Co-benefits and trade-offs between biodiversity, carbon storage and water flow regulation

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Abstract

The trade-offs between biodiversity, carbon storage and water flow regulation were analysed in a biosphere reserve area. With the aim of proposing criteria for conservation plans that would include ecosystem services and biodiversity, a Geographic Information System (GIS)-based approach was designed to estimate and map the value of the biodiversity and ecosystem services. The actual protected areas, namely, coastal ecosystems and Cantabrian evergreen-oak forests, were found to be important for the overall biodiversity and included some important portions of the other services. The non-protected natural forests, such as the mixed-oak, beech and riparian forests, are biodiversity hotspots, and they contribute to the carbon storage and water flow regulation services. Thus, even though these areas are small, their inclusion in conservation proposals should be considered. The pine and eucalyptus plantations contribute to ecosystem services but have negative effects on biodiversity and cause environmental problems. In contrast to the plantations of fast-growing species, the increase in broadleaf plantations will exhibit a positive trend due to the benefits they provide. Our study highlights that the inclusion of ecosystem services in conservation planning has a great potential to provide opportunities for biodiversity protection; however, strategies of conservation based only on specific ecosystem services may be detrimental to the biodiversity and may cause other environmental problems.

Keywords: Biodiversity; Carbon storage; Ecosystem services; Forest plantation; Hotspot; Water flow regulation.

1. Introduction

Biodiversity and ecosystem services are intrinsically linked: the former supports most ecosystem services, and the maintenance of the latter is often used to justify biodiversity conservation actions because of the importance of these services to humans (Millennium Ecosystem Assessment, 2005). The perspective of ecosystem services can contribute to the development of sound land-use policies and planning actions (Viglizzio, 2012), but it remains unclear how ecosystem services relate to biodiversity and to what extent the conservation of biodiversity will ensure the provision of such services. Recently, some members of the conservation community have used ecosystem services as a strategy to conserve biodiversity, while others have criticised this strategy as a distraction from the aim of biodiversity conservation. Although the debate continues (Reyers et al., 2012), conserving biodiversity and ecosystem services may require different strategies because they are a function of many ecosystem properties (Egoh et al., 2009).

It is necessary to understand the spatial relationships between the conservation priorities for biodiversity and ecosystem services (Bai et al., 2011), but quantifying the levels and values of these services has proven difficult (Nelson et al., 2009). Published results regarding the relationship between the positive effects of biodiversity and ecosystem services differ from author to author. Whereas some authors have found a low correlation and moderate overlap between biodiversity and ecosystem services (Chan et al., 2006), others have revealed a high overlap between biodiversity conservation and ecosystem service priorities (Egoh et al., 2009). Moreover, different regions respond differently to human intervention, both economically and ecologically. Any application of land-use strategies to different biomes may lead to undesirable outcomes (Carreno et al., 2012). Recent research confirms that biodiversity and ecosystem services supply both decline with land use intensification (Schneiders, 2012). Clearly, there is a need to investigate other areas in the world at different levels, from global to regional and local scales. Our hypothesis is that while there are important synergies between biodiversity and some ecosystem services, some systems, such as forest plantations, can deliver important services but be detrimental to biodiversity.

Northern Spain represents a good opportunity to study the spatial relationship between biodiversity and ecosystem services due to the high biodiversity and heterogeneity of its landscapes. Furthermore, additional information is needed to apply new criteria to define the policies and strategies of conservation in this region. In this study, we focused on the Urdaibai Biosphere Reserve (UBR). In 1984, this area was declared a reserve to protect the *core areas* because of their extraordinary biodiversity (salt marshes, coastal ecosystems and Cantabrian evergreen-oaks). The Basque Government established a special legislation in 1989 to protect the integrity and promote the recovery of the natural ecosystems in terms of the natural and recreational interest, which has been a focus of controversy between stakeholders in recent years. On the one hand, land owners wanted to plant pines to produce timber; on the other hand, environmentalists proposed a plan to regenerate natural forests. Currently, only approximately 17% of the ecosystems are natural, whereas much of the natural forests have been predominantly replaced with forest plantations of *Pinus radiata* (Rodríguez-Loinaz et al., 2011). Management plans for biodiversity conservation and sustainable development have been proposed by the local administration, but they have been applied slowly due, among other causes, to the conflict of interest between the stakeholders. A new Plan for Management of Natural Resources must be proposed by the Reserve Management Body to reconcile the conservation of the natural resources with their sustainable use. Therefore, this area is an appropriate place to define strategies for land management that are based on both biodiversity and ecosystem services. With this study, we attempted to evaluate the co-benefits or possible trade-offs between biodiversity and ecosystem services to help develop a conservation plan that includes the conservation of both.

The aim of the study was to determine the spatial distribution and congruence among the hotspots of biodiversity, carbon storage and water regulation services that are likely to appeal to stakeholders when defining strategies for land management. The conservation of biodiversity is one of the important issues in a biosphere reserve, and carbon storage is an important global service (Dymond et al., 2012) and can be of concern of land owners interesting in planting forests. Lastly, water flow regulation was chosen due to the importance of the water flow in the area, which is a watershed.

We examined the trade-offs between the biodiversity and ecosystem services to analyse the implications of developing a conservation plan that includes both. The study aims to answer the follow questions: i) How much of the study area produces each service, and how much of each service is generated by each ecosystem? ii) To what extent do the biodiversity, carbon storage and water regulation hotspots overlap? iii) Which ecosystems are the most important providers of biodiversity, carbon storage and water regulation?

2. **Methodology**

2.1. Study area

The study was conducted in the UBR, Biscay, northern Spain (43º19´N, 2º40´W). The UBR is bordered by the Oka River water catchment and occupies an area of 220 km^2, with approximately 45,000 inhabitants. The economic activity is essentially based on metallurgy, fishing, and the development of the local natural resources, particularly farming, grazing, and forestry. The average temperature is 12.5 ºC, and the rainfall distribution is uniform throughout the year, with an average annual rainfall of 1.200 mm.

The Cantabrian evergreen-oak forest is one of the most highly valued natural ecosystems of the reserve, and a great portion of the land has a potential vegetation of mixed-oak forest dominated by *Quercus robur* L. (Onaindia et al., 2004). However, this forest was fragmented during the 19th and 20th centuries, and it currently occupies a small proportion of its potential area because it has been replaced with forest plantations of *Pinus radiata* and *Eucalyptus* sp. (Rodríguez-Loinaz et al., 2007). Indeed, the native forests throughout northern Spain have suffered substantial degradation during the last centuries. In the 1950s, strong industrialisation in the area initiated a crisis in the rural regions that resulted in farm abandonment and the spread of rapid-turnover *P. radiata* plantations. The type of management applied to the plantations has given rise to environmental problems, including soil and nutrient loss (Merino et al., 2004).

2.2. Mapping ecosystem services

We analysed the biodiversity and the provision of two important services in the study area: carbon storage and water regulation. These ecosystem services were selected on the basis of their importance in the area, their relevance to conservation planning and the availability of data. Carbon storage is a global service, and water flow control regulation is more of a local service in relation to the quantity of water that is retained from the water flow for the functioning of ecosystems.

A GIS-based approach was designed to spatially estimate the value of the biodiversity and certain ecosystem services. The results were mapped because of the important role maps play during the entire process of spatial planning, while more easily bringing the ecosystem services to the attention of stakeholders during negotiations (van Wijnen et al., 2012). The software used for the geoprocessing was ArcGIS 9.3 (ESRI, 2009), and the spatial units of the mapping were grid cells with a size of 4 m^2.

The environmental units were defined according to the European Nature Information System (EUNIS) developed by the European Environment Agency (EEA, 2002). For this study, the 86 habitats present in the study area were aggregated into the 15 environmental units most relevant to the region (salt marshes and continental waters were not include in the study due to the different methodology needed for the analysis of these types of ecosystems) (Fig. 1). The sources of the cartographic data are explained in Annex 1.

Biodiversity and ecosystem services were mapped as hotspots and ranges, where hotspots identify those areas with a high value of biodiversity or ecosystem service and ranges identify areas that provide medium amounts of biodiversity or service (Egoh et al., 2008). Areas with the highest value for biodiversity are hotspots of biodiversity, and areas where the carbon accumulation is the highest are hotspots for carbon storage. The hotspots of water flow regulation are areas where the water retention is the highest. To define hotspots and ranges, the maximum value of biodiversity obtained in the area was divided into three equal thresholds. The lowest value was then rejected, the medium value was considered a range and the highest value was considered a hotspot. For the continuous variable maps of carbon storage and water flow regulation, these thresholds were determined using the Jenks Natural Breaks classification in ArcGIS (Reyers et al. 2009; O´Farrell et al. 2010). Natural Breaks classes are based on natural groupings inherent in the data. Class breaks identify the best group of similar values, and they maximise the differences between classes. The data are divided into classes whose boundaries are set where there are relatively large differences in the data values.

2.3. Biodiversity

The biodiversity value integrated information on several levels of biodiversity as a function of the plant richness, successional level and existence of a legally protected feature, using raster calculation tools provided by Spatial Analysis in ArcGIS.

B = f (r, q, p), where
B = Biodiversity
r = the richness, as the number of native plant species
q = the habitat quality (successional level)
p = the degree to which the land is legally protected.

The number of vascular plant species (richness) was used as a proxy of biodiversity. Only native species were taken into account to avoid alien species or invasive species in the border areas. The number of native plant species in each environmental unit was calculated based on the literature (Onaindia, 1989; Benito and Onaindia, 1991; Onaindia et al., 1991; Onaindia et al, 1996; Onaindia et al., 2001; Amezaga et al., 2004; Onaindia and Mitxelena, 2009). The plant richness values were ranged on a scale from 1 to 4, using equal intervals from the maximum value to the minimum value, where: >65 = 4; 45-65 = 3; 25-45 = 2; and <25 = 1 (Fig. 2).

The successional level was used as an indicator of biodiversity because it depends on the degree of matureness of the ecosystem. The potential vegetation was the forests throughout the study area, where bushes and grasslands are the second and third phases of succession, respectively (Biurrun et al., 2009). Narrow areas of bushes and grasslands along the coast, classified as coastal habitats, were also considered potential vegetation (Aseguinolaza et al., 1988). Following these criteria, the assigned values for the successional level were: 4 = forests and coastal habitats, 3 = bushes, 2 = grasslands, and 1 = others.

The values obtained for biodiversity based on plant richness and successional conditions were overlapped with data of legal protection, and the results were ranged to define ranges and hotspot areas. The values were 1 (legally protected by European directives or regional laws) or 0 (non-protected). It is important to take into account that the presence of relevant flora, fauna and singular landscapes are included to define protected areas in the region. A summary of the method to evaluate biodiversity is explained in Figure 2.

2.4. Carbon storage

We estimated the amount of carbon stored in the biomass and soil in the study area. We focused on storage rather than sequestration because of the considerable uncertainty regarding sequestration and the importance of preventing the loss of stored carbon (Chan et al., 2006). Forest ecosystems include five carbon storage pools: living trees, down dead woods, understory vegetation, forest floor, and soil (Hu et al., 2008; Woodbury et al., 2007). For the valuation of C stored in the soil, we use the "Inventory of organic C stored in the first 30 cm of the soil" of the Basque Country (Neiker-Ihobe, 2004). This map was obtained by means of interpolation techniques from more than a thousand samples of organic C concentrations (g kg^{-1}) and soil bulk density (g cm^{-3}) after combining the samples according to land uses (e.g., coniferous forest, broadleaf forest, grasslands, scrublands). Although the C storage in soils may not be related to the current land cover, as it can be influenced by the previous land uses (Kasel and Bennett; 2007; Schulp and Verburg, 2009), after the land use changes it can be assumed that the C stored in the first 30 cm of the soil reaches a new equilibrium after 20 years (IPCC, 2003). The land use has changed in only 11.8% of the study area in the last two decades (Rodríguez-Loinaz et al., 2011).

For the C stored as biomass, we considered that in ecosystems other than forests the amount of C stored as biomass was insignificant compared with the C stored in the soil. For forest ecosystems, C stored in the understory, herbaceous layers and dead organic matter was ignored because C estimates could not be generated for these portions of the studied forest ecosystems. In addition, the C contained in the understory components and in dead organic matter is often ignored in biomass estimates due to the low carbon content of these compartments in forests compared with tree biomass (Birdsey, 1992; Woodbury et al., 2007; Zhang et al., 2007; Chen et al., 2009). In this study, therefore, we focused on the C stored in living trees (aboveground and belowground), which was obtained as follows (IPCC, 2003):

$$CB = V*BEF*(1+R)*D*CF$$

CB = the carbon stocks in living biomass (includes above- and belowground biomass), tonnes C ha^{-1}

V = the merchantable volume, m^3 ha^{-1}

BEF = the biomass expansion factor for the conversion of merchantable volume to aboveground tree biomass to include branches and leaves, without units

R = the root-to-shoot ratio to include belowground tree biomass, without units

D = the basic wood density, tonnes d.m. m^{-3} merchantable volume

CF = the carbon fraction of dry matter, tonnes C $(\text{tonne d.m.})^{-1}$

The merchantable volume data for the different forests were obtained from the Forest Inventory of the Basque Country for the year 2005. The wood densities were obtained from the plantations of the northern Iberian Peninsula (CPF, 2004; Madrigal et al., 1999), and the biomass expansion factors were obtained from the study region (Montero et al., 2005).

2.5. Water flow regulation

Water regulation involves the influence of natural systems on the regulation of hydrological flows at the earth's surface, and water flow regulation is a function of the storage and retention components of the water flow (de Groot et al., 2002). The ability of a catchment to regulate the flow is directly related to the volume of water that is retained or stored in the soil and groundwater.

The water regulation ecosystem function is distinct from the disturbance regulation because it refers to the maintenance of normal levels in a watershed and not the prevention of extremely hazardous events. The ecosystem services derived from the water regulation function are, among others, the maintenance of the natural irrigation and drainage and the provision of a medium for transportation. A regular distribution of water along the surface is essential, as too little or too much runoff can present serious problems (de Groot et al., 2002).

We used the fraction of the annual water flow stored in the soil to measure the water flow regulation service. The calculations of the water flow regulation were based on the TETIS model developed for the region (the model is not a groundwater model) (Vélez et al., 2009), whereby the volume of water produced by the area is determined primarily by the rainfall patterns, which depend mainly on abiotic parameters (regional climate and topography). Ecosystems also play a key role in the water flow due to the amount of water they retain in the soil and return to the atmosphere by evapotranspiration. Data are integrated using raster calculation tools provided by Spatial Analysis in ArcGIS. Thus, the water flow regulation service (WC) was calculated as follows:

$WC = Hu/R$

$R = P - Ev_c$

WC = the water flow regulation

Hu = the water storage in the soil (mm / year)

R = the annual water flow (mm / year)

P = the annual rainfall (mm / year)

Ev_c = the corrected annual potential evapotranspiration (mm / year)

The potential evapotranspiration was modified by correction factors for the different vegetation types to obtain a more realistic value for the evapotranspiration. The correction factors used were those in the InVEST-Integrated Valuation of Ecosystem Services and Tradeoffs (Tallis et al., 2011). The water storage in the soil map and the annual potential evapotranspiration map were supplied by the Water Agency of the Basque Government. The annual rainfall map was supplied by the Meteorological Agency of the Basque Government.

3. **Results**

3.5. Biodiversity

Biodiversity-integrated values were calculated for each ecosystem (Fig. 3). The natural forests were the ecosystems that most contributed to the biodiversity, with the Cantabrian evergreen-oak forest contributing more than half (54%) of the biodiversity hotspots and the mixed-oak forest another 28%. The other natural forests, such as beeches and riparian forests, were small compared with the other units, resulting in small percentages as biodiversity hotspots. The coniferous and eucalyptus plantations did not contribute at all to the biodiversity, and the costal habitats had a low contribution to the biodiversity hotspot area (Table 2).

In relation to the relative contribution of each environmental unit, most areas comprising the coastal habitats and natural forests were included as biodiversity hotspots, even though they had small areas (Fig. 4, a).

3.6. Carbon store

The carbon store in the soil and biomass was calculated for each ecosystem (Annex 2, a), and the threshold value for the hotspot was 150 Tm C.ha^{-1} (Fig. 3). The natural forest contributed the most to the hotspot of carbon storage, with the mixed-oak forest at 42% and the Cantabrian evergreen-oak forest at 22%. Moreover, the coniferous plantations contributed 22% to the hotspot and 83% to the range of services (Table 2).

In relation to the relative contribution of each environmental unit, most of the area of the natural forests contributed to the carbon storage hotspots. Only 10% of the coniferous plantations were included in the carbon hotspots, but 90% were included in the range of this service (Fig. 4, b).

3.7. Water flow regulation

The values for water flow regulation were calculated for each ecosystem (Annex 2, b), and the threshold value for the hotspot was 40% (Fig. 3). The coniferous plantations contributed the most to the hotspot (67%) and to the range (31%). The other environmental units did not contribute significantly to the water flow regulation service (Table 2).

In relation to the relative contribution of each environmental unit, the entire area of natural beech forests contributed to the hotspot, and more than half the other natural forests also contributed. More than half the surface area of the forest plantations and the coniferous, eucalyptus and broadleaf forests were also included in the hotspot for the water flow regulation service (Fig. 4, c).

3.4. Overlap between biodiversity and the provision of ecosystem services

A total of 15 environmental units were defined based on the EUNIS classification system (Fig. 1). Nearly half the surface area was covered by pine plantations, whereas natural forests (Cantabrian evergreen-oak forest and mixed-oak forests) comprised only approximately 15% of the area, with grasslands and hedges at 19%. Most of the surface of the UBR was important for both biodiversity and ecosystem services (at least one service was found in 60% of the area).

There was a medium biodiversity value in 33% of the surface and a hotspot in 12% of the area (Fig. 5). In relation to the carbon storage, there was a medium service in 50% of the surface area and a hotspot in 20%. A water flow regulation medium service (range) was produced in 35% of the area and was very high in 48% (Fig. 5). The biodiversity and the studied ecosystem services overlapped by 36%, which is 4% of the total study area; 100% of this area was composed of natural forests (99% non-protected). The overlap between the biodiversity and carbon storage was 68%, with 100% of this area being natural forests (33% non-protected). The overlap between the biodiversity and the water flow regulation was a 49%, with 51% of the overlap being natural forest (11% non-protected). Finally, the carbon storage and water flow regulation overlapped by 64%, with 60% of this area being forest plantations and the rest natural forest (99% non-protected).

4. **Discussion**

4.1. Synergies between biodiversity, carbon storage and water flow regulation.

The biodiversity, carbon storage and water flow regulation hotspots have a spatial congruence of 40%, which is 4% of the area of the biosphere reserve, namely, the area composed by natural forests. It is known that the carbon storage by forests can help mitigate global changes. Forests are also important for the regulation of hydrologic dynamics through rainfall interception, and they can contribute to the maintenance of slope stability during storms (Band et al., 2012). Thus, the conservation of biodiversity will ensure the provision of the studied ecosystem services. Moreover, taking ecosystem services into account can optimise the conservation strategies for multiple ecosystem services, and the biodiversity network will protect a considerable supply of ecosystem services

The most important contribution to biodiversity is made by the protected Cantabrian evergreen-oak forests, but a high contribution to the biodiversity and ecosystem services is made by the non-protected natural forests. The small and fragmented areas of mixed-oak, beech and riparian forests have a high contribution to biodiversity, carbon storage and water regulation. However, the riparian forest has not shown any recovery during the last 20 years, despite its ecological importance, mainly due to the continuation of plantation and grazing activities (Rodríguez-Loinaz et al., 2011). The conservation and regeneration of these small areas, which are actually only 5% of the area, would contribute to a conservation of 33% of the biodiversity hotspot, more than 40% of the carbon storage and almost 13% of the water flow regulation. The accurate scale of the local study allowed the role of these small forests to be analysed, which in turn allowed the determination of the importance of small ecosystems, such as coastal habitats and riparian forests, which make a large contribution to the biodiversity hotspot.

Our study highlights that the inclusion of ecosystem services in conservation planning has a great potential to provide opportunities for biodiversity protection. Ecosystem services can be used to strengthen biodiversity conservation in some instances (Egoh et al., 2009). Because planning frequently fails to include the valuation of services (Gret-Regamey et al., 2008), regional and local studies are needed to understand these relationships better, as the trade-offs between the biodiversity and ecosystem services are likely to be different under different conditions.

4.2. Conservation based only on specific ecosystem services?

The coniferous plantations are not at all important for biodiversity, but they contribute a quarter of the carbon storage and make the most important contribution to the water flow regulation. Moreover, the carbon storage and water flow regulation overlapped by more than a 60%, just in areas most covered by forest plantations. The rapid growth of forest plantations simultaneously increases carbon accumulation and the interception of water. As a result, there will be a reduction of water yields in the watershed. Recent reports confirm that forest plantations that maximise carbon sequestration have a considerable impact on runoff and decrease stream flow (Jackson et al., 2005). Even if water yield is generally not a problem in the study area at the moment, it may become an important problem in future scenarios under climate change.

Taking into account the importance of forest plantations for carbon storage, it is necessary to consider the environmental consequences of carbon storage and sequestration strategies (Jackson et al., 2005). In fact, the conversion to these fast-growing tree plantations in the study area has led to a decrease in the water quality due to the increased sediment loads associated with clear cuts (Lara et al., 2009; Garmendia et al., 2011). Other adverse environmental impacts of pine plantations have been reported in such regions as South Africa, where they have had negative consequences for biodiversity (Chisholm et al., 2010).

Forest plantations of pine and eucalyptus can also function in water flow regulation, but they can also acidify soils (Jackson et al., 2005) and generate erosion and nutrient loss (Merino et al., 2004). Temporal considerations are also important because pine plantations are harvested every 35 years and eucalyptus plantations every 12 years, but the effects of these plantations on the carbon storage and water regulation are only valid with an accompanying canopy closure, which disappears after cutting and can take up to 5 years to close after planting. In the study area, strategies of conservation based only on carbon storage and water flow regulation to promote forest plantations may be detrimental to the biodiversity and to other services, such as water yield.

However, due to economic considerations, the pine and eucalyptus plantations have continued to thrive in all areas, even in protected zones, during the last 20 years (Rodríguez-Loinaz et al., 2011). Considering that the current timber production is not such a highly profitable activity, it is necessary to develop approaches to manage plantations that produce a more global benefit, a goal that implies the comprehensive management of plantations and native woodlands to maintain biodiversity and ecosystem services. Global declines in biodiversity and the degradation of ecosystem services have led to urgent appeals to safeguard both, and the responses include pleas to integrate the needs of the biodiversity and ecosystem services into the design of conservation interventions (Carpenter et al., 2009; Egoh et al., 2010). In a biosphere reserve, it is necessary to manage forests to produce goods, such as timber, or to accumulate carbon and enhance biodiversity. This management involves trade-offs that require a clear understanding of the ecological environment and agreement among the stakeholders (Carnus et al., 2006).

5. **Conclusions**

- Our study indicates that taking ecosystem services into account can optimise the conservation strategies for multiple ecosystem services and that a biodiversity network would protect a considerable supply of ecosystem services. The actual protected areas, namely coastal ecosystems and Cantabrian evergreen-oak forests, are the most important for biodiversity. However, the non-protected natural forests are also very important for biodiversity, carbon storage and water flow regulation.
- Natural forests are fundamental for biodiversity and for all the studied ecosystem services. Even if they are small, the protection of areas covered by mixed-oak, beech and riparian forests contribute to biodiversity and to carbon storage and water flow regulation services. The inclusion of these areas should be considered in conservation proposals together with new strategies of regeneration.
- Pine and eucalyptus plantations contribute to ecosystem services, but they have negative effects on biodiversity and cause environment problems. The replacement of pines and eucalyptus with broadleaf forests will be a positive trend due to the carbon storage and services they provide.
- The inclusion of ecosystem services in conservation planning has a great potential to provide opportunities for biodiversity protection, whereas strategies of conservation based only on specific ecosystem services may be detrimental to biodiversity and may cause environmental problems.

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Figure captions:

Figure 1. Map of the defined environmental units. Coniferous plantations are dominant (44%), and natural forests (15%) are highly fragmented.

Figure 2. Sources of cartographic data.

Figure 3. Map of the ranges and hotspots of biodiversity (a), carbon storage (b) and water flow regulation (c).

Figure 4. Percentage of each ecosystem that is included in the ranges and hotspots of biodiversity (a), carbon storage (b) and water flow regulation (c).

Figure 5. Percentage of the total area of the UBR that delivers services: ranges and hotspots for biodiversity, carbon storage and water regulation.