Received: 6 August 2020 | Accepted: 26 September 2020

DOI: 10.1002/pan3.10161

PEOPLE AND NATURE | BRITISH ECOLOGICAL SOCIETY

MANAGING FOREST REGENERATION AND EXPANSION AT A TIME OF UNPRECEDENTED GLOBAL CHANGE

Research Article

Spontaneous forest regrowth in South-West Europe: Consequences for nature's contributions to people

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Funding information
Spanish Ministry of Economy, Industry and Competitiveness, Grant/Award Number: CGL2017-83170-R; Spanish Research Agency (AEI) and the Spanish Ministry of Economy, Industry and Competitiveness (MINECO), Grant/Award Number: PCIN-2016-055; German Research Foundation; Comunidad de Madrid, Grant/Award Number: TE-CM. S2018/EMT-4338

Handling Editor: Patricia Balvanera

Abstract

1. European forests are expanding and becoming denser following the widespread abandonment of farmland and rural areas. Spontaneous forest regrowth provides a cost-effective opportunity to restore ecosystems, enhance multifunctionality and sustainability and mitigate climate change. Yet, little is known about the goods and services that such forests provide to people. We assessed the changes in nature's contributions to people (NCP) from spontaneous forest regrowth, i.e. forest expansion and densification, in South-West Europe.
2. We investigated 65 forest plots in four different landscapes with contrasting ecological and societal contexts. Two landscapes are located in rural areas undergoing human exodus and forest expansion and densification; the other two, in peri-urban areas with intense land use and forest densification but negligible expansion. For each forest plot, we estimated variables related to ten out of the 18 main NCP defined by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). Regulating and material NCP were addressed using variables measured in the field as proxies. Non-material NCP were studied through stakeholder interviews.
3. Our results show across the cases that forest expansion and densification are generally associated with greater climate regulation and energy provision. Changes in other NCP, especially in non-material ones, were strongly context-dependent. The

Arndt Hampe and Fernando Valladares contributed similarly.

social perception of spontaneous forest regrowth was primarily negative in rural areas and more positive in peri-urban landscapes.
4. Passive restoration through spontaneous forest expansion and densification can enhance regulating and material NCP, especially when adaptive management is applied. To optimise NCP and to increase the societal awareness of and interest in spontaneous forest regrowth, the effects of this process should be analysed in close coordination with local stakeholders to unveil and quantify the many and complex trade-offs involved in rural or peri-urban social perceptions.

KEYWORDS
forest densification, forest expansion, passive restoration, rural abandonment, social perception, spontaneous forest regrowth, stakeholder

1 | INTRODUCTION

Human societies have always depended on the goods and services that nature provides in terms of food, energy and shelter. However, current development models are having a huge impact on global planetary processes, transforming landscapes and affecting the functioning of ecosystems and their contributions to people's quality of life (Valladares et al., 2019). This impact threatens ecosystem integrity (De Groot et al., 2010) through land use changes, namely urbanisation, landscape fragmentation and deforestation caused by the conversion of former forest to agricultural surfaces (Foley et al., 2005, 2011). The threat is further exacerbated by global climate change (IPCC, 2014). To counteract the impacts of global change upon biodiversity and ecosystem services (ES) and to move towards a more sustainable development model, several intergovernmental initiatives have arisen, including ones oriented to mitigate CO_2 emissions (CBD, 2010; European Commission, 2019a), to restore green infrastructure and degraded ecosystems (acknowledge in the Aichi Targets for Biodiversity; CBD, 2010) and to transform current economics-based models (European Green Deal; European Commission, 2019b). In relation to forests, these initiatives range from incentives to reduce deforestation and forest degradation (e.g. REDD+, see Angelsen et al., 2012) or policies tackling sustainable management or combating illegal logging (Leipold et al., 2016) to ones oriented to restoring forest ecosystems (Mansourian & Vallauri, 2005; the Bonn Challenge). These initiatives focus largely on the tropics and low-income countries of the Southern hemisphere, where deforestation rates remain high (Curtis et al., 2018; Song et al., 2018; Turubanova et al., 2018). In contrast, many parts of Europe are already undergoing active afforestation and spontaneous forest regrowth (Chazdon et al., 2020; Navarro & Pereira, 2015; Perino et al., 2019). From the nineteenth century, the European continent has experienced a transition from a net loss to a net increase in forest cover (Kauppi et al., 2018; Vallet et al., 2016; Wilson et al., 2017). Since then European forests as a total have been gaining around 0.8 million hectares annually (FAO, 2010; Forest Europe, 2015) and this increase is predicted to continue in the coming decades (Schröter et al., 2005). While active afforestation predominates in Central and Northern Europe, having been reinforced by European and national land-conversion policies and actively supported plantings on farmlands (ENRD, 2014), spontaneous forest regrowth predominates in South-Eastern and South-Western Europe (Forest Europe, 2015). This regrowth has been spurred by a widespread abandonment of rural landscapes (e.g. agrarian activities; Fuchs et al., 2013) and migration towards urban centres that has been occurring since the 1960s (Milanova, 2005).

Spontaneous forest regrowth entails two processes: (a) forest expansion, by increasing the surface of novel forests established on former agricultural areas and (b) forest densification after the initial forest establishment (Cramer et al., 2008; Hobbs & Cramer, 2007; MacDonald et al., 2000). Both processes affect the amount and characteristics of the goods and services that are provided by these forests to the society. These goods and services have recently been conceptualised by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) within the Nature's Contributions to People (NCP) framework (Díaz et al., 2018). NCP have been defined as 'the contributions, both positive and negative, of living nature (diversity of organisms, ecosystems and their associated ecological and evolutionary processes) to people's quality of life' (Díaz et al., 2018; Pascual et al., 2017). The NCP framework builds on the ecosystem services (ES) concept (MEA, 2005); highlighting more the importance of cultural and social viewpoints, it includes a stronger context-specific perspective (see Supporting Information S2 for further explanation). For instance, while the category of regulating ES focuses on intangible ecological processes that people cannot readily perceive (e.g. flood prevention, erosion control), that of regulating NCP focuses instead on how people experience nature under specific conditions created by living organisms and ecosystems. Thus, the NCP framework has been acknowledged to be more useful for policymakers as it engages the society more explicitly in ecosystem management and conservation. In this regard, the assessment of NCP changes associated with spontaneous forest regrowth (i.e. forest expansion and densification) informs societal perceptions of the threats and opportunities

(Queiroz et al., 2014). Forest regrowth may then be related to concerns about the loss of certain non-material NCP, such as cultural landscape values and heritage. For instance, this has occurred when the traditional agrosylvopastoral systems began to disappear, as is the case for the Iberian *dehesa* landscapes (Fischer et al., 2012; Plieninger et al., 2015; Rey Benayas & Bullock, 2012). Furthermore, unmanaged forests undergoing densification (i.e. increasing tree density and secondary growth) are often seen as a threat as they can be more prone to wildfires and the spread of exotic species (Hurteau et al., 2008; Lapin et al., 2019). Nevertheless, spontaneous forest regrowth on former agricultural lands constitutes an opportunity for people to experience positive contributions derived from forest ecosystems and their biodiversity. For example, novel forests can act as corridors or stepping stones that facilitate the movement of forest species across the landscape (Rautiainen et al., 2011). Moreover, European forests make a relevant contribution to climate change mitigation, acting as natural carbon (C) sinks (719 million tons of C were stored in forest biomass in Europe between 2005 and 2015; Canadell & Raupach, 2008; Forest Europe, 2015) and regulating atmospheric air quality. Applying the NCP framework to spontaneous forest regrowth not only informs the society about the (dis)benefits of the novel forests, but it also supports policies aiming for an ecological transition towards a decarbonised economy, such as the European Green Deal (European Commission, 2019b), and those addressing biodiversity conservation and human well-being by ecosystem restoration, such as the Biodiversity Strategy 2030 (European Commission, 2020). To get the most from passive ecosystem restoration (Prach & Pyšek, 2001) and the spontaneous regrowth of forests on former farmlands, a process-oriented approach is required. This approach relies on the thorough understanding of the mechanisms underlying both forest expansion and densification, and their relationships with the given landscape and the socio-cultural contexts (Hampe et al., 2020). Hence, there is a need for a careful analysis combining ecological and sociological investigations to disentangle the NCP net balance that novel forests deliver to the society, including the perceptions of this process by stakeholders and local populations.

The main goal of this study was to assess the changes in NCP associated with spontaneous forest regrowth, including both forest expansion and densification processes, in four South-West European landscapes from two different socio-ecological contexts. Two of the four case studies focus on economically marginal rural areas with extensive abandoned agricultural surfaces; the other two, on densely populated and prosperous areas located nearer to urban centres (hereafter termed 'peri-urban'). Specifically, we aim to study (a) the consequences of forest expansion for NCP (in the rural areas) and (b) the consequences of forest densification (in both the rural and the peri-urban areas).

Our results contribute to a better understanding of the interconnections between humans and forest ecosystem dynamics and provide management guidelines to optimise NCP in spontaneously regrowing forests in coherence with current and future socio-economic contexts.

2 | MATERIALS AND METHODS

2.1 | Case studies

To address the consequences of spontaneous forest regrowth, we selected two case studies located in socio-economically marginal rural areas and two others located in more intensely managed peri-urban areas. Despite these contrasting socio-economic settings, all four case studies aligned with the urban-economic development pathway identified by Rudel et al. (2005). Each case study included a set of spontaneously established regrowing forest stands dominated by the tree species that is the most abundant native forest tree in the surrounding landscape. Hereafter we refer to each case study using the name of the predominant tree species.

One of the rural landscapes is located in the Alto Tajo Natural Park (1,023 km^2; Guadalajara province, Castilla La Mancha) in central Spain; the other is in the Serra Transversal Mountains, a montane zone of the Catalan pre-Pyrenees (153 km^2; Girona province, Catalonia) in north-east Spain (Figure 1). Both areas have experienced massive population exodus since the 1950s and are today sparsely populated (<40 inhabitants per km^2), economically marginal and with little perspectives of socio-economic development (Cervera et al., 2019). The abandonment of farming practices has frequently led to the recolonisation of former farmlands by the surrounding forest vegetation. Spanish juniper (*Juniperus thurifera* L.) is the dominant tree in the Alto Tajo forests, while European beech (*Fagus sylvatica* L.) is the most abundant and characteristic forest tree species in the Catalan pre-Pyrenees. The ownership structure in the two regions is similar, with Catalonia having 73% of its forest land in private hands, and Castilla La Mancha 63% (Fletas et al., 2012).

For the peri-urban landcapes, one is located in the Vallès lowland, surrounding the metropolitan area of Barcelona (636 km^2; Barcelona province) in northeastern Spain; the other is between the city of Bordeaux and the Arcachon Basin (1,200 km^2; Gironde province) in south-west France (Figure 1). Both areas are characterised by vigorous economic activity and intensive landscape management for diverse purposes; the Barcelona metropolitan area has a very high population density (>5,000 inhabitants/km^2), and the Gironde province a medium one (>150 inhabitants/km^2). Traditional agriculture has decreased since the early 20th century in the Barcelona metropolitan area, enabling the widespread establishment and densification of forests of holm oak (*Quercus ilex* L.). The Gironde area was once largely covered by a mosaic of marshlands and broadleaf forests dominated pedunculate oak (*Quercus robur* L.). After minimal forest cover in the mid-19th century, the region has been extensively afforested with maritime pine (*Pinus pinaster* Ait.). The resulting silvicultural management has also favoured a widespread spontaneous establishment and densification of *Q. robur*, which is the target species of the case study in this region.

The four cases studied here not only reflect different socio-ecological contexts, they also combine distinct environmental requirements and adaptations. Two of the four species (*F. sylvatica* and *Q. robur*) are widely distributed in the Eurosiberian floristic region,

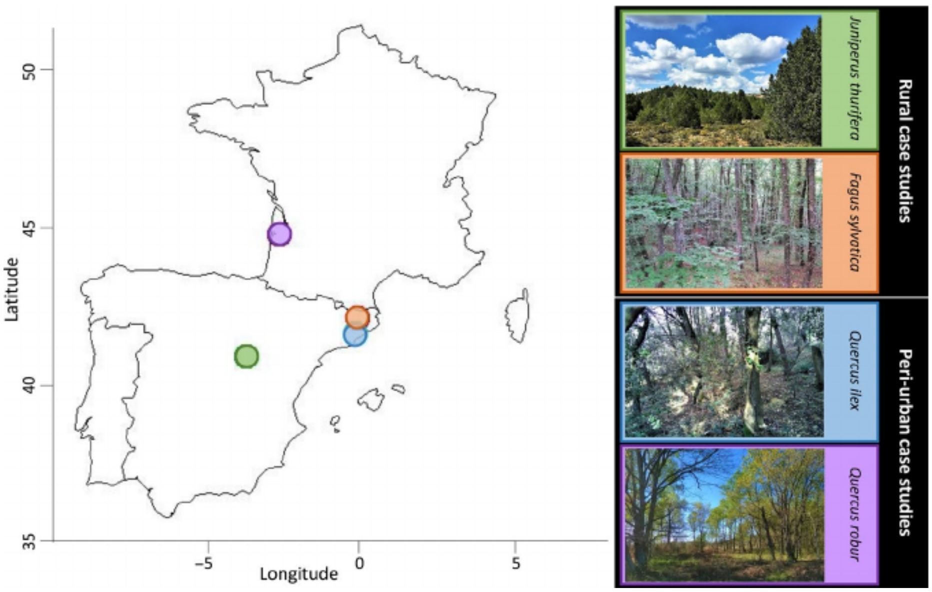

FIGURE 1 Map including the location of the four case studies, two rural and two peri-urban, in Spain and France

while the other two species (*J. thurifera* and *Q. ilex*) are emblematic members of the Mediterranean Basin. All four are dominant forest trees and foundation species (sensu Ellison et al., 2005) with diverse associated communities across much of their distribution range. Detailed descriptions of the four case studies can be found in both the Supporting Information S1 and in recent studies specific for each of them (*J. thurifera*: Acuña-Míguez et al., 2020; Villellas et al., 2020a; *F. sylvatica*: Alfaro-Sánchez et al., 2019; *Q. ilex*: Ruiz-Carbayo et al., 2020a; *Q. robur*: Valdés-Correcher et al., 2019), as well as a comprehensive analysis of societal perceptions towards these systems in Frei et al. (2020).

The selection of forest stands for each of the case studies relied on four criteria: (a) tree layer dominated by the given target tree species (>75% of all established trees present); (b) sufficient distance between stands to consider interactions among them negligible; (c) range of stand ages and development stages and (d) for novel stands, similar past land uses (to minimise confounding legacy effects). Note that the selection of stands for study and the field methodology had to sometimes be adapted to the constraints imposed by the specificities of a given landscape and nature of the dominant species (see below and Appendix S1 for details). Most importantly, in the two rural landscapes forest expansion has tended to occur over larger areas, creating larger stands; in the two peri-urban landscapes there are spatial constraints due to surrounding land use. This obliged us to use subsampling protocols in some cases instead of an otherwise privileged exhaustive sampling.

2.2 | Forest expansion and densification

We studied the consequences of forest expansion in the two rural landscapes (the *J. thurifera* and *F. sylvatica* case studies) by comparing long-existing forest stands with more novel ones. The consequences of forest densification upon NCP were studied in all four cases, the above-mentioned case studies and the two peri-urban landscapes (the *Q. ilex* and *Q. robur* case studies). The two oak case studies consisted of novel (i.e. established after 1950s) isolated forest patches embedded in a different habitat matrix. We quantified forest density in each study plot by calculating the basal area per hectare, a convenient combination of tree size and abundance.

2.3 | NCP estimation

Like the classification of ecosystem services by the Common International Classification of Ecosystem Services (CICES; Haines-Young & Potschin, 2012), the NCP framework distinguishes three categories of contributions (Table 1): material (directly sustaining people's physical existence), non-material (affecting subjective or psychological aspects that underpin people's quality of life) and regulating (modifying the environment and affecting the provision of material and non-material contributions; Díaz et al., 2018; Table 1). For each of the four case studies, we collected information to estimate ten NCP out of the 18 defined by Díaz et al. (2018), conducting ecological fieldwork in a total of 65 study plots. The considered NCP included four regulating, three material and three non-material NCP as well as one NCP common to all categories. The four regulating NCP were habitat creation and maintenance; pollination and dispersal of seeds and other propagules; regulation of climate through biological carbon (C) sequestration and storage; and regulation of detrimental organisms and biological processes. The two material NCP were energy; and medicinal, biochemical and genetic resources. The three non-material NCP were learning and inspiration; physical and psychological experience; and supporting identities. The NCP common to all categories was the maintenance of options, reflected in maintaining biodiversity (estimated in this case with the Shannon diversity index; Table 1). We did not assess changes in all 18 NCP described in Díaz et al. (2018) because some NCP were not relevant to the process of spontaneous forest regrowth (e.g. regulation of ocean

TABLE 1 Nature's Contributions to People (NCP) assessed in this study as classified according to the Common International Classification of Ecosystem Services (CICES) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) framework together with the proxy or procedure employed to assess each of them

CICES	IPBES	NCP	Brief description	Proxy or procedure employed
Regulating ES	Regulating NCP	NCP1	Habitat creation and maintenance	Connectivity: % of forest in a 500 m radius buffer area (only for forest densification in highly managed areas)
		NCP2	Pollination and dispersal of seeds and other propagules	Sapling and seedling density per hectare (indiv/ha)
		NCP4	Regulation of climate	Overall C stock in biomass per hectare (kg/ha)
		NCP10	Regulation of detrimental organisms and biological processes	Percentage of herbivory (except in *Juniperus thurifera* system)
Provisioning ES	Material NCP	NCP11	Energy	Biomass of thick and medium branches per hectare (kg/ha)
		NCP14	Medicinal, biochemical and genetic resources	Gene diversity per plot corrected by sample size (He)
Cultural ES	Non-material NCP	NCP15	Learning and inspiration	Stakeholders interviews (label: educational services)
		NCP16	Physical and psychological experiences	Stakeholders interviews (label: tourism, recreation, health, landscape aesthetics)
		NCP17	Supporting identities	Stakeholders interviews (label: cultural heritage, sense of belonging, spiritual and religion)
All	All	NCP18	Maintenance of options	Shannon–Wiener diversity index (H': $-\sum_{i=1}^{S} p_i \log_n p_i$), where S is the species richness and p_i is the relative abundance of the species

acidification; formation, protection and decontamination of soils and sediments) or not measurable through readily observable proxies. Further details on the nature and classification of the NCP are given in Supporting Information S1 and S2.

2.3.1 | Field sampling

We included a total of 65 study plots and 2,837 individual trees in the analyses. The sampling design in the *J. thurifera* case study consisted of 17 plots following a gradient of forest expansion including three stages: long-existing forests, intermediate forests and novel forests. In the *F. sylvatica* case study, we selected 18 plots comparing long-existing forests with novel ones. The assignment of individual study plots to the different forest types in both these cases was performed based on a series of aerial photographs dating back to 1950s (see Alfaro-Sánchez et al., 2019; Espelta et al., 2020a; Villellas et al., 2020a; Supporting Information S1 for further information). Three forest stages could readily be distinguished in the *J. thurifera* case thanks to the large spatial dimension of its expansion, which has originated discernible 'recolonisation waves' spanning up to a few kilometres; such a distinction, however, was unfeasible in the *F. sylvatica* case, whose expansion has occurred more locally.

Each of the peri-urban landscapes (*Q. ilex* and *Q. robur* case studies) included 15 plots. Plots in the *Q. ilex* case are spontaneously regrowing on former croplands (Başnou et al., 2016) while in the *Q. robur* case they are embedded in maritime pine plantations (see Valdés-Correcher et al., 2019, and Supporting Information S1).

2.3.2 | Regulating NCP estimation

We assessed four regulating NCP. Habitat creation and maintenance (NCP1; note that we have kept the original order for NCP than in Díaz et al., 2018) was calculated by computing the spatial connectivity of the study plots. Spatial connectivity was chosen as a proxy for ecological connectivity, which is known to enhance biodiversity by providing shelter and habitat for native species. Moreover, forest connectivity helps attenuate climatic conditions as it provides more shaded areas that are preferably selected by people for outdoor activities (Giacomelli et al., 2020), thus being directly linked to human well-being (Barton et al., 2009. Spatial connectivity was inferred by calculating the percentage cover of broadleaved forest in a circular buffer (radius = 500 m) around each plot (Table 1; Supporting Information S1). We quantified this NCP only for the *Q. robur* and *Q. ilex* case studies because the lack of readily identifiable forest patches precluded its estimation for the *J. thurifera* and *F. sylvatica* case studies.

Pollination and the dispersal of seeds and other propagules (NCP2) are intricately linked to human well-being. These key ecological processes support wild plant reproduction and productivity. This then forms the basis for food and feed, as well as for crop and energy production (Potts et al., 2016), and contributes to gene flow and ecosystem restoration. We assessed this NCP by quantifying the density of recruitment of the focal tree species. The rationale underlying this proxy is that, in forest stands, offspring that remain close to conspecifics rarely survive for a noteworthy period of time (Gerzabek et al., 2017). We counted all seedlings and saplings (i.e. all individuals smaller than a given threshold for each species, based on the diameter at breast height (dbh); Table 1; see Supporting Information S1 for

further information) and divided them by the plot area to obtain the density of saplings per hectare.

Climate regulation in terms of biological C storage and sequestration (NCP4) was estimated by the overall C stock contained in the trees of the study plots. Climate mitigation associated with forest establishment and densification has direct consequences on human health and well-being as far as it improves the air quality by filtering pollutants (Nowak, 2006; Nowak et al., 2014). Likewise, it indirectly affects human economies by ameliorating climate-induced extreme events and improving human health (Pillay & van den Bergh, 2016). We calculated the total biomass per tree using species-specific allometric equations that combine the dbh and the height of the sampled trees (Ruíz-Peinado et al., 2011, 2012; Solla-Gullón et al., 2006). We also calculated the C stock per tree multiplying the obtained biomass by the percentage of C in each species (Montero et al., 2005; Table 1; Supporting Information S1).

The regulation of detrimental organisms and biological processes (NCP10) was assessed using the percentage of invertebrate herbivory. Herbivory affects plant biomass, regulates competition and modifies plant community structure with diverse consequences for biodiversity (see for instance Borer et al., 2014). Changes in biodiversity (of plants, herbivores and predators) can in turn affect human well-being via changes in different dimensions of ecological functionality that are related to primary materials, energy provision and health protection (Naeem et al., 2016). For all except the *J. thurifera* case study (as this species generally experiences very little herbivory), we determined herbivore damages by visually estimating the percentage of leaf area removed by invertebrates (Supporting Information S1).

2.3.3 | Material NCP estimation

We assessed two material NCP. Energy provision (NCP11) was understood as the production of biomass-based fuels such as fuelwood (Díaz et al., 2018). Plant biomass is a widely used proxy to measure the contributions of forests as an energy source (Porter et al., 2009). We estimated biomass input from thick and medium branches (i.e. the tree parts normally employed as fuelwood) for each tree within plots. Biomass input from thick and medium branches was calculated from allometric equations specific for each species (Ruíz-Peinado et al., 2011, 2012; Solla-Gullón et al., 2006). Beyond the social value of novel forests, they are particularly productive for fuelwood, which in turn is considered a major use of these forests (Vilà-Cabrera et al., 2017). Furthermore, forest-derived products such as biomass for energy production have recently gained recognition as a sustainable development opportunity for forest-dependent communities (Cambero & Sowlati, 2016).

The provision of medicinal, biochemical and genetic resources (NCP14) includes the production of plant genes and genetic information (Díaz et al., 2018). Genetic diversity has been proposed as a proxy to assess the value of nature conservation as a provisioning service to preserve crop resilience to climate change (Kole et al., 2015) or gene pools for species breeding and reintroduction programs (Luck et al., 2003). Thus, genetic diversity reinforces the contribution of nature to food security and all goods and services derived from biodiversity conservation. In each plot we quantified gene diversity corrected for sample size (*He*; Nei, 1978). For this purpose, all individuals were genotyped using sets of 66 to 141 single nucleotide polymorphism (SNP) markers (see Supporting Information S1 for details).

2.3.4 | Non-material NCP estimation

We assessed all three non-material NCP. We analysed the non-material NCP learning and inspiration (NCP15), physical and psychological experiences (NCP16) and supporting identities (NCP17) at the case study level (i.e. rather than individual plots). These non-material NCP are clearly related to the way in which humans experience nature through direct and indirect interactions. Our analysis was built on qualitative social science research (Yanow, 2007). A total of 40 semi-structured interviews with stakeholders from conservation, agriculture, forestry, tourism, governmental agencies, local populations and other social actors were undertaken by the European Forest Institute (EFI) across the four case studies, ranging from eight to 12 interviews each. As the EFI does not have an ethics committee, the data were collected following the principle of informed consent. Thus, all interview partners were requested individually for an interview. Interviewers explained in detail the purpose of the research project and of the interview, the expected duration, the further use of the data and the expected ways of dissemination. This ensured that participation from all interview partners was voluntary and that they were fully informed of both the purpose of the research and how their input was going to be used. This informed consent was also obtained once again at the beginning of each interview. To ensure data security and respect for the rights and well-being of participants, all interview transcripts were anonymised, social data are not made publicly available so that individuals cannot be connected to their statements and only the EFI institution as responsible for the task has access to the data. The transcribed interviews were analysed using a coding scheme that referred to distinct ecosystem services. Especially relevant for the non-material NCP were the text segments that referred to cultural ecosystem services. Therefore, the following categories were used for assessing the non-material NCP: educational services (NCP15); tourism and recreation, health, aesthetic appreciation and landscape aesthetics (NCP16); sense of place (belonging), cultural heritage and spiritual and religious experience (NCP17). Based on the coded text segments, the effects of forest expansion and densification on the three non-regulating NCP were disentangled for each stakeholder and each case study, and classified into positive, negative, neither or no data available. Subsequently, the overall values for each NCP were calculated for each case study. Learning and inspiration was possible to assess regarding forest expansion, but not regarding forest densification (see Supporting Information S1 and S3 for further information).

2.3.5 | Across NCP categories: Maintenance of options estimation

The maintenance of options (NCP18) includes the benefits associated with species diversity (Díaz et al., 2018). Biodiversity has been directly related with human well-being through the physical and psychological benefits of nature (Fuller et al., 2007), humans' sense of place (Hausmann et al., 2016), and health (Mills et al., 2017). We scored woody species richness and abundance and computed the Shannon diversity index as proxy (Table 1; Supporting Information S1).

2.4 | Statistical analyses

We performed three major types of data analyses corresponding, respectively, to the ecological measures associated with forest expansion and with densification, and to the social science data. All ecological analyses were conducted at the plot or the individual tree level, while the social science analyses were performed regionally with regards to the area in question for each case study.

To address the consequences of forest expansion in the *J. thurifera* and *F. sylvatica* cases, we tested for differences among forest stages. For the proxies measured at plot level (sapling and seedling density, gene diversity and Shannon diversity index for woody species), we carried out one-way ANOVAs or Kruskal–Wallis tests. For the proxies measured at individual tree level (C storage, percentage of herbivory and biomass contained in thick and medium branches) we applied linear mixed effects models (LMEMs) with a Gaussian error distribution using the R package LME4 (Bates et al., 2014). The forest stage was included as a fixed effect and the plot identity as a random effect. Significance values for fixed effects were calculated with a type III ANOVA using the LMERTEST package (Kuznetsova, 2017). Model validation was based on visually assessing the normality of residuals (Zuur et al., 2009). Bonferroni post hoc tests were performed to identify differences among stages when variables were found to be significant in the LMEM. We calculated marginal (i.e. the proportion of variance explained by fixed effects) and conditional (i.e. the proportion of variance explained by fixed and random effects) R^2 for the LMEMs using the 'MuMIn' R package (Barton, 2018).

To assess the consequences of forest densification for material and regulating NCP, we first calculated overall C storage and biomass contained in thick and medium branches per hectare and the mean percentage of herbivory for each plot. Afterwards, we conducted Pearson correlation analyses between these proxies and the basal area per hectare of the target species within each plot. Additionally, we conducted Pearson correlation analyses between the same proxies and the forest stand age (i.e. the average age of individual trees in each plot), a variable that we computed as a proxy for the putative age of each plot. All analyses were conducted in R version 3.2.3 (R Core Team, 2015).

The consequences of forest expansion and densification on non-material NCP were assessed through qualitative analyses of the social science data.

3 | RESULTS

3.1 | Forest expansion: Regulating, material and maintenance of options NCP

Forest expansion generally increased regulating NCP in both case studies, whereas higher provision rates were associated with older forest stages. Specifically, the C stock per individual tree for *J. thurifera* was significantly larger in long-existing forests than in intermediate and novel forests ($M \pm SE$: 88.2 ± 4.18 kg vs. 45.3 ± 4.10 kg and 25.1 ± 4.60 kg respectively). Similarly, C stocks were greater in long-existing *F. sylvatica* forest stands than in novel ones (141 ± 7.5 kg vs. 105 ± 5.3 kg). We also detected a tendency for invertebrate herbivory to be larger in novel forests than in long-existing ones (% herbivory ± SE: 5.96 ± 0.15 vs. 4.36 ± 0.22, respectively; Table 2).

The effect of forest expansion upon material NCP differed between the two case studies. Energy did not differ between long-established and novel *F. sylvatica* forests, whereas it was larger in long-existing *J. thurifera* forests than in the intermediate and novel ones ($M \pm SE$: 49.6 ± 3.7 kg vs. 23.9 ± 4.07 kg and 15.2 ± 5.36 kg, respectively). Finally, we did not detect differences among forest stages in terms of woody species diversity (Table 2).

3.2 | Forest densification: regulating, material and maintenance of options NCP

Forest densification was consistently related with an increase in the regulation of climate through C sequestration. Nevertheless, this did not entail changes in the density of recruitment of the focal tree species or in invertebrate herbivory in any of the case studies (Table 2). Habitat connectivity showed a marginally significant tendency to decrease with densification in the *Q. robur* case study, while we did not detect any variation in the other case studies (Table 2).

Among the material NCP, energy increased with forest densification across all case studies (although the trend was only marginally significant in the *Q. robur* case). In turn, gene diversity decreased with densification in the *Q. robur* case study, whereas we did not detect any relationships in the other case studies (Table 2).

The Shannon diversity index for woody species as a proxy of maintenance of options did not change with forest densification (Table 2).

Finally, the correlation analysis between the mean tree age per plot and the different proxies largely confirmed the previous trends (see Supporting Information S4). Additionally, we observed

TABLE 2 Changes in regulating and material NCP associated with the process of forest expansion (E) and/or densification (D). Wald χ^2 and levels of significance were calculated with type III ANOVA for forest stages (i.e. long-existing (L), intermediate (I) and novel forests (N) for *Juniperus thurifera* and long-existing (L) versus novel forests (N) for *Fagus sylvatica*). Different letters indicate significant differences among stages of the forest expansion according to Bonferroni post hoc tests. Regarding changes in NCP associated with forest expansion, *r* is the correlation coefficient between the proxy and the basal area calculated at plot level. Significance levels: ***≤0.001, **≤0.01, *≤0.05, ·≤0.1. Blank spaces refer to data not available while ns refers to non-significant changes

		J. thurifera		*F. sylvatica*		*Q. ilex*	*Q. robur*
IPBES	**NCP**	**E**	**D**	**E**	**D**	**D**	**D**
Regulating	NCP1					ns	$r = -0.51·$
	NCP2	ns	ns	ns	ns	ns	ns
	NCP4	$\chi^2 = 25.34^{***}$ $L_a\ I_b\ N_c$	$r = 0.99^{***}$	$\chi^2 = 5.23^{*}$ $L_a\ N_b$	$r = 0.99^{***}$	$r = 0.99^{***}$	$r = 0.84^{***}$
	NCP10			$\chi^2 = 2.78·$ $L_b\ N_a$	ns	ns	ns
Material	NCP11	$\chi^2 = 12.05^{***}$ $L_a\ I_b\ N_b$	$r = 0.98^{***}$	ns $L_a\ N_a$	$r = 0.90^{***}$	$r = 0.93^{***}$	$r = 0.49·$
	NCP14	ns	ns	ns	ns	ns	$r = -0.54^{*}$
All	NCP18	ns	ns	ns	ns	ns	ns

Note: NCP1 = habitat creation and maintenance; NCP2 = pollination and dispersal of seeds and other propagules; NCP4 = regulation of climate; NCP10 = regulation of detrimental organisms and biological processes; NCP11 = energy; NCP14 = medicinal, biochemical and genetic resources; NCP18 = maintenance of options.

TABLE 3 Perceptions (either positive, negative or neutral) of the interviewed stakeholders on the changes in non-material NCP associated either with forest expansion (E) or densification (D). Blank spaces indicate that no information is available for stakeholders, processes and/or case studies

			Juniperus thurifera		*Fagus sylvatica*		*Quercus ilex*	*Quercus robur*
IPBES	**Brief description**	**Stakeholder**	**E**	**D**	**E**	**D**	**D**	**D**
Non-material NCP	Learning and inspiration (NCP15)	Environmental			POSITIVE			
		Tourism	POSITIVE					
	Physical and psychological experiences (NCP16)	Environmental	POSITIVE		POSITIVE		POSITIVE	
		Agricultural	NEGATIVE		NEGATIVE			POSITIVE
		Forestry			NEGATIVE		POSITIVE	
		Tourism	POSITIVE		NEGATIVE		POSITIVE	POSITIVE
		Political	NEGATIVE		POSITIVE			NEGATIVE
		Local people	NEGATIVE				POSITIVE	POSITIVE
		Other					POSITIVE	
	Supporting identities (NCP17)	Environmental	NEUTRAL		NEUTRAL		POSITIVE	POSITIVE
		Agricultural	NEGATIVE	NEGATIVE	NEGATIVE	NEGATIVE		
		Forestry	NEGATIVE	NEGATIVE	NEGATIVE	NEGATIVE	NEGATIVE	POSITIVE
		Tourism	NEUTRAL		NEUTRAL			POSITIVE
		Political	NEGATIVE		NEGATIVE		POSITIVE	NEGATIVE
		Local people	NEGATIVE		NEGATIVE			POSITIVE
		Other						POSITIVE

a positive correlation between the density of the recruitment and the mean tree age per plot in the *J. thurifera* and *F. sylvatica* case studies. In the case of *F. sylvatica*, genetic diversity was also positively correlated with mean tree age per plot (see Supporting Information S4).

3.3 | Non-material NCP

We obtained contrasting results for the two rural and the two peri-urban landscapes regarding non-material NCP associated with cultural values and ecosystem services. In the peri-urban landscapes,

forest densification normally entailed an increase in positive physical and psychological experiences and supporting identities, whereas in rural landscapes it was always associated with a negative trend in supporting identities, especially pointed out by forestry and agricultural stakeholders (Table 3; see Supporting Information S5 for a summary of stakeholders' preferences in each landscape). Learning and inspiration was only assessed in relation with forest expansion in the two rural case studies. We observed a positive trend in both: related to ecotourism activities and environmental education in the *J. thurifera* forests, and related to environmental conservation in the *F. sylvatica* forests (Table 3). Finally, trends in physical and psychological experiences varied among stakeholders: environmental actors held a neutral point of view while tourists and political stakeholders were positive (Table 3; Supporting Information S5).

4 | DISCUSSION

A rapid recovery of forest cover has become a major goal of national and international environmental policies world-wide (Bastin et al., 2019; Fagan et al., 2020). While active approaches are currently in the spotlight in forest restoration (Holl & Brancalion, 2020; Seddon et al., 2020), a systematic implementation of spontaneous forest establishment can be a valuable tool for cost-efficient passive restoration programs (Chazdon & Guarigata, 2016; Crouzeilles et al., 2020), especially when the social context is properly analysed and addressed. While novel forests may be valued as green infrastructures and biodiversity hotspots in urban areas (Carrus et al., 2015), a widespread recolonisation of abandoned farmlands by woody vegetation in economically marginal regions may have both positive and negative impacts for local populations (Navarro & Pereira, 2015). Within this greater context, our results showed that both the establishment of novel forests and the densification of existing ones can provide diverse NCP. Especially for non-material NCP, these are highly dependent on the socio-ecological context.

4.1 | Regulating, material and maintenance of options NCP

European forest ecosystems provide a significant amount of environmental goods and services (Hanewinkel et al., 2013; Liquete et al., 2015), serving as relevant C sinks (Bonan, 2008; Pan et al., 2011) as well as sources of raw materials such as timber, firewood and non-timber products. Thus, both forest expansion and densification can be expected to increase NCP related to forest productivity (Naime et al., 2020). In line with this, our results showed that both processes entailed a generalised increase in climate regulation and energy provision through C accumulation. While the trend as such is unsurprising (Kuemmerle et al., 2011), its magnitude should be particularly high in secondary forests that grow on former farmlands owing to land use legacy effects, such as high soil nutrient content (De Schrijver et al., 2011) or favourable microbiome composition (Mills et al., 2017), which considerably enhance tree growth and biomass accumulation (Alfaro-Sánchez et al., 2019; Vilà-Cabrera et al., 2017). The resulting elevated C sequestration potential of secondary forests represents a social benefit by improving human health and mitigating climate change and its subsequent impact in the economies (Nowak, 2006; Nowak et al., 2014; Pillay & van den Bergh, 2016). Additionally, there are other social implications derived from C sequestration that could lead to changes in local economies related to C assets (Lipper & Cavatassi, 2004). An increasingly common example are payments to forest owners for ecosystem services related to C stocks that support new decarbonised economic models and serve as an incentive to stop land degradation and desertification (Jayachandran et al., 2017; Salzman et al., 2018). These different advantages render passive restoration strategies based on spontaneous forest regrowth a potentially powerful tool for achieving the ambitious reforestation goals that diverse national and international policy initiatives have formulated in recent years (e.g. European Commission, 2019a, 2019b; see also Fagan et al., 2020).

Trends in other material or regulating NCP were less evident in our study. Spontaneous forest regrowth tends to increase the connectivity of forested habitats, both in forest-dominated and non-dominated landscapes (Palmero-Iniesta et al., 2020; Benayas et al., 2008). Our contrasting observation that denser *Q. robur* forest patches occurred in areas with lower habitat connectivity is hence likely to reflect a sampling effect because the proliferation of novel, and still sparse, forest patches is most likely to occur where forests are already abundant. The study context prevented us from performing similar analyses for the *J. thurifera* and the *F. sylvatica* case studies, yet field observations suggest that both systems follow the broadly expected trend (i.e. denser forests tend to occur where landscape-scale habitat connectivity is higher). On the other hand, the lower genetic diversity in denser *Q. robur* forest patches is in line with expectations as it reflects an increasing dominance of local reproduction, and hence genetically related recruits, with increasing stand age and density.

Finally, we could not confirm that woody species diversity is reduced in novel forests compared to long-existing ones, a common phenomenon called colonisation credit (Başnou et al., 2016). This result suggests that those places that provide suitable conditions for the establishment of late-successional foundation tree species such as the ones targeted by this study can also rapidly be colonised by associated woody species; this should favour a quick build-up of structural and functional diversity in these novel forests. On the other hand, the colonisation by highly specialised species and those with little mobility can still take a much longer time (Fuller et al., 2018; Naaf & Kolk, 2015).

4.2 | Non-material NCP

Changes in non-material NCP were highly context and stakeholder dependent. The contrasting results for rural and peri-urban landscapes regarding supporting identities can be explained by different

social demands to the landscape in each region, ranging from farming to leisure activities (Buijs et al., 2006). Over centuries, agrarian activities have been the main economic source for the studied rural landscapes; thus, forest expansion and densification processes are perceived by many locals as a loss of their heritage and their own identity connected to the landscape (Fernández-Giménez, 2015). This relates to clear trade-offs in the rural landscapes, where learning and inspiration showed a positive trend, whereas physical and psychological experiences as well as supporting identities showed a negative trend related to the perceived loss of cultural heritage in the region. While we did not systematically consider differences among human generations within our assessment, some interviewees stated that younger generations are more used to the changing landscape and therefore their perception would be more positive.

Independent from the context, different stakeholder groups can perceive the effects of forest expansion and densification on NCP in different and sometimes contradictory ways (Table 3; Supporting Information S5), as also shown in other studies (Frei et al., 2020; Hunziker et al., 2008; Soliva et al., 2008). It is important to consider such differences among stakeholder groups when dealing with management and conservation strategies (Howe et al., 2014; Sterling et al., 2017).

Our interviews showed that forest expansion and especially densification is usually associated with a lack of management, which was negatively perceived by landowners and managers. The intensity of management is closely related to the land ownership structure. In Mediterranean areas for instance, where the profitability of timber is low, large areas of privately owned forestland often leads to a focus on management instead of non-timber forest products, such as recreation (Weiss et al., 2019). In turn, managed forests were positively commented on by most stakeholders because they potentially reduce risks (particularly wildfires), maintain land accessibility (e.g. roads and paths), deliver forest resources (e.g. timber and biomass) and keep landscapes more open and heterogeneous (agreeing with Ribe, 2009). These results are in line with previous research that identified a bias in the social perception of ecosystem services related to the local context and the history of land use (Martín-López et al., 2012). Moreover, it is useful to integrate this local knowledge in management and conservation strategies (Raymond et al., 2010). Thus, if carefully managed, the effect of forest expansion and densification on NCP could potentially be more positive regarding people's perception.

Critical social perceptions of forest expansion can jeopardise ideas to use this process for forest restoration and conservation. Therefore, proper communication about forest regrowth ecological functions (Lamarque et al., 2011) and potential to provide NCP, and an integration of local stakeholders and the population in local landscape governance (Winkel et al., 2015) is recommendable. Such an integration will smooth the translation of ecosystem complexity and functioning in nature's contributions to local communities (Albert et al., 2014). This can result in a bidirectionally beneficial process: by giving local people ownership in governing passive forest restoration processes, the co-production of NCP results is enhanced (Palomo et al., 2016; Raymond et al., 2018). Thus, planning human activities in novel forests (e.g. learning, recreation and creative activities, participatory monitoring, mapping), as well as managing these novel areas for various NCP involving the local population, will increase their value for local communities and with that the potential for large-scale forest restoration (Allen, 1988; Chazdon et al., 2020; Constant & Taylor, 2020; Janzen & Hallwachs, 2020).

4.3 | Constraints and limitations of the study

While this comparative study involves an extensive overall sampling effort, its results still represent a very incomplete picture given the inherent complexity and idiosyncrasy of each case study. Thus, we were only able to address 10 of the 18 identified NCP. The particular characteristics of each target tree species and the forests it builds obliged us to adapt our sampling designs to different contexts. Moreover, the limited number of study plots and individuals per plot within each investigated case study renders our empirical observations susceptible to extensive background noise. We realise that these constraints may well have hampered a more straightforward identification of trends in several NCP. However, many other case studies would not have allowed contrasting rural and peri-urban settings within the same larger geographical region. The selection of study plots was driven by our specific interest in the initial stages of spontaneous forest regrowth, a critical phase in landscape dynamics that has received very little attention by scientists (see also Valdés-Correcher et al., 2019). Given this context, the results reported here should be seen as starting points for more targeted in-depth studies of particular aspects.

5 | CONCLUSIONS

Spontaneous forest regrowth, including both expansion and densification, offers an economically cost-effective opportunity to restore ecosystem functioning and to increase nature's contributions to people of diverse landscapes, while helping to achieve environmental policy goals. Our results reveal that it can represent a valuable tool for passive restoration when the social context is properly addressed and considered. Different stakeholder perceptions and trade-offs between competing land uses need to be carefully addressed in order to enhance forest multifunctionality and sustainability. In this sense, alternative management practices could modify NCP, especially in rural areas where the protection of traditional activities and heritage should be as encouraged as conservation policies.

ACKNOWLEDGEMENTS

This work was funded by the grants SPONFOREST [BiodivERsA3-2015-58, PCIN-2016-055, financed by the Spanish Research Agency (AEI) and the Spanish Ministry of Economy, Industry and Competitiveness

(MINECO)], COMEDIAS (MINECO, CGL2017-83170-R), REMEDINAL TE (Ref. TE-CM. S2018/EMT-4338, 2019-2023-Comunidad de Madrid) and the German Research Foundation. We are especially grateful for the help, advice and support provided by Belén Acuña-Míguez, David López-Quiroga, José Miguel Olano, Adrián Escudero, Pablo Álvarez, Esteban Manrique, Eduardo Serna, Miguel Díaz, Alicia Forner, Ludmila Aglai, Jesús Villellas, Cristina C. Bastias, Bárbara Carvalho, Raquel Benavides, Stephanie Mariette, Erwan Guichoux, Marie Massot, Bastien Castagneyrol, Marina Palmero-Iniesta, Joan Pino, Alistair Jump, Marta Ramírez, Ohiane Díez-Nogales, Audrey Bourdin, Xavier Capdevielle, Yannick Mellerin, Inge van Halder, Didier Bert, Gilles Saint-Jean, Victor Rébillard, Martine Martin-Clotte, Erwan Guichoux, Marie Massot, Adline Delcamp, Fabrice Vetillard, Elias Garrouj, Jakob Derks and Inazio Martínez de Arano. We are also thankful to José Antonio Lozano, director of the Alto Tajo Natural Park, for facilitating the research at the park. Thanks are also due to the interviewees and the local population of the sampled villages for their willingness to contribute to the study. We would also like to thank Robin Chazdon, Alejandro Rescia and the associated and lead editors of People and Nature for their valuable suggestions.

CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

AUTHORS' CONTRIBUTIONS

I.M.-F., A.B.-O. and F.V. conceived the ideas; I.M.-F., R.A.-S., T.F., C.R.F.-B., G.G., E.V.-C. and A.H. collected the data; I.M.-F. analysed the data; I.M.-F. led the writing of the manuscript with help from R.A.-S., S.M. and A.H. All authors contributed critically to the drafts and gave final approval for publication.

DATA AVAILABILITY STATEMENT

Data are deposited in the Dryad Digital Repository https://doi.org/10.5061/dryad.z612jm69k (Martín-Forés et al., 2020). Complementary data from associated studies can be found in Villellas et al. (2020b) https://doi.org/10.20350/digitalCSIC/12519, Espelta et al. (2020b) https://doi.org/10.6084/m9.figshare.12646400.v1, in Ruiz-Carbayo et al. (2020b) https://doi.org/10.5061/dryad.rxwdbrv4v and in the Supporting Information of Valdés-Correcher et al. (2020).

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

How to cite this article: Martín-Forés I, Magro S, Bravo-Oviedo A, et al. Spontaneous forest regrowth in South-West Europe: Consequences for nature's contributions to people. *People Nat*. 2020;00:1–15. https://doi.org/10.1002/pan3.10161