Ecosystem service trade-offs from supply to social demand: A landscape-scale spatial analysis

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HIGHLIGHTS

- Supply and demand of ecosystem services are analyzed across different landscape units.
- Spatial mismatches between the biophysical, socio-cultural and economic value of ecosystem services are identified.
- High mountain and coastal platform units show the highest discrepancies.
- Different value-dimensions of ecosystem services give complementary information for landscape planning.

ABSTRACT

Quantitative studies that assess and map the relationship between the supply and social demand of ecosystem services are scarce. Here we address both supply and social demand sides by spatially analyzing ecosystem service trade-offs from three value-dimensions – i.e., biophysical, socio-cultural and economic, and across different landscape units in southeast Spain. To accomplish this goal, within different landscape units, we quantify the supply side by mapping the biophysical values of five ecosystem services, and the social demand exploring their socio-cultural and economic values by analyzing social preferences and contingent valuation methods, respectively. Our results show that the assessments of ecosystem services using different value-dimensions are complementary and useful for (1) identifying ecosystem service trade-offs, both on the supply- and on the social demand-side, and (2) analyzing spatial mismatches among the three value-dimensions of ecosystem services. We also believe that our approach facilitates the exploration of ecosystem services trade-offs on a spatial landscape scale, and results can be used by managers to identify areas in which services are declining or priority areas for conservation based on maximizing ecosystem services, and will be useful in detecting potential conflicts associated with new management and planning practices.

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1. Introduction

Over the past two decades, the ecosystem service concept, i.e., benefits that humans obtain from ecosystems (MA, 2005), has gained importance among scientists, managers and policymakers worldwide as a way to communicate societal dependence on ecological life support systems that integrate perspectives from both the natural and social sciences. While researchers from different disciplines including ecology, geography and economics have begun to address ecosystem services (e.g., Turner, Morse-Jones, & Fisher, 2010; Verburg, Koemen, Hilferink, Pérez-Soba, & Lesschen, 2012; Willemen, Hein, & Verburg, 2010; Willemen, Veldkamp, Leemans, Hein, & Verburg, 2012), studies combining disciplines are uncommon (Müller, Burkhard, & Kroll, 2010). However,
interdisciplinary approaches examining ecosystem services are greatly needed because accurate quantification of these services requires spatially mapping the biophysical, socio-cultural and economic values of services (Chan, Satterfield, & Goldstein, 2012; de Groot, Wilson, & Boumans, 2002).

A challenge in ecosystem services research is to identify an ecosystem’s capacity to provide services (supply side) and the social demand for those services (demand side) (Martín-López, Gómez-Baggethun, García-Llorente, & Montes, 2014). Addressing both of these sides demonstrates that the status of an ecosystem service is influenced not only by an ecosystem’s properties but also by societal needs (Castro, García-Llorente, Martín-López, Palomo, & Iniesta-Arandía, 2013). Burkhard, Kröll, Nedkov, and Müller (2012) defined supply side as the capacity of a particular area to provide ecosystem services, and demand side as the sum of ecosystem services currently consumed, used, or valued in a particular area over a given time period. Martín-López et al. (2014) recently developed an approach for quantifying ecosystem services that spans both supply and demand-side services. Using this approach, the supply-side can be measured as biophysical indicators, such as hec toliters of water supplied or tons of carbon sequestered by ecosystems. Social demand can be valued using non-monetary indicators including assessment of people’s perceptions of the importance of different services (Martín-López et al., 2012) or using economic valuation techniques in real or hypothetical markets (Turner et al., 2010). The combination of these different approaches can provide an integrative methodological framework for assessing ecosystem services (Tallis & Polasky, 2009).

Ecosystem services that are provided, and thus trade-offs among those services, will vary with different landscapes. Thus, it is important to examine the role of landscape in identifying trade-offs. Our goal was to identify ecosystem service trade-offs across landscapes by estimating their biophysical, socio-cultural, and economic values. For six different landscape units in southern Spain, we mapped the spatial variation of the biophysical values of five ecosystem services (supply side). Then, based on a previous study by Castro et al. (2011), we explored their socio-cultural and economic values through social preferences analysis and contingent valuation methods respectively (social demand side). Following the Common International Classification of Ecosystem Services (CICES) (Haines-Young & Potschin, 2013), we examined one provisioning (cultivated crops through agricultural production) and four regulating (climate regulation through carbon stocks, water flow maintenance through groundwater recharge, control of erosion through soil loss, and maintaining habitats based on potential habitat area for threatened species) services. We did not include cultural services due to the difficulty in accurately quantifying their biophysical and economic values (Pleninger, Dijks, Oteros-Rozas, & Bieling, 2013).

2. Study area

Our study was conducted in eastern Andalusia in the southeastern Iberian Peninsula and covers approximately 28% (2459 km²) of Almeria province (8774 km², 700,000 inhabitants, 79.7 inhab/km²) (Fig. 1). Approximately a third of the province is protected, including mountains, coastal regions and agricultural lands. Almeria is semi-arid and considered one of the driest regions in Europe (Armas, Miranda, Padilla, & Pugnaire, 2011), with average rainfall of 250 mm per year (Castro et al., 2011). Winter temperatures vary between 12 and 15 °C, and average summer temperatures are as high as 40 °C (Lázaro, Rodrigo, Gutierrez Carretero, Domingo, & Puigdefábregas, 2001).

We used Metzger, Bunce, Jongman, Mührer, and Watkins’ (2005) approach to map six ecologically homogeneous landscape units in the study area that differed from their surroundings based on a previous landscape stratification of Andalusia (Montes, Borja, Bravo, & Moreira, 1998; Fig. 1). Landscape units were: (1) sedimentary mountains (average altitude 1210 meters above sea level (masl), annual mean rainfall of 331 mm, and an annual mean temperature of 13.5 °C), (2) metamorphic mountains (average altitude
3. Methods

3.1. Conceptual approach

Our approach allowed us to explore ecosystem service trade-offs across the six landscape units and consider both the provisioning of ecosystem services and the use of ecosystem services by beneficiaries (Fig. 2). Because landscape units vary in the ecosystem services they provide, we tested whether they can be classified as service-providing units (SPUs), a concept that describes portions of the territory with the ability to provide multiple ecosystem services (Luck et al., 2009). To do this we first modeled and mapped the biophysical dimension of ecosystem services by quantifying biophysical services delivery within the six landscape units. Secondly, within each landscape unit, we determined which ecosystem services stakeholders considered important for maintaining their wellbeing. The stakeholders’ sample included local residents and tourists (on both extended holidays and day-trips) that were randomly sampled during February and March 2008, representing the late winter outdoor tourist season (Castro et al., 2011). Third, we examined the economic dimension within each landscape unit using contingent valuation to estimate individual willingness to pay (WTP) for the preservation of ecosystem services. The contingent valuation method (CVM) has been widely used to capture socio-economic information that is relevant to ecosystem services by establishing how much people are willing to accept as compensation for the loss of services, or their WTP for services preservation (Castro et al., 2011). Finally, we examined ecosystem service trade-offs across landscapes units and explored potential mismatches between the three value-dimensions (i.e., biophysical, sociocultural and economic).

3.2. Supply of ecosystem services: modeling and mapping

We used spatial models and biophysical indicators to quantify the supply of ecosystem services (Table 1, Appendices D–E). Cultivated crops were quantified using the average annual yield of the most economically important crops (i.e., tomato, cucumber, zucchini, pepper and eggplant). We used carbon stocks as a proxy of climate regulation, which was estimated from measurements of soil organic carbon, density (kg/m³), horizon thickness (m), and lithology and soil maps (Oyonarte, Almendros, Delgado, Perez-Pujalte, & Delgado, 1994). To estimate water flow maintenance, we used the APLIS model to quantify the distribution of aquifer recharge expressed as the percentage of the average annual rainfall (Andreo et al., 2008; Quintas-Soriano, Castro, García-Lorenzo, Cabello, & Castro, 2014). We used the Universal Soil Loss Equation (USLE) model to estimate soil loss (Kandziora, Burkhard, & Müller, 2013). Finally, we used the biodiversity combined index (BCI) model (Rey Benayas & de la Montana, 2003) to characterize the ecosystem service associated with maintaining habitats for threatened vertebrate species. A full description of each model is included in Appendix E.

3.3. Ecosystem services social demand: socio-cultural and economic valuation

The socio-cultural and economic values of the selected services were determined based on face-to-face, questionnaire-based surveys within each landscape unit (Fig. 1). To quantify both the socio-cultural and economic values for each landscape unit, surveys were conducted at several sampling points within each landscape unit (see sampling sites in Fig. 1). Questionnaires included 27 questions, divided into five sections: (1) type of visit; (2) preferences for ecosystem services; (3) economic valuation questions; (4) environmental attitudes and environmental knowledge; and (5) socioeconomic data. Finally, the survey included various case-based follow-up questions about gender of the interviewee, location of the survey, attitude of the interviewee, and understanding of the questionnaire. Surveyed stakeholders were also asked if they thought that the study area provided important benefits to society. We used the results of these questionnaires to calculate the percentage of people who viewed a particular ecosystem service as important and to value the five selected ecosystem services by proportionally distributing the total amount of money they were willing to pay for the delivery of each service (see further details in Castro et al., 2011).

The sample population was randomly chosen within each landscape unit including protected areas, urban zones, recreational areas, visitor centers, beaches, and agricultural fields. Surveys were conducted between February and March 2008. There was a total of 340 surveyed stakeholders who were assumed to be representative of resource users in their respective landscape units (including locals and tourists); i.e., 29 questionnaires in sedimentary mountains, 171 in metamorphic mountains, 51 in high mountains, 32 in sedimentary valleys, 38 coastal platform, and 19 in saline marshlands. The sampling was stratified according to the regional population of each landscape unit.

3.4. Analysis of ecosystem service trade-offs across landscape units

The trade-offs analysis was performed by quantifying the biophysical delivery of ecosystem services and then exploring the mismatch between the socio-cultural and economic values of those
Table 1
Indicators used for ecosystem services assessment in biophysical, socio-cultural and economic terms. In parenthesis we expressed the data collection type. CICES, the common international classification of ecosystem services; SOC, soil organic carbon; APLIS, acronym of the Spanish initials of the five variables which comprise its: altitude, slope, lithology, infiltration and soils); USLE, universal soil loss equation, BCI, biodiversity combined index.

<table>
<thead>
<tr>
<th>Ecosystem services</th>
<th>Supply-side Biophysical indicator</th>
<th>Demand-side Socio-cultural indicator</th>
<th>Economic indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provisioning</td>
<td>Cultivate crops</td>
<td>Agricultural production (obtained from statistics, REDIAM data set)</td>
<td>Social importance in a close-format question (face-to-face questionnaires)</td>
</tr>
<tr>
<td>Regulating</td>
<td>Climate regulation</td>
<td>Soil carbon stocks (SOC model; Oyonarte et al., 1994)</td>
<td>Social importance in a close-format question (face-to-face questionnaires)</td>
</tr>
<tr>
<td>Water flow</td>
<td>Water flow maintenance</td>
<td>Aquifer recharge (APLIS model; Andreo et al., 2008; Quintas-Soriano et al., 2014)</td>
<td>Social importance in a close-format question (face-to-face questionnaires)</td>
</tr>
<tr>
<td>Control of erosion</td>
<td>Control of erosion</td>
<td>Soil loss (USLE model; Kandziora et al., 2013)</td>
<td>Social importance in a close-format question (face-to-face questionnaires)</td>
</tr>
<tr>
<td>Maintaining habitats</td>
<td>Maintaining habitats</td>
<td>Threatened species conservation (BCI model; Rey Benayas &amp; de la Montana, 2003)</td>
<td>Social importance in a close-format question (face-to-face questionnaires)</td>
</tr>
</tbody>
</table>

services across the six landscape units. We defined an ecosystem service trade-off as when the delivery or value of one or multiple ecosystem services compromised another (Raudsepp-Hearne, Peterson, & Bennett, 2010). A common example of this occurs when agricultural development results in decreased capacity of soil fertility. A trade-off can also occur when there is a disconnect between the biophysical capacity of a particular landscape to deliver services and the socio-cultural and economic values given by stakeholders on one or multiple services (Quintas-Soriano et al., 2014). An example would be when people do not consider the importance, both in terms of social and economic benefits, of groundwater recharge in a landscape unit characterized by dry conditions. Finally, we examined the spatial correspondence between the three value-dimensions of ecosystem services (i.e., biophysical, socio-cultural and economic) across landscape units with Spearman’s rank correlation. For the biophysical dimension, we used a minimum–maximum normalization to organize results to a 0–1 scale according to Willemen et al. (2010). Because this technique is sensitive to minimum and maximum values, and to erroneous transformations due to outliers, ecosystem services maps were first winzoned such that values outside the 5th or 95th percentile were assigned the 5th or 95th value respectively (Willemen et al., 2012). Using spatial analysis techniques (Zonal statistic tool in ArcGIS Spatial Analyst, version 2010) the biophysical supply of each ecosystem service was calculated within each landscape unit. We then examined differences between ecosystem services supplied by the different landscape units with the Kruskal–Wallis test as the variables were non-normally distributed. We used Chi-square to examine differences in social preferences toward services and ANOVA to examine differences in WTP for each ecosystem service among the landscape units. WTP followed a normal distribution for all ecosystem services.

4. Results

4.1. Modeling and mapping of ecosystem service delivery

The biophysical supply of ecosystem services varied across landscape units, with the greatest delivery of provisioning and regulating services occurring in distant areas (Figs. 3 and 4). Cultivated crops were mainly delivered in the southern coastal platform and regulating services were greatest in the central and northern mountains. In the coastal platform most cultivated crops (85%) were characterized as intensive agriculture (harvested two to three times per year) of tomatoes, cucumbers, zucchini, peppers, and eggplant in greenhouses (Fig. 3a). Most of the greenhouses are in the south of the study area (Fig. 3a), which had the highest agricultural production. Non-greenhouse agriculture is mainly distributed along the sedimentary valleys (e.g., Nacimiento and Andarax River valleys, Figs. 1 and 3a), but has much lower level of production (15% of total production). Soil carbon stock was most pronounced in high mountains due to the high carbon contents of Cambisols and Regosols (Figs. 1 and 3b). This area was also dominated by coniferous and sclerophylous forests (80%).

Mean groundwater recharge for the study area was 70 mm year⁻¹, approximately 25% of mean annual precipitation. Based on a modification applied to the APLIS model accounting for reduction in permeability for specific land cover types (e.g. greenhouses and urban areas), the total water recharge by aquifers for the study area was reduced by 50%, from 367 hm³ year⁻¹ to 170 hm³ year⁻¹ (Appendix F). The highest groundwater recharge was in Sierra de Gádor, a karst system in the sedimentary mountains (Figs. 1 and 4c).

Erosion control capacity was relatively low throughout the entire study area, with 70% of the area suffering high soil loss (more than 10 tons ha⁻¹ year⁻¹). Flatter slopes and areas with denser tree coverage had greater erosion control, while areas with steeper slopes and torrential rainfall experienced the greatest soil losses. The lowest soil losses occurred in sedimentary valleys (the Andarax and Nacimiento river valleys) and in the coastal platform, particularly in the Campo de Dalias (Fig. 1). The highest soil losses were calculated for the southern slope of Sierra Nevada and Tabernas Desert (Fig. 3d).

Finally, our analysis of maintaining habitats for threatened vertebrates based on the biodiversity combined index showed that the whole study area is more important for bird conservation (BCI mean of the area = 0.11, SD = 0.3) than for mammals (mean = 0.06, SD = 0.17), reptiles (mean = 0.01, SD = 0.07), or amphibians (mean = 0.0003, SD = 0.002). The higher number of threatened birds compared to other vertebrates in the study area explains the high BCI value across the study area (Appendices E and G). There was a strong, positive correlation between rarity and vulnerability within taxonomic groups (Rho = 0.97, p < 0.0001, n = 10117).
4.2. Demand for ecosystem services: socio-cultural and economic valuation

Analysis of social preferences showed that 78% of the stakeholders think that the study area provides important ecosystem services to society. The preferences analysis also showed that regulating services were most frequently perceived to be important by the stakeholders, followed by provisioning services. Water flow maintenance was judged to be the most important service by all stakeholders, followed by global climate regulation and maintaining habitats (Table 2). In contrast, control of erosion and crop cultivation were the least important to the stakeholders. A similar pattern was obtained using the economic approach, as stakeholders were most willing to pay for water flow maintenance, followed by climate regulation. Control of erosion was the service with the lowest WTP for its maintenance.

High mountain and saline marshland were the landscape units perceived as most important in terms of providing ecosystem services to society. The major discrepancies regarding socio-cultural and economic values occurred in high mountain landscape, where the water flow maintenance and the climate regulation were considered the most important, but the least economically valued services (Fig. 4).

4.3. Analysis of ecosystem service trade-offs across landscape units

The analysis across the different value-dimensions suggests that biophysical, socio-cultural, and economic dimensions to address ecosystem services generate different but complementary results (Table 2; Fig. 4). Trade-offs between the different ecosystem services can be observed, particularly in the landscape units where the delivery of cultivated crops is compromising habitat maintenance for vertebrates (Figs. 3 and 4a). The socio-cultural values showed different preferences for all ecosystem services across landscape units, specifically for climate regulation, erosion control,

Table 2

<table>
<thead>
<tr>
<th>Ecosystem services</th>
<th>Socio-cultural dimension</th>
<th>Economic dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% of respondents (n)</td>
<td>( \chi^2 )</td>
</tr>
<tr>
<td>Provisioning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cultivate crops</td>
<td>23.24 (79)</td>
<td>16.42**</td>
</tr>
<tr>
<td>Regulating</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climate regulation</td>
<td>47.06 (160)</td>
<td>28.56**</td>
</tr>
<tr>
<td>Water flow maintenance</td>
<td>61.18 (208)</td>
<td>24.69*</td>
</tr>
<tr>
<td>Control of erosion</td>
<td>25.88 (88)</td>
<td>17.92*</td>
</tr>
<tr>
<td>Maintaining habitats</td>
<td>30.29 (103)</td>
<td>28.99**</td>
</tr>
</tbody>
</table>

\*\* p-value < 0.05.
** p-value < 0.01.
Fig. 4. Ecosystem services values for each value-dimension (biophysical, socio-cultural and economic) considering the different landscape units. Biophysical dimension express the spatial average mean delivery standardized from 0 to 1. Socio-cultural dimension is expressed as the % of total beneficiaries interviewed. Economic dimension shows the mean scores for WTP (euros/year) for ecosystem services.

and cultivated crops (Fig. 4b). However, perceptions for water flow maintenance were homogenous across landscape units, indicating a consensus of its consideration as the most socially valued service. The economic valuation across landscape units also showed that regulating services, i.e., water flow maintenance and climate regulation, had higher values than the provisioning services, i.e., cultivated crops (Fig. 4c). The economic values of services varied widely across landscape units, and were particularly significant for cultivated crops, which was considered as the most important service in high mountains, and valued lowest in the metamorphic mountains, sedimentary valleys, and saline marshlands.

Overall, without considering the role of landscape units in our analysis, non-significant correlations were found between the three value-dimensions of ecosystem services. However, including the different landscape units in the correlation analysis, a significant and positive correlation was found between the socio-cultural and economic value-dimensions (Rho = 0.900; p-value < 0.1).

The trade-offs analysis using the three value-dimensions indicated different results for each value-dimension. First, we found trade-offs between the biophysical delivery and socio-cultural values of ecosystem services. For biophysical values, we found weak correlations between climate regulation and water flow maintenance (Rho = 0.943; p-value = 0.017), and between erosion control and climate regulation (Rho = 0.892; p-value = 0.058). We also found a negative correlation between cultivated crops and maintaining habitats (Rho = −0.943; p-value = 0.017), which is likely due to the impact that agricultural intensification has on species protection. Regarding socio-cultural values, significant negative correlations were found between cultivated crops and erosion...
control ($Rho = -0.871; \ p-value < 0.05$). No significant correlations were found between the WTP for services protection across landscape units.

Secondly, the mismatch analysis indicated differences when comparing the biophysical service delivery levels and social and economic values within landscape units (Fig. 4). For example, in the high mountains, there is no economic value for cultivated crops and we did not expect agriculture to be viewed as important because most of this area is protected (Fig. 1, Sierra Nevada National Park); nonetheless, the sociocultural and economic perception of agriculture was high. In contrast, within the coastal platform, a mismatch is observed between the high biophysical supply and the poor sociocultural value of cultivated crops. Generally, we did not find significant correlations (positive or negative) between economic and biophysical dimensions, which emphasizes the effect of landscape units on the provision level and the WTP for services protection, and demonstrates the complementarity of all dimensions in the ecosystem services assessment.

5. Discussion

Human systems and ecological systems are inextricably linked, representing social-ecological systems (Chin, Florshiem, Wohl, & Collins, 2014; Ostrom, 2009). We mapped landscape units in a manner that characterizes and maps ecologically homogenous subunits, based on the identification of common environmental factors (i.e., climate variables, geomorphology or altitude) that control ecosystem properties across different temporal and spatial scales (Metzger et al., 2005). These mapped landscape units reveal the complexity of organizational, spatial, and temporal couplings within an area (McConnell, Millington, Reo, Alberti, & Asbjornsen, 2011). However, our approach also considered the social sub-system by exploring how people interact with nature, creating an understanding of coupled natural and human systems (Brunckhorst, Coop, & Reeve, 2006). Finally, the ecosystem services framework (Fig. 2) allowed to explore the spatial linkages between the biophysical capacity of landscapes to provide benefits (supply side) and societal needs for those benefits (demand side). The end result is a spatially explicit description of the coupled ecological and social subsystems, which ultimately can be used for sustainable management (Carpenter et al., 2009).

Studies that carry out explicit spatial comparisons between the biophysical supply of and societal demand for ecosystem services are uncommon and represent a current challenge (Burkhard, et al., 2012a; Seppelt, Dormann, Eppink, Lautenbach, & Schmidt, 2011; Seppelt et al., 2012). We found that spatially examining different value-dimensions of ecosystem services (biophysical, socio-cultural and economic) provides complementary information and allows identification of trade-offs between the supply of and demand for services. We also found that trade-offs among services vary across different landscape types. Because our methodology compares the biophysical delivery of services with social preferences and economic values across different landscapes, it provides an interesting approach to identifying areas where the delivery of services and social demand for those services are mismatched (Burkhard, de Groot, Costanza, & Seppelt, 2012; Burkhard, Kroll, et al., 2012; García-Nieto, García-Llorente, Iniesta-Arandia, & Martín-López, 2013). This information on mismatches should lead to better and more efficient landscape planning, and should be particularly helpful in identifying priority areas for conservation (Luck et al., 2009; Raudsepp-Hearne et al., 2010).

We found trade-offs in the biophysical deliveries of ecosystem services among all landscape units (Fig. 4a). For example, low habitat maintenance in the coastal platform is due to intensification of cultivated crops. We also observed trade-offs and synergies in socio-cultural and economic dimensions across landscape units. For example, habitat maintenance was considered very important in saline marshlands and much less important in sedimentary mountains, while cultivated crops were most highly valued in the high mountains and least valued in saline marshlands (Fig. 4b). These trade-offs demonstrate the importance of evaluating multiple dimensions of ecosystem services (Carpenter et al., 2009; Chan, Shaw, Cameron, Underwood, & Daily, 2006; Daily et al., 2009; de Groot et al., 2002; Schneider, Van Daele, Van Langhuy, & Van Reeth, 2012).

Recent publications recommend that ecosystem service research should consider and implement different value-dimensions (biophysical, socio-cultural and economic) to provide complementary information regarding ecosystem services (Jax, Barton, Chan, Groot, & Doyle, 2013; Martín-López et al., 2014). In our study, we found disconnects between the biophysical delivery of ecosystem services and the services that people found important, reinforcing the importance of this recommendation. Currently, most studies assign monetary value to ecosystem services (Busch, La Notte, Laporte, & Erhard, 2012; Chan et al., 2012), which greatly undervalues services that are not easily converted into marketable commodities (e.g. the existence value of biodiversity). Our approach provides a framework where biophysical and socio-cultural properties can be compared in a spatial context beyond their monetary value (Tallis and Polasky, 2009). We also believe that differences across landscape units between sociocultural value (services importance) and economic dimension (WTP for services conservation) could be useful for conservation actions. On one hand, when the importance of services is considered by the general public, those opinions and views must be considered by managers and policymakers and included in decision-making processes. On the other hand, identifying aspects of these services that are perceived as the least important or those that people are not willing to pay for is useful in detecting potential conflicts of interest associated with new management and planning practices.

Spatial scale is a key issue in ecosystem services research since there is often a mismatch between the scale at which services are delivered and the scale at which those services are used, valued, or managed (García-Nieto et al., 2013; Palomo, Martín-López, Potschin, Haines-Young, & Montes, 2013), and researchers have proposed that assessment and mapping ecosystem service trade-offs should be made at the landscape level (Bennett, Peterson, & Gordon; Nelson et al., 2009; Raudsepp-Hearne et al., 2010; Rodrigue et al., 2006). We found that the landscape level is an appropriate scale to identify mismatches between the biophysical supply of and social demand for services. For example, in the coastal platform, a very low economic and socio-cultural value was placed on cultivated crops despite the high biophysical delivery of crops in this landscape unit (see Fig. 4a). This mismatch demonstrated that locals were unaware of the driving force, water recharge of aquifers, supporting the local economy of Almeria province (Downward and Taylor, 2007; Tschakert, 2007). Water flow maintenance was considered to be the most important service in terms of socio-cultural and economic dimension for all landscape units, however mismatches between its supply and demand across specific landscape units were found. For example, in saline marshland water flow maintenance was considered to be an important service with high economic value, even though its delivery was low compared to other landscape units. This supports the findings of Ward (2007) that stakeholders who are involved in intensive agriculture in water-limited areas (e.g. saline marshland) have a better understanding of water conservation issues. In our case, the greater WTP for water flow maintenance was likely associated with the perception that this service sustains the local economy (Downward and Taylor, 2007; Castro et al., 2011).
Our results should be interpreted within the limitations of our methodological approach. We assumed linearity between selected ecosystem services and the biophysical proxies used to quantify the landscapes’ capacity to deliver services, a common approach in the assessment of ecosystem services (Castro et al., 2013; Quintas-Soriano et al., 2014). For example, we used tons of cultivated crops per hectare as a proxy to estimate croplands production. This estimation could be more accurate if we had more detailed information on the resources required to produce tomatoes versus cucumbers, for example. Egoñ, Drakou, Dunbar, Maes, and Willemen (2012) reviewed this issue and stated that while provisioning services can be directly quantified, most regulating services are less straightforward and researchers must rely on indicators or proxy data for their quantification. Examples include our use of soil carbon stocks as a proxy for climate regulation and groundwater recharge as a proxy for water flow maintenance, as climate regulation and drinking water were the terms used to explain the derived benefits in the socio-cultural and economic assessments, respectively. Our study is a landscape scale, interdisciplinary assessment of different ecosystem services. Our results compare the potential capacity of different landscapes to preserve ecosystem services; this approach differs from more traditional, smaller-scale ecological studies. Assessing the social demand for ecosystem services through spatially explicit exercises is challenging (Brown and Kytta, 2014). While our study does not provide maps of socio-cultural and economic dimensions, our assessments of these dimensions are spatially explored with particular landscape units.

Understanding and quantifying trade-offs between ecosystem services is a key challenge for implementing ecosystem service approaches in land management and planning. Our study demonstrates the importance of integrating biophysical, socio-cultural and economic dimensions to assess the supply of and social demand for services. Our approach can be used by land managers to help in the identification of areas in which services are declining or priority areas for conservation based on maximizing ecosystem services, and will be useful in detecting potential conflicts associated with new management and planning practices.

Acknowledgments

Funding for the development of this research was provided by the Andalusian Center for the assessment of Global Change (CAESGC) (GLOCHRARD project), the ERDF (FEDER), Programa de Cooperación Transferizadora Espana – Fronteras Exteriores (POXTFEX-Transhabitat), Andalusian Regional Government (Junta de Andalucía SEGALERT Project, P09-RNM-5048), and Ministry of Science and Innovation (Project CGL2010–22314). The Oklahoma Biological Survey at the University of Oklahoma at the University of Oklahoma (US) has provided support for A.J.C., and the EU FP7 project OPERAs has provided support for P.V. We thank all the people who kindly responded to the interviews and the questionnaire.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.landurbplan.2014.08.009.

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