JOURNAL OF MAPS
2023, VOL. 19, NO. 1, 2223597
https://doi.org/10.1080/17445647.2023.2223597

SCIENCE

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Potential priority areas for forest-dwelling species in Spain based on the degree of forest fragmentation

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ABSTRACT

Habitat fragmentation is a process that may impair the "habitat provision" ecosystem service provided by forests. Thus, it is relevant to quantify the degree of forest fragmentation, since higher levels are expected to have greater effects on forest species. Our goal was to deploy the Forest Area Density (FAD) metric as a tool to derive maps localizing potential priority areas for species requiring large, relatively undisturbed blocks of forest. The Spanish Forest Map (1:50,000) provided comprehensive data on forestland in the country. We defined forest types considering the ten most abundant species in Spain and pure and mixed stands. Then, we calculated FAD by forest type and produced a set of maps showing the results by general management scenario, namely habitat conservation and restoration. To develop forest planning, specific actions can be implemented within these areas in later steps, fostering biodiversity at national or smaller scales.

ARTICLE HISTORY
Received 30 May 2022
Revised 17 May 2023
Accepted 18 May 2023

KEYWORDS
forest conservation; forest restoration; forest types; landscape structure; FAD; Guidos Toolbox

1. Introduction

Habitat fragmentation is a process during which 'a large expanse of habitat is transformed into a number of smaller patches of smaller total area, isolated from each other by a matrix of habitats unlike the original' (Wilcove et al., 1986). This process, which according to this definition involves both habitat loss and the breaking apart of habitat, gives rise to several negative ecological effects (Fahrig, 2003), impairing the provision of Ecosystem Services (ES) in general, and diminishing connectivity at the landscape scale in particular. Moreover, populations may decline due to an increased number of small habitat patches (Robinson & Wilcove, 1994), whose size may not be above the minimum patch size threshold of reproductive success (Butcher et al., 2010), or may suffer a reduction in gene flow (Adams & Burg, 2015; Coulon et al., 2004).

This being so, the effects of habitat fragmentation are species-dependent and context-specific (Chetcuti et al., 2020; Herrera & García, 2010; Hertzog et al., 2019), so it is important to notice that, in the case of forests, the specialist species dwelling in this particular habitat are those which suffer the negative effects. Thus, since forest fragmentation damages the 'habitat provision' ES of forests, it is relevant to measure the level reached by this process, as if habitat fragmentation effects are greatest in the smallest and most isolated fragments (Haddad et al., 2015), more negative effects are expected the higher the level reached. Moreover, the identification of continuous habitat areas could be of importance for conservation strategies of some species, although fragmented landscape structures may also play important roles in many situations (Fahrig et al., 2022).

Quantifying the degree of fragmentation requires measuring the pattern of habitat on the landscape (Fahrig, 2003). With this purpose, several metrics to be used as indicators have been proposed. One such approach for pan-European monitoring and analysis is the indicator 4.7 'Forest fragmentation' from the report 'State of Europe's Forests 2020' (Raši et al., 2020; https://foresteurope.org/), based on the Forest Area Density (FAD) quantification (Riitters et al., 2002; Riitters & Wickham, 2012). But transcending these purposes at pan-European level, more detailed analyses at national level are needed.

From a broad ecological perspective, the objective of habitat conservation is to protect and sustain existing diversity of ecosystems, species and their functions (Chazdon, 2019). Conservation actions, such as preserving extant habitat patches (Bodin & Saura, 2010) can prevent habitat fragmentation. Ecological restoration, on the other hand, entails assisting in the

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Supplemental map for this article can be accessed at https://doi.org/10.1080/17445647.2023.2223597.
This article has been corrected with minor changes. These changes do not impact the academic content of the article.

recovery of ecological functions, species composition, and productivity of land (Chazdon, 2019). Through restoration actions, such as the addition of new habitat patches (García-Feced et al., 2011), fragmentation can be reduced. Within the framework of large-scale forest planning, these general definitions are transposed into European and national planning instruments, in which multifunctional and sustainable forest management (SFM) is adopted, and thus the 'habitat provision' ES is included as an element to be taken into account.

In view of the above, to identify and locate management opportunities on a coarse-filter approach, two general management scenarios can be considered, namely conservation scenario and restoration scenario. Both scenarios may contribute to and are aligned with the Spanish Forest Plan (SFP), which articulates and allocates in space and time the policy lines defined in the National Forest Strategy. The SFP is structured in eight action lines, including two dealing with, respectively, the restoration of vegetation and the conservation of biological diversity in forest areas. Moreover, biodiversity conservation is also an implicit objective of all the action lines of the SFP (Solano López, 2006). In addition, these management scenarios may also apply to cover some of the commitments from the New EU Forest Strategy for 2030, the EU Biodiversity Strategy for 2030 and the Spanish National Strategy for Green Infrastructure and the Ecological Connectivity and Restoration (NSGIECR), recently approved on July 2021. Within both scenarios, specific measures at the regional or district level, for the development of the SFP or the green infrastructure (GI) elements, can be designed and implemented in later steps.

Mapping quantitative information on ecosystems is crucial for land use planning at different scales (Mancebo Quintana et al., 2010; Martín et al., 2016) and an important contribution toward forest management (Burkhard et al., 2012; Pedrotti, 2013; Puletti et al., 2017). Thus, focusing on forest planning at national level, our goal is to deploy FAD as a tool to derive maps localizing potential priority areas for forest-dwelling species (i.e. those that require large, relatively undisturbed blocks of forest and benefit from less edge) under the previously outlined habitat conservation and restoration scenarios. The degree of forest fragmentation is one of the many variables involved in the assessment of habitat condition. We postulate its inclusion to support decision-making eventually following our results. The habitat type selected, forest, is one of the most diverse terrestrial ecosystems and provide habitats for a substantial proportion of plant and animal species (Millennium Ecosystem Assessment, 2005; Potapov et al., 2008). Furthermore, the study area (i.e. Spain, mainland territory and Balearic Islands) is of particular interest as it includes part of a world biodiversity hotspot (Myers et al., 2000). To facilitate subsequent prioritization for targeted management actions, our mapped results provide stakeholders and managers a coarse-grain tool to locate a bunch of candidate areas, split by pure and mixed Forest Types (FTs) of the ten most abundant tree species in Spain.

2. Methods

2.1. Study area and data source

The study area was mainland Spain and Balearic Islands, within which we focused on the forestland. This forestland encompasses about 16 million ha, from the total 50 million ha of the whole territory. Spanish forests cover a range of environmental conditions, such as altitudes from sea level to circa 3400 m, calcareous lithologies mainly in the Eastern area and acidic in the Western, and different subtypes of Mediterranean climate in the entirety of the country except the more Atlantic area situated in the Northern and North-Western region.

We located all extant forestland by means of the Spanish Forest Map 1:50,000 (1997–2006) (in Spanish 'Mapa Forestal de España 1:50.000', MFE50) (MAGRAMA, 2013). This map is the most accurate (spatially and thematically) and comprehensive map produced to locate and characterize Spanish forests. The MFE50 map is delivered in vector format, with a minimum mapping unit of 2.25 hectares, and provides homogeneous polygons in relation to their forest data. Up to three dominant tree species are reported for each polygon in the MFE50 database, in conjunction with their single crown cover in percentage, rounded to tens. The total number of tree species listed in the MFE50 is 178, as in the National Forest Inventory, but a large majority of them are not dominant in the stands or cover a very small area.

2.2. Forest type mapping

The appropriateness of the application of Forest Types (FTs) to report at the European level, which can be extended to the country level, was stated by Barbati et al. (2014), so we conceptually followed a similar approach. We divided the total forestland from the MFE50, aiming to stratify into specific and ecologically sound units to frame the levels of forest fragmentation. Moreover, using FTs instead of just one single category encompassing all types of forests is likely to be more relevant to management, as they may accommodate, for example, a specific type of silviculture, or a specific guild of species using a FT as habitat. Our FTs were defined according to the dominant tree species of each polygon and the presence or absence of other accompanying tree species (i.e. pure and mixed stands, being pure those with an occupancy of the dominant species in relation to the total canopy cover greater than 70% and mixed stands in other case).

To produce the four Main Maps here presented, we retained the FTs corresponding to the ten most spatially abundant species in Spain, both in pure and mixed stands, considering in the focal FTs (Figure 1) the MFE50 polygons with a total canopy cover of the dominant species of at least 20% (i.e. 20% not in relation to the sum of the cover of all the species, but to the total patch area), which corresponds to 11 million ha of forestland in total. This gave rise to 20 FTs (ten species into two species composition categories). As dominant tree species we selected: *Pinus halepensis, Pinus nigra, Pinus pinaster, Pinus pinea, Pinus sylvestris, Fagus sylvatica, Quercus faginea, Quercus ilex, Quercus pyrenaica, Quercus suber*, and any tree species different from the focal FT (Figure 1) as accompanying in the case of mixed stands. The definition of mixed forests is a complex issue in which several approaches exist (Bravo-Oviedo et al., 2014). The occupancy threshold of 70% that we selected agrees with official considerations from the national environmental authority (MAGRAMA, 2014). Into this criterion we also considered the maximum total canopy cover achieved in Spain by each species, so the 70% threshold was relative to these species' maximums (only *Quercus suber* stands did not reach a maximum of 100% of total canopy cover). Table 1 shows key ecological characteristics of the main species from the FTs that were analyzed.

Finally, the MFE50 polygons were filtered using the FTs definitions and subsequently rasterized at 30-m resolution. This resolution was adopted to produce a tractable dataset in computational terms, but also in accordance with that used in previous works in the USA (e.g. Riitters & Wickham, 2012) and Landsat imagery, permitting comparability of results coming from different studies. It is worth noting that crosswalks between the FTs here defined and the European Forest Types (EFTs) from Barbati et al. (2014) can be easily accomplished by using the 'tree species matrix' (Pividori et al., 2016), which assigns single tree species with different abundances to the different EFTs. Additionally, an interesting feature of our work is that the accuracy of the base data we used (i.e. MFE50) allowed us to map the FTs occurrences with a thematic resolution as good as the highest used in the EFTs, but here in combination with a spatial resolution of 30 m, which constitutes a level of detail currently only possible at the national level.

2.3. Calculation of the degree of forest fragmentation

To assess the degree of forest fragmentation we used the Forest Area Density (FAD) metric (Riitters et al., 2002; Riitters & Wickham, 2012), which is the basis of the forest fragmentation indicator (4.7) adopted

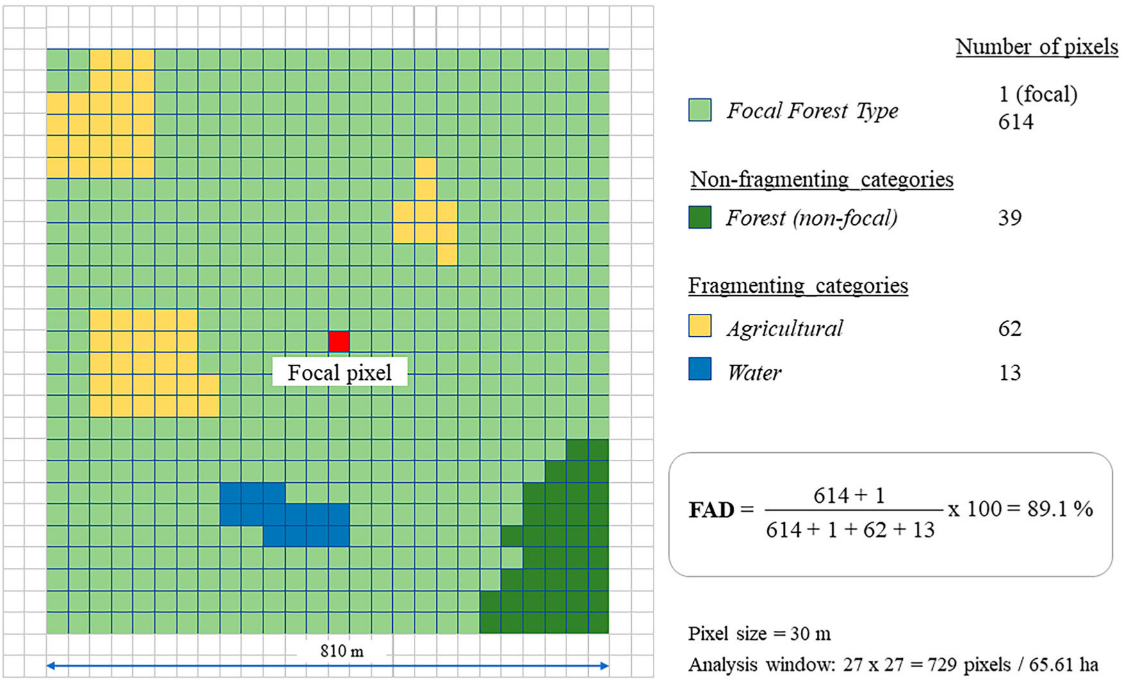

Figure 1. Example of Forest Area Density (FAD) calculation. Focal Forest Type (FT) is one out of the 20 analyzed (ten dominant species into two categories, pure or mixed). Forest (non-focal) are the remaining FTs but also any other tree species. All other categories, any not considered as forest (total canopy cover < 20%), are fragmenting. Note non-fragmenting categories are not incorporated in the calculation.

Table 1. Total area in Spain of the Forest Types (FTs) considered and environmental site characteristics of the dominant tree species habitats (Source: authors, summary after species cards from Pemán García et al. (2012)).

Tree species group	Dominant species	Site characteristics in Spain (climate/soil/altitude)	FT area (ha) Pure	FT area (ha) Mixed
Conifers	*Pinus halepensis*	High temperatures and prolonged drought resistant / Indifferent, but preference for calcareous / Up to 1600 m	1,468,142	345,129
	Pinus nigra	Cold hardy, can take severe frosts / Calcareous / 800 to 2000m	526,595	295,746
	Pinus pinaster	Any non-extreme climate / Prefers siliceous, tolerant to rocky / Up to 1700m	862,721	350,848
	Pinus pinea	Summer drought and high mean temperatures resistant, does not tolerate severe frosts / Prefers siliceous, especially sandy and uncompacted / Up to 1000 m	317,001	93,277
	Pinus sylvestris	Cold and wet, frost hardy / Non-calcareous and deep / 800–2400 m	876,796	263,422
Broadleaved	*Fagus sylvatica*	Abundant rainfall and high humidity / Indifferent, fresh and fertile soils / 300–2500 m	352,905	100,570
	Quercus faginea	Withstands continental contrasted climates / Indifferent / Up to 1900m	232,633	163,173
	Quercus ilex	Adapted to dry environments, cold hardy / Indifferent, prefers calcareous / Up to 1500 m	3,395,069	651,757
	Quercus pyrenaica	Adapted to dry environments, cold hardy / Siliceous / 400–1600 m	709,447	166,787
	Quercus suber	Adapted to dry environments and cold tolerant (less than *Q. ilex*) / Siliceous / Up to 800 m	256,219	143,405

by FOREST EUROPE (Raši et al., 2020) (and also see Vogt et al., 2019).

In its most general definition, FAD is a metric of forest amount that considers the proportion of forest in an analysis window (Riitters et al., 2000) (Figure 1), but more specific definitions of forest (or even habitat) can also be used, as for example forest communities defined from tree species composition (Riitters et al., 2012). For the calculations of FAD, we used GuidosToolbox 2.9. rev.1 software (GTB) (Vogt & Riitters, 2017; https://forest.jrc.ec.europa.eu/en/activities/lpa/gtb/). GTB calculates the metric for every forest pixel, with values ranging between 0 and 100, considering all pixels surrounding the focal one (i.e. included within the analysis window). If the proportion of the FT in the analysis window is high, the metric value will be close to 100, so the degree of forest fragmentation is low in such cases and high on the contrary.

The FAD metric was computed for each of the ten 'pure' FTs and the ten 'mixed' FTs. As size of the analysis window (i.e. landscape size) we considered 27×27 pixels, which implies an analysis area of 65.61 hectares, a reasonable size for carrying out field projects in Spain. Some wildlife species sensitive to this landscape size in Spain are the red squirrel (*Sciurus vulgaris*) and the Iberian magpie (*Cyanopica cooki*), with home ranges of this order of magnitude (De la Cruz & Valencia, 2016; Purroy, 2017). Moreover, other forest wildlife species (e.g. pine marten (*Martes martes*), capercaillie (*Tetrao urogallus*)), with bigger home ranges, could also benefit from continuous forest area at this scale, as they may use these areas as stepping-stones for dispersal (Bodin & Saura, 2010), or as a supplementary source of resources if located close to other habitat patches. In addition, this window size alongside the pixel size adopted are coincident with those previously used in the USA (Riitters et al., 2012), enabling comparison if desired.

Taking a management perspective, we considered forests as habitats, so from a species-centered view, forest areas not belonging to the focal FT were supposed not to entail major difficulties for species dispersal or movement nearby (i.e. within the analysis window). Therefore, no forest area was included into the fragmenting categories for the FAD calculations.

2.4. Conservation and restoration management scenarios

Dennis et al. (2014) pointed out that the term 'habitat' has been used to refer to a biotope in two ways, one more general as to identify a particular species' living space, and a second, which 'often heralds a focus of attention on a distinctive vegetation/substrate target and its fauna for priority conservation action, as in the case of the European Habitats Directive'. Framed within the latter, we regarded forests, and specifically its more detailed divisions by FTs, 'as recognizable zones in which a collection of species live and thus, by implication, have all or most of their key resources' (Dennis et al., 2014). In this sense, we considered the concept of habitat for forest-dwelling species, as related to the FTs and the communities associated to each of them.

In forest landscapes, planning should 'focus on restoring forest functionality: that is the goods, services and ecological processes that forests can provide at the broader landscape level as opposed to solely promoting increased tree cover at a particular location' (Maginnis & Jackson, 2005). It is straightforward to extend this focus to the conservation (i.e. protection) of forests in good condition, thus exhibiting adequate functionality. In light of these considerations, and applying the abovementioned habitat interpretation, we defined the following two general management scenarios according to their main objectives, to which typically other variables should be added to effectively identify management priority areas:

Conservation scenario: FAD values $\geq 90\%$ and $\leq 100\%$. That is, forest areas on which the focal FT is clearly dominant and continuous at the analysis scale (27 × 27 pixels; 65.61 hectares), which we assume to be the most valuable areas for ES provision, and specifically as habitat providers for forest specialist species. Typically, the potential priority areas located under this criterion could include Natural Parks, Natura 2000 sites, or forest areas designated for biodiversity and landscape protection (*sensu* Forest Europe SFM indicator 4.9). This range of FAD values is coincident with the 'interior' and 'intact' categories in GTB and in accordance with their definitions in Riitters et al. (2012).

Restoration scenario: FAD values ≥ 60% and < 90%. Forest landscape restoration is 'a planned process that aims to regain ecological integrity and enhance human well-being in deforested or degraded landscapes' (Rietbergen-McCracken, et al., 2007). After this definition, we selected those forest areas exhibiting an intermediate degree of fragmentation of the focal FT, that is, areas perforated by other fragmenting land covers that still retain a remarkable forest character. These areas merit to be deemed potential priority areas as may permit forest restorations not as costly as in the most deforested ones. By restoring tree cover (e.g. by reforestation of degraded scrub formations), an increment of continuous habitat for forest specialists is likely to be obtained with relative lower effort. A similar rationale is proposed by Volis (2018) who states that 'the priority should be given to the least altered habitats' still having 'a reasonable chance of approaching a primary habitat'. In this case, the range of FAD values is coincident with the 'dominant' category in GTB and in accordance with its definition in Riitters et al. (2012).

3. Results

The main result of this work is a set of four maps (Main Maps) of potential priority areas for forest-dwelling species based on the FAD fragmentation metric in Spain, mainland territory and Balearic Islands. The 'Conservation' maps show, by Forest Types (FTs), the areas identified as candidates to be preserved due to their very low or even null degree of fragmentation of the focal FT. As for the 'Restoration' maps, they show by FTs the areas best suited for ecological restorations devoted to reducing forest fragmentation and favoring forest specialist species by extending the continuous forest habitat. The FTs correspond to ten dominant tree species, so the maps were divided into two pages by groups of FTs for a better conveyance of information. One page shows the five pure coniferous FTs (*Pinus halepensis, Pinus nigra, Pinus pinaster, Pinus pinea* and *Pinus sylvestris*) in both the conservation and restoration scenarios, while the other page is analogous, but for the five pure broadleaved FTs (*Fagus sylvatica, Quercus faginea, Quercus ilex, Quercus pyrenaica,* and *Quercus suber).* In addition, within the FTs depicted in the maps, the mixed stands for each group were included.

Complementary to the Main Maps, three additional synoptic maps were added in each page: (i) a map showing all forestland in Spain independently of the main tree species (including main tree species not analyzed as focal FT); (ii) a map showing the total forestland for the five coniferous and the five broadleaved FTs considered in the Main Maps, split into pure stands and mixed stands; and (iii) a map that merges the potential priority areas under the conservation and restoration scenarios. The symbology of the Main Maps identifies the dominant tree species, with the legend in the form of a qualitative color ramp.

4. Discussion and conclusions

The results of this study, a set of maps identifying potential priority areas for forest-dwelling species in Spain, were based on the degree of forest fragmentation as measured by the FAD metric. By presenting the results for two management scenarios with complementary main objectives (i.e. habitat conservation and habitat restoration) and by FTs, the four Main Maps make up a valuable set to be used in the context of forest planning at large-scale. These scenarios allow to consider habitat-oriented management targets for forest specialist species (i.e. the habitat provision ES), and facilitate the assessment of the management opportunities of the whole study area on a coarse-filter approach. Furthermore, the Main Maps may contribute to SFM, aiding inlocating feasible areas for deploying the recommendations and fulfill the commitments of different planning instruments. Specifically, the management scenarios here defined are aligned with the line A1 'Restoration of vegetation cover and extension of the forest area', and the line A4 'Conservation and enhancement of biological diversity in forest areas' from the SFP. And also, with the New EU Forest Strategy for 2030, which in its third section deals with 'Protecting, restoring and enlarging EU's forests', as well as with the EU Biodiversity Strategy for 2030, which has proposed an overall target to protect at least 30% of the EU land area under effective management regime, to which forests should contribute.

Additionally, moving apart from the sectoral planning, the NSGIECR presents eight goals, being the number two specifically devoted to 'restoration of degraded ecosystems', and the number zero to the spatial identification of Green Infrastructure (GI) elements. Within the latter, as a guideline for the development of the action line 0.03, a typology is given distinguishing GI conservation areas (i.e. areas that provide key ecological functions and should be conserved to maintain connectivity), and GI restoration areas (i.e. areas that still provide important ecological functions, but whose enhancement to the conservation type by some form of restoration would result in an increase of the resilience of the GI network). This typology is totally coincident with the terms of the management scenarios we defined, so our results could assist in the identification of GI areas in the context of this national strategy. In this sense, it would be interesting to overlay the Natura 2000 network with the 'Conservation' maps and identify areas falling outside that, which could locate potential priority areas to complement the protected network. It should be added that the SFP is currently (as for nov./2022) under revision, and, added to the action lines from the plan in effect, specific measures to coordinate forest conservation and restoration with the NSGIECR are set out. As seen, our maps could be useful in developing this task.

When utilizing our maps, it must be taken into account that if a pixel falls within a potential priority area depicted in the Main Maps, the corresponding area to be preserved/restored would encompass the surrounding analysis window (27×27 pixels; 65.61 ha), that is, the pixels classified as focal FT in the conservation scenario and as fragmenting in the restoration one. In addition, given the good spatial resolution of our results, despite being produced at the national level, they can also be used at more detailed regional levels, which is an interesting feature as the responsibility for forest management and regional planning lies with the Autonomous Communities in Spain. Moreover, as mentioned in the introduction, our results are solely based on the degree of forest fragmentation and identify potential areas within which other prioritization criteria (e.g. the type of property, soil erosion level, presence of protected species, etc.) may rank sites by order of importance, which can be done both at the national or regional level.

Regarding the specific results, the Spanish Forest Map shows that forestland covers approximately a quarter of Spain, being many interior and Mediterranean coastal zones dominated by agricultural lands. Larger continuous forestland is identified in the South-West, Mid-East and North-East zones of Spain, coinciding in most cases with mountain ranges. The coastal North-Western forestland is spatially more discontinuous than the remaining. Coniferous forests are especially concentrated in the Western half, while broadleaved in the Eastern one, somehow following the principal environmental gradient between the humid and temperate North-Western and the dry and hot South-Eastern regions (Elena-Rosselló et al., 1997). In the North-West, characterized by a wetter Atlantic climate, coniferous and broadleaved species mix.

The Main Maps 'Conservation' depict the pixels with FAD values equal or higher than 90%. In these maps, without regard to the FTs' main species, large continuous forestland is located mainly in the Western half, Mid-East and North regions. These areas are coincident with the historically less industrially developed rural areas devoted to agriculture and forest use. Although fragmenting agriculture is intermixed with forests, in these regions very large expanses of forestland exists, mainly due to two reasons: (i) because they are mountainous areas, as in the Mid-East, primarily around Cuenca city and in the Pyrenees (North region), and (ii) because in the Western half forest management blends with agriculture and livestock production in the so-called 'dehesas'.

The Main Maps 'Restoration' depict the pixels with FAD values in the 60% – 90% interval. In this case the forestland is much more scattered in the territory, also being the continuous areas smaller than in the conservation scenario. For all FTs, the potential priority areas for tree cover restoration are concentrated around the largest conservation area. If these areas are effectively restored, it could entail major benefits compared to restoring isolated areas. However, it is important to consider the unequal enhancement of both biodiversity and the different types of ES after restoration (Benayas et al., 2009) should also be considered.

Figure 2 illustrates the total areas and percentages for every FT, by group of main species (i.e. conifers and broadleaved), in both the conservation and restoration management scenarios. For reporting and enhance visual interpretation of the Main Maps, all mixed FTs were merged into a single category. No clear differences are apparent between groups when comparing them by management scenarios (percentages of total area are markedly similar), but they arise when splitting data by dominant species. The dominant species with a lower percentage of conservation area, that is, more fragmented overall, are *Pinus halepensis*, *Quercus faginea* and *Quercus pyrenaica*. On the contrary case are *Pinus nigra*, *Pinus sylvestris* and *Quercus suber*, which could be traced back to their distributions, as pines dwell mainly in mid and high mountainous areas, hence with lower built-up area, or in 'dehesa' formations which are typically extensive. The FTs with the highest relative restoration area coincide with those with the lowest relative conservation area, namely *Pinus halepensis*, *Quercus faginea* and *Quercus pyrenaica*, and also include *Fagus sylvatica* and *Pinus pinaster* (Figure 2).

The methodology we followed is based on the measurement of forest fragmentation through the calculation of the FAD metric, which deals with forest amount. An interesting future research line could be focused on exploring the relationships between our results and those derived from landscape configuration metrics, such as the classical metrics originally described in FRAGSTATS (McGarigal & Marks, 1995). Another aspect to consider in the future is

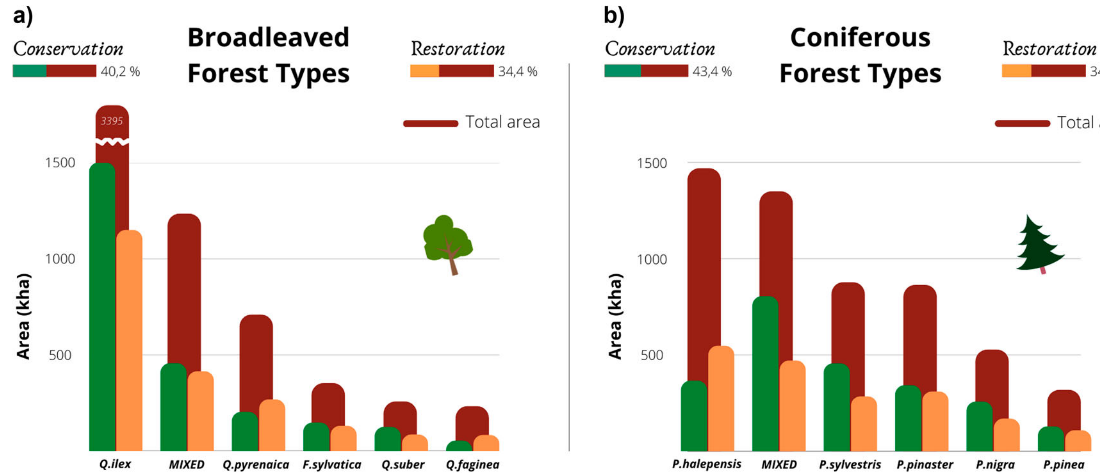

Figure 2. Total area (brown), conservation area (green) and restoration area (salmon) for pure Forest Types (FTs) and all mixed FTs joined ('MIXED'), by groups of dominant species; (a) broadleaved, and (b) coniferous. The conservation and restoration bars depict in each case the joint percentage of total area across all FTs.

related to the primary data we used in this study, which were downloaded from the open sources specified in the Data Availability Statement. Therefore, the accuracy of the Main Maps is dependent on these data sources. These data are expected to be updated for the entire country in the mid-term, which could permit to improve the results presented here.

It is worth noting that the adopted FAD thresholds heavily influenced the areas depicted in the Main Maps. We adopted the 60% and 90% values aligning with previous works in which this range comprises the so-called 'dominant', 'interior' and 'intact' categories (e.g. Riitters et al., 2012; Riitters & Wickham, 2012), but other values could be used. Moreover, here we presented the maps for a single size of analysis window (i.e. 65.61 ha) which allows for a good representation at the national scale, but a multiple scale analysis considering other smaller or larger sizes would be complementary if more detailed analyses were to be carried out (e.g. regional scale, or different guilds of species).

The maps provided in this paper offer valuable insights as they constitute a comprehensive reference at the national level for forest managers, stakeholders and scientists. The study area (Spain) encompasses a range of different ecosystems and habitats, with its Mediterranean region enclosed within a world biodiversity hotspot for conservation priority (Myers et al., 2000). This fact is acknowledged by practitioners, authorities and stakeholders, so our maps may be of importance as a screening tool to locate management opportunities, in a coarse-scale first approach. Ultimately, the potential priority areas shown in the Main Maps may aid in biodiversity promotion and enhancement through different applications.

Software

ESRI ArcGIS 10.5 was used to pre-process the data from the Spanish Forest Map 1:50,000, GuidosToolbox 2.9 was used to calculate Forest Area Density values, and ESRI ArcGIS 10.5 was used to create the maps.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This research was carried out within the framework of the project 'Herramientas Cartográficas para el Desarrollo Urbano y Regional Sostenible' (RP22 0430C 029) funded by Universidad Politécnica de Madrid.

Data availability statement

The data that support the findings of this study are available from the corresponding author, SGA, upon reasonable request. These data were derived from the following resources available in the public domain: https://www.miteco.gob.es/es/biodiversidad/servicios/banco-datos-naturaleza/informacion-disponible/mfe50_descargas_ccaa.aspx

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References

Adams, R. V., & Burg, T. M. (2015). Gene flow of a forest-dependent bird across a fragmented landscape. *PLOS*

ONE, *10*(11), Article e0140938. https://doi.org/10.1371/journal.pone.0140938

Barbati, A., Marchetti, M., Chirici, G., & Corona, P. (2014). European forest types and forest Europe SFM indicators: Tools for monitoring progress on forest biodiversity conservation. *Forest Ecology and Management*, *321*, 145–157. https://doi.org/10.1016/j.foreco.2013.07.004

Benayas, J. M. R., Newton, A. C., Diaz, A., & Bullock, J. M. (2009). Enhancement of biodiversity and ecosystem services by ecological restoration: A meta-analysis. *Science*, *325*(5944), 1121–1124. https://doi.org/10.1126/science.1172460

Bodin, O., & Saura, S. (2010). Ranking individual habitat patches as connectivity providers: Integrating network analysis and patch removal experiments. *Ecological Modelling*, *221*(19), 2393–2405. https://doi.org/10.1016/j.ecolmodel.2010.06.017

Bravo-Oviedo, A., Pretzsch, H., Ammer, C., Andenmatten, E., Barbati, A., Barreiro, S., Brang, P., Bravo, F., Coll, L., Corona, P., Ouden, J. D., Ducey, M. J., Forrester, D. I., Giergiczny, M., Jacobsen, J. B., Lesiński, J., Löf, M., Mason, B., Matović, B., … Zlatanov, T. (2014). European mixed forests: Definition and research perspectives. *Forest Systems*, *23*(3), 518–533. https://doi.org/10.5424/fs/2014233-06256

Burkhard, B., Kroll, F., Nedkov, S., & Müller, F. (2012). Mapping ecosystem service supply, demand and budgets. *Ecological Indicators*, *21*, 17–29. https://doi.org/10.1016/j.ecolind.2011.06.019

Butcher, J. A., Morrison, M. L., Ransom, D., Slack, R. D., & Wilkins, R. N. (2010). Evidence of a minimum patch size threshold of reproductive success in an endangered songbird. *Journal of Wildlife Management*, *74*(1), 133–139. https://doi.org/10.2193/2008-533

Chazdon, R. L. (2019). Towards more effective integration of tropical forest restoration and conservation. *Biotropica*, *51*(4), 463–472. https://doi.org/10.1111/btp.12678

Chetcuti, J., Kunin, W. E., & Bullock, J. M. (2020). Habitat fragmentation increases overall richness, but Not of habitat-dependent species. *Frontiers in Ecology and Evolution*, *8*, Article 607619. https://doi.org/10.3389/fevo.2020.607619

Coulon, A., Cosson, J. F., Angibault, J. M., Cargnelutti, B., Galan, M., Morellet, N., Petit, E., Aulagnier, S., & Hewison, A. J. M. (2004). Landscape connectivity influences gene flow in a roe deer population inhabiting a fragmented landscape: An individual-based approach. *Molecular Ecology*, *13*(9), 2841–2850. https://doi.org/10.1111/j.1365-294X.2004.02253.x

De la Cruz, C., & Valencia, J. (2016). Rabilargo – Cyanopica cooki. In A. Salvador, & M. B. Morales (Eds.), *Enciclopedia virtual de los vertebrados españoles, museo nacional de ciencias naturales*. http://www.vertebradosibericos.org/

Dennis, R. L. H., Dapporto, L., & Dover, J. W. (2014). Ten years of the resource-based habitat paradigm: The biotope-habitat issue and implications for conserving butterfly diversity. *Journal of Insect Biodiversity*, *2*(8), 1. https://doi.org/10.12976/jib/2014.2.8

Elena-Rosselló, R., Castejón, M., Sánchez Serrano, F., & Tella, G. (1997). *Clasificación biogeoclimática de españa peninsular y balear*. Ministerio de Agricultura, Pesca y Alimentación.

Fahrig, L. (2003). Effects of habitat fragmentation on biodiversity. *Annual Review of Ecology, Evolution, and Systematics*, *34*(1), 487–515. https://doi.org/10.1146/annurev.ecolsys.34.011802.132419

Fahrig, L., Watling, J. I., Arnillas, C. A., Arroyo-Rodríguez, V., Jörger-Hickfang, T., Müller, J., Pereira, H. M., Riva, F., Rösch, V., Seibold, S., Tscharntke, T., & May, F. (2022). Resolving theSLOSSdilemma for biodiversity conservation: A research agenda. *Biological Reviews*, *97*(1), 99–114. https://doi.org/10.1111/brv.12792

García-Feced, C., Saura, S., & Elena-Rosselló, R. (2011). Improving landscape connectivity in forest districts: A two-stage process for prioritizing agricultural patches for reforestation. *Forest Ecology and Management*, *261*(1). https://doi.org/10.1016/j.foreco.2010.09.047

Haddad, N. M., Brudvig, L. A., Clobert, J., Davies, K. F., Gonzalez, A., Holt, R. D., Lovejoy, T. E., Sexton, J. O., Austin, M. P., Collins, C. D., Cook, W. M., Damschen, E. I., Ewers, R. M., Foster, B. L., Jenkins, C. N., King, A. J., Laurance, W. F., Levey, D. J., Margules, C. R., … Townshend, J. R. (2015). Habitat fragmentation and its lasting impact on earth's ecosystems. *Science Advances*, *1*(2), Article e1500052. https://doi.org/10.1126/sciadv.1500052

Herrera, J. M., & García, D. (2010). Effects of forest fragmentation on seed dispersal and seedling establishment in ornithochorous trees. *Conservation Biology*, *24*(4), 1089–1098. https://doi.org/10.1111/j.1523-1739.2010.01459.x

Hertzog, L. R., Boonyarittichaikij, R., Dekeukeleire, D., de Groote, S. R. E., van Schrojenstein Lantman, I. M., Sercu, B. K., Smith, H. K., de la Peña, E., Vandegehuchte, M. L., Bonte, D., Martel, A., Verheyen, K., Lens, L., & Baeten, L. (2019). Forest fragmentation modulates effects of tree species richness and composition on ecosystem multifunctionality. *Ecology*, *100*(4), Article e02653. https://doi.org/10.1002/ecy.2653

Maginnis, S., & Jackson, W. (2005). *Restoring forest landscapes*. International union for conservation of nature (IUCN). Gland, Switzerland. http://cmsdata.iucn.org/downloads/restoring_forest_landscapes.pdf

MAGRAMA. (2013). *Mapa forestal de españa. Escala 1:50.000*. Ministerio de Agricultura, Alimentación y Medio Ambiente. Retrieved April 28 2022. https://www.miteco.gob.es/es/biodiversidad/servicios/banco-datos-naturaleza/informacion-disponible/mfe50.aspx

MAGRAMA. (2104). *Diagnóstico del sector forestal español*. Ministerio de agricultura, alimentación y medio ambiente. Análisis y Prospectiva, número 8, Octubre 2014. https://www.mapa.gob.es/es/ministerio/servicios/analisis-y-prospectiva/AyP_serie%20n%C2%BA8%20diagn%C3%B3stico%20sector%20FORESTAL_tcm30-88409.pdf

Mancebo Quintana, S., Martín Ramos, B., Casermeiro Martínez, M., & Otero Pastor, I. (2010). A model for assessing habitat fragmentation caused by new infrastructures in extensive territories – evaluation of the impact of the spanish strategic infrastructure and transport plan. *Journal of Environmental Management*, *91*(5), 1087–1096. https://doi.org/10.1016/j.jenvman.2009.12.013

Martín, B., Ortega, E., Otero, I., & Arce, R. M. (2016). Landscape character assessment with GIS using map-based indicators and photographs in the relationship between landscape and roads. *Journal of Environmental Management*, *180*, 324–334. https://doi.org/10.1016/j.jenvman.2016.05.044

McGarigal, K., & Marks, B. J. (1995). *FRAGSTATS: spatial pattern analysis program for quantifying landscape structure*. Gen. Tech. Rep. PNW-GTR-351. Portland, OR: U.S. Department of agriculture, Forest Service, Pacific Northwest Research Station.

Millennium Ecosystem Assessment. (2005). *Ecosystems and human well-being: Synthesis*. Island Press.

Myers, N., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A. B., & Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature*, *403*(6772), 853–858. https://doi.org/10.1038/35002501

Pedrotti, F. (2013). *Plant and vegetation mapping*. Springer Science & Business Media.

Pemán García, J., Navarro Cerrillo, R. M., Nicolás Peragón, J. L., Prada Sáez, M. A., & Serrada Hierro, R. (Coords.). (2012). *Producción y manejo de semillas y plantas forestales*. Organismo Autónomo Parques Nacionales. MAGRAMA. ISBN: 978-84-8014-837-5. https://www.miteco.gob.es/es/parques-nacionales-oapn/publicaciones/naturaleza-parques.aspx

Pividori, M., Giannetti, F., Barbati, A., & Chirici, G. (2016). European forest types: Tree species matrix. In J. San-Miguel-Ayanz, D. de Rigo, G. Caudullo, T. Houston Durrant, & A. Mauri (Eds.), *European atlas of forest tree species*. https://ies-ows.jrc.ec.europa.eu/efdac/download/Atlas/pdf/European_Forest_Types_tree_species_matrix.pdf

Potapov, P., Yaroshenko, A., Turubanova, S., Dubinin, M., Laestadius, L., Thies, C., Aksenov, D., Egorov, A., Yesipova, Y., Glushkov, I., Karpachevskiy, M., Kostikova, A., Manisha, A., Tsybikova, E., & Zhuravleva, I. (2008). Mapping the world's intact forest landscapes by remote sensing. *Ecology and Society*, *13*(2), https://doi.org/10.5751/ES-02670-130251

Puletti, N., Giannetti, F., Chirici, G., & Canullo, R. (2017). Deadwood distribution in European forests. *Journal of Maps*, *13*(2), 733–736. https://doi.org/10.1080/17445647.2017.1369184

Purroy, F. J. (2017). Ardilla roja – Sciurus vulgaris. In A. Salvador, & M. B. Morales (Eds.), *Enciclopedia virtual de los vertebrados españoles, museo nacional de ciencias naturales*. http://www.vertebradosibericos.org/

Raši, R., Vogt, P., Biala, K., & Köhl, M. (2020). Indicator 4.7 Forest fragmentation. In FOREST EUROPE, 2020, State of Europe's Forests 2020. Ministerial Conference on the Protection of Forests in Europe - FOREST EUROPE. https://foresteurope.org/wp-content/uploads/2016/08/SoEF_2020.pdf

Rietbergen-McCracken, J., Maginnis, S., & Sarre, A. (2007). *The forest landscape restoration handbook*. International union for conservation of nature and the international tropical timber organization.

Riitters, K. H., Coulston, J. W., & Wickham, J. D. (2012). Fragmentation of forest communities in the eastern United States. *Forest Ecology and Management*, *263*, 85–93. https://doi.org/10.1016/j.foreco.2011.09.022

Riitters, K. H., & Wickham, J. D. (2012). Decline of forest interior conditions in the conterminous United States. *Scientific Reports*, *2*(1), https://doi.org/10.1038/srep00653

Riitters, K. H., Wickham, J. D., O'Neill, R. V., Jones, K. B., Smith, E. R., Coulston, J. W., Wade, T. G., & Smith, J. H. (2002). Fragmentation of continental United States forests. *Ecosystems*, *5*(8), 815–822. https://doi.org/10.1007/s10021-002-0209-2

Riitters, K. H., Wickham, J. D., Vogelmann, J. E., & Jones, K. B. (2000). National land-cover pattern data. *Ecology*, *81*(2), 604. https://www.srs.fs.usda.gov/pubs/ja/ja_riitters001.pdf

Robinson, S. K., & Wilcove, D. S. (1994). Forest fragmentation in the temperate zone and its effects on migratory songbirds. *Bird Conservation International*, *4*(2-3), 233–249. https://doi.org/10.1017/S0959270900002793

Solano López, J. M. (2006). El plan forestal español: La naturaleza que todos queremos. In O. Carrillo Bovillo (Ed.), *Planificación forestal en españa*. OAPN, Ministerio de Medio Ambiente.

Vogt, P., & Riitters, K. (2017). Guidostoolbox: Universal digital image object analysis. *European Journal of Remote Sensing*, *50*(1), 352–361. https://doi.org/10.1080/22797254.2017.1330650

Vogt, P., Riitters, K. H., Caudullo, G., Eckhardt, B., & Raši, R. (2019). *An approach for pan-European monitoring of forest fragmentation*. Publications Office of the European Union, EUR 29944 EN. Luxembourg. https://doi.org/10.2760/991401

Volis, S. (2018). Plant conservation in the anthropocene: Definitely Not Win–Win But maybe Not lose–lose? In D. A. Dellasala, & M. I. Goldstein (Eds.), *Encyclopedia of the anthropocene* (pp. 389–397). Elsevier. https://doi.org/10.1016/B978-0-12-809665-9.10505-1

Wilcove, D. S., McClellan, C. H., & Dobson, A. P. (1986). Habitat fragmentation in the temperate zone. In M. E. Soule (Ed.), *Conservation biology: The science of scarcity and diversity* (pp. 237–256). Sinauer Associates.