Chapter 29
Ecosystem Services Provided by Pine Forests

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29.1 Introduction

Pines are a key element in forests and other woodland areas across the Mediterranean region. Pines form many natural pure and mixed stands, but have also been planted in many areas inside and outside their native ranges, significantly increasing their original representation in Mediterranean landscapes. They have been widely used in reforestation projects for soil protection and hydrological purposes due to their rapid growth, tolerance to poor soils and summer drought, and easy cultivation in nurseries (Fady et al. 2003; Burylo et al. 2012; Enescu et al. 2016; Mauri et al. 2016). Furthermore, they provide economically valuable forest products such as timber and firewood, resin and pine nuts, giving justification for their maintenance, management and expansion.

The multi-purpose usefulness that promoted the expansion of pines by humans falls nowadays within the broad term of ecosystem services, conceived as the direct and indirect contributions of ecosystems to human well-being (Montes et al. 2011). Several classifications have been proposed for ecosystem services according to different criteria (Burkhard and Maes 2017), but the categorization used by the Millennium Ecosystem Assessment (2005) comprises provisioning (i.e., something that can be exploited), regulating (e.g., protection from erosion) and cultural services

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is widely used. The ecological processes that underpin these three groups of services are considered a fourth type in the Millennium Assessment, named supporting services, but more recent assessments omit this category (Montes et al. 2011). Pine forests provide all these groups of services, which depend on their persistence and proper functioning. However, these services may be put at risk by threats to pine forests such as wildfires, land-use change or diseases; the onset of global change has enhanced them and also generated other new threats.

This chapter addresses the ecosystem services provided by natural and planted pine forests across the Mediterranean Basin and addresses the main threats to pine forest maintenance and provisioning of ecosystem services.

29.2 Ecosystem Services Provided by Pine Forests

29.2.1 Provisioning Services

Pine forests and plantations provide multiple provisioning, regulating and cultural ecosystem services. Wood production has traditionally been the main service responsible for the management, plantation and resulting expansion of pine forests (Masiero et al. 2016; FAO and Plan Bleu 2018). In the Mediterranean region, conifers represent 41% of the total growing stock (FAO and Plan Bleu 2018). The main product from most pines in the Mediterranean region is timber, with prevalence of *Pinus sylvestris* L., *P. nigra* J.F.Arn and *P. pinaster* Ait. (Durrant et al. 2016; Enescu et al. 2016; Viñas et al. 2016a). Industrial timber is the most important forest product (Masiero et al. 2016). In Spain, more than half of the wood cut in 2017 corresponded to conifers (9.6 Mm^3 of cut wood), although approximately one third of this (3.6 Mm^3) corresponded to *P. radiata* D.Don plantations outside the Mediterranean region *sensu stricto* (MAPA 2017). Subsequently, *P. pinaster* was by far the most cut, with 3.4 Mm^3 of cut wood, which far exceeds other native species (e.g., next were *P. sylvestris* and *P. nigra* with 1.4 and 0.6 Mm^3, respectively) and all of the native broad-leaved species (e.g. *Populus spp.* accounted for 0.5 Mm^3 cut) (MAPA 2017). In Spain, the main destination of cut wood from most Mediterranean pines is timber, but the wood of *P. halepensis* Mill. is used for pellets, woodchips and briquettes (MAPA 2017). Other than timber, pines also provide biomass. In the southern Mediterranean, the primary forest product is firewood (Masiero et al. 2016) for which *P. halepensis* and *P. brutia* Ten. are used (Fady et al. 2003; Mauri et al. 2016). Biomass from pines is a resource with increasing potential to supply renewable energy demands (Perea-Moreno et al. 2017). All these activities require management actions such as shrub removal or thinning that improve stand structure and lower fire risk (García-Gonzalo et al. 2014; Madrigal et al. 2017), otherwise Mediterranean pinewoods are at risk of burning, as has happened extensively in recent decades (see Sect. 29.3.1).

In addition, pine forests provide a wide range of non-wood forest products (NWFP) (FAO and Plan Bleu 2018). In fact, NWFP account for the main use of forests in the Middle East and northern Africa (Croitoru 2007; Croitoru and Liagre 2013). Resin is one such forest product; it is obtained from *P. pinaster* in the western Mediterranean, although *P. halepensis* can also be tapped in the eastern Mediterranean (Calama et al. 2010; Spanos et al. 2010). Nowadays resin is a minor product, with an estimated value between €2.6 M and €3.2 M in Spain, Greece and Turkey (Masiero et al. 2016), but there has been an increase of resin production in Spain in recent years, from 1402 t in 2009 to 13,001 t in 2017 (MAPA 2017). Resin used to be the main product in many inland Spanish forests until it became unprofitable and exploitation of the forests was abandoned, resulting in improper management of pine stands and thus increasing fire risk, but also promoting a transition to *Quercus*-dominated or mixed *Quercus-Pinus* stands after fire (Torres et al. 2016).

Another very valuable NWFP that Mediterranean pine forests provide is pine nuts from *P. pinea* L. Production of pine nuts is very variable, because *P. pinea* is affected by climatic conditions and is also a masting species (Calama et al. 2011; Mutke et al. 2012; Pasalodos-Tato et al. 2016). Between 2003 and 2017, the average production in Spain was 6100 t/year (MAPA 2017), while the estimated annual pine nut production in the Mediterranean is estimated at around 30,000 t in shell, mostly in Portugal and Spain, but also in Italy and Turkey (Mutke et al. 2012). This high value has led to extensive planting of *P. pinea* in recent years in countries such as Portugal and Turkey (Küçüker and Baskent 2017; Valdiviesso et al. 2017).

Additionally, pine forests promote the growth and production of wild edible mushrooms with commercial value (e.g., *Boletus* and *Lactarius*, among others) to which forest management may be oriented (Tomao et al. 2017). As with other NWFPs, the estimated value of mushrooms may be equal or even greater than that of timber (Bonet et al. 2008; Calama et al. 2010; Rincón et al. this volume, Chapter 20).

Another NWFP produced by pines with an important contribution to the local economy is pine honey, produced by bees that collect the honeydew secreted by aphids sucking on *P. brutia* and *P. halepensis*. It represents about half the total honey production in Greece and Turkey (de-Miguel et al. 2014) and is the main source of income for nearly ten thousand families in Turkey (Croitoru and Liagre 2013).

29.2.2 Regulating Services

In addition to provisioning services, pine forests supply important regulation services. Forests are essential in preventing soil erosion (Anaya-Romero et al. 2016; Guerra et al. 2016; FAO and Plan Bleu 2018), and pines are particularly well suited to this since they are pioneer species that can withstand poor soils, steep slopes, strong radiation and other harsh conditions, and therefore have been used to reforest degraded landscapes (Fady et al. 2003; Burylo et al. 2012; Enescu et al. 2016; Mauri et al. 2016) and stabilize sand dunes (Cutini 2002; Pereira 2002; Viñas et al. 2016a,

b). For example, most pine plantations in Spain have been established to regulate hydrological processes that carried important erosion and flood risk (Valbuena-Carabaña et al. 2010). Also, they have been used as pioneer species, which are more drought-tolerant and better adapted to poor soils, in order to restore and promote growth of other species. Pine forests, particularly those that have received management treatments (Rodríguez-Calcerrada et al. 2007; Prévosto et al. 2011), create suitable conditions for the recruitment of oak and other broad-leaved species in their understory (Sheffer 2012 and references therein; Van de Peer et al. 2018; Waitz and Sheffer this volume, Chapter 16), thus increasing the biodiversity of the ecosystem, which plays an important role in the maintenance and delivery of the goods and services that pine forests provide (Martínez-Jáuregui et al. 2019). Pine forests also harbor associated species with high conservation value. This is the case of sub-Mediterranean *P. nigra* forests, a priority habitat in the EU Habitats Directive, in which the largest European vulture, the black vulture (*Aegypius monachus* L.) nests in part of its range (Zaghi 2008).

Another important regulating service that pine forests provide is carbon sequestration. Pines are fast-growing species and store large amounts of carbon in their wood (Klein this volume, Chapter 7) and in the soil. In Italy, Mediterranean pines (*P. pinaster*, *P. halepensis*, *P. pinea*) accounted for 132.8 t carbon per ha in 2008–2009, which is higher than the carbon storage of most Mediterranean broad-leaved species (Gasparini and Di Cosmo 2015). In Spain, more than half of the total CO_2 stored in pine forests is due to *P. pinaster* and *P. sylvestris* forests (Montero et al. 2005; del Río et al. 2017), and pine forests accumulated over 535 Mt CO_2 in 1990 (Montero et al. 2005). The relevance of pine forests as a carbon pool becomes more prominent in more Mediterranean environments, with increased aridity, such as southern Spain, where conifer forests (mainly *P. pinaster*) account for the highest density of carbon (Anaya-Romero et al. 2016) and, during the twentieth century, pine plantations (mainly *P. halepensis*, *P. pinaster* and *P. sylvestris*) captured nearly as much carbon as oaks in a mountain ecosystem (Padilla et al. 2010).

29.2.3 Cultural Services

Pine forests provide a wide array of recreational and cultural services (see Orenstein this volume, Chapter 30). Hunting, as a highly regulated activity, is the most salient in the available statistics. Although no data exist for the specific contribution of pine forests to income from hunting, this activity accounts for 75% of the annual income from the category “other uses” (which also includes profit from water, recreational uses or aggregate extraction) of forest statistics in Spain (MAPA 2017). However, this evaluation is probably biased since hunting provides an easily accountable source of income, while carbon fixation and emission, recreation and other landscape values are omitted or undervalued (Campos et al. 2019). In fact, when these are accounted for, such as in the *P. sylvestris* forests in Sierra de Guadarrama, central Spain, very close to a large city such as Madrid, recreation accounted for half

the value of timber, followed by conservation value (Caparrós et al. 2001). Recreational use is an increasing value of forests, including pine forests. For instance, there has been a pronounced increase in the forest area with recreational use as a main management goal since 2005 in south-eastern European countries (Forest Europe 2015). Finally, pine forests are used in a diverse range of scientific and educational activities.

29.3 Ecosystem Services Under Global Change

29.3.1 Fire and Ecosystem Services Provided by Pines

Wildfires can have positive and negative impacts on the ecosystem services provided by pine forests. In the short term, many of the services provided by pine forests are at risk of deterioration when they are affected by fire (Górriz-Mifsud et al. 2016). Fires obviously cause changes in esthetics that affect recreation and other cultural services. Also obvious are the potential losses of wood and wood products, but fires also affect the provisioning of other NWFPs. For instance, fire strongly decreases the production of mushrooms in pine forests (Martín-Pinto et al. 2006; Gassibe et al. 2011, 2014; Mediavilla et al. 2014). Regulating services can also be affected; many of the pine forests in Spain that come from plantations planted in the twentieth century are lacking adequate management and could easily be affected by fire (Valbuena-Carabaña et al. 2010). Therefore, the regulatory function that pine forests provide is highly vulnerable to fire, and soil erosion and runoff increase significantly after fire when pine forests and other Mediterranean vegetation burns (Cosandey et al. 2005; Mayor et al. 2007; Shakesby 2011; Wittenberg this volume, Chapter 23). Furthermore, a considerably large fraction of the carbon pool stored in pine forests is prone to mobilization during wildfire. Montealegre-Gracia et al. (2017) estimated CO_2 emissions ranging from 20 to 100 t/ha in a *P. halepensis* forest. In addition, common post-fire practices, such as salvage logging, seem to reduce carbon sequestration (Serrano-Ortiz et al. 2011). However, fires also produce pyrogenic organic matter that remains in the soil, acting as a potentially important carbon sink (Santín et al. 2015).

Pine forests are among the main vegetation types affected by wildfire, and will likely continue so since climate change will increase fire risk (Moreno et al. this volume, Chapter 21). Most pine species show adaptations to fire (Ne'eman and Arianoutsou this volume, Chapter 22), and the most Mediterranean pines (i.e., *P. halepensis*, *P. brutia*, *P. pinaster*) can regenerate even after crown fires thanks to their serotinous cones. In the case of pines with adaptations to frequent, low intensity surface fires, such as *P. nigra* (Tapias et al. 2004; Fulé et al. 2008), absence of fire can lead to fuel accumulation and crown fires after which the species, and the services provided by the pines, disappear and thus fire within a specific, historical fire regime may have beneficial results (Morales-Molino et al. 2017; Pausas and

Keeley 2019). However, increased frequency of fires with intervals shorter than the time needed to resupply the canopy seed bank and high fire severity can both constrain the regeneration of even the most fire-adapted *P. halepensis* and *P. brutia* (Kazanis and Arianoutsou 2004; Tessler et al. 2014; Kavgaci et al. 2016). For the more fire-sensitive mountain pines, *P. sylvestris* and *P. nigra*, a lack of regeneration after wildfires is a common phenomenon (Rodrigo et al. 2004; Vilà Cabrera et al. 2012; Christopoulou et al. 2014).

Because of the multiple services they provide, pines have been used in afforestation and reforestation projects throughout the Mediterranean Basin. However, due to their high susceptibility to burning, provision of such services may cease. The balance between planting of pines and pine stands being burned can illustrate the role of pines in forest fires. While most countries compile data about wildfires, these are usually not complete or accessible. To illustrate our point, we will focus on Spain, since fire statistics have been rather complete and available for over half a century. In a study of the fire history of Spain for the years 1974–1995, Moreno et al. (1998) showed that coniferous forests amounted to approximately 31% of the total burned area. Within the treed burned areas, the *Pinus* species that burned the most were *P. pinaster* (594 kha, 33%), *P. halepensis* (468 kha, 26%), *P. sylvestris* (162 kha, 9%), *P. pinea* and *P. nigra* (57 kha, 3% each). The burned pine trees were, on average, rather young, with a mean age for all pine species of 24.2 years, with little differences among species or over time in the last four decades (Table 29.1).

If we sum the entire burned area of *Pinus* species during the period of nearly 50 years of available statistics (1967–2015) (Fig. 29.1) and compare it with their plantation area from 1940 to 2013, we can roughly evaluate the role of pines in forest fires (Fig. 29.1). *Pinus pinaster* was the species most burned (826 kha) but was also the species most planted (912 kha), thus its balance was positive but only slightly. The next species in area burned was *P. halepensis*, with 709 kha burned, compared to 631 kha planted, thus it had a negative balance. The third-ranked species in area burned was *P. sylvestris* (192 kha), which had 659 kha planted, thus its balance was positive (70% remained unburned). In fact, many of these plantations were made in the wetter north-west of the country, and while this region is a hotspot for fires (Urbieta et al. 2019) many trees are still able to grow and be harvested (Schelhaas et al. 2018). *Pinus radiata* had 126 kha burned, and 254 kha planted.

Table 29.1 Mean age at burning of five *Pinus* species based on fire reports for two periods (1974–1994 and 1974–2010)

	Mean age at burning	
Pinus species	1974–1994	1974–2010
P. halepensis	23.8	24.5
P. nigra	24.4	25.3
P. pinea	25.2	24.1
P. pinaster	23.2	24.2
P. sylvestris	21.4	23.0

Data from: Moreno et al. (1998), Vázquez de la Cueva (2016)

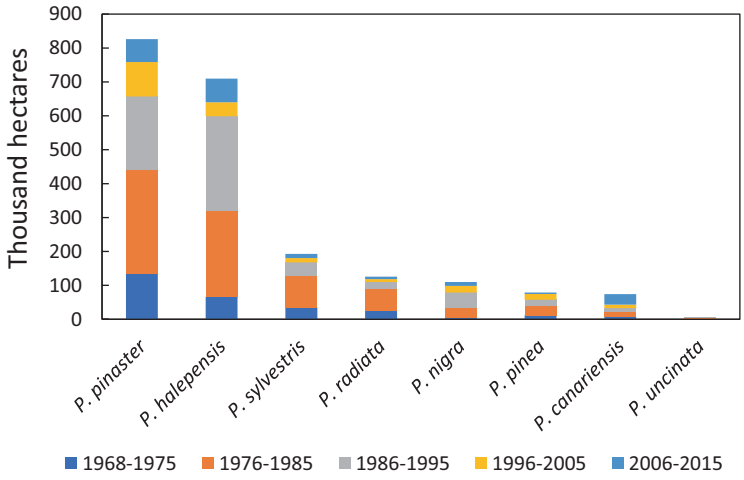

Fig. 29.1 Total area burned (kha) of the various species of *Pinus* growing in Spain (including the Canary Islands) from 1968 until 2015. Source: Estadística de incendios forestales, Ministerio para la Transición Ecológica y el Reto Demográfico, Government of Spain, https://www.mapa.gob.es/es/desarrollo-rural/estadisticas/Incendios_default.aspx)

This species, which is planted in the wet, non-Mediterranean northern Spain, had a positive balance, but still half of the area planted burned. *Pinus nigra* had 110 kha burned of 441 kha planted, for a 75% positive balance, *P. pinea* had 79 kha burned from 337 kha planted (76% positive balance) and *P. canariensis* had 74 kha burned, from only 37 kha planted, for a negative balance of 50%. Overall, of 3299 kha of all the species that were planted, 2118 kha burned, that is, only 36% remained. This analysis, while rough, because there is no match between the areas planted and burned, shows that fires have very markedly affected *Pinus* species in Spain and that the probability of a pine plantation surviving in the long term was quite low overall during that period. The balance of the more typical Mediterranean species of the lowland areas (*P. halepensis*, *P. pinaster* and *P. pinea*) was nearly neutral (only 14% more area planted than burned).

29.3.2 Other Threats to Ecosystem Services

In addition to fire, pine forests are facing threats that may constrain their functionality and thus limit their ability to provide ecosystem services. For most pine species in Spain, increased aridity and competition with oaks severely limits their recruitment (Carnicer et al. 2014; Gazol et al. 2018). A decade-long drought episode in a *P. pinaster* forest in central Spain had negative impacts on growth and recruitment, and on tree survival during the decade following drought (Madrigal-González et al. 2017). For pines that have the limit of their distribution in the Mediterranean region,

such as *P. sylvestris*, drought can limit growth and increase mortality at the most xeric sites (Gea-Izquierdo et al. 2014), and future predictions of growth for this and other species indicate a reduction in Spain and the rest of the Mediterranean (Gómez-Aparicio et al. 2011; Camarero et al. 2013; Sánchez-Salguero et al. 2017; Dorado-Liñán et al. 2019). Furthermore, the upward migration of *P. sylvestris* under climate change may be restricted by increased herbivory at the tree line during dry summers (Herrero et al. 2012).

Finally, increased warming induced by global change is affecting pines via increased pressure from pests and diseases – either new, introduced species, or existing species that become more aggressive with increased warming (Oliva this volume, Chapter 10). The case of the pine processionary moth (*Thaumetopoea pityocampa* Denis & Schiffermüller, 1775) is illustrative of a pest with economic importance (Gatto et al. 2009) that is increasingly affecting pine stands due to global change. Warmer winter temperatures have been responsible for its expansion in recent decades (Hódar et al. 2003; Battisti et al. 2005). Furthermore, its expansion has been aided by human-mediated dispersal most likely by accidental introduction of pupae in the soil when transplanting large trees (Robinet et al. 2012), while the abundance of pine plantations throughout the Mediterranean also favors its expansion (Doblás-Miranda et al. 2017). The pine wood nematode (*Bursaphelenchus xylophilus* (Steiner & Buhrer) Nickle) is another example of a recently introduced pine pathogen with potential for expansion throughout the Mediterranean Basin (Naves et al. 2016).

29.4 Conclusions

Pine forests and plantations constitute a very important source of ecosystem services in the Mediterranean Basin. Regarding provisioning services, wood production for both timber and firewood are important but with different uses and intensities depending on the pine species and with different geographical patterns (i.e. firewood plays a more important role in the southern Mediterranean Basin). Non-wood forest products are equally important, but resin tapping has experienced a declining trend in recent decades while pine nuts, edible mushrooms and pine honey production are still important contributors to local economies, and to which management of pine stands may be oriented. Pine forests and plantations provide valuable regulating services that can explain the historical plantation of pines throughout the Mediterranean Basin for erosion control and hydrological regulation. Nowadays they still fulfill that role, while their relevance as habitats for biodiversity and as carbon sinks is recognized. Additionally, pine forests are providers of cultural services that when accounted for can result in similar values as those of some provisioning services. Many of these ecosystem services can be interrupted or heavily modified, at least in the short term, by risks related to global change. Wildfire, drought and pests affect pine forests alone or in combination, and thus it is essential to properly evaluate services and risks to adapt their management.

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