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ORIGINAL PAPER

Use of ecosystem information derived from forest thematic maps for spatial analysis of ecosystem services in northwestern Spain

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Abstract A clear link between ecosystem services (ES) and human well-being has been established in the recent decades. Thus, forests are recognised as extremely important ecosystems in relation to their capacity to provide goods and services to society. Nevertheless, this capacity greatly depends on the type of forest and on the management applied. Some types of data often used for this type of analysis, such as land use/land cover maps produced for general purposes, are not always appropriate for representing forest ecosystems and the services they offer. In this study, we used a forest map (Spanish National Forest Map: scale 1:25,000) and information describing composition and structure to assess six services closely associated with forest ecosystems in a forest-dominated zone of northwestern Spain on a regional scale. The following ES were considered: provision of food (basically fruits), provision of materials (timber and pulp), provision of biomass for energy (firewood), climate regulation (carbon storage by above-ground biomass), erosion regulation (protection against erosion), and cultural (recreational use and nature tourism). By combining information about tree species and cover with forest harvest data and other statistics, we established representative spatial models for the six ES representing different categories of the potential supply of each one. The six models were analysed by different methods (Spearman's correlation, Moran's I and Getis-Ord Gi*), enabling detection of hotspots and coldspots and the characteristic spatial scales for ES supply. The combined use of highly detailed map data, nonspatial databases and spatial analysis yielded accurate ES supply assessment.

Keywords Multiscale analysis · Forest ecosystem services · Thematic cartography · European Atlantic region · Hotspots · Coldspots

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Introduction

The concept of ecosystem services (ES) has become increasingly important in different fields of ecology, environmental management and land-use planning in recent years, and these topics have been addressed in many articles, projects and initiatives (e.g. MEA 2005; EME 2011; Seppelt et al. 2011; Schägner et al. 2013). ES studies are performed at multiple spatial and temporal scales and involve different ecological zones and ecosystem types. Forests are of particular importance for ES supply because of the large surface area covered, the high biodiversity and the multiple ES supplied. Their importance as ES providers has been highlighted by different authors (e.g. Turner et al. 2007; Patterson and Coelho 2009). Amongst the wide range of forest ES identified, those associated with habitat maintenance, provision of materials and energy, regulation of climate, erosion prevention, flood and biological cycles, cultural services such as recreation, aesthetic values and traditional knowledge, are particularly important (Duncker et al. 2012; Gamfeldt et al. 2013; García-Nieto et al. 2013). For quantification and assessment of ES, it is important to differentiate between potential ES supply (the capacity of a spatial unit to provide a specific ES in a certain time period) and ES flow—the actual amount of a specific ES used (Burkhard et al. 2014). In order to integrate ES assessment with land-use planning and management tools, several authors have focused on spatial analysis of ES. This has led to the development of conceptual frameworks that have improved methods of ES mapping, modelling and spatial analysis (i.e. Maes et al. 2012; Crossman et al. 2013; Mouchet et al. 2014). Spatial aspects such synergy, and tradeoffs between different types of ES—e.g. between provisioning services and regulation or cultural services (García-Nieto et al. 2013; Martín-López et al. 2014)—and their relationships with biodiversity and landscape heterogeneity (Turner et al. 2012; Anderson et al. 2009) should be considered in land-use planning. Identification of areas with high or low ES supply (hotspots or coldspots) is key to developing ES-based land-use policies and related environmental management policies (Egoh et al. 2009).

Land-use/land-cover (LULC) data are often used to map and analyse ES supply. However, there are some uncertainties associated with ES mapping approaches based only on LULC data (Hou et al. 2013). For example, the transfer of sampled point data to larger spatial units such as LULC types leads to generalisations for the whole study area. In reality, ES supply does not take place homogeneously within an LULC type or across different spatial scales (Eigenbrod et al. 2010). In addition to LULC or ecological processes on large spatial scales, some ES are associated with structural landscape elements, such as corridors and habitat patches. Such elements normally cover small areas or are fragmented in small patches. Therefore, the spatial resolution of geographic data used for ES assessment should enable their identification (Kandziora et al. 2013). The thematic resolution of the spatial database (e.g. number of LULC types) may also affect ES assessment, especially when the number of attributes does not sufficiently reflect the spatial peculiarities of the study area. Some LULC data, such as the European CORINE Land Cover (CLC; http://www.eea.europa.eu/data-and-maps/figures/corine-land-cover-types-2006), include different ecosystem types within one class. This is the case, for example, for the CLC type 3.1.1. broadleaved forest, which includes different types of forest ecosystems with distinct species composition, and spatial structure and ecological dynamics, such as native forest woodlands and plantations of exotic broadleaved species, which also provide different ES (Rodríguez-Loinaz et al. 2013). Consequently, the potential of LULC spatial data to characterise ES depends greatly on its spatial resolution, thematic degree of detail and associated information.

Similar issues have been identified in the study area (the northwestern Iberian Peninsula) (see "Study area" section), which can be considered forest dominated in relation to land use. Indeed, previous studies carried out in the study area addressed ES supply by using LULC maps (Roces-Díaz et al. 2014a) and remote sensing information (Roces-Díaz et al. 2015) as basic data sources for the analysis. In these studies, forest ecosystems were identified as dominant elements in the landscape, with a high potential for service supply. From the point of view of climate, the potential productivity in the area is high, especially in low-lying areas (Benavides et al. 2009). Although the area spans <10 % of the total surface area of Spain, it provides 60 % of the annual Spanish timber harvest volume (MAGRAMA 2013a). This is basically provided by plantations of *Eucalyptus* spp. and *Pinus* spp. These plantations have become more important since the second half of the twentieth century (Teixido et al. 2010) and have significantly altered the configuration of the traditional agricultural and forest landscape in the area (Saura and Carballal 2004). These plantations are highly productive (Lopes et al. 2009; Castedo-Dorado et al. 2012) and are intensively managed with the aim of providing forest products, such as pulp for paper production and timber. ES supply is therefore very different from that of native forests in the area, such as *Quercus* spp. (*Quercus robur* L., *Quercus petraea* (Matt.) Liebl.) and *Fagus sylvatica* L. (Onaindia et al. 2013; Rodríguez-Loinaz et al. 2013). Thus, accurate data on these forest ecosystems are needed to identify and quantify ES. In addition, sustainable forest planning, forest resource management and biodiversity conservation are based on the integration of various aspects of spatial and thematic ecosystems (García-Nieto et al. 2013; Onaindia et al. 2013). By analysing these aspects in different forest ecosystems, synergy and tradeoffs between different forest ES can be identified, quantified and assessed in relation to the type of management applied (Duncker et al. 2012).

Thus, the objectives of this study were as follows: (1) to quantify the potential supply of six ES by using a detailed forest map with high thematic and spatial resolution and including information about tree species composition and tree cover; and (2) to analyse the spatial distribution of forest ES supply and detect major hotspots and coldspots at different geographical scales.

Materials and methods

Study area

The study was carried out in northwestern Spain in the autonomous communities of Asturias and Galicia located in the European–Atlantic Region (EEA 2011). These autonomous communities comprise 63 % of the Atlantic region in the Iberian Peninsula (Fig. 1). The study region covers an area of 40,200 km^2, of which ~40 % comprises forest land. The elevation ranges between 0 and >2500 m, and the terrain is rugged, especially in the eastern zone. The climate is oceanic throughout most of the area, and the mean precipitation exceeds 1000 mm/year (Ninyerola et al. 2005). Although the amount of precipitation decreases in summer, physiological drought only occurs in an area of ~5000 km^2 in the southwestern part of the study area, which is within the Mediterranean climate region. This zone is one of the most densely forested regions in Spain (MAGRAMA 2013a). During the last century, human activities have greatly transformed the most easily accessible areas at low and medium elevations (<1000 m). Much of the low-lying land is used to produce fast-growing species, such as *Eucalyptus* spp. and *Pinus* spp. for timber production. Remnants of natural forests with *F. sylvatica*, *Betula* spp. and *Quercus* spp. can still be found as the main species in this area (Roces-Díaz et al. 2014b). However, these forests are more abundant in the mountainous zones than in low-lying areas (Garcia et al. 2005), and their ecosystems are often scattered within habitats associated with livestock use, such as meadows and heathlands. The timberline is represented by deciduous forest and rarely exceeds an elevation of 1700 m (Díaz and Fernández-Prieto 1987).

Data sources

Forest database

The main data source used in this study was the Spanish National Forest Map (1:25,000), constructed and provided by the Spanish Environmental Agency (MAGRAMA 2013b). The map is based on data collected over a period of 6 years (2007–2012) and work including the digitising of orthophotographs of the study area. Homogeneously occurring spatial features were digitised by focusing on forest features and with a minimum mapping unit of 1 ha for forest areas. For each type of feature digitalised in the map, an exhaustive, hierarchical classification based on forest structural type was developed: information on cover classification, strata level, canopy cover, structural type and main-component tree species is available for each polygon. As a consequence, detailed information on the forest ecosystem structure is available, constituting a reliable source of data for assessment of ES supply.

The spatial databases of five administrative zones (Spanish provinces of A Coruña, Asturias, Lugo, Ourense and Pontevedra) included in the forest map were merged in a shapefile that contained 129,556 individual polygon features. Information about the three main forest species (SP_i code), area covered (% of total area within the polygon) and total vegetation cover in the patch (% of total patch area) was attributed to each polygon.

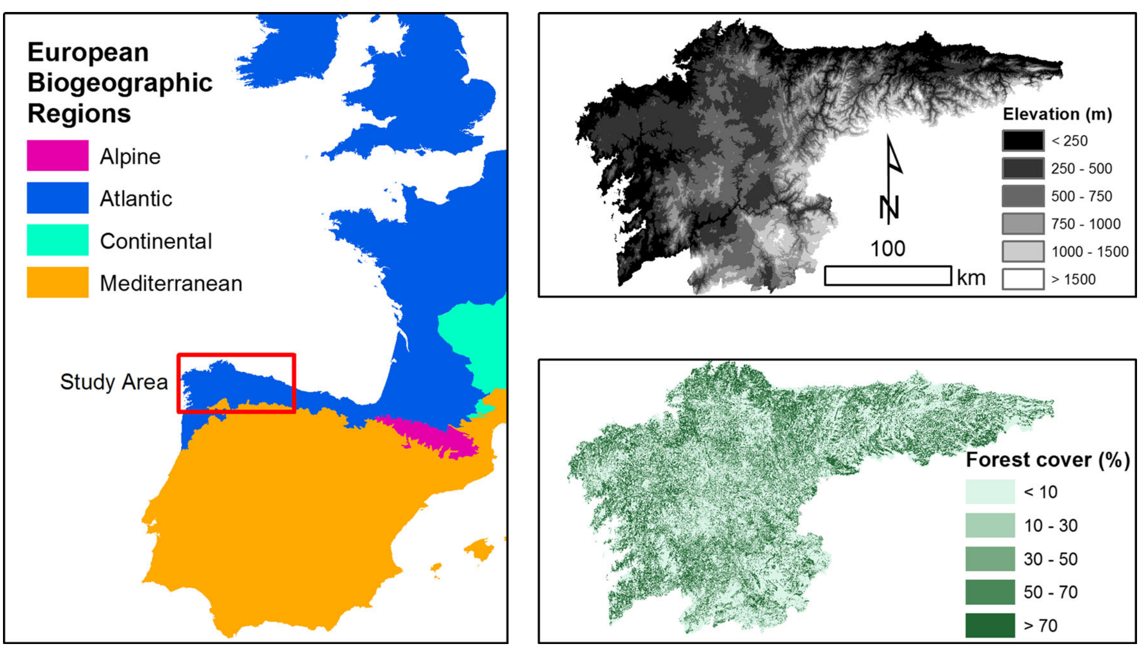

Fig. 1 Location and biogeographical classification of the study area (*left*; based on EEA 2011). Digital elevation model (*top right*; taken from IGN 2014) and forest cover (*below right*) based on the Spanish National Forest Map (MAGRAMA 2013b)

Selection of ecosystem services

The potential supply of six forest ES was analysed. The ES were selected from the most extensive types of ES classification (i.e. MEA 2005; Haines-Young and Potschin 2015), considering their representativeness and specific importance to the study area. We thus selected ES closely associated with forest ecosystems that can be analysed with the type of information provided by our data. The following six ES were considered:

(1) Provision of food (basically fruits provided by forest tree species)

(2) Provision of materials (mainly timber and pulp)

(3) Provision of biomass for energy (firewood for domestic use)

(4) Climate regulation (carbon storage by aboveground forest biomass)

(5) Erosion regulation (protection against erosion by forest cover)

(6) Cultural (including aspects such as recreational use and nature tourism)

Assessment of potential ES supply

The assessment method is outlined in Appendix S1 (Supplementary Material). For each ES, the individual potential supply was assessed on the basis of different types of information: (1) forest statistics for the study region, (2) scientific literature and (3) expert criterion on the basis of observed data (available forest statistics) and previously reported information on ES. We established criteria for classifying the potential supply of each ES. The expert criterion was used to complement the assessment of some ES, for which data were otherwise difficult to obtain. Experts involved in this process include a forestry engineer with experience in the Spanish Ecosystem Services Assessment (EME 2011), a forestry engineer with experience in forest cartography and inventory, an agricultural engineer with experience in landscape ecology, two geographers with extensive experience in ecosystem services assessment and a biologist with extensive experience in ecosystem analysis and modelling. Specific information about the classification of potential supply capacities of each of the six selected ES, the different criteria and data used are provided in the Supplementary Material.

We basically identified which species from the whole database have the potential to supply each ES in each patch (polygon). On the basis of the three above-mentioned data sources, the selected polygons were classified into six categories of potential ES supply: no relevant, very low, low, intermediate, high and very high. The method and assignment of classes (matrix method) have previously been described (Burkhard et al. 2009, 2012). For example, for food provision, forest tree species that could provide fruits for human consumption (i.e. 11 tree species) were first identified (Appendix S1). Patches where these specific tree species were present were then identified and classified according to their spatial cover (%) within the six potential ES supply classes. For provision of materials, species that have often been harvested during the last 25 years were identified using forest statistics for the area. The polygons covered by these species were then assigned to the six potential ES supply classes. A detailed description of the assessment process is given in Supplementary Material.

Analytical methods

For each ES, a map of the potential supply was created. Each of the six maps were then analysed at (1) regional and (2) local spatial levels using a Geographic Information System (GIS). A more detailed description of these methods is provided in Appendix S2.

Analysis at the regional level

Spatial relationships between the different ES were analysed using a large sample of GIS 12,000 points randomly distributed over the whole study area. Sample size was selected after trials with different sizes (from 5000 to 15,000). Results obtained for samples >12,000 points were similar, and therefore, we used this size as representative of the study area. For this sample, Spearman's correlation coefficients between these points were calculated for the six ES to compare their spatial pattern. In order to explore the characteristic spatial scales of each ES supply pattern, the incremental spatial autocorrelation (ISA) for the 12,000-point sample was calculated. The ISA runs the Moran's I index (Appendix S2; Moran 1948; ESRI 2013a) for a series of increasing window sizes, measuring the intensity of spatial clustering for each size. The curve for the Z_I scores (vertical axis) and window sizes (horizontal axis) shows peaks that indicate distances where the spatial processes of clustering are most pronounced: this enables detection of the spatial scales at which the clustering based on Moran's I took place.

In order to identify areas of high and low ES supply (respectively hotspots and coldspots) in each ES map, the Getis-Ord Gi* statistic (Getis and Ord 1992, Ord and Getis 1995) was calculated (see Appendix S2). For a given data set, the Getis-Ord Gi* statistic identifies clusters of spatial features with values (of potential forest ES supply) higher (or lower) than those expected to be found by random chance (ESRI 2013b). The output of the Gi* is a Z-score for each feature that represents statistical significance of clustering for a specified distance. Higher Z-scores indicate higher intensity of feature value (ES supply) clustering and hotspots of ES supply. Negative Z-scores indicate clusters with low ES supply values (coldspots).

Analysis at the local level

The six ES were analysed at the local level for the 393 municipalities in the study area. Administrative units are often used as spatial references in official statistics and play an important role in planning and decision-making processes. It was therefore important to analyse how the spatial distribution of ES supply is represented at the basic levels of spatial administration. For this purpose, each cell was assigned a value between 0 (no relevant potential supply) and 5 (very high potential supply). The values of cells for each municipality were summed to produce a map with the classification of potential forest ES supply within the municipal spatial limits of the area. The Getis-Ord Gi* statistic was calculated (as described above) for each ES to detect clusters of municipalities with high or low levels of potential ES supply.

Results

Maps of potential supply of forest ecosystem services

The maps in Fig. 2 show the potential supply of the six selected forest ES and the spatial supply pattern of each ES in the study area compiled at a comparably high spatial resolution of 1:25,000. Substantial differences in the no relevant potential supply areas were observed for each ES. These zones are larger for some ES, such as food provision and culture, and smaller for others, especially for erosion regulation. Most areas supplying food are in the central and eastern parts of the study area. Zones with no relevant potential supply of food provision cover 88.8 % of the study area, while such zones cover between 0.1 and 4.5 % for the five remaining classes (see Fig. 2). Zones with high and very high potential supply of materials provision services comprise 20.6 % of the study area and are mainly located in areas close to the coast, especially in central and western areas. Energy provision and climate regulation services show a similar pattern, with smaller areas of no relevant supply (53.5 % for both ES) and a broader distribution over the study area. For these two forest ES, zones with medium, high and very high potential ES supply make up >25 % of the whole area. Erosion regulation shows a quite different pattern from the other ES. No relevant supply areas are found in only 9.6 % of the area, mainly in the western part. More than 75 % of the area is covered by intermediate, high and very high potential erosion regulation ES supply areas. Finally, cultural forest ES include large zones of no relevant supply (67.3 % of the study area). Zones of intermediate, high and very high cultural supply together comprise 28.6 % of the area and are mainly located in mountainous areas away from coastal zones.

Regional analysis

Table 1 shows the Spearman correlation coefficients between supply values for the sample. All forest ES are positively and significantly correlated (at $P < 0.01$). Correlation coefficients varied from 0.27 (food vs. materials provision) to 0.96 (energy provision vs. climate regulation). For example, correlation coefficients for food provision were <0.56 for the remaining five ES. Materials provision was highly correlated with energy provision and climate regulation. Energy provision was closely correlated with materials provision, climate regulation and cultural ES.

Results of the incremental spatial autocorrelation method enabled identification of different spatial patterns and characteristic scales of forest ES supply. Figure 3 shows Z_I-score (vertical axis) values of Moran's I coefficient for different window sizes, which delimit a spatial domain definable as the characteristic scale at which the ES is provided (horizontal axis, from 5000 to 150,000 m). No curve shows a clear peak on the range of distances analysed. The food and materials provision services show similar curves until a spatial domain defined by a window of 20,000 m. From this window size onwards, food provision has higher values and does not show a clear peak, while materials provision has a small peak at 95,000 m. Curves for the remaining ES have lower values, with a small increase for the smallest windows and a flat shape for larger sizes. Thus, curves for cultural services and erosion regulation are of similar shape for sizes <35,000 m, while curves for energy provision and climate regulation have similar shapes up to 75,000 m.

Calculation of the Getis-Ord Gi* statistic enabled identification of hotspots and coldspots in the potential supply of each ES (Fig. 4). Hot/coldspots are zones with spatial clustering of features with high/low values of ES supply. They show different spatial distributions for the six ES. For example, hotspots of food provision are clustered in the central and eastern zones, whereas there is a very large coldspot covering almost the whole western part of the study area. Materials provision hotspots appear on the coast of the central and western zone. Energy provision, climate regulation and cultural services show similar distributions, and erosion regulation services show hotspots in the eastern part of the study area, distributed following the direction of the Cantabrian Mountains.

Local analysis

Analysis of the potential supply of the six forest ES in the 393 municipalities in the study area yielded different results from those obtained at the regional level. Local-level analysis shows differences in spatial distribution of

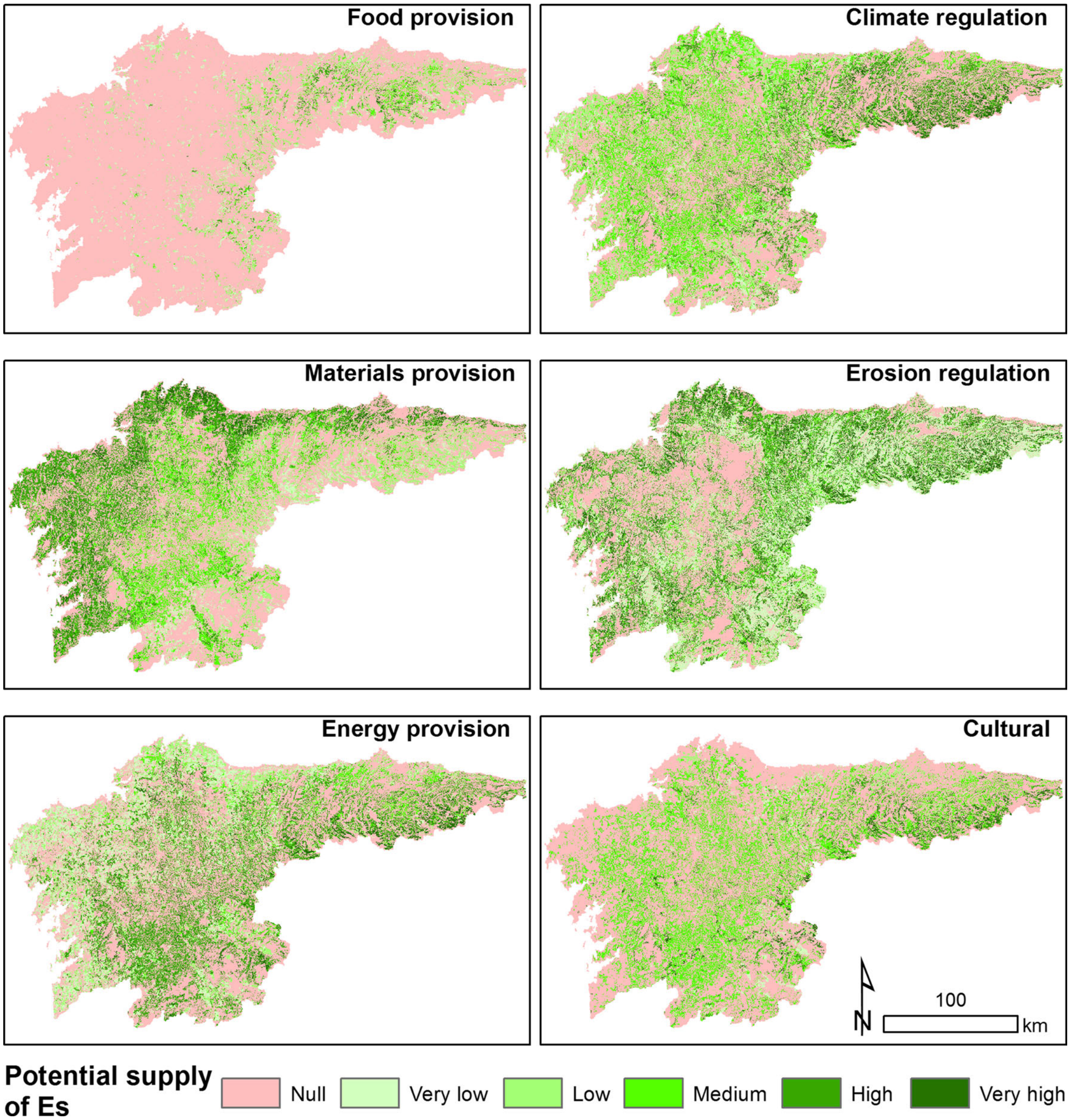

Fig. 2 Maps of potential supply of forest ecosystem services (ES). Values represent percentage of total study area covered by each potential forest ES supply class

Table 1 Correlation coefficients for the potential supply of the six forest ES (data of the 12,000 points sample)

Forest ES	Materials provision	Energy provision	Climate regulation	Erosion regulation	Cultural
Food provision	0.27	0.46	0.56	0.31	0.50
Materials provision	–	**0.82**	**0.85**	0.42	0.55
Energy provision	–	–	**0.96**	0.48	**0.86**
Climate regulation	–	–	–	0.50	**0.84**
Erosion regulation	–	–	–	–	0.40

Bold indicate correlation values higher than 0.8

the ES. Nevertheless, the extent of administrative units obviously influences results, with higher values obtained in the largest municipalities (Fig. 5). For food provision, municipalities with highest values are located in the eastern areas, where respective hotspots are also located. The western zones comprise a large coldspot. The highest

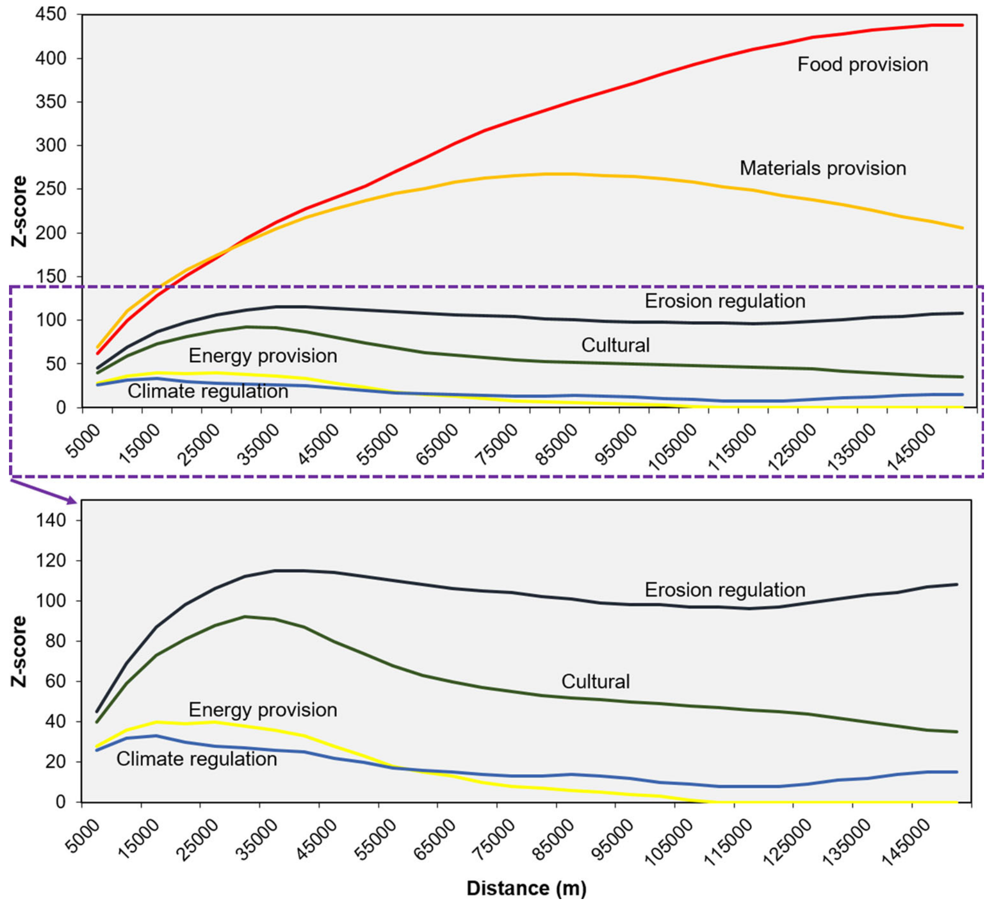

Fig. 3 Curves of incremental spatial autocorrelation analysis for the potential supply of the six ecosystem services (data representing the sample of 12,000 points)

values for materials provision (and corresponding hotspots) occur in zones close to the coast. The remaining four ES show a similar pattern, and municipalities with highest values of ES supply occur in inland zones of the eastern half, where hotspots are basically located in the zone comprising the Cantabrian Mountains.

Discussion

Cartographic information about forest ecosystems in the northwest of the Iberian Peninsula was used to estimate the potential supply and spatial distribution of six forest ES. Data are based on precise information about structural characteristics of forest features. In addition to type of forest, each map polygon contains information about tree species structure, composition and cover. This information enabled us to characterise the ecosystems beyond the thematic classification, thus enhancing data analysis and interpretation in comparison with ES mapping based solely on land-cover data. In addition to the higher thematic resolution, spatial resolution is also high. Data were mapped at a scale of 1:25.000, with a minimum mapping unit of 1 ha for forest areas. These resolutions enabled us to include some ecosystems that, although of small extension, have a valuable potential of supply for different ES (e.g. riverbank woodlands). In addition, information associated with each patch regarding its internal structure and species composition allowed us to determine some ES related to the presence of some forest species (e.g. food provision by tree with fruits; materials provision by forest plantation of *Eucalyptus* sp. or *Pinus* sp.; etc.). However, these criteria cannot be used to analyse all ES, because less information is available in the database about non-forest ecosystems than about forest ecosystems. When using these forest data as a basis for identifying ecosystems and their services, both factors enabled (1) removal of some of the bias derived from the use of overgeneralised and simplified LULC proxies in ES assessments (Eigenbrod et al. 2010), and (2) reduction in uncertainties associated with this type of analysis (Hou et al. 2013). Higher-resolution cartographic data are therefore useful for characterising ES supply if they provide ecosystem characteristics at a sufficient level of detail (Kandziora et al. 2013).

As already mentioned, the spatial pattern of ES for this study area was previously analysed by using an LULC map (Roces-Díaz et al. 2014b) and remote sensing data (Roces-

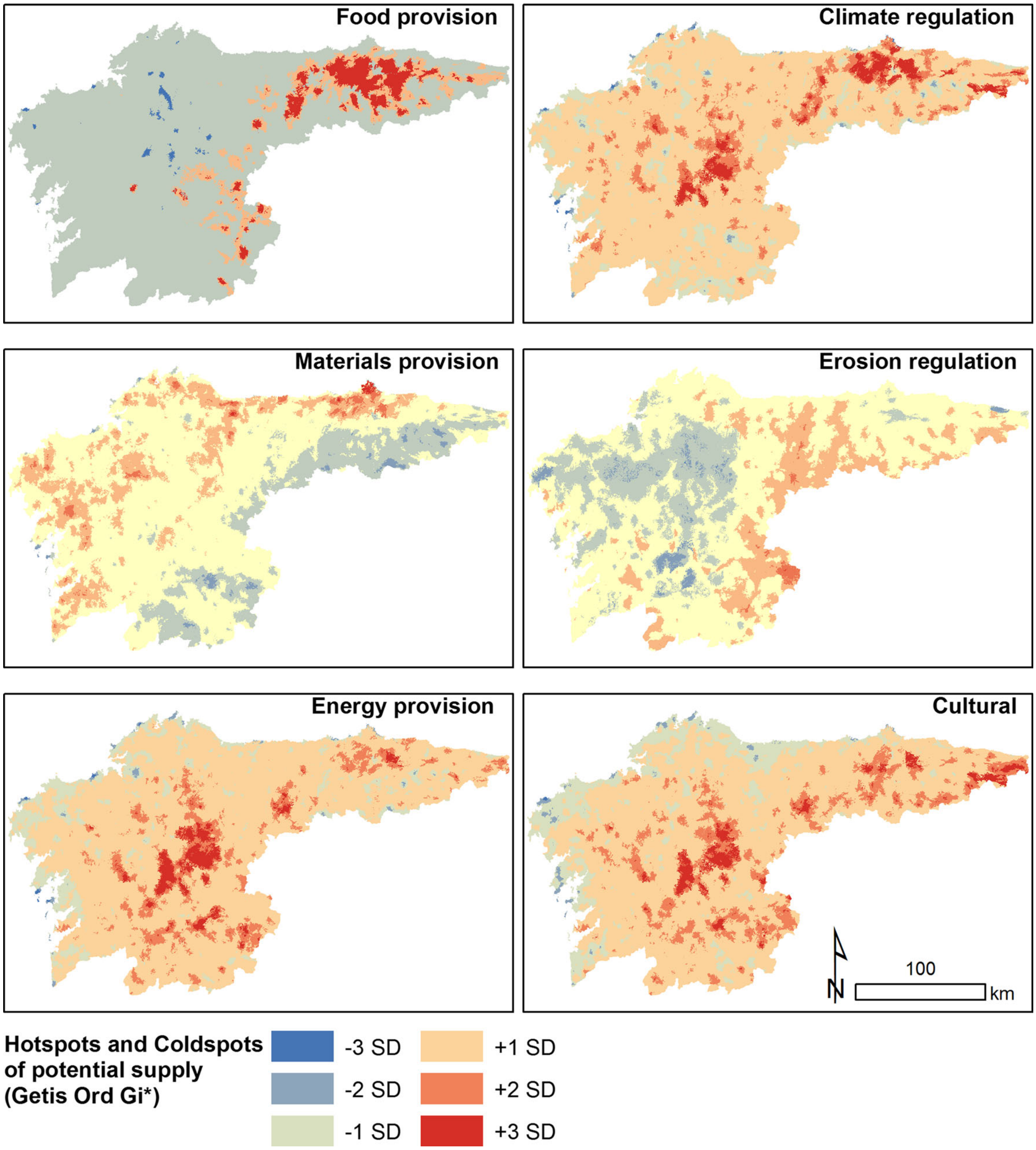

Fig. 4 Maps of hotspots (+1, +2 and +3) and coldspots (−1, −2 and −3) of potential forest ecosystem services (ES) supply based on standard deviation of Getis-Ord Gi* statistic

Díaz et al. 2015). However, LULC and remotely sensed information sources do not include relevant aspects about forest ecosystems. Due to the importance of such ecosystems in the study area, the approach used in the study integrates information about species composition and forest structure, thus allowing more detailed analysis of the ES supplied. Results show differences between the spatial patterns of the six ES analysed. Food supply and cultural services have larger areas of no relevant potential supply and more clustered patterns of areas with high supply than the other ES. Regulating services show larger potential supply areas, which are distributed throughout the study area. Comparable results were obtained in studies focusing on the spatial characterization of ES patterns in areas both close to (García-Nieto et al. 2013; Roces-Díaz et al. 2015) and distant from the study area (Qiu and Turner 2013). Incremental spatial autocorrelation (ISA) analysis enabled identification of spatial clustering and specific spatial scales of ES supply. The relevance of spatial scales in ES assessment has been highlighted in different studies (i.e. Martín-López et al. 2009; Roces-Díaz et al. 2014a; Castro et al. 2014; Geijzendorffer et al. 2015). Ecological

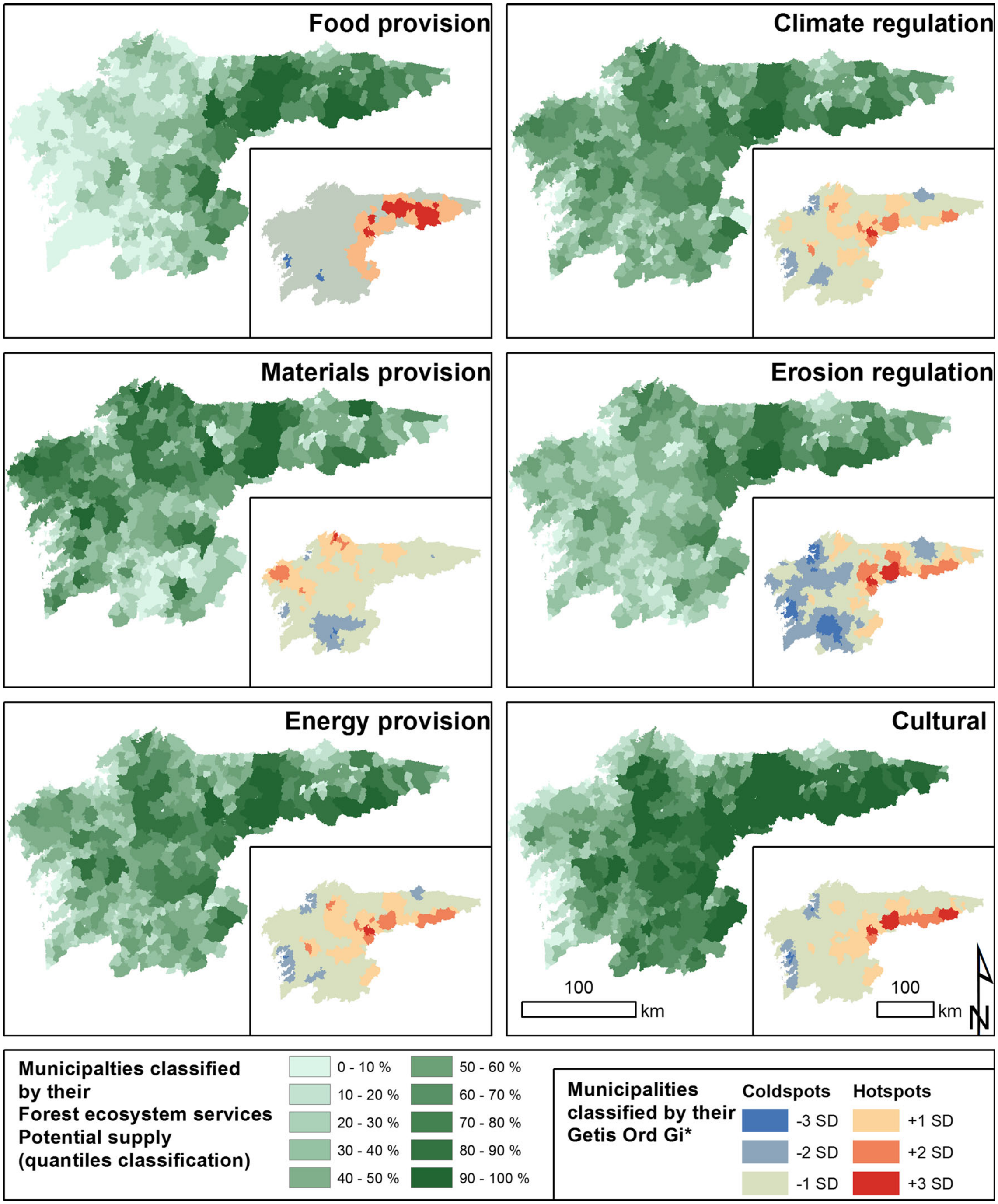

Fig. 5 Sum of potential supply of forest ecosystem services (ES) by municipalities and detection of hotspots (+1, +2 and +3) and coldspots (−1, −2 and −3) of potential ES supply based on standard deviation of the Getis-Ord Gi* statistic

processes operate at different spatial and temporal scales (Hein et al. 2006), generating different ES at each scale.

Each ES showed scale-specific behaviour. Thus, food ES showed very definite areas of supply and were clearly concentrated in eastern parts of the area. ISA results showed a curve of increasing values, higher than for the other ES and without any peak or inflexion point. This can be interpreted as spatial clustering of the areas of supply, which would transcend the limits of the geographical area under study. Thus, two domains of scale may be taken into consideration: one higher than the study area and another identifiable only within the definite areas previously described and which may require partition of the study area in two smaller areas (eastern and western). ISA results for materials provision show a peak corresponding to a window size of 95,000 m and with higher values than for the other ES, except food provision. This peak could define the spatial scale at which the provision of materials is manifested in the area. The spatial heterogeneity and Z-scores of these two ES were higher than for the others. Moran's I index values were also much higher for food and materials provision than for the other ES. Two main trends can be detected for energy provision and cultural services, both of which show an initially increasing trend, peaking at, respectively, 30,000 and 35,000 m and then decreasingly sharply and finally adopting a more moderate but decreasing trend. Such peaks can be interpreted as the extension at which the maximum spatial variability of the Z-score is verified and can be identified as a characteristic scale for supply of the service. Beyond these peaks, variability decreases as area size increases. Consequently, any increase in area size defined by peaks would not yield relevant changes in spatial pattern (i.e. spatial pattern shows a high degree of scale independence). Erosion and climate regulation initially showed a similar trend, with peaks defining similar spatial domains. However, instead of a continuous decrease after the peak, the curve tended to increase towards the end. This may reveal a possible second spatial domain, identifying clustering at a new spatial level beyond the study region.

In summary, our analysis identified four different spatial scale conditions: supraregional clustering (food), clustering at intermediate subregional levels (materials), clustering at low subregional levels (energy and cultural) and two-level clustering (climate and erosion). The method used and results obtained have some points in common with other techniques that have been successfully applied in recent research for detecting spatial patterns of ES supply, such as lacunarity analysis (Roces-Díaz et al. 2014a) and four-term local quadrat variance (4LTQV; Roces-Díaz et al. 2015). Our results were supported by results of the correlation analysis, which enabled identification of different levels of positive correlation between the different ES. Correlation analysis is a usual method of exploring the occurrence of ES tradeoffs and bundles (Egoh et al. 2009; Mouchet et al. 2014). Regulating (climate and erosion) services, materials provision and cultural services were generally more closely correlated with each other than with food provision. This may be due to the wood-density criterion that was selected for the classification. Wood density was strongly correlated with the amount of aboveground carbon stored in the ecosystem, which is usually high in native forest ecosystems such as *Quercus* spp. and *F. sylvatica* forests. Despite the high levels of carbon in forest soils of the area (Doblas-Miranda et al. 2013), the approach used for the climate regulation ES is not based on soil carbon content, as there were no available data sources with a similar spatial resolution to that used in our study. This is clearly a limitation of the model obtained for this ES. These forests are also important for the supply of cultural and erosion regulation services. Although fast-growing plantations with *Pinus* spp. and *Eucalyptus* spp., which are common on the study area, have a high potential supply of materials provision services (Lopes et al. 2009), their potential to supply other ES is comparably low. Native deciduous forests have lower growth rates (Castedo-Dorado et al. 2012) but have a higher potential supply of ES, such as climate regulation and cultural services (i.e. Rodríguez-Loinaz et al. 2013; Onaindia et al. 2013; Palacios-Agundez et al. 2014). Such differences in ES supply indicate the importance of ES-based forest (Fürst et al. 2013; Frank et al. 2015) and landscape (Castro et al. 2014) planning. Sustainable planning approaches should take into account ES to integrate multifunctional and multiple ES considerations. Our results are consistent with comparable ES correlation analyses. For example, Wu et al. (2013) and Raudsepp-Hearne et al. (2010) found that the two large groups of regulating and cultural services show clear tradeoffs with provisioning ES. Regulating and cultural services are often correlated in spatial ES analyses, and their occurrence is often higher in areas that are important for biodiversity conservation (Gimona and van der Horst 2007; Egoh et al. 2009).

Spatial analysis of hotspots and coldspots of ES supply are common (e.g. Egoh et al. 2009; Bai et al. 2011; García-Nieto et al. 2013; Schulp et al. 2014; Franko et al. 2015; Schröter and Remme 2016). However, few studies (e.g. Timilsina et al. 2013; Homolová et al. 2014) have used the Getis-Ord Gi* statistic to analyse them. Hotspots and coldspots can be interpreted as areas (grid cells) with very high/very low values of one variable used for assessing ES supply. The Getis-Ord Gi* is a simple and useful method for locating hotspots and coldspots of ES supply (Schröter and Remme 2016), with straightforward application to maps by using GIS software (ESRI 2013b). However, the method is sensitive to the spatial arrangement of groups for the source-point data, and careful interpretation of results is required. In this study, the Getis-Ord Gi* method was used to identify features (1) with a high/low value of potential ES supply and (2) that are surrounded by other features with high/low values. This means that detecting hotspots and coldspots depends on the spatial configuration of the study area. The patterns of ES hotspots and coldspots clarify the general spatial distribution of ES supply. They also help explain the differences in clustering from the ISA analysis, as explained above. Analysis based on municipal borders yielded a different spatial pattern than that based on database information for the forest-patch level. Results show a strong influence of the administrative unit area when this is used to obtain the relative values (i.e. level of provision by surface unit), which can result in misleading interpretations. Administrative units corresponding to different European NUTS levels are often used in ES assessments at different scales (Haines-Young et al. 2011) or regional municipalities (Rodríguez-Loinaz et al. 2015). However, using higher spatial and thematic resolutions for ES analyses is of interest in order to detect spatial patterns and local variations, such as hotspots and coldspots, which the municipal scale did not show. This must be taken into account in planning processes, especially with those instruments using administrative limits. The poor capacity to consider internal variability in the ES provision pattern could be improved by the use of systematic sampling units (i.e. cell grids of a certain resolution). These could reveal hotspots and coldspots more precisely due to the use of a regular pattern to derive the relative value of ES provision in a given geographical area and the capacity of such a pattern to reveal transitions related to changes in the physical environment, with no artificial limits.

Conclusions

Detailed data from thematic forest cartography were used to analyse the potential supply of six forest ES. Compared with common LULC-based approaches, the use of additional information in the database about forest species structure and composition enabled more accurate spatial ES assessment, although only in relation to forest ecosystems. We conclude that this type of map should be included in the analysis of ES on a regional scale. Results indicated differences between ES supply patterns. Different patterns of spatial clustering and scale were identified and are explicitly shown in the spatial representation of hotspots, which were calculated using the Getis-Ord Gi* statistic. Interrelationships were revealed by Spearman correlation analysis, which identified synergy between cultural and regulating services. We conclude that a method combining spatial and nonspatial statistics with highly detailed ecosystem data appears to be suitable for application in spatial planning and forest management and could be used to implement the ES framework on forest planning at a regional scale.

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