Chapter 13
Climate-Smart Forestry Case Study: Spain

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Abstract In Spain, 55% of land area is covered by forests and other woodlands. Broadleaves occupy a predominant position (56%), followed by conifers (37%) and mixed stands (7%). Forest are distributed among the Atlantic (north-western Iberian rim), Mediterranean (rest of the peninsula including the Balearic Islands) and Macaronesian (Canary Islands) climate zones. Spanish woodlands provide a multiplicity of provisioning ecosystem services, such as, wood, cork, pine nuts, mushrooms and truffles. In terms of habitat services, biodiversity is highly relevant. Cultural services are mainly recreational and tourism, the latter being a crucial economic sector in Spain (including rural and ecotourism). Regulatory services, such as erosion control, water availability, flood and wildfire risk reduction, are of such great importance that related forest zoning and consequent legislation were established already in the eighteenth century. Climate change in Southern Europe is forecast to involve an increase in temperature, reduction in precipitation and increase in aridity. As a result, the risks for natural disturbances are expected to increase. Of these, forest fires usually have the greatest impact on ecosystems in Spain. In 2010–2019, the average annual forest surface area affected by fire was 95,065 ha. The combination of extreme climatic conditions (drought, wind) and the large proportion of unmanaged forests presents a big challenge for the future. Erosion is another relevant risk. In the case of fire, mitigation strategies should combine modification of the land use at the landscape level, in order to generate mosaics that will create barriers to the spread of large fires, along with stand-level prevention measures to either slow the spread of surface fires or, more importantly, impede the possibility of fire crowning or disrupt its spread. Similarly, forest management can play a major role in mitigating the impact of drought on a forest. According to the land use, land-use change and forestry (LULUCF) accounting, Spanish forests

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absorbed 11% of the total greenhouse gas emissions in 2019. Investments in *climate-smart forestry* provide opportunities for using all the different parts of the Spanish forest-based sector for climate mitigation—forest sinks, the substitution of wood raw materials and products for fossil materials, and the storage of carbon in wood products. Moreover, this approach simultaneously helps to advance the adaptation of the forest to changing climate and to build forest resilience.

Keywords Mediterranean forest · Wildfires · Forest bioeconomy · Non-wood forest products · Resilient landscapes · Unmanaged forests

13.1 Introduction to Spanish Forests and Their Utilisation

As in many other southern European regions, the land cover of Spain has changed considerably in the last century. The abandonment of a substantial proportion of rural activities in the primary sector since the 1960s has led to a progressive, spontaneous afforestation of many parcels. Consequently, Spain today has 55% of its land area covered by forests and other woodlands (Ministerio para la Transición Ecológica [MITECO] 2018). Broadleaves occupy a predominant position (56%), followed by conifers (37%) and mixed stands (7%) (Fig. 13.1). The most widespread forest formations are open forest (the *dehesas*), typically used for agroforestry, followed by Mediterranean oak (chiefly *Quercus ilex*) and pine

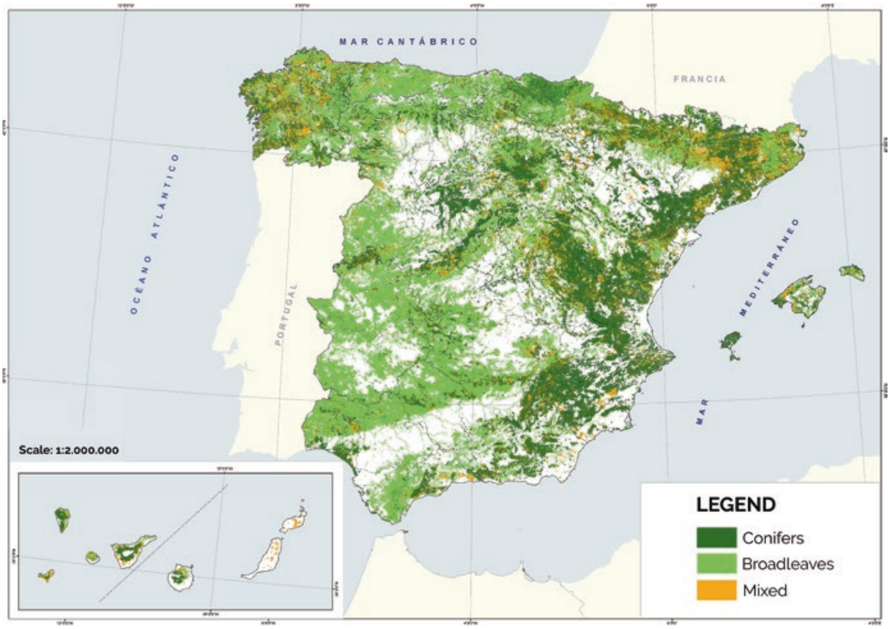

Fig. 13.1 Forest cover map of Spain. (Source: Ministerio de Medio Ambiente, Medio Rural y Marino, 2008)

(chiefly Aleppo pine). However, *Pinus pinaster* and *Pinus sylvestris* are the most important tree species in terms of timber volume. The rich ecosystem diversity is reflected in the more than 20 dominant tree species, which are distributed among the Atlantic (north-western Iberian rim), Mediterranean (rest of the peninsula including the Balearic Islands) and Macaronesian (Canary Islands) climate zones.

There is a large potential for increasing the use of domestic wood in Spain. Far from the typical European harvest rates, only one-third of the annual growing stock in Spain is harvested (Fig. 13.2) (Montero and Serrada 2013). While Spanish citizens tend to only consume small amounts of wood (0.8 m^3/inhabitant/year – about half that of Central Europe and well below what Northern European countries consume), the aggregated annual timber consumption is almost double the domestic harvest. This means that, despite the available timber stock, over half of the demand needs to be covered by imported wood. The harvest intensity, however, varies considerably among autonomous communities, ranging from 10 to 30% in most Mediterranean regions, up to 60–70% in the Atlantic northern and north-western regions (with a maximum of 88% in Galicia).

Highly fragmented private parcels constitute most of the forest land (MITECO 2018), with more than 99% occupying less than 10 ha. Despite the clear management challenges this situation implies, over 80% of the wood harvest takes place on

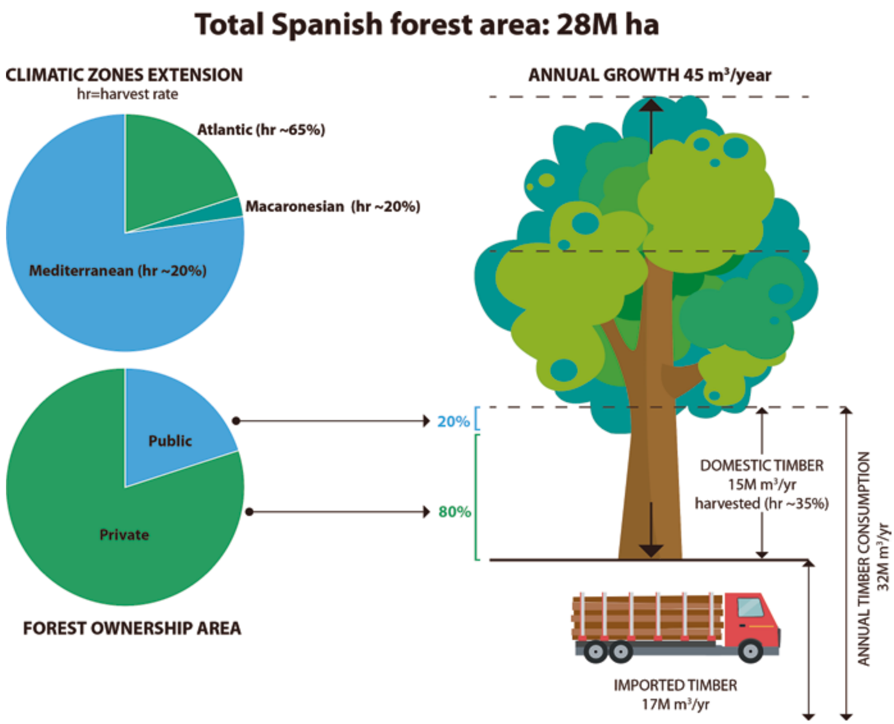

Fig. 13.2 Key Spanish forest and forestry data. (Source: Author elaboration based on MITECO 2018, Montero and Serrada 2013)

privately owned land, indicating that most productive forests (*Eucalyptus, Pinus radiata*, both of which are introduced species) tend to be owned by family forest owners. Only 18% of the forested land is subject to a management plan (MITECO 2018).

Beyond timber and fuelwood, Spanish forests also produce relevant non-timber forest products such as cork, pine nuts, chestnuts, resin, black truffles and wild mushrooms. Their value and markets are often imperfectly captured by the trade statistics, as are other ecosystem services (e.g. biodiversity conservation, water provision, amenities, carbon sequestration). Of the Spanish forests, 41% are nature-protection areas.

13.2 Impacts of Climate Change in Spanish Forests

13.2.1 Climate Change and Spanish Forests

Climate change in Southern Europe, and in Catalonia (north-eastern Spain) in particular, is forecast to involve an increase in temperature, reduction in precipitation and increase in aridity. Based on recent forest simulation studies (Trasobares et al. 2022; Morán-Ordóñez et al. 2020), the average annual mean temperature is projected to increase in Catalonia by 1.7–4.2 °C in this century, under Representative Concentration Pathways (RCPs) 4.5 and 8.5 (see Chap. 3). Consequently, climate change is expected to impact Spanish forests in several ways: (i) by decreasing water availability due to increased evapotranspiration due to the temperature increase; (ii) by increasing wildfire virulence as a result of reduced relative air humidity and increased wind speeds; (iii) by intensifying downpours, and increasing torrentiality and erosion-risk, especially in south-eastern Iberia and the Canary Islands, intimately linked to desertification; (iv) by increasing the frequency of wind storms, with stronger winds causing structural tree damage; (v) by expanding pest and disease areas and/or active periods due to reduced cold weather; and (vi) by modifying the phenology and physiology of plants and animals, with additional effects on biomass growth (Serrada Hierro et al. 2011). Altogether, these impacts will likely affect the current composition of forest species, as well as the provision of ecosystem services, while increasing forest risks.

13.2.2 Forest Species Composition

Climate change projections predict a significant contraction of the distribution of most mesic species in the Iberian Peninsula by 2100, but for widespread species in the Mediterranean Basin, the impact will be lessened (Lloret et al. 2013). In the mid-term (by 2040), in monospecific Catalan forests (Gil-Tena et al. 2019), a temperature increase of 1.2 °C (with a concomitant reduction in precipitation) may entail risk for *Pinus nigra*, *P. sylvestris*, *P. uncinata*, *Fagus sylvatica* and *Quercus pubescens*, while other tree species, such as *Pinus halepensis*, may have a lower risk. Forest stands in wetter and mountainous climatic sub-regions will attract higher risk than drier sub-regions, where *Pinus halepensis* prevails. This climatic risk will endanger the stand suitability of tree species that are less tolerant of drought conditions (i.e. causing a shift in tree species) and/or that have lower growth rates and a greater vulnerability to biotic hazards. Tree species dynamics are already showing rapid species shifts from conifers towards broadleaves (Vayreda et al. 2016), partly due to climatic variation, but also due to the legacy of human land use, mainly agricultural abandonment and reduced forest management intensity (e.g. coppicing for fuelwood). In some areas, tree species that used to be secondary are starting to become predominant. These changes also have economic consequences because the tree species that are becoming more common tend to have lower economic value in the markets.

13.2.3 Provisioning of Wood and Other Ecosystem Services

Spanish woodlands provide a multiplicity of ecosystem services (i.e. products), wood being the most relevant, followed by cork, pine nuts, mushrooms and truffles. In terms of habitat services, biodiversity is highly relevant. Cultural services are mainly recreational and tourism, the latter being a crucial economic sector in Spain (including rural and ecotourism). Regulatory services, such as erosion control, water availability, flood and wildfire risk reduction, are of such great importance that related forest zoning (*Montes de Utilidad Pública*) and consequent legislation were established as far back as the eighteenth century, and are still largely valid.

For some regions, in the short term, climate change may cause an increase in CO_2 sequestration and forest biomass productivity, such as in areas where water availability does not restrict growth, due to an increase in the vegetative period; this would benefit intensive silviculture (Serrada Hierro et al. 2011). On the other hand, a climate-sensitive forest scenario analysis conducted by Nabuurs et al. (2018), Morán-Ordóñez et al. (2020) and Trasobares et al. (2022) in north-eastern Spain indicated that, for the business-as-usual (BAU) scenario, climate change is expected to lead to denser forests with smaller tree diameter sizes, higher mortality rates and lower volume growth, and with a significantly greater risk of *forest fires* (see below). Morán-Ordóñez et al. (2020) found that the RCP8.5 scenario resulted in a decrease in all ecosystem services for all pine forests. The use of a BAU scenario with low-intensity harvesting resulted in the greatest *soil erosion mitigation* and *CO_2storage,* but predicted lower (blue) water provision. Pardos et al. (2017) determined that, for Scots pine and Pyrenean oak forests in Valsaín (central Spain), wood production would decrease from 2060 onwards using the BAU. Nabuurs et al. (2018) and Trasobares et al. (2022) showed that the balance in net carbon emissions (also taking into account the life span of wood products, the substitution of fossil-based products, etc.) improved in management scenarios where *climate-smart forestry* and forest bioeconomy strategies were followed; that is, an increase in the managed area, improved silvicultural methods and incentivising the demand for construction timber in the medium term (2040–2050 onwards), with improved fire-risk prevention, drought and blue water provision in the shorter term.

The environmental conditions for cork oak have been predicted to decrease moderately in Andalucía under climate change. The risk will be more pronounced in the cork oaks planted in 1993–2000 as part of the EU's Rural Development Programme because many of these forests are located outside the optimal locations for these trees (Duque-Lazo et al. 2018a). Wild mushroom productivity may also be highly climate-dependent, with the extension of summer-like weather into the fruiting season (i.e. autumn) expected to diminish production. Surprisingly, Karavani et al. (2018a, b) predicted an increase in mushroom yield in pine forests in Catalonia under RCP4.5 and RCP8.5 during the twenty-first century. The autumn precipitation and soil moisture are expected to remain more or less stable (or even to increase slightly) during the fruiting season in 2016–2100, although temperatures are expected to increase compared to 2008–2015. This would mean the mushroom fruiting season would extend towards winter. Herrero et al. (2019) found consistent wild mushroom yields for *Pinus pinaster* in Castilla-y-León. Truffle productivity is also expected to shift under climate change, leading to lower-market-value species (summer truffles) becoming dominant relative to the current situation (Büntgen et al. 2012). Thomas and Büntgen (2019) also predicted a reduction in black truffle productivity in Spain due to climate change. Under RCP4.5, there could be an 88% harvest reduction due to increased summer temperatures and a 15.6% harvest reduction due to reduced summer precipitation. Under RCP8.5, there would be a total collapse in production. These effects could be at least partially overcome by the increased use of irrigation in specialised plantations.

Under climate change, *Pinus pinea* forests would have reduced pine nut yields (Pardos et al. 2015). Given that these forests are typically managed for pine cone productivity, future scenarios call for combining pine nuts with timber production. In terms of resin, the impact of climate change is still uncertain due to a lack of impact studies. However, based on our current understanding, a reduction in the tapping season is expected during the warmest months (June–September) (Rodríguez-García et al. 2015). Similarly, in years with a rainy summer and/or dry spring, a slightly longer tapping season might result, as resin yield increases after such events.

13.3 Forest Disturbances

13.3.1 Wildfires

The risks for abiotic (forest fires, erosion, drought, storms, etc.) and biotic (insects, disease) natural disturbances are expected to increase due to climate change (e.g. Seidl et al. 2014). Of these, forest fires usually have the greatest impact on ecosystems in Spain. In 2010–2019, the average annual forest surface area affected by fire was 95,065 ha (MITECO 2021a). The combination of extreme climatic conditions (drought, wind) and the large proportion of unmanaged forests presents a big challenge for the future. Erosion is another relevant risk. Most Spanish forests located on the steepest alpine and sub-alpine slopes are protected (Nabuurs et al. 2018).

Under climate change, extreme fire-weather conditions that can lead to large and catastrophic fires are expected to become more common (Piñol et al. 1998) as the number of extreme dry periods increases. Climate-change scenarios indicate an increase of 2–2.5 times the number of fires, 3.4–4.6 times the forest area burned, and 3–3.9 times the wooded area burned (Vázquez De La Cueva et al. 2012). An important aspect to consider is that the long-term impact on the vegetation or the adaptation of plants to fire does not depend on single events, but on fire regimes—that is, the fire characteristics for a given area over a certain period (Krebs et al. 2010). However, climate change is not the only factor that will modify the fire regimes on the Iberian Peninsula; other factors will define the size, frequency and/or severity of the fires (Moreno et al. 2014). Moreover, changes in the fire activity have not been, and probably will not be, homogeneous over the Spanish territory. Past observations (Moreno et al. 2014) and future predictions (Jiménez-Ruano et al. 2020) have indicated that, in north-eastern Spain, there has been a general increase in fire activity both over an entire year and during the vegetative season, although this tendency is expected to decrease in the medium term (2036). On the other hand, in Spain overall, there is a trend towards fewer wildfires with lower intensities, and a reduction in the area burnt (MAPA 2019). This decrease can be attributed to improvements in, and expenditure on, fire suppression over the last few decades. However, even though past observations and future forecasts seem relatively optimistic, it is widely understood that the accumulation of fuel resulting from agricultural abandonment (Pausas and Paula 2012), areas of past fire exclusion (Piñol et al. 2005) and the expected increase in the number of days subject to extreme fire weather may lead to the unexpected occurrence of very large and catastrophic fires (Costa et al. 2011).

13.3.2 Water Scarcity and Drought

Interactions between the multiple drivers of global change can have diverse effects on the future condition of Mediterranean forests. Water scarcity will certainly be one of the most important agents of forest dynamics and their provision of services in the coming decades. The expected increase in evapotranspiration rates due to rising temperatures will come with a general reduction in water availability and greater precipitation irregularity, leading to more frequent, intense and prolonged droughts and hot spells. Many tree species in Spain will be particularly vulnerable to these events, including *Pinus sylvestris*, *Fagus sylvatica* and *Abies alba*. Decline in growth and increased die-back have already been reported in *Pinus sylvestris* populations in north-eastern Spain (Martínez-Vilalta and Piñol 2002) and in the southernmost populations of *Abies alba* in the Spanish Pyrenees (Macias et al. 2006). However, this phenomenon will not only affect the least-tolerant species–drought-adapted species are also likely to suffer the consequences of increased drought conditions. Drought has been linked to the general die-back of *Quercus ilex* in south-western Spain known as '*seca*', where weakened trees are more susceptible to attack by *Phytophthora* (Sánchez-Salguero et al. 2013). It has also been reported to cause growth decline in several pine species in south-eastern Spain (Sánchez-Salguero et al. 2012). We can expect a general reduction in site productivity in the medium and long terms, particularly in species or populations growing in water-limited environments, which includes most Iberian forests (Coll et al. 2021).

More importantly, we can expect different responses to disturbances across forest types. Evergreen gymnosperms growing in drought-prone areas have exhibited low resistance to, but faster recovery after, drought events compared to trees from temperate regions (Gazol et al. 2018). Therefore, the response of vegetation to changes in climate may be different as droughts become more intense and/or more frequent. This may ultimately affect forest compositions and species distributions. In the driest areas, desertification might advance and become a major problem (Karavani et al. 2018a).

Forest structure will also play a fundamental role in the response of the vegetation to drought, with dense, unmanaged forests being generally more vulnerable (Lindner and Calama 2013). Forests in dry areas are able to accommodate fewer trees per hectare for a given average size, and reduced stand density is known to increase drought resistance in several species (Martín-Benito et al. 2010). Earlier, more-intense thinnings have been proposed as a fundamental method in the toolkit of forest managers to help forests adapt to climate change (Vilà-Cabrera et al. 2018; Coll et al. 2021), constituting the basis of 'ecohydrological' or 'hydrology-oriented' silviculture (del Campo et al. 2017). Several modelling exercises have indeed suggested that intense reductions in stand density can help to reduce the impacts of climate change on stress-related mortality, particularly on xeric sites (Ameztegui et al. 2017).

13.3.3 Pests and Diseases

Climate change may affect the distribution of pathogens and hosts. Among the most relevant pests, the pine processionary moth causes most concern for conifer forests in Spain. It is expanding northwards and towards higher elevations due to milder winter conditions (Roques et al. 2015)—a trend shared across western Mediterranean Europe. This expansion may eventually accelerate the process of natural succession (i.e. the replacement of conifers by *Quercus* species), although higher rates of forest compositional change may be expected if more-destructive pest outbreaks than pine processionary moth occur (Gil-Tena et al. 2019). Imported pests, such as the pine nematode, entail additional relevant threats. Haran et al. (2015) indicated an expected expansion of the pine nematode towards higher altitudes, with the probability of it spreading into the Pyrenees, towards France and the rest of Europe.

In terms of disease, the pine pitch canker that affects *Pinus pinaster* and *Phytophthora cynnamomi* that mainly affects oaks can be highlighted. Serra-Varela et al. (2017) found that almost the entire Spanish distribution of *Pinus pinaster* will face an abiotic-driven exposure to pitch canker (due to the predicted increase in drought events under climate change), while the north-western edge of the Iberian Peninsula is predicted to face reduced exposure. Duque-Lazo et al. (2018b) indicated that oak decline provoked by *Phytophthora cynnamomi* may be reduced in Andalusian forests (southern Spain) until 2040, although the suitability of the habitat is predicted to increase after that.

13.4 Nexus for Adaptation and Resilience, and the Mitigation of Climate Change

13.4.1 Adaptation to Climate Change and Risk Management

Two of the most significant threats to Spanish forests, where the risk might be heightened in the future, are drought and fire. In the case of fire, it is widely recognised that mitigation strategies must be implemented at different scales (Gil-Tena et al. 2019). These should combine modification of the land use at the landscape level, in order to generate mosaics that will create barriers to the spread of large fires, along with stand-level prevention measures to either slow the spread of surface fires or, more importantly, impede the possibility of fire crowning or disrupt its spread (Loepfe et al. 2012). When implementing forest management interventions, it has been demonstrated that modifying the structure and composition of the forest at the stand level has an impact by reducing fire occurrence and damage (González et al. 2007). Consequently, specific management methods are being applied in certain regions of Spain (Piqué et al. 2017). It is clear that integrating these methods into the landscape, considering the spatial component of fire spread, has a much greater chance of mitigating the negative impacts of forest fires, or will facilitate the efficiency of suppression efforts, if specific measures are applied to high-priority areas (Gonzalez-Olabarria et al. 2019). Similarly, forest management can play a major role in mitigating the impact of drought on a forest (Martínez-Vilalta et al. 2012). Many of the management options considered to be appropriate for reducing competition for water resources (e.g. thinning) or for increasing the efficiency of the uptake and use of existing water (i.e. by favouring certain species admixtures based on their functional traits) (De Cáceres et al. 2021) may also be considered beneficial for reducing fire risk. The National Plan for Adaptation to Climate Change 2021–2031 actually considers these risks and mitigation goals as part of a broad, intersectoral plan (MITECO 2021b) and more-detailed forest-accountability plan (MITECO 2018).

13.4.2 The Role of Spanish Forests and Wood Products in Climate Change Mitigation

According to the land use, land-use change and forestry (LULUCF) accounting, Spanish forests absorbed 11% of the total greenhouse gas (GHG) emissions in 2019 – 314.529 Kt CO_2 eq. Table 13.1 details the impact of different forest subsector activities. The substitution of *forest biomass* for fossil-based energy in Spain is also important to take into account in this balance because of its potential and low cost (Turrado Fernández et al. 2016). The current energy consumption derived from biomass is close to 4 Mtoe. The 2030 bioenergy target of the National Integrated Plan for Energy and Climate indicates a need for an additional 1.6 Mtoe $year^{-1}$ of electricity generation and 0.41 Mtoe $year^{-1}$ for heating (MITECO 2020). These targets are perfectly achievable considering the estimated Spanish potential biomass for energy of 88.7 Mtoe $year^{-1}$ (or 17.3 Mtoe $year^{-1}$ for heating), with the portion coming from forests being 33.8 Mtoe $year^{-1}$ (or 5.8 Mtoe $year^{-1}$ for heating). This includes lumber industry residues, roundwood and other woody biomass from forestlands. Notably, the above figures do not take into account other potential sources, such as woody energy crops, and residues and side streams of the pulp and paper industry (Paredes-Sánchez et al. 2019). The use of timber in housing and construction (e.g. cross-laminated timber, plywood and sawn wood) is gaining more importance, although it is still far from reaching its potential use. Wood can store carbon for decades in buildings and can replace the use of fossil-intensive materials, such

Table 13.1 Contribution of Spanish forests and wood products to the GHG balance in 2019, and the forest reference levels (FRLs)

IPCC LULUCF sub-classes	GHG (Kt CO_2 eq.)	FRL 2021–2025
Forestland remaining as forestland	−29372.48	−29,303
Land converted to forestland	123.84	
Cropland converted to forestland	−2386.28	
Grassland converted to forestland	−1417.93	
Wetlands converted to forestland	−2.31	
Settlements converted to forestland	0.00	
Other land converted to forestland	−46.43	
Forestland converted to cropland	91.31	
Forestland converted to grassland	292.00	
Forestland converted to settlements	201.71	
Forestland converted to other land	0.00	
Harvested wood products	−2191.22	−1732
Wildfires (N_2O, CH_4)	Not available	330
Prescribed burning (N_2O, CH_4)	Not available	2
Forest contribution to the 2019 GHG balance	−34707.78	−30,703

IPCC Intergovernmental Panel on Climate Change
Source: MITECO (2018, 2021a)

as steel and concrete, therefore offering opportunities for climate mitigation in one of the most CO_2-intensive industry sectors.

Investments in *climate-smart forestry* provide opportunities for using all the different parts of the Spanish forest-based sector for climate mitigation—forest sinks, the substitution of wood raw materials and products for fossil materials, and the storage of carbon in wood products (Nabuurs et al. 2018). Moreover, this approach simultaneously helps to advance the adaptation of the forest to changing climate and to build forest resilience. The potential of *non-wood forest products* as substitutes for non-renewable materials has been poorly assessed so far. However, in terms of cork, Sierra-Pérez et al. (2018) comprehensively assessed its life-cycle for the purpose of building insulation. According to the study, using cork for insulation can have a positive CO_2 mitigation impact. The benefits are obvious when contrasted with mainstream, inorganic fibrous materials. Similarly, PricewaterhouseCoopers (PwC) and ECOBILAN (2008) found that the production of cork stoppers emitted less CO_2 (1.53 g CO_2/piece) than screw caps (37.17 g CO_2/piece) and synthetic caps (14.83 g CO_2/piece). When also accounting for the offsetting effect resulting from cork-oak forest management, cork stoppers become even more competitive (−113.2 g CO_2/piece).

13.4.3 Resilience of Spanish Forests

Many Mediterranean tree species have traits that give them the capacity to respond to the most frequent disturbances in an area—most notably, wildfires and drought events (response traits). However, because of the speed of current environmental change, the occurrence and severity of most disturbances has increased in forests across Europe (Senf and Seidl 2021). In the Mediterranean region, the severity, frequency and size of burned forest areas has increased over the last few decades (Turco et al. 2018), as have drought severity, heat waves and insect outbreaks (Balzan et al. 2020). The increasing frequency, size and severity of these disturbances will, in many cases, be beyond historical norms, and forests will likely often be overcome, particularly at the southern edges of their distributions (Vilà-Cabrera et al. 2012).

The concern about forest responses to disturbances has made resilience a new paradigm for researchers, managers and policy-makers. Considering resistance and resilience as two related, but distinct, components of ecosystem responses to disturbances, the resistance–resilience framework can provide a good understanding of post-disturbance forest dynamics (Sánchez-Pinillos et al. 2019), and may contribute to guiding climate-smart forestry and adaptive silviculture. Sánchez-Pinillos et al. (2016) developed the Persistence Index (PI) to assess the capacity of communities to maintain their functions and services following disturbances. The PI is based on the diversity, abundance and redundancy of response traits, under the assumption that an ecosystem will be more resilient and resistant to disturbances if it contains a greater share of species with a given set of traits that allow them to cope with disturbances. The application of the PI to Iberian forests highlights the importance of functional diversity rather than number of species as an indicator of forest resilience (Gazol et al. 2018). It can be used to operationalise the concepts of resistance and resilience in real-world management strategies, providing evidence for the adaptive management of forest ecosystems. However, vulnerability to disturbances can also vary along successional trajectories, which underscores the need to consider the temporal dimension in risk management.

Species-specific interactions may be altered under climate change and, according to the stress gradient hypothesis (Maestre et al. 2009), facilitative effects may become more frequent. The role of shrubs as nurse vegetation for pine seedlings has already been documented in semi-arid and arid Mediterranean regions (Gómez-Aparicio et al. 2008), but also in sub-Mediterranean pine woods (Sánchez-Pinillos et al. 2018). This role could become even more important in the future. The succession of disturbances may also impose a significant limitation on the resilience of forest stands. For example, the regeneration of *Pinus nigra* after wildfire depends both on the existence of nearby, unburned vegetation patches and on the climatic conditions in the years following the fire (Sánchez-Pinillos et al. 2018). The succession of fires and droughts, therefore, could trigger massive failures in regeneration, leading to a change in the ecosystem towards a greater dominance of oak. In the driest areas, the *combined effect of several disturbances* is likely to exceed the response capacity of the organisms, leading to the extinction of some species and even the disappearance of vegetation cover, which introduces a high risk for soil erosion, degradation and desertification.

13.5 Potential for a Forest-Based Bioeconomy in Spain

The Spanish forest sector accounted for 0.6% of the Gross Added Value in 2018, of which 0.9% came from forestry works, 0.19% from the timber and cork industry and 0.36% from the paper industry (INE 2021b). However, these figures do not consider the added value generated by most of wildfire management activities, hunting or forest foods (truffles, mushrooms, chestnuts, etc.), and therefore it clearly underestimates the total value of the forest-based sector. In 2011–2019, the Spanish forest sector employed about 130,000 people (INE 2021a).

Policies will be crucial for implementing a successful transition to a sustainable, circular bioeconomy and in contributing to the EU Green Deal Objectives in the coming decades. Policies such as the Next Generation Funds for COVID-19 recovery are supporting these objectives. For example, the funds include initiatives for increasing cross-laminated timber production, and the number of bioenergy plants and biorefineries. Spain's Bioeconomy Strategy 2015–2030 (Lainez et al. 2018) and the Climate Change Law 7/2021 provide incentives for moving to carbon neutrality, a necessary part of which will involve sustainable forest management and adapting forests to the changing climate.

Using forest biomass to replace fossil raw materials and products—the root cause of climate change—is essential. This implies increasing the use of forest biomass in, for example, the construction, packaging and textile sectors, and also for energy purposes, at least in the coming decade or two before other renewables (e.g. hydrogen) become more available. However, in Spain, forest management is the responsibility of the autonomous regions, and therefore it is crucial that they are ready to make the necessary changes at the regional level. Despite the large expansion of Spanish forestland in recent decades, the agricultural component of most bioeconomic initiatives is also important, and so it is necessary to advance and coordinate actions in both sectors. This is indeed being done, for example, in the Catalan Bioeconomy Strategy (2021–2030), the Basque Roadmap towards a Bioeconomy (2019), the Andalusian Circular Bioeconomy Strategy (2018), the Galician Agenda for the Forest Industry (2018), the recently established Research Centre for Rural Bioeconomy in Aragón, the CLAMBER project (Castilla–La Mancha Bio-Economy Region), and the Plan for Boosting Agro-food Bioeconomy in Castilla-y-León. The climate-smart forestry approach could play an important role in achieving the objectives of these strategies in the coming decades.

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