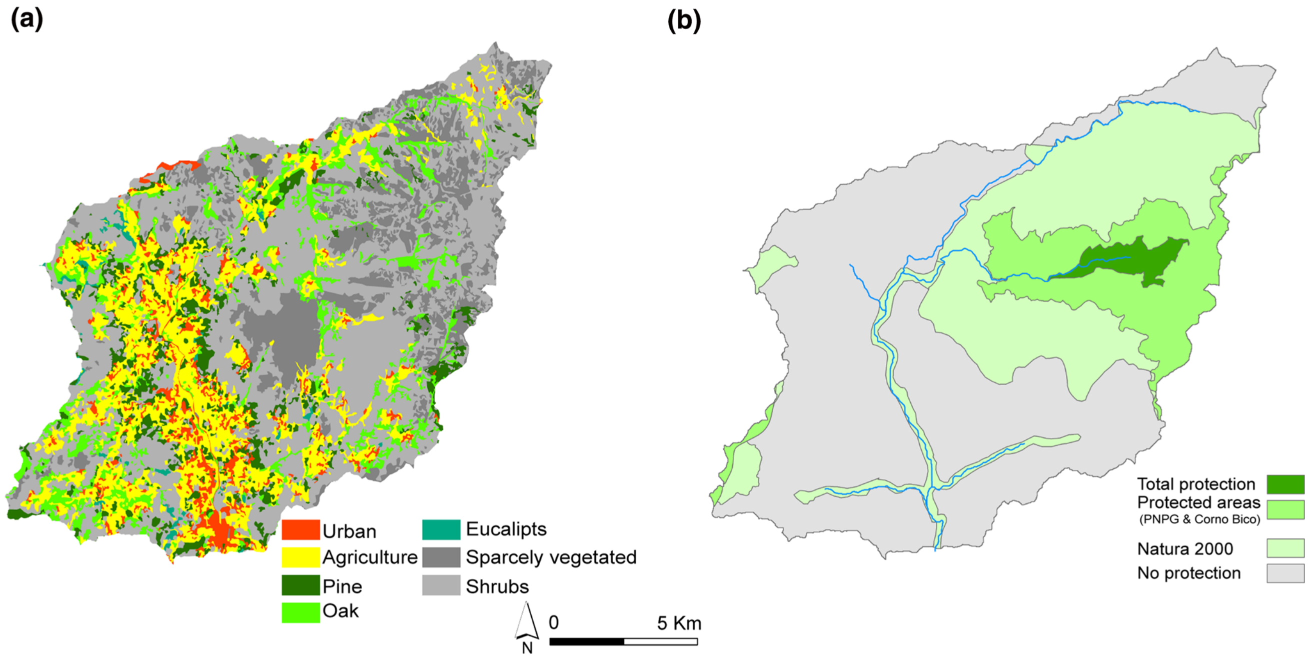


Fig. 2 **a** Land cover map of Vez watershed (year 2006), **b** Biodiversity protection levels in the Vez watershed

quantity (total annual water yield), timing (seasonal distribution of the flows) and quality (removal of pollutants and trapping sediments); (b) and water damage mitigation (flood mitigation and soil erosion control). They were considered for modelling and mapping in the Vez watershed (Table 1). The accuracy of the hydrological services modelling improves when using daily runoff models, such as SWAT (Vigerstol and Aukema 2011; Crossman et al. 2013). SWAT is a deterministic, physically based and semi-distributed hydrological model used successfully around the world (Arnold and Fohrer 2005). The watershed is first divided into sub-basins, and after each sub-basin is divided into HRUs (hydrologic response units), corresponding to polygons of varying size, but with the same land cover, soil type and slope class (Gassman et al. 2007). These units are spatially explicit and provide different contributions to the provision of hydrological services. However, SWAT is not a completely distributed model,

Table 1 SWAT indicators for ecosystem services provision analysis used in the Vez watershed

Ecosystem Service	SWAT outputs (HRU)	Indicators for service provision (rationale)
Water supply		
Quantity	WYLD—Water yield (mm/year)	Contribution of each HRU in delivering water for the stream
Timing	SW_END—Soil water content (mm/year)	Amount of water in the soil profile, indicating soil storing capacity and water available for use. Is an indication of seasonality of flows and drought protection
Quality	Total nitrogen (*N* kg/ha year) (sum of: ORGN; NSURQ; NLATQ; NO3GW)	The lower the exports, the higher the contribution to the water quality (1/total *N*)
Water damage mitigation		
Soil erosion control	SYLD—sediment exports (t/ha year)	The higher the exports, the lower the contribution to the erosion control service (1/SYLD)
Flood regulation	SURQ_GEN—surface runoff (mm/year)	Flash floods are mainly generated by the surface runoff. The lower the surface runoff, the higher the contribution (1/SURQ_GEN)
Biomass production	BIOM—total biomass (t/ha year)	Aboveground and roots biomass reported as dry weight
Carbon storage (climate regulation)	Fraction of total biomass (tC/ha year)	Carbon stored in vegetation as a fraction of 50 % of dry matter

meaning that inside a given sub-basin, such unique combination of land cover, soil type and slope (HRU) can be found in different non-adjacent places. The hydrological contribution of the several areas belonging to a given HRU is considered the same. The use of HRUs and the analysis of their contribution for services provision converge with the ecosystem services providing (Esp) units concept used for ecosystem services analysis and evaluations (Rounsevell et al. 2010).

SWAT was recently applied in the Vez watershed (see Carvalho-Santos et al. 2015) for a more detailed description of the model setup and parameterization). The watershed was divided into 10 sub-basins with a total of 500 HRUs (320 HRUs for oak and 320 for eucalyptus/pine scenario), based on land cover (Fig. 2a), soil types (described in "Study area" section) and slope classes (three classes: 0–10, 10–25 and >25 %). SWAT was forced with daily climatic data for the watershed (precipitation, maximum and minimum temperature, solar radiation, relative humidity and wind speed) (Appendix A). As precipitation is the most important parameter for hydrological modelling, five climatic stations inside the basin were used for a better spatial coverage (Fig. 1). Daily gaps were filled based on regression analysis with ten surrounding stations (Carvalho-Santos et al. 2015). Finally, a calibration exercise (using daily climatic data from 1999 to 2008) was performed, in which some parameters (related to streamflow, groundwater, soil erosion, vegetation) were adjusted in order to achieve the best approximation to the reality. Calibration was performed against daily observed discharge (2003–2008) and monthly observed sediments and nitrates (Appendix B and C). An independent simulation against discharge (1984–1989) was done for validation using the same parameters from the calibration exercise. The absence of sediments and nitrate data for this period avoided validation for these parameters (Carvalho-Santos et al. 2015). A good agreement between model predictions and field observations related with discharge was obtained for calibration and validation exercises (Appendix B). Model performance was considered good according to a Nash–Sutcliffe efficiency (NSE) of 0.76 and a percentage of bias (PBIAS) of -15 % for calibration (Moriasi et al. 2007). Validation performance was considered satisfactory (NSE = 0.38 and PBIAS = 6 %). The calibration between observed sediments and nitrates exports with the SWAT simulated values can be considered adequate given the limitations of observed data (Appendix C).

The model outputs were analysed at the HRU and sub-basin level and adapted to each service provision (Table 1). Three major sub-basins were used here to facilitate the spatial description of the service provision inside the watershed: high mountain, low mountain and valley (Fig. 1). As the outputs from water quality, soil erosion control and flood mitigation services do not have a direct reading (i.e. higher values correspond to lower contributions for service provision), there are no units in the respective maps in Fig. 5. Thus, the values of each HRU were subjected of a ration of 1, allowing the HRU with more sediment exports, for instance, to have the lowest value for the erosion control service, showing the contribution for the service provision.

Biomass production and carbon storage

Biomass production is a proxy indicator for the service food and timber production, according to the underlying land cover (i.e. timber production in forest patches, pasture for grazing in shrublands patches and food/fodder in agricultural land). Carbon storage is a proxy indicator of the climate regulation service, considering that forests and other stable vegetation types (e.g. shrublands) store, on average, 50 % of their dry biomass as carbon (Paladinic et al. 2009; Olschewski et al. 2010). Biomass is thus the baseline indicator to calculate carbon storage and used in many studies (Nelson et al. 2009; Crossman et al. 2013). SWAT has a vegetation growth model incorporated, which interacts with evapotranspiration considering plant phenology, leaf growth and light interception (based on observed solar radiation) to produce biomass during the simulation period (Neitsch et al. 2011). This was calibrated for each land cover using parameters that were adjusted based in the literature (Appendix D). In this study, the SWAT biomass output (t/ha) at the HRU level was used to map the biomass production service, which serves as proxy indicator for pulp production in the eucalypt patches, wood for pine and oak patches, and fodder in agricultural and shrubland patches.

Carbon storage (tC/ha) was calculated as a fraction of 0.50 of the SWAT biomass output for vegetated land cover classes (forest, shrub and agriculture) (Olschewski et al. 2010). In the literature, there are different carbon fractions reported for forest types (e.g. pine = 0.51; eucalyptus and oak = 0.48) (Pereira et al. 2010). Nevertheless, as the difference is negligible and for simplicity, the fraction of 0.50 was applied to all land cover types. Only the carbon stored in the vegetation (above and below ground pools) was considered, since there were no available data to calculate the other carbon pools (e.g. soil organic matter). Forests are known for being important ecosystems for carbon sink, since they maintain a growing biomass for many decades, if no disturbance occurs (deforestation, fire, pests) (Shvidenko et al. 2005; Deal et al. 2012). Carbon fraction in the biomass varies according to the environmental conditions of each region and the different tree species and increases with the age of trees or stands. In this study, the biomass value used was an annual average for the simulation period.

Assessment of biodiversity conservation value

Biodiversity enhances the ability of ecosystems to maintain multiple functions, such as carbon storage, productivity or pollination (Elmqvist et al. 2009; EASAC 2009; Maestre et al. 2012). However, different planning options may induce trade-offs or synergies between the provision of goods and services, and the conservation of biodiversity (Egoh et al. 2009; Onaindia et al. 2013). Therefore, an evaluation of multiple ecosystem services is most relevant if considered together with the mapping of biodiversity conservation value (Nelson et al. 2009). In this study, the biodiversity conservation value was computed based on the average intrinsic value of each land cover/habitat type and on the presence of several nature conservation or protection statutes. The conservation value attributed to each land cover type was based on a previous study in the region (Honrado and Vieira 2009), a mountain area with similar characteristics to the Vez watershed. A total biodiversity conservation value was calculated for each land cover class, resulting from the sum of the values for the conservation of several terrestrial biodiversity groups (see Appendix E). These values ranged from 1 (indicating low conservation value) to 5 (indicating high value) and were attributed by regional experts of each taxonomic group, considering previous studies, GIS analysis of pre-existing data and the relevant literature.

Finally, the average intrinsic value for biodiversity conservation of each land cover class was weighed according to a factor of nature protection (Fig. 2b). Weighting values ranged from 1 (no protection regime) to 2 (according to the increasing level of protection) (Appendix E). Protection classes were defined as follows: (1) areas included in the Natura 2000 network (factor 1.5); (2) areas of Natura 2000 belonging also to the national network of protected areas (Peneda-Gerês National Park and Corno do Bico Protected Landscape) (factor 1.75); and (3) areas classified as of total protection inside the National Park (factor 2).

Spatial analysis

Since forestation actions are known as an effective management option to improve ecosystem services in general, two forestation scenarios (eucalyptus/pine and oak) were simulated in SWAT and compared with the current land cover of shrubland dominated (Table 2). The scenarios keep the urban, agricultural (CORN) and sparsely vegetated (BSVG) areas as constant. What changes is the shrubland area, which is occupied by eucalypts and pines in 63.5 % of the area (two tree species that are widely planted in the region as monocultures or mixed stands for pulp or timber production). In the case of the oak scenario, the shrubland area is occupied in 63.5 % of the area by the European oak (mainly as a result of spontaneous encroachment of this native tree species after abandonment or farming and grazing activities). The maps for these two scenarios were obtained by changing the attributes of the land cover map of the year 2006 (SIGN II 2008), replacing the shrubland areas by either eucalypts/pine or oak. The modelling and mapping exercise was developed as described in the previous sections using the SWAT hydrological model with ArcSWAT interface (Olivera et al. 2006). The maps for each service under the different scenarios were produced at the HRU (polygons of different sizes corresponding of units with the same land cover, soil and slope) and classified in five classes using the same ranking for each service. The maps considered the contribution of each HRU for a given service provision (Fig. 5). Complementary, an analysis of a statistical measure (average of the distribution) was performed to evaluate which scenario is recommended for a given service provision. The statistical calculations for the spatial analysis were performed in R statistical software (R Core Team 2014). For comparing the seven ecosystem services in each scenario (considering the whole watershed), the average values were weighted by the area of each HRU. This was accomplished by multiplying ES values by the log10 of the respective HRU area, thus weighting the area effect. The logarithm transformation of HRU areas allowed standardizing the effect of very large areas. The plots in Fig. 5 describe, in spatial and statistical terms (plots), which scenario performs better for the respective service provision.

Finally, to assess the spatial trade-offs between biodiversity conservation and ecosystem services provision, under different land cover scenarios, a statistical correlation was calculated, using the Spearman rank correlation (Table 3) (Maritz 1995). This nonparametric measure of statistical dependence between two variables was used here to inspect positive or negative correlations in the spatial intersection of biodiversity conservation value and ecosystem services provision. The biodiversity conservation value was computed as described in "Assessment of biodiversity conservation value" section, considering the land cover map for each scenario (Fig. 4). Then, a spatial interception of the biodiversity value map with the respective ecosystem service map, at the HRU level, was done. Finally, the correlation for all the services and scenarios was done in R statistical software.

Table 2 Percentage of land cover types in each scenario simulated in SWAT for the period 2003–2008

% Land cover	Shrub (current)	Eucalyptus/pine intensification	Oak conservation
CORN	18.7	18.7	18.7
EUCL/PINE	8	**63.5**	–
OAK	8.7	–	**63.5**
BSVG	13.8	13.8	13.8
MIGS	**47.2**	–	–
URLD	4	4	4

Urban low density (URLD), CORN and BSVG (sparsely vegetated) areas are constant in all scenarios. Numbers in bold show the most representative land cover types for each scenario

Table 3 Spearman's correlation test between the services provision and biodiversity value, in the three different land cover scenarios (the comparison for each land cover scenario was made with the respective map of biodiversity value—Fig. 4)

Services	Shrub	Eucalyptus/pine	Oak
W_quantity	**0.40**	**0.58**	−0.08 (ns)
W_timing	−0.02 (ns)	0.01 (ns)	−0.16 ***
W_quality	−0.17	**−0.26**	**0.36**
S_erosion_contol	−0.09 *	**−0.40**	**0.53**
Flood_reg	**−0.24**	**−0.34**	0.10 *
Biomass	0.06 (ns)	0.004 (ns)	**0.42**
C_storage	0.06 (ns)	0.004 (ns)	**0.42**

All the analysis were statistically significant p value < 0.0001, with exception of the ones identified with *** $p \leq 0.001$; * $p \leq 0.05$ and *ns*, non-significant. In bold are the strong correlations

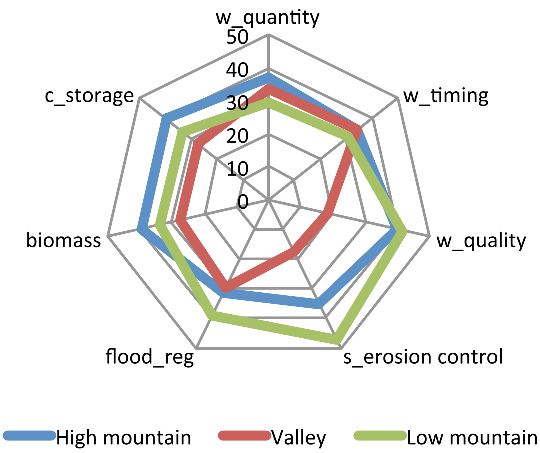


Fig. 3 Ecosystem services provision by the major sub-basins (% of the service in the whole watershed). The values were weighted by the area of each HRU and by the area of the basin

Results

Current patterns of ecosystem services provision

Under current land cover (shrubland dominant), the valley sub-basin is the one with the lowest contribution for ecosystem services provision in the Vez watershed, except for water quantity (Fig. 3). In the valley, the low provision of soil erosion control and water quality services is related to the high concentration of agricultural land in this part of the watershed. The high mountain is the sub-basin with the most balanced provision for all the services (Fig. 3), yielding the highest contribution for the provision of water quantity, biomass and carbon storage (these two last services have the same pattern of provision because the SWAT indicator is the same, BIOM—see Table 1). Given the high humidity in the upper Vez watershed, large and dense shrubland areas (scrub and heath) occupy the high mountain areas, with high potential for grazing biomass production and carbon storage. Here, the high water quantity is associated with the high rates of precipitation and the lower water demand of shrubs compared with other land cover types, as well as bare rock areas associated with thin soils. In turn, the low mountain sub-basin has the best performance for erosion control, flood regulation and water quality services provision (Fig. 3). This area includes patches of oak and pine forest associated with more gentle slopes, which decreases surface runoff therefore, contributing to the erosion control and flood regulation services.

Current patterns of biodiversity conservation value

Regarding the current distribution of biodiversity conservation value, the higher values are located in the high mountain sub-basin, which largely coincides with the Natura 2000 network and the National Park (Fig. 4a). The highest values correspond to patches of European oak forest in the total protection zone (Figs. 2b, 4a). The low mountain sub-basin presents a fair distribution of low and high values, with the latter coinciding with Natura 2000 areas. The valley sub-basin, where the majority of the villages and agricultural areas are located, presents the lowest biodiversity conservation value overall. An exception occurs in the extreme southwest where there is some coverage of common oak woodland, partially included in Natura 2000 areas.

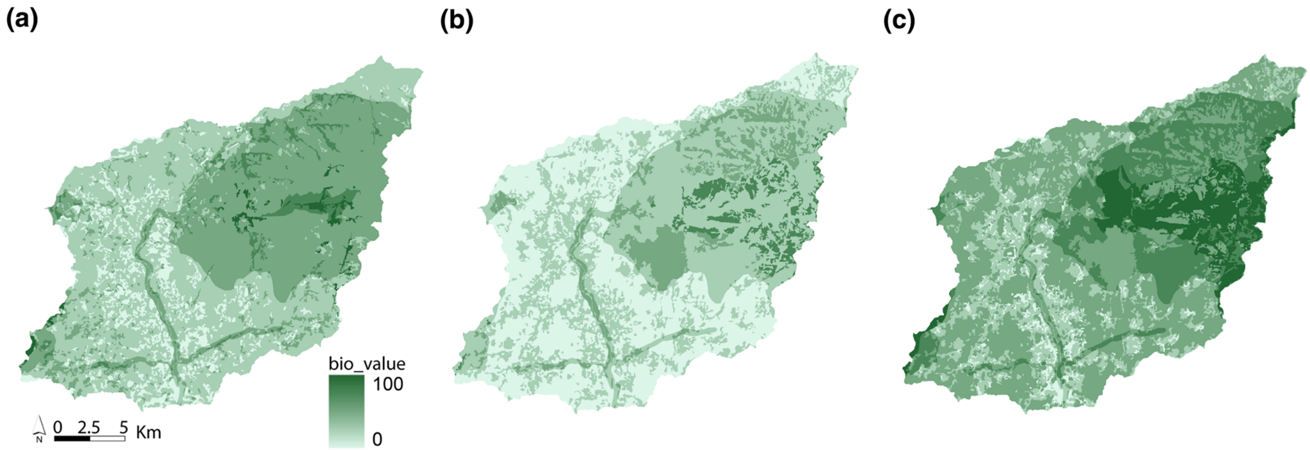


Fig. 4 Spatial distribution of biodiversity conservation value in the Vez watershed, **a** current pattern of shrubland dominated, **b** future pattern under eucalyptus/pine scenario, **c** future pattern under oak scenario

Ecosystem services and biodiversity conservation value under land cover change scenarios

The application of land cover scenarios in the Vez watershed affects the several services differently (Fig. 5). The current shrubland situation and oak scenario would have the best performance for the water supply service (quantity, timing and quality) as well as for biomass production and carbon storage. Conversely, the eucalypt/pine scenario would perform better for the water mitigation services, namely soil erosion control and flood regulation.

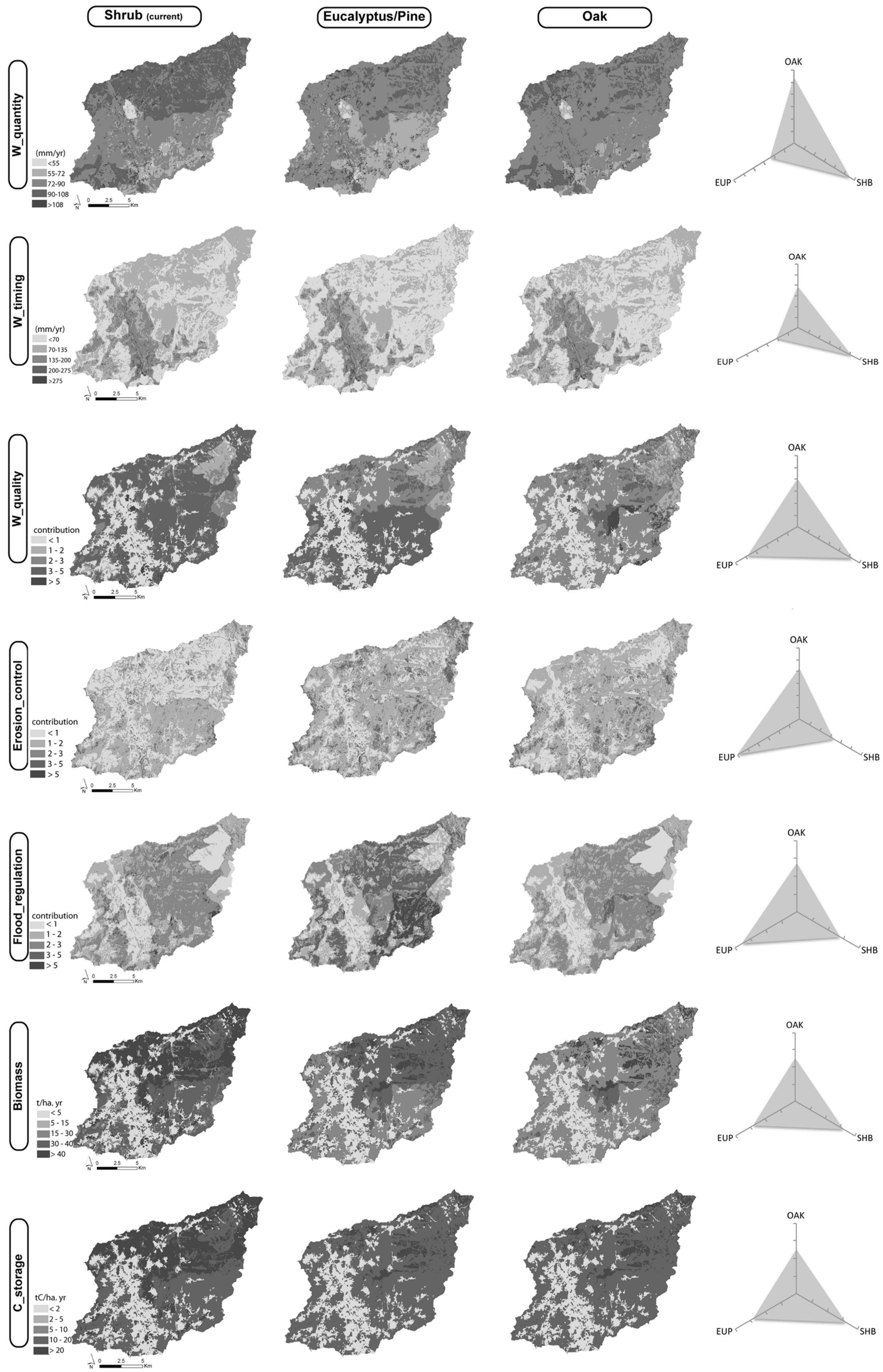
The conservation value for biodiversity in the Vez watershed would decrease dramatically under the eucalyptus/pine scenario (Fig. 4b), but it would increase in the oak scenario (Fig. 4c) when compared to the current shrubland dominated landscape (Fig. 4a). In the latter, conservation value has a negative or low spatial correlation with most ecosystem services, with water quantity as the only exception with a high correlation (Table 3). Oak scenario presented the strongest positive correlations with biodiversity conservation value, except for water quantity and timing. Conversely, implementing the eucalyptus/pine scenario would hold advantages for several services (such as erosion control or flood regulation), but at the expense of strong negative effects on biodiversity conservation (Fig. 4, Table 3).

Fig. 5 Maps of the ecosystem services provision simulated in SWAT ▶ at the HRU level, for the three land cover scenarios in the Vez watershed. Water quantity—water yield (mm/year); water timing—soil water content (mm/year); water quality, soil erosion control and flood mitigation—contribution for the service provision: <1 very low; 1–2 low; 2–3 medium; 3–4 high; >very high; biomass—total biomass (t/ha year); carbon storage—fraction of biomass (tC/ha year). *Plots* show the performance for the provision of each ecosystem service under different land cover scenarios, based on the average values for the basin, weighted by the area of each HRU (plots: SHB—shrubland; OAK—oak; EUP—eucalyptus/pine)

Discussion

Land cover and ecosystem services in the Vez watershed

Mapping ecosystem services at the watershed scale, which includes identifying the areas where the provision of a certain service needs to be improved, is an important communication tool for proper management (Hauck et al. 2013). In the Vez watershed, the high mountain sub-basin is the one where the water quantity service is currently provided at the highest levels (Fig. 5). This pattern is due to the high values of rainfall in the mountain, associated with the low water use of the dominant shrub vegetation and the presence of bare rock and thin soils (Carvalho-Santos et al. 2015). Oak scenario also shows good performance. This is related to oaks being in dormant state during winter months (deciduous trees), decreasing rain interception and transpiration fluxes, allowing water to either infiltrate or run to the rivers as surface runoff (Rosenqvist et al. 2010). In turn, the eucalyptus/pine scenario is the less favourable for the water quantity service (more water use because eucalypts are evergreen trees associated with rapid growth rate). This tendency is observed in several studies, for instance in watersheds of northern Spain, in which exotic species are negatively correlated with water yield (Garmendia et al. 2012). The same pattern applies to the water timing service (seasonality of flows and drought protection), although here the most important explaining factor is the existence of poor and thin soils, associated with decreasing water storage capacity and infiltration rates


Shrub (current)
Eucalyptus/Pine
Oak
W_quantity
(mm/yr)
<55
55-72
72-90
90-108
>108
W_timing
(mm/yr)
<70
70-135
135-200
200-275
>275
W_quality
contribution
< 1
1 - 2
2 - 3
3 - 5
> 5
Erosion_control
Flood_regulation
Biomass
t/ha. yr
< 5
5 - 15
15 - 30
30 - 40
> 40
C_storage
tC/ha. yr
< 2
2 - 5
5 - 10
10 - 20
> 20
OAK
EUP
SHB
0
2.5
5
Km
N

(Li 2004; Ilstedt et al. 2007). The best performance for the water timing takes place at the valley and low mountain sub-basins, due to the presence of deeper soils. In the Vez watershed, water scarcity has not been a problem, even in summer where normally rainfall is scarce and plants need to use water stored in the soil. Nonetheless, different land management strategies should be considered according to their effects on the water quantity and timing especially during the summer months. In fact, an acknowledged problem is the occurrence of floods, associated with intense rain episodes and the rapid flow of water that is typical from mountainous watersheds. In the Vez watershed, the flood regulation service would be best delivered under eucalyptus/pine forestation scenario. Eucalypt and pine species are associated with a reduction in peak flows, mainly due to their rapid growth rates and the ability of their canopy to intercept rainfall during the rainy season (Robinson et al. 2003; Rodriguez-Suarez et al. 2014). The potential for flood regulation in the low mountain sub-basin would be particularly increased under the eucalyptus/pine scenario (Fig. 5), suggesting this scenario to be favoured if the options for management would focus on the regulation of peak flows. On the other hand, under the same scenario, the provision of water quantity in the low mountain would decrease, which should be considered in a context of climate change in the Vez watershed (Carvalho-Santos et al. 2015).

Soil erosion control is performed better under the eucalyptus/pine and the shrubland scenarios (Fig. 5). In general terms, erosion rates appear to be related to the role played by vegetation in protecting the soil surface (Nunes et al. 2011). However, eucalypt and pine stands should not be intensively managed; otherwise, the effect on soil erosion control would be the opposite (Figueiredo et al. 2011). This service was predicted to be less important under oak forestation scenario, since deciduous trees do not protect the soil effectively during the rainy season (Fig. 5). It should, however, be noted that SWAT does not consider the structure of understory vegetation, which is usually more complex in native woodlands than in managed planted stands (Nunes et al. 2011). In all cases, fires are an underlying cause of soil erosion and degradation in the Mediterranean region, especially in Portugal where erosion by fires has been a major concern in the last decades (Shakesby 2011; García-Ruiz et al. 2013). Fires in Portugal are prone to occur particularly in pine, eucalypt and shrubland areas (Barros and Pereira 2014).

Biomass production and carbon storage were predicted as slightly higher under the current shurbland dominated cover (Fig. 5). However, the type of biomass from forest stands has a higher economic value (e.g. pulp from eucalypt, timber and wood from pines and oaks), which should be regarded as a good asset to improve the landowners' income. Usually, the carbon storage service is more relevant in areas with stable vegetation (e.g. forests) and when this type of vegetation is not used for fuel (Chan et al. 2006). In addition, the long-term carbon sequestration potential of forests can be destroyed by fires, an important carbon emissions component, due to be influenced by climate change (Sommers et al. 2014). In the Vez watershed, fires have been a constant source of disturbance causing degradation processes, as revealed by the extent of low vegetation areas (scrub and heath), impacting not only the resilience of the biotic communities, but also the carbon storage and the overall provision of ecosystem services (Proença et al. 2010b).

A flow of ecosystem services provision can be observed in the Vez watershed, especially in the case of hydrological services, since the high and low mountains are the sub-basins where these ecosystem services are best delivered, whereas most of the corresponding benefits are actually felt downstream in the valley. This is in line with the traditional ecosystem services provision knowledge, in which the production of services can be considered directional, e.g. the regulation of water by forests in the upstream mountains in a watershed resulting in a benefit downstream (Fisher et al. 2009).

Trade-offs with biodiversity conservation and implications for land management

Oak forestation would be the most favourable scenario for biodiversity conservation value, whereas eucalyptus/pine the least favourable (Fig. 4). Eucalypt is an exotic tree species widely planted in Portugal for pulp production, and usually associated with low levels of biodiversity in their stands when compared to native stands (Kardell et al. 1986; Brockerhoff et al. 2013). Plant and bird diversity in the Vez watershed region is highest in oak forests, followed by pine stands and far less in eucalypt plantations (Proença et al. 2010a). This is particularly important inside protected areas, where eucalypt stands, even if contributing to ecosystem services provision, have negative effects on biodiversity, as emphasized in a recent study in Spain (Onaindia et al. 2013).

In our hypothetical eucalyptus/pine forestation scenario for the majority of the watershed, a large proportion of eucalypts and pines would be located inside protected areas. Here, the level of naturalness should be maintained, investing in measures for natural regeneration of oak and avoiding ecosystem degradation related with fires and invasive species (Proença et al. 2010a). Forest certification requiring the management for biodiversity conservation objectives would also be an important action to promote native forests (Thompson et al. 2011).

Based on the patterns, flows and dynamics of ecosystem services as well as their trade-offs with biodiversity conservation, some recommendations may be suggested regarding the effects of different land cover scenarios on the ecosystem services provision. Considering that flood regulation was identified as a key issue in the watershed, which can be aggravated in the context of climate change (Carvalho-Santos et al. 2015), the eucalyptus/pine scenario would appear to be the best option for future management strategies. However, there are three major disadvantages that should be considered: (1) the trade-offs with other services, namely water timing (considered here as the maintenance of summer low flows), which is better provided under the oak and shrubland scenarios; (2) the fire proneness of eucalypt and pine forests (Barros and Pereira 2014; Fernandes 2013), especially during summer, and the consequences for soil erosion and landscape degradation; and (3) the trade-offs with biodiversity conservation, mainly inside protected areas but also across the watershed. For the latter, conservation strategies considering incentives for the use of native species, especially inside protected areas, would be a good option to promote biodiversity and ecosystem services (Proença et al. 2010a; Onaindia et al. 2013). Fire smart-management interventions on vegetation allowing the reduction of flammability and increased resilience (e.g. using native species) in relation to the fire regime can be pointed as efficient strategies (Fernandes 2013). Considering the trade-offs related to the provision of other ecosystem services, spatial optimization simulations could be developed, in which eucalypts and pines can be assigned to areas where flood risk mitigation is strategically more effective or highest priority. Also a mosaic of different age stands can improve water yield provision. Other types of forests could be assigned to different areas in order to improve ecosystem services, for instance oaks in protected mountain areas for water timing with increased positive feedbacks for biodiversity conservation. The creation of mosaics of native trees well connected through corridors will improve the resilience and connectivity at a landscape scale (Brockerhoff et al. 2013). This would also contribute to maintain and promote landscape diversity across the watershed, which is known for sustain social–ecological resilience and adaptive capacity in a changing world (Chapin et al. 2010).

SWAT as an effective tool for mapping ecosystem services

The inclusion of additional ecosystem services in our framework using SWAT is an added value for understanding the processes and services provision using a daily runoff model. Similar efforts have been previously developed (Logsdon and Chaubey 2013). However, to our knowledge this is the first time a special emphasis is placed on analysing ecosystem service dynamics under different forestation scenarios, while also considering spatial trade-offs with biodiversity conservation value. Based on our results, and further supported by previous studies, we advocate SWAT as an important tool for modelling and mapping ecosystem services related to the biophysical processes at the watershed scale, when accurately calibrated (Carvalho-Santos et al. 2015). Although it is known as a tool without a central focus on ecosystem services modelling due to a primary module on the hydrological processes and the absence of the demand side of ecosystem service modelling (Vigerstol and Aukema 2011; Bagstad et al. 2013), it can be used effectively for the biophysical modelling of all hydrological services and as a complementary tool in more comprehensive modelling approaches.

Future land cover/use policies should consider a holistic perspective as the one presented here, not only considering the hydrological/ecological processes with their related implications for ecosystem services provision, but also considering the spatial conflicts and synergies with biodiversity conservation value. In this regard, a current limitation of SWAT is the single consideration of a bundle of ecosystem services, namely those related to watershed processes (hydrological services, biomass production and carbon storage). Nonetheless, SWAT has proved to be an important tool for modelling and mapping the potential provision of ecosystem services at the watershed scale, thereby contributing to analyse and test different scenarios for land management and watershed governance.

Conclusions

SWAT was used to model and map the provision of hydrological services, biomass production and carbon storage, at the HRU (hydrological response unit) level considering two forestation scenarios (eucalyptus/pine and oak) in comparison with current land cover conditions dominated by shrubland. SWAT was calibrated and validated against daily discharge with a good agreement between model predictions and field observations. A comparison between monthly observed sediments and nitrates with SWAT simulated values can consider the exercise adequate given the limitation of observed data.

In addition, biodiversity conservation value was mapped to assess the spatial trade-offs between ecosystem services provision. The current delivery of ecosystem services in the Vez watershed is higher at the high and low mountain sub-basins, with less performance in the valley. The high mountain sub-basin is strong in providing water quantity, biomass production and carbon storage. The low mountain is prone to deliver higher soil erosion control and flood mitigation services. When considering the two different forestation scenarios, the provision of water quantity decreases considerably in the eucalyptus/pine scenario. Remarkably flood mitigation and soil erosion control are improved with eucalyptus/pine scenario, particularly in the low mountain region. However, this scenario is the one with more spatial trade-offs with biodiversity conservation value, especially inside the protected areas. Several strategies may be suggested for an effective land use planning in the Vez watershed, according to each sub-basin priority. Eucalyptus/pine is the scenario with greater results for flood regulation and soil erosion control, but cautions should be taken regarding strategies for biodiversity conservation (preferably by favouring native oak species), as well as the potential increase in fire risk.

SWAT has been proved to be an important tool for modelling and mapping ecosystem services provision generated at the watershed scale, thereby contributing to test and improve the options for land management.

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