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Resilience as a Moving Target: An Evaluation of Last Century Management Strategies in a Dry-Edge Maritime Pine Ecosystem

Daniel Moreno-Fernández [1,*], Miguel A. Zavala [1], Jaime Madrigal-González [2] and Francisco Seijo [3]

[1] Grupo de Ecología y Restauración Forestal (FORECO), Departamento de Ciencias de la Vida, Universidad de Alcalá, Alcalá de Henares, 28805 Madrid, Spain; ma.zavala@uah.es

[2] Climate Change Impacts and Risks in the Anthropocene, Institute for Environmental Sciences, University of Geneva, 66 Boulevard Carl Vogt, 1205 Geneva, Switzerland; Jaime.MadrigalGonzalez@unige.ch

[3] Instituto de Empresa School of Global and Public Affairs, Calle de María de Molina, 13, 28006 Madrid, Spain; fseijo@faculty.ie.edu

* Correspondence: danielmorenofdez@gmail.com

Abstract: Forests are intrinsically coupled to human dynamics, both temporally and spatially. This evolution is conditioned by global changes in climatic conditions (teleconnections) and distant socio-economical processes (telecoupling). The main goal of this study is to describe the teleconnections and telecoupling dynamics that have shaped structure and processes in a dry-edge—highly vulnerable to desertification—Mediterranean pine forest during the last century and to evaluate the contribution of historical management strategies to this coupled human and natural system's (CHANS) overall resilience. For this study, we collected relevant human and natural system data from a dry edge *Pinus pinaster* Ait. located forest in Central Spain using a CHANS analytical framework operationalizing telecoupling and teleconnection. A key extractive economic activity in the studied forest was resin tapping, which was the main form of land use from the 1920s to the 1950s. Since the 1950s changes in the Spanish economy linked to the emergence of new resin-producing countries, such as China, led to a sharp decline in resin production. Despite additional human system transformations affecting forest governance (e.g., the Spanish Civil War, the transition to democracy, European integration, etc.) and changes in biophysical conditions linked to climate change (e.g., aridification, CO_2 fertilization), the standing stocks of *P. pinaster* increased during the monitoring period due to sound technical and management planning bolstering overall resilience. These historical management decisions, we argue, successfully reconciled overall resilience goals (defined as the maintenance of forest function beyond and desertification avoidance) with three successive historical forest use challenges: intensive firewood collection by local communities in fragile sandy soils, extensive pastoralism in the forest understory and tradeoffs between resin tapping damaged trees, timber production and tree cover as well as the emerging risks of wildfire and climate change.

Keywords: CHANS; globalization; historical data; socio-ecological frameworks; dry-edge

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1. Introduction

Human beings have altered ecosystem structure, function and disturbance throughout history to obtain goods and services from Nature [1,2]. This has been the case for Mediterranean forest ecosystems, which throughout history have provided different functions and services such as wood production [3], carbon storage [4], biodiversity [5], aesthetic functions [6], forage for livestock [7], hunting [8], as well as non-wood products such as resin [9], cork [10] or pine cones [11]. For centuries, humans have exploited Mediterranean forests attempting to maximize economic (e.g., provision of wood, fuelwood, hunting), cultural (e.g., hunting and ecotourism), social (e.g., resources for local communities) and strategic needs (e.g., intervention by the public administration for energy use, water reservoirs, economic production or conservation goals). However, over the last decades, the compounded effects of climate change, human system transformations (e.g., local and international market fluctuations in the demand for forest products) and changes in forest policy governance priorities have pressured the capacity of Mediterranean forests to maintain provision of ecosystem services [12]. Furthermore, as a consequence of changing national and international legislation, new conflicts of interests between stakeholders have emerged which may require changes in local management strategies [13].

These complex social-ecological interactions have been traditionally analyzed through socio-ecological sustainability frameworks [14]. The coupled human and natural systems (CHANS) analytical framework, however, which we apply in this study goes beyond the socio-ecological sustainability approach by focusing on human and natural system feedback couplings, understood as flows, and emergent system properties and how these interactions vary across alternative spatial, temporal and scales [15–17] (we refer readers to the Material and Methods section for further details of the CHANS approach).

The CHANS approach is of particular importance when analyzing ecosystem dynamics as ecosystems change constantly and their functions do not remain in an equilibrium state but rather evolve permanently in time and space. Indeed, ecosystems can cross ecological thresholds or tipping points after which the ecosystem may cease to provide certain functions [18,19]. These spatio-temporal fluctuations may be driven by anthropogenic activities or natural forcings that may interact in complex ways [12,20]. Human activity, through alternative forest management regimes, may modify stand structure and species composition to increase the provision of some functions with lasting legacy effects [12,21,22]. Furthermore, national and international agreements claim to promote afforestation and reforestation programs to enhance the carbon sink capacity of ecosystems, achieve sustainable development goals as well as control soil erosion and regulate the hydric cycle [23,24]. This, in fact, has resulted in land use and CHANS feedback modifications in the targeted territories of developing countries [25,26]. Environmental drivers, such as climate fluctuations or wildfires can interact with biotic drivers, competition, herbivory or pathogens to drive forest dynamics [27,28] and constrain the provision of wood and non-wooden products [29,30].

One of the greatest challenges facing forest managers is climate change, which cannot be analyzed locally since changes in biophysical conditions in one site may influence very distant sites through atmospheric circulation. This phenomenon is known as teleconnection [31]. An additional challenge for current forest managers is economic globalization, which increasingly determines that human land use is also affected by international markets and manufacturing costs [32–34]. In turn, these changes condition local management decisions and may result in tipping points for example in community species (substitution of one forest species with a more lucrative one) [35]. Indeed, the production of an ecosystem good in a given area of the world can be reduced because the manufacturing costs of the by-products are much lower in other areas located thousands of kilometers away [36].

Both human and climatic drivers have both direct and indirect effects on forest dynamics and forest resilience. However, the concept of forest resilience is difficult to define and can be explained through three different, though complementary conceptualizations: engineering, ecological and socio-ecological resilience [37,38]. Whereas engineering and ecological resilience refer to the ability of a system to return to its pre-disturbance stage and the capacity to absorb change and disturbance while maintaining similar feedback dynamics with social or political system variables, respectively [39,40]. Social-ecological resilience, on the other hand, considers the preservation of natural and human system couplings and the adaptive capacity of the entire CHANS [38]. The differences among the three conceptualizations can lead to alternative indicators being employed to quantify or describe forest resilience. According to Nikinmaa et al. [38], the most common indicators in engineering and ecological resilience studies are related to forest structure and biodiversity, while the indicators linked to economic activities as well as financial and technical infrastructure are mainly used to evaluate social-ecological resilience. These authors also argue that the target organization level also varies amongst the different conceptualizations but are nested: that is, engineering resilience (tree level) is nested within ecological resilience (forest level) which is nested within social-ecological resilience (CHANS level).

Due to the complexity of the factors driving the provision of forest ecosystem services, efforts have been made to identify spatial [41,42] and, to a lesser extent, temporal trends [43,44] of multifunctionality. However, data on the effects of distant socio-economic and environmental interactions on the supply of ecosystem services is scarce [34]. Yet, a temporal perspective is critical in order to assess potential shifts in stable states and tipping points, particularly in dry edge ecosystems highly vulnerable to desertification. In this regard, Anderegg et al. [45] state that climatic stress has surpassed the physiological and ecosystem-level tolerance of woody species growing at the driest edges of their geographic ranges leading to processes.

The main goal of this study is to describe the CHANS dynamics that have shaped forest structure and dynamics during the last century in a Mediterranean forest ecosystem and to examine the forest resilience to key human and natural system transformations. In particular, we explore whether the forestry management strategy developed in Spain since the beginning of the 20th century (i.e., "Ordenaciones de Montes" [46–48]) has been able to bolster the social-ecological forest resilience by reconciling multiple human use demands under intensifying globalization, local socio-demographic transitions and global environmental changes while maintaining key ecosystem function and services in the public "Las Pegueras" forest of Cuellar, Segovia. In previous studies we have shown evidence of resilience in tree growth and stand dynamics in Las Pegueras Forests along the last century and considering teleconnections [49,50]. Here we investigate for the first time resilience of the managed system (sensu Nikinmaa et al. [38]) describing last century patterns in key forest functions and products. To pursue this research goal, we have integrated human and natural system data from historical management records relevant to the case study of Las Pegueras Forest in Central Spain and have interpreted observed patterns following a CHANS conceptual framework. The studied forest is publicly owned and has been managed by the public administration since the beginning of the 20th century.

2. Materials and Methods

2.1. Biophysical Description of Las Pegueras Forest

Las Pegueras Forest (≈7000 ha) is located in Central Spain (41°21′ N, 4°12′ W; Figure 1) and grows on sandy, unconsolidated (inland dunes), siliceous and flat soils at altitudes ranging from 820 to 880 m asl [51]. The annual mean temperature is 12 °C and the annual rainfall is around 460 mm, although the annual rainfall displays high interannual variability [52]. The summer is characterized by severe drought which, together with the low soil water-holding capacity, constrains the establishment of new cohorts [53].

The dominant species is *Pinus pinaster* Ait., commonly known as Maritime pine, representing more than 90% of the trees, while the remaining trees are montane pines (*Pinus sylvestris* L. and *Pinus nigra* Arn.), oaks (*Quercus ilex* L., *Q. faginea* Lam. and *Q. pyrenaica* Willd.) and riparian species (*Salix* spp, *Populus* spp, *Alnus glutinosa* (L.) Gaertn. and *Fraxinus* sp). The understory is composed of disperse annual plants and dwarf shrubs such as *Thymus* spp and *Genista* spp. The above-mentioned site characteristics make the study area the dry edge of *P. pinaster* distribution in its natural range.

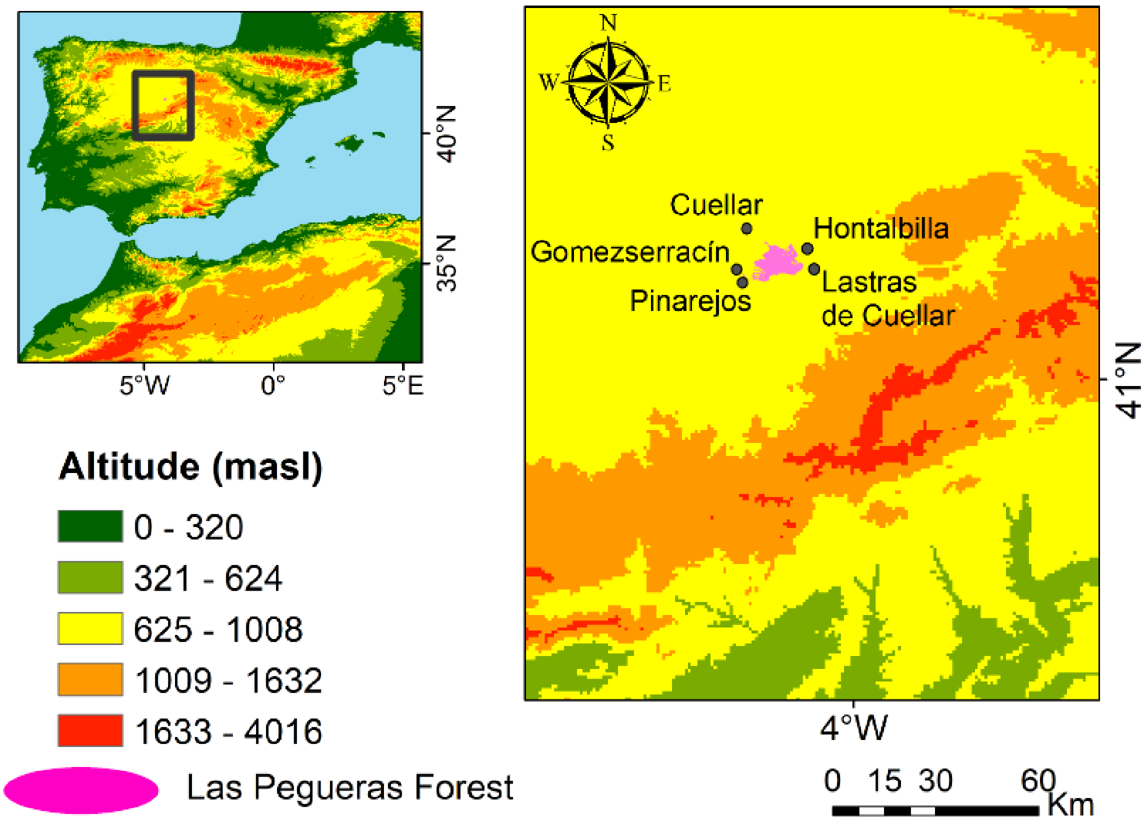

Figure 1. Location of Las Pegueras Forest and the five villages surrounding the forest.

2.2. Socioeconomic Context & Historical Data

Las Pegueras Forest is a public forest belonging to 36 villages although it is managed as a single administrative entity by the autonomous community public forest administration of the Castilla y Leon regional government (Figure 1). The Pegueras forest is considered a "public utility" forest ("Monte de Utilidad Pública") by the Junta de Castilla y Leon regional government. The "public utility" status was accorded during the 19th century as a legal mechanism for protecting socially and ecologically valuable forests, from a preservationist point of view, from extractive economic uses that could degrade their social or ecological protective nature while also preventing their privatization [54,55]. In the case of Las Pegueras forest, its economic use has been, in addition, regulated since 1912 through a forest management plan ("Instrucciones de Ordenación de Montes" [46,47]). This system enables the public administration to guarantee a rational, socially beneficial use of the resources of a given public or private forest. This forest management system in Las Pegueras managed by the Spanish state forest administration first and the autonomous community later has been maintained through changing political conditions in Spain, ranging from the Primo de Rivera and Franco dictatorships, the Spanish Civil War, and finally the democratic regime which initiated the integration of Spain in European Union governance and regional administrative devolution (i.e., from the central Spanish government to autonomous communities). The management plans for Las Pegueras Forest are reviewed every ten years (Table 1). These plans lay down specific spatial and temporal prescriptions for the exploitation and conservation of the forest. The forest (≈7000 ha) is divided into 10 management units which are selectively exploited using the permanent block system in a rotation period of 80 years. In addition, the uniform shelterwood system is applied over a 20-year regeneration period as the method to achieve natural regeneration. When a proper number of new individuals is not achieved, forest managers turn to artificial regeneration. The thinning regime is low. Each management unit is split into four blocks where the trees are expected to be 0–20, 21–40, 41–60, 60–80-year-old.

Table 1. Year of implementation and monitoring period of the management plan and its revisions.

Forest Management Plan	Year	Monitoring Period
Original management plan *	1912	-
1st Revision *	1922	1912–1922
2nd Revision	1932	1922–1932
3rd Revision	1942	1932–1942
4th Revision	1952	1942–1952
5th Revision	1962	1952–1962
6th Revision	1972	1962–1972
7th Revision	1982	1972–1982
8th Revision	1993	1982–1993
9th Revision	2003	1993–2003
10th Revision *	2013	2003–2013

* Data not available.

We obtained the population temporal series of the five villages surrounding the forest (number of inhabitants) from the Spanish Statistical Institute (http://www.ine.es/, accessed on 17 May 2021). These five villages have a close economic relationship with the forest in terms of economic use of ecosystem goods and services. Long-term resin production and imports/export data in Spain and other international markets were obtained from the Spanish Ministry of Agriculture. In order to characterize climatic change impacts in Las Pegueras forest, we calculated the 12-month Standardised Precipitation-Evapotranspiration Index (SPEI_12) for the study area (https://spei.csic.es/spei_database, accessed on 17 May 2021) over the last century [56]. Negative values of SPEI_12 indicate a negative water cumulative balance as a function of precipitation and temperature at a 12-month temporal scale.

2.3. The Coupled Human and Natural Systems (CHANS) Conceptual Framework

The CHANS scheme is composed of five major components: (i) sending, receiving, spillover systems; (ii) material, energy or information flow; (iii) agents (e.g., landowners, governments, companies); (iv) economic, political, environmental feedbacks and, (v) environmental and socioeconomic impacts (e.g., loss of biodiversity and ecosystem services, displacement of local people) [57]. CHANS theory has suggested that the compounded interactions of teleconnection and globalization should be integrated into what they define as the telecoupling framework [57]. This approach, which we will be applying in this study, allows for the identification of exchange flows of material/energy or information, agents promoting or hindering these flows, and the environmental and socioeconomic impacts of telecoupling within and between distant CHANS [36].

To cope with the need of considering the temporal complexity of CHANS interactions, Seijo and Gray [58] and Steen-Adams et al. [59] proposed and developed a framework focusing on historical data. This approach provides information on the influence of long-term interactions on current and future human and forest conditions in different historical periods [15,59]. Accordingly, we split the temporal series into three historical periods for the analysis of CHANS interactions. For the sake of simplicity and synthesizing the available information and data we divided historical human forest use into three phases: the Pre-industrial phase (1900s–1960s), the Industrial phase (1960s–1980s) and the Post-industrial phase (1980s–to date) though temporal and spatial uses overlap (eg. industrial phase resin tapping was already present in the late 19th century and preindustrial phase firewood collection and pastoralism lasted until well into the industrial 20th century phase). Figure 2 summarizes in a flow chart our operationalization of the historical telecoupling framework for Las Pegueras.

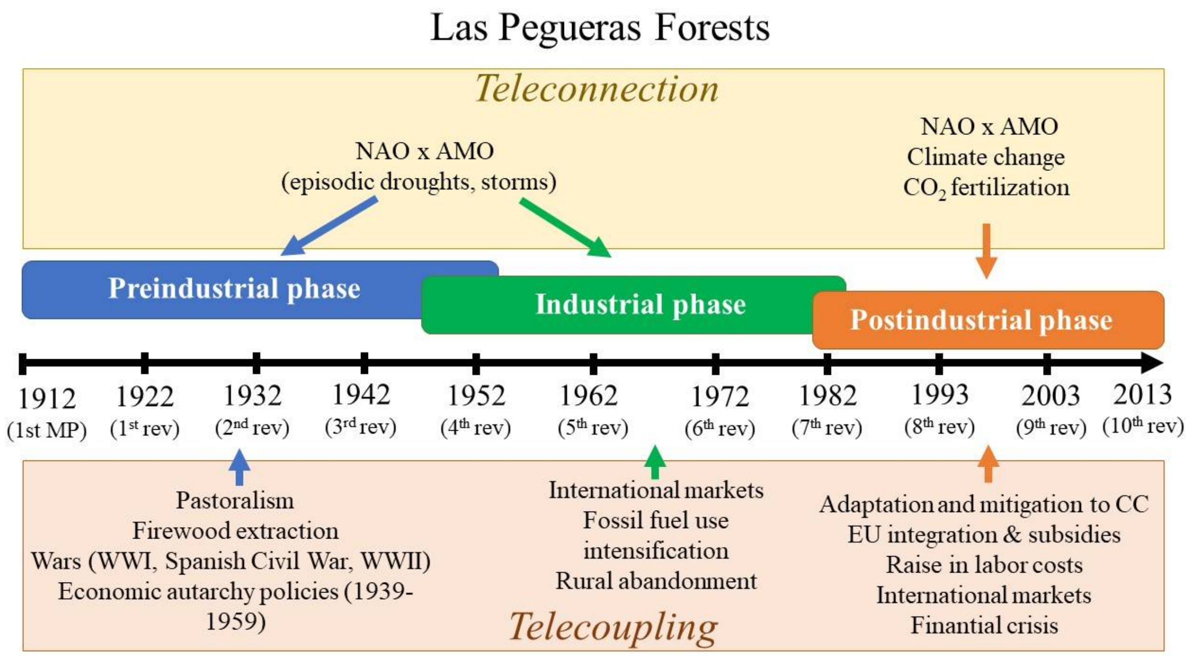

Figure 2. Flow chart of Las Pegueras Forest and the historical telecoupling framework. MP: Management plan. Rev: revision of the management plan.

3. Results and Discussion

Below, we provide a detailed description of the long-term historical data, link these data to telecoupling phenomena during the different historical periods and discuss the effects of the public administration historical management strategies on forest ecosystem resilience.

3.1. Human System Cycles Conditioning the Management Plans of Las Pegueras Forest

3.1.1. From the Preindustrial Phase to the Mid-20th Century

During the Holocene, *P. pinaster* together with *Pinus pinea* L., were the dominant species in these inland dunes [60,61]. However, up until the beginning of the 20th century Las Pegueras Forest, like many other forests in Spain (see for instance Moreno-Fernández et al. [4]) was not regulated by a management plan that ensured the preservation of the forest and the sustainability of its economic uses. The resin sector experienced significant growth during the first decades of the 20th century which led to the implementation of forest management plans to increase the resin tapping potential [62]. The forest was managed for the maximization of resin tapping from the *P. pinaster* trees and, to a lesser extent, timber production. The stand density was low (mean tree density of the blocks is around 390 trees with dbh $\geq$ 20 cm per ha and ranges between 200–800) even in mature stands, to promote trees with large diameter and crown that maximize individual tree resin production [9,63]. Despite the fact the forest was managed for the maximization of resin tapping from the *P. pinaster* trees, the first 1912 management plan prescribed four income-generating economic extractive uses compatible with the forest "public utility" status: (i) resin tapping, (ii) timber production, (iii) firewood extraction from downed branches, litter, twigs as well as other small pieces of wood laying on the ground and (iv) pastoralism with goat herds. Each plan records information on the tree stocks (m^3, number of trees), timber removals (m^3, number of trees, pesetas [Spanish currency before the Euro], €), resin tapping (kg, pesetas, €, number of tapped trees), firewood extraction (pesetas) and pastoral activities (pesetas). Resin tapping takes place annually from March to October in logging units selected by the public administration. Trees were originally tapped using the Hugues method until the middle of the 20th century when it was replaced by a novel system that combines sloped stripes wounds in an upward direction with acid stimulation to promote resin exudation. This method is described in detail in Rodriguez-García et al. [9,63]. Timber extraction was mainly focused on the trees felled during regeneration cuttings of the uniform shelterwood while firewood collection was carried out by the local population. Other functions that have gained importance in later years such as biodiversity conservation, the reduction of soil losses (note that the soils are inland dunes), hunting, fishing, mushroom picking or recreational uses were not contemplated in the management plans.

Once the plan was implemented, the forest yielded higher production of resin, timber stocks and extracted wood (Figure 3). Interestingly, both the resin production and the number of tapped trees peaked during this period (Figure 3A,B). The standing wood volume increased progressively (Figure 3C) while the number of adult trees experienced a rapid increase from 1912 to 1932 when tree density finally stabilized (Figure 3D). This evidence suggests that tree size has increased over the monitoring period.

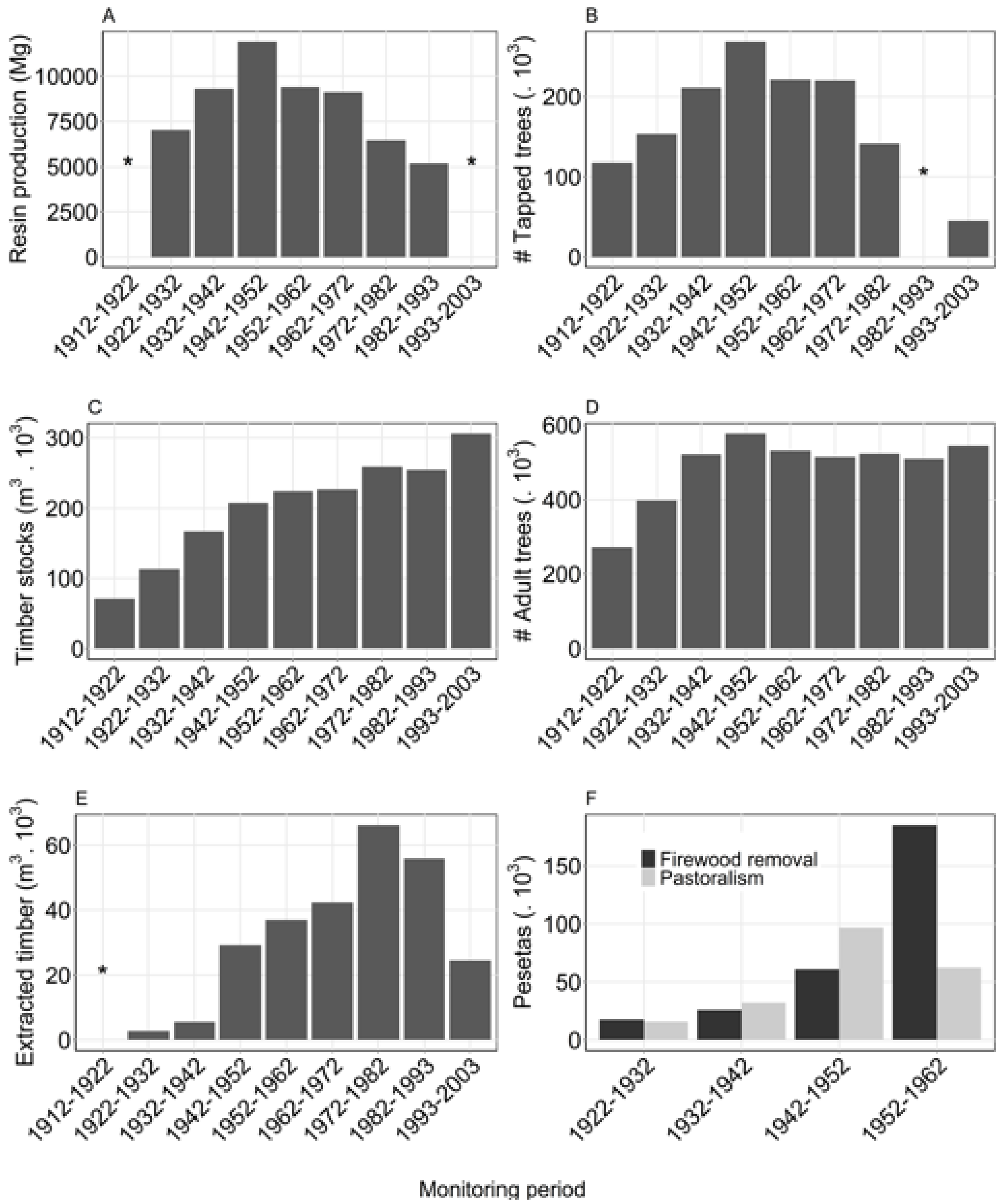

Figure 3. Evolution of resin production (**A**), number of tapped trees (**B**), standing timber stocks (**C**), number of adult trees (dbh > 20 cm) (**D**), extracted timber (**E**), firewood removal and pastoralism (**F**) in Las Pegueras Forest over the study period (1912–2003). Asterisks indicate data non-availability.

During the pre-industrial phase, resin and timber extraction were harmonized with pre-industrial era subsistence economy activities such as hunting, pastoralism and firewood extraction. According to the forest engineer's notes recorded in the management plans, there was an increased social demand for firewood extraction rights. Note that the populations of the villages that own the forest increased during this period (see Figure 4). As a consequence of the increased social demand for firewood, the wood extracted from Las Pegueras increased from 1922 to the mid-20th century (Figure 3F). Similarly, incomes generated from pastoralism reached their maximum values from 1942 to 1952. At this point, it is important to take into account that industrialization in Spain lagged behind other European countries although the economic transition was spatially and temporally very heterogeneous across the Iberian Peninsula and was delayed due to the economic isolation faced by the Franco regime. For example, firewood was still a key energy source in Spain during the first decades of the 20th [64] century and, together with pastoralism, was a fundamental subsistence economy activity for local populations.

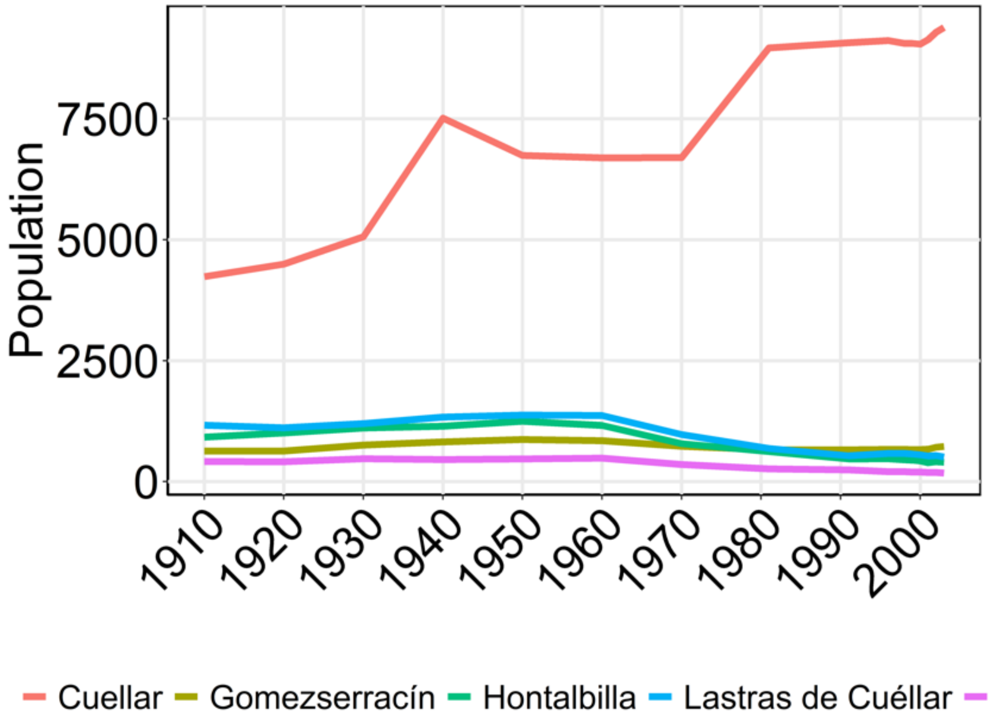

Figure 4. Population trends (number of inhabitants per village) of the five villages that own the forest.

The Las Pegueras Forest, was directly affected by the Spanish Civil War (1936–1939) and indirectly by the First and Second World Wars. The Spanish Civil War resulted in a change in the political regime, that economically isolated Spain from Europe and interrupted the increased integration of Spanish and European markets observed since the end of the 19th century [65]. Additionally, the decades of the 1950s–1960s were especially dry (see low values for SPEI in Figure 5). Despite social-economic upheaval and harsh climatic conditions, timber stocks, resin production and firewood extraction displayed an increment in Las Pegueras Forest.

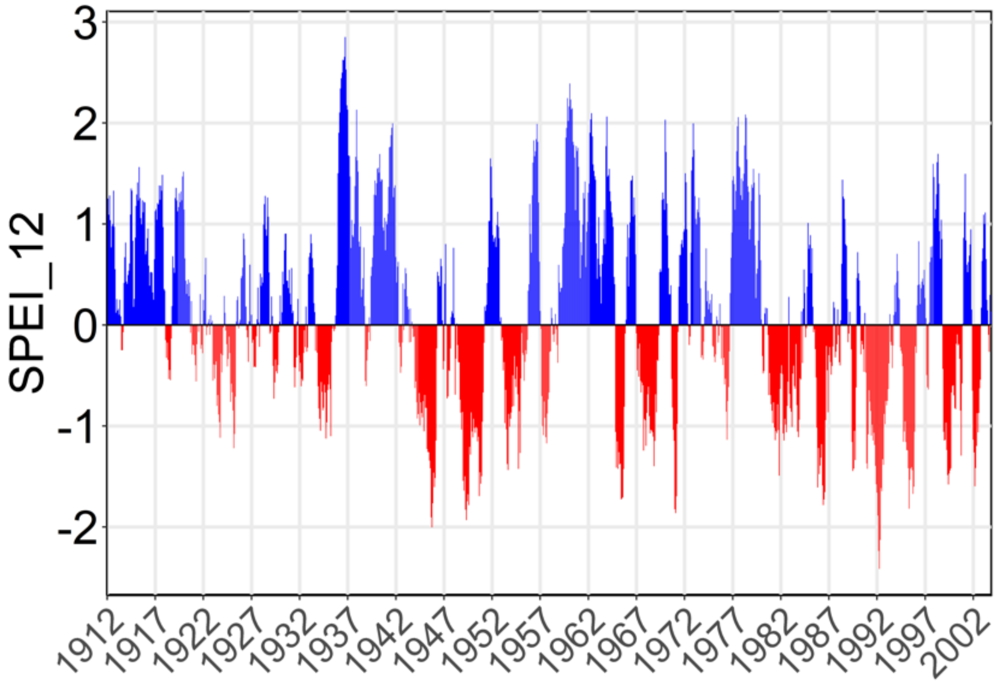

Figure 5. 12-month Standardized Precipitation Evapotranspiration Index (SPEI_12) for the study area from 1902 to 2018.

In sum, during the pre-industrial phase, the public administration management regime was superimposed on traditional ecological knowledge (TEK)-based extractive economic uses by local communities [66,67]. Though the impact on overall forest resilience of these TEK-based practices (firewood extraction, pastoralism) remains an underresearched topic (for instance, the impact on soil nutrient availability due to goat manure) it is clear that the gradual disappearance of these practices led to an increase in standing timber stocks and forest cover based on the evidence available to this study.

3.1.2. From the Mid-20th Century to Industrialization

Spain underwent important economic reforms in the 1960s, which stimulated internal economic demand and jumpstarted the industrialization of the country and the forest sector through a gradual liberalization of the economy [65,68]. This led to an increment in the cost of field labor and progressive rural hollowing or abandonment. Another important consequence of industrialization and the greater interconnectedness of the Spanish with the global economy were the changes in the source of heat energy for homes and industry owing to an increment in the importation of fossil fuels [65,69]. In Las Pegueras Forest, this seems to be related to the observed drop in firewood extraction in the 1960s (Figure 3F). Since the beginning of the 20th century, forest managers recommended phasing out this activity because firewood represents one of the few sources of nutrients in these sandy soils. Finally, the phasing out of pastoralism was also recommended as goats remove shrubs and lichens that contribute to control soil erosion and to avoid damage on the regeneration. Probably, the changes in local energy sourcing, which may have led to a consequent drop in the demand for firewood from local communities, allowed forest managers to restrict firewood extraction and meet this goal. Paradoxically, therefore, as carbon emissions from fossil fuels in the surrounding region of Las Pegueras increased, due to greater telecoupling with international energy markets, local carbon sequestration probably increased as a result of increased forest cover. Again, this possible new function of the forest ecosystem as a carbon sink deserves further research though the issue is beyond the scope of this study.

In this phase both resin variables, i.e., resin production and the number of tapped trees decreased in Las Pegueras Forest (Figure 3A,B, respectively). Similar to the resin tapping trends observed in Las Pegueras, national resin production initially peaked at the beginning of the 1960s industrial boom with productions larger than 50,000 tons and then dropped dramatically [62]. This drop can be linked to the liberalization of the Spanish economy and the emergence of new producing countries such as China and, to a lesser extent, Brazil and Indonesia (see Liu [36] for export trends of forest products from China from the 1960s to 2010s). The incorporation of these new producers in addition to the greater use of fossil fuels by rural communities resulted not only in a telecoupling feedback in Las Pegueras Forest, but also in the entire Iberian Peninsula [70,71] where the emergence of distant resin producing countries due to lower field labor costs resulted in a local reduction of resin tapping in Las Pegueras Forest. Telecoupling feedbacks also led to an increase in the consumption of resin by-products, which resulted in a deficit in their production at the national and also at the European level [71,72]. Consequently, according to the management plans, resin tapping activity in Las Pegueras was maintained thanks to economic subsidies from the public administration.

The drop in resin production in Las Pegueras Forest coincides with a drop in population in the four smallest villages that own the forest (Figure 4). This phenomenon is known as rural abandonment or hollowing. Rural abandonment was common in Spain during this period but was somewhat more contained in resin-producing villages as resin tapping served to generate rural employment [71]. However, it became increasingly difficult to recruit workers for resin tapping due to the arduous nature of the job with scarce rural workers preferring more stable jobs in the industrial belt surrounding Cuéllar. Cuéllar, with more than 5000 inhabitants, in fact did not seem to be affected by demographic abandonment which may have been driven, in part, by the contraction of the resin sector.

Similar to the observed trends for resin variables, the extracted timber followed a bell-shaped reaching a maximum during the 1970s.

3.1.3. From the Late 20th Century to the Post-Industrial Phase

The aforementioned resin sector telecoupling feedback started changing at the beginning of the 21th century when China experienced an industrialization process similar to the one that had occurred in Spain during the 1950s and 1960s. Both processes have resulted in similar consequences, such as rural abandonment, rural aging and raised field-labor costs [73,74]. European Union integration together with the new paradigm in European rural governance via the European budget (tiny rural repopulation and recovery of traditional uses) opened up by post-2008 financial crisis European stimuli spending led paradoxically to a re-emergence of the demand for resin tapping. However, this increased resin tapping activity has been accomplished through public administration subsidies which may undermine its economic sustainability in the context of greater public sector indebtedness. In this regard, Soliño et al. [75] analyzed local community perception of subsidized resin-tapped *P. pinaster* forests in Central Spain. They highlighted that, overall, local communities agreed with the idea of promoting resin tapping activities again in these forests and that its promotion could result in lower wildfire risk due to associated understory fuel reduction (for instance, a resin tapper needs to tap about 1000 trees to obtain profitability which requires an open forest structure to facilitate access to individual trees) and the maintenance of rural population. Again this is a topic that needs to be further researched from the point of view of overall CHANS sustainability and the emerging discussion of payment for ecosystem services schemes at a European and Spanish level [76].

3.2. Ecological Legacy Effects of Past Uses and Emerging Resilience Challenges

Our results indicate an increase of the standing timber stocks together with an increment of productivity in terms of resin production and timber extraction since the implementation of the first management plan. Though many individual trees have been damaged by resin tapping with the consequent loss of radial growth [77], standing timber stocks were four times larger in 2003 than in 1912. This huge increment in forest cover is positively linked to other ecosystem functions. First, the increase in forest cover is expected to reduce wind erosion and promote soil consolidation and stabilization [78,79]. Secondly, the maximization of standing stocks favors the fixation of carbon and contributes to the mitigation of climate change [4,80]. As discussed previously, the decline in the two main income-generating forest functions, resin tapping and timber removal, were influenced by telecoupling feedbacks over which the historical management plans had little influence rather than by a dramatic fall in the potential productivity of these activities. In addition to changing telecoupling feedbacks the evolution of this CHANS is largely driven by the impacts of teleconnection with the global climate system which might threaten social-ecological resilience. The maintenance of wood stocks over the study period, however, indicates that ecological resilience has not been decreased due to varying teleconnection feedbacks (i.e., climate change). The extracted timber and resin production —that is, human use—has declined due to telecoupling feedbacks, but they have the potential to be restored or maximized with better human system management.

Madrigal-González et al. [50] have studied global climate impacts via transformations in the North Atlantic Oscillation (NAO) and the Atlantic Mediterranean Oscillation (AMO) on tree dynamics in Las Pegueras Forest (engineering resilience). For instance, the NAO affects tree growth in Las Pegueras through increased aridity due to reduced annual precipitation. Hence, the frequency of dry years has increased since the 1980s (Figure 5). Similarly but at the forest level (ecological resilience), Madrigal-González et al. [49] studied the demographic resilience of Las Pegueras over the last century and identified that the ecological resilience is high but the forecasted increment of droughts episodes, in terms of severity and frequency, could exceed the resilience of the system. In this regard, thinning operations prescribed by the management plans (applied from the beginning of the rotation period to the beginning of the regeneration period) attenuated the impact of dry years on tree growth [81]. These cycles are not, however, explicitly accounted for in management prescriptions plans which are based on average climatic expectations.

Regeneration is a key process for ensuring the renewal and persistence of forests [82]. Success in the regeneration of Mediterranean tree species is constrained by summer droughts, among other factors [83], which are forecasted to increase in severity, extent and frequency [84–86]. In our case study, the uniform shelterwood cuttings, which are carried out over the last 20 years of the rotation period, achieved the establishment of new cohorts and, therefore, the renewal of the forest [87]. Although *P. pinaster* is a light demanding species, summer climatic conditions can be so harsh that partial cover is needed to ensure regeneration. Then, to alleviate the effects of the limiting summer conditions on seedling establishment and to assure sufficient natural regeneration [83], the recent revisions of the management plans extended the regeneration period to 25 years. The uniform shelterwood method manipulates stand density to optimize seedling survival along the shade-drought tolerant tradeoff that is key in the assembly of Mediterranean forests [88,89]. Given long term forest function maintenance the management method (permanent blocks and the uniform shelterwood system) used in Las Pegueras Forest seems to have successfully contributed to CHANS resilience though more research is needed to evaluate its impact on rural depopulation. This forest, however, faces new challenges mainly associated with climate change adaptation, mitigation and renewable energy production policies in Europe and Spain. Many forests of *P. pinaster* surrounding the study area are affected by decline processes, that are expressed through attenuated forest growth rates, increments in mortality and failure in regeneration [53,90]. This situation is aggravated by the overexploitation of aquifers for agricultural purposes, which results in strong fluctuations of the water table [53,83]. Moreover, advances in stimulants for resin tapping may promote the yield as well as this rural activity [91] though its reformulation as a subsidized payment for ecosystem services scheme may be necessary due to its low profitability and high volatility given international market conditions. Additionally, preliminary studies from an ongoing research project indicate that the tapped *P. pinaster* trees are valid for structural uses [92].

4. Conclusions

The observed long-term ecological forest functionally is intrinsically coupled with global human system telecoupled components and biotic legacy effects resulting from past uses. This study highlights the role of the historical forest management legacies as well as telecoupling phenomena driven by accelerating globalization and climate system teleconnections with current forest dynamics, processes and functionality. The Las Pegueras CHANS has been affected by a civil war, changes in political regimes, telecoupling processes in the global economy as well as drought periods but the persistence and ecological functions provided in part by the historical management regime has successfully mitigated many of these pressures. Therefore, at the forest landscape level, the application of the permanent block method in conjunction with the regeneration stimulated by the uniform shelterwood cuttings system has alleviated the impacts of socioeconomic and climatic changes promoting increased forest resilience. Therefore, our results highlight the social-ecological resilience of the forest which confirms that found at lower hierarchical levels (see Madrigal-González et al. [50] for engineering resilience-tree level and Madrigal-González et al. [49] for ecological resilience–forest level).

The generation of a continued income stream for local populations may have led to stakeholder general acceptance of the governance system but more research into local community perceptions of the governance system is needed. Finally, our results suggest that it is necessary to further research historical legacy effects of past human uses as well as teleconnection and telecoupling feedbacks when analyzing forest ecosystem functions in addition to addressing local and short-term temporal features. Integration of these levels of complexity—local and global feedbacks—may not necessarily increase model complexity but could result in a more realistic description of this ecosystem than models based on ecological processes alone.

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