J. For. Res. (2017) 28(3):431–443
DOI 10.1007/s11676-016-0338-7

REVIEW ARTICLE

The changing Himalayan landscape: pine-oak forest dynamics and the supply of ecosystem services

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Received: 23 June 2015 / Accepted: 17 November 2015 / Published online: 15 November 2016

Abstract This review summarizes the current state of knowledge on pine and oak forest dynamics in the mid-montane central Himalayan forest and the ecosystem services associated with these vegetation types. Forest ecosystems play a crucial role in the livelihood of the central Himalayas as well as the adjacent plains, providing a number of tangible and intangible ecosystem services, at each stage of succession. The successional sequence starts from warm temperate grasslands, followed by early successional pine forests, mid-successional pine-oak mixed forests and eventually culminating in a late successional oak community. This successional sequence is considerably influenced by disturbances like fire, grazing, and lopping, which maintain the vegetation types in their current form and can act as potential drivers of change. Fire and grazing in grasslands and pine forests inhibit the successional process by hindering the establishment of pioneer and late successional species, respectively. Potential land-cover changes with forest succession can lead to changes in ecosystem services supply. We found that the number of ecosystem services associated with these vegetation types increase from early to late successional community. Current management approaches fail to include the dynamic nature of vegetation, which is essential for maintenance of ecosystem service supply. In conclusion, the trade-offs between ES of global (biodiversity and carbon) and local importance (fuel wood and fodder) have to be examined carefully in order to have effective conservation and management plans for the region.

Keywords Disturbance · Ecosystem services · Himalaya · Oak · Pine

Introduction

Forest ecosystems provide human society with a variety of services that are essential for our wellbeing, including provisioning (e.g. fuel, timber, and food), regulating (e.g. climate regulation, soil and water conservation), and cultural (e.g. recreation) services (Millennium Ecosystem Assessment (MEA) 2005; Costanza et al. 2014). In order to sustain these ecosystem services, humans have altered forest ecosystems to various degrees (Kremen 2005), through the use of disturbances such as fire, cutting, and grazing, and maintained them in these modified states (Ford et al. 2012; Schmerbeck et al. 2015; Triviño et al. 2015). The increasing pressure on forests involves trade-offs in provision of ecosystem services where overuse of one particular ecosystem service (ES) endangers the supply of other related ecosystem services (Rodríguez et al. 2006; Balthazar et al. 2015; Triviño et al. 2015). For instance the role of intensive grazing, especially with aid of fire to enhance grass production, in reducing the capacity of the soil to regulate hydrological cycles (Savadogo et al. 2007; Allred et al. 2011; Shakesby 2011) or the influence of excessive logging on the carbon storage potential of forests (Triviño et al. 2015) represent such trade-offs in ES. The decision regarding management for procuring an

The online version is available at http://www.springerlink.com

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ecosystem service, and therefore the trade-offs involved, depends on the prerogative of the forest manager. However, both degraded ecosystems and their ecosystem services can be restored, since forest ecosystems are inherently dynamic and adaptive (Messier et al. 2013) and undergo constant changes even without humans utilising them (Barnes et al. 1998; Kneitel 2012).

Studies on the dynamics of forest ecosystems are primarily concerned with changes in the structure and composition of forests over time, which includes the response of forests to various natural and anthropogenic disturbances (Pretzsch 2009; Taylor et al. 2009; Kneitel 2012). Adding the ES perspectives here is crucial as the supply of ecosystem services from the forests relies on dynamics of vegetation communities. In order to maintain ecosystem service supply, forest-users have management systems, such as the application of fire, grazing, or artificial regeneration, that lead to changes in or maintenance of the current state of vegetation (Kremen 2005; Guo et al. 2010; Ma et al. 2012) (Fig. 1). This relationship between dynamism in forest structure and composition and human wellbeing becomes even more important in areas where a large proportion of the population is dependent on forest resources (Semwal et al. 2007; Grêt-Regamey et al. 2012; Ma et al. 2012), like the Himalayan region.

The forests of the Himalaya have shown a great degree of variation ever since the emergence of the mountains, 60–70 million years ago, but changes in the past few decades have been extremely drastic, primarily driven by human activities (Khera et al. 2001; Arya and Ram 2011). These include trans-human grazing, conversion of forests to agricultural land, lopping in oak forests, timber extraction, surface burning, and litter removal (Rao and Pant 2001; Singh 2002).

In the most populated zone (1500–2000 m) of the central Himalaya, pine and oak forests appear in different densities providing the local population with a number of life-supporting ecosystem services (Singh and Singh 1992; Semwal et al. 2007; Arya et al. 2011, 2012; Negi et al. 2011). However, with increasing exploitation and human disturbances, these forests are constantly changing, which will eventually bring a change in the supply of services (Kumar and Ram 2005; Arya et al. 2012; Singh 2014). The link between successional dynamics of pine and oak forests in the Central Himalaya and the supply of ES remains untouched by the scientific community so far. This review summarises the body of knowledge on pine-oak dynamics in the central Himalayan forests, ecosystem services they provide, and the trade-offs for ecosystem-service supply due to the natural dynamics of these forested landscapes.

The Central Himalaya

Mountain systems of the world are key providers of ecosystem services that benefit both the low-land and high-land populations. These services range from provision of fresh water, climate regulation, biodiversity, and habitat conservation to social aspects like recreation, religion, and tourism, making them significant in all aspects of our lives (Körner and Ohsawa 2005; Grêt-Regamey et al. 2012).

The central part of Indian Himalayan mountains falls in the hill state of Uttarakhand (Ahmad 1993) hereafter referred to as Central Himalaya. Like many other mountain forest systems of the world, Central Himalayan forests have had a rather turbulent ecological history, which is evident from its vegetation (Singh and Singh 1992). Most forests in the region represent human-induced vegetation communities instead of the potential forests for the given climatic conditions (Khera et al. 2001; Sinha 2002). The intensive human-driven disturbances have now made it extremely difficult to predict the original and potential vegetation.

Forest management history and present

The local communities of the Central Himalaya have traditionally used the forest for their livelihood (Tucker 1982; Singh and Singh 1992; Ahmad 1993; Ramakrishnan 2007). In

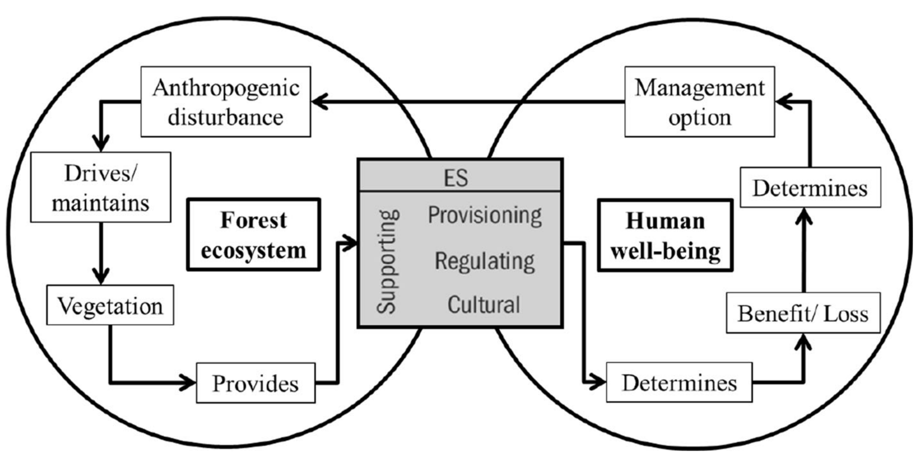


Fig. 1 Relationship between forest dynamics and human well-being. Modified after Schmerbeck (2011)

the beginning of the 19th century, the *Gurkha* community, from Nepal, expanded their rule to the *Garhwal* and *Kumaun* kingdoms of the Central Himalaya and exploited the forest wealth of the region before their overthrow by the British in the year 1815 (Tucker 1982; Negi et al. 1997). The early accounts of the British administrators, who settled in the *Kumaun* hills in 1815, describe the forests as randomly degraded (Tucker 1982). In the subsequent years, the British administration (under the leadership of G.W. Traill), worked on reclaiming the fertility and prosperity of the hill and foothill forests, but the approach was primarily focused on revenue instead of conservation. In the 1860 s, the expansion of agriculture, development of canal networks, and construction of railways took a heavy toll on the health of the mountain ecosystem (Tucker 1982; Singh and Singh 1992; Negi et al. 1997). *Pinus roxburghii* plantations were favoured, owing to its superior timber quality and fast growth, and large areas of *Quercus leucotrichophora* and *Shorea robusta* forests, in the mid and low altitudes, were converted to pine plantations for economic benefits (Negi et al. 1997; Sinha 2002).

Wood demand increased tremendously during the World War II, which led to further deterioration of the forests; to an extent, that they became inadequate for the subsistence-level utilization by villagers who resorted to large-scale, deliberate burning in order to meet fodder demands (Singh and Singh 1992). In the mid-20th century, establishment of large-scale hydroelectric power projects in the mountains proved to be a major setback to the already depleted forest resources (Singh and Singh 1992; Negi et al. 1997). As a consequence of all these activities, it is estimated that in the early 1980s the dense forests cover (>60% tree canopy cover) was reduced to merely 4.4% of the total forest area in the Himalaya (Singh and Singh 1987).

By the1990s, with rising awareness about the detrimental environmental effects of indiscriminate tree felling in the Himalayan forests, there were a number of protests staged by local populations. The *Chipko* "tree-hugging" protest started by the locals in central Himalayan forests forced timber contractors to return empty handed. These protests led to the 1989 landmark decision by the government of India, banning all tree felling in the Himalayan forests above an altitude of 1000 m (Singh 2014). Since then, the management approach in the Himalayan forests is focussed on protection, with a blanket ban on tree felling. However, local utilization of oak and lopping of oak branches for fuel and fodder has continued over the years (Makino 2011; Singh 2014). No management plans based on ecosystem services are in place at the moment.

Social reliance on ecosystem services in the Central Himalayas

The Himalayan Mountains hold immense social value for the predominately agro-pastoral local population (Semwal et al. 2007). Livelihoods of the rural Himalayan population have been dependent on forest-based products for many generations (Singh et al. 2010). Even with the relative increase in accessibility to the mountains, most of the population continues to practice the traditional forest-centred livelihood practices primarily due to poverty, unemployment, and lack of alternatives (Sharma et al. 2009; Singh et al. 2010; Sandhu and Sandhu 2015).

Apart from the pastoral residents, the mountain ecosystem also plays a vital role in the lives of *Kashmiri* and *Himachali* pastoral transhumance communities like *gaddis* and *bakarwalas* who travel with their cattle and goats to suitable foraging grounds every year (Rao and Pant 2001). These mountains also provide equally important ES to the much larger population residing in the Indo-Gangetic plains (Singh 2002; Rao and Pant 2001).

Forest dynamics and supply of ecosystem services

In one of the pioneering studies on succession, Odum (1969) characterised it as a reasonably directional process of community development, in response to modification of the physical environment by the community itself, in addition to external environmental changes. It would eventually culminate in a stabilized ecosystem with maximum biomass and symbiotic functions between organisms that are maintained per unit of available energy flow. Since then, many definitions have been developed to describe the succession with emphasis on the changes of environmental factors triggered by the vegetation itself in the course of succession (Whitmore 1998; Fischer 2003; Ghazoul and Sheil 2010).

Succession is a multi-dimensional process driven by a variety of factors (Fig. 2). The regional and local climate along with physiography, vegetation patterns, landform, soil, and species distribution determine the course of succession at the landscape level (Pickett et al. 1987; Khera et al. 2001; Pandolfi 2008; Kneitel 2012). On a localized level (forest stand) other factors—including local disturbance regimes, seed sources, species traits, dispersal vectors, and site history—determine the successional pattern (Tasser and Tappeiner 2002; Begon et al. 2006; Pandolfi 2008; Holzmueller et al. 2012; Kneitel 2012). Since a number of ecological and environmental factors are involved in the process, it is difficult to determine an exact pattern of succession that is similar for all regions (Pickett et al. 1987; Barnes et al. 1998).

The ecological requirements of species and the site conditions are the key factors driving the growth and establishment of a particular species in an ecosystem in absence of external disturbances. Pioneer species have the potential of coping with extreme conditions and establishing in relatively nutrient-deprived areas consequently

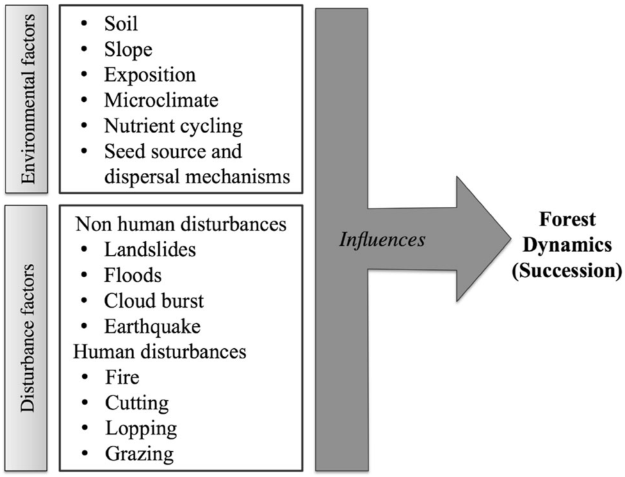


Fig. 2 Major environmental and disturbance factors influencing forest dynamics (succession)

resulting in changes in the site conditions and creating conditions for establishment of other successional species in the region (Walker and Moral 2003).

In due course, pioneers support the establishment of mid- and late successional species in the understory (White et al. 2011), which are more demanding in terms of site conditions, and require shade, moisture, and nutrient rich soil for establishment. However, natural systems are not devoid of disturbances, which play a significant role in determining the plant community structures in a forest ecosystem (Wilfahrt et al. 2014). Chronic disturbances at the stand level often maintain the vegetation community at an arrested early successional stage (White et al. 2011; Wilfahrt et al. 2014). These patterns of succession can also be applied to the pine and oak forests of the Himalaya, which suffer from chronic anthropogenic disturbances like cutting, lopping, grazing, and forest fires (Singh et al. 2014).

Anthropogenic disturbances affecting forests are usually resources extraction practices by which local communities procure ecosystem services necessary for sustaining their livelihoods. Ecosystem services (ES) are the benefits that human beings derive from the ecosystem (Millennium Ecosystem Assessment (MEA) 2005), which classifies them into supporting, provisioning, regulating, and cultural services, which are interconnected with various aspects of human well-being like security, health, basic material for good life and good social relations. Ecosystem services from pine and oak forests include tangible provisioning services like fuel and fodder to intangible supporting, regulating, and cultural services such as air purification, soil protection, hydrology, and recreation. At each stage of succession, the Himalayan forests provide a set of ecosystem services that may be similar to or different from the previous successional stage. However, collating this knowledge on the changes of ecosystem services is of utmost importance for effective forest management in these mountain forests.

Pine and oak dynamics: succession in the Central Himalayas

Ecological characteristics of pine and oak species

As mentioned earlier, one of the primary factors affecting the occurrence of a species at any point of time in a successional sequence are its inherent ecological requirements and tolerances. Similarly, the position of pine and oak in the successional sequence is an outcome of their ecological characteristics, summarized in Table 1.

There are five pine species indigenous to India: *Pinus wallichiana* (blue Pine), *P. roxburghii* (*chir* Pine), *P. kesiya (khasi* Pine*)*, *P. gerardiana (chilgoza* Pine*)* and *P. merkusii* (Merkus's Pine). Out of them *P. roxburghii*, *P. wallichiana* and *P. gerardiana* are found in the central Himalaya (Singh and Singh 1992). *Pinus* species are commonly known to occur on coarse dry soils throughout the world but they have the maximum potential for fecundity and growth on well-drained porous soils containing a balanced proportion of sand and fine mica (Barnes et al. 1998).

In the mid-montane Central Himalayan forests, *P. roxburghii* is the most abundant pine species (Sinha 2002) mainly distributed between 1200 and 1800 m (Champion and Seth 1968). It is found association with *Shorea robusta* and *Quercus sp.*, in lower and upper altitudinal zones respectively, or as pure pine forest stands (Chaturvedi and Singh 1987; Sinha 2002; Arya and Ram 2011). The species can occur on a variety of geological formations, like tertiary sandstone, mica, schist, gneiss, shale and quartzite (Troup 1921). Although *P. roxburghii* can establish on all the expositions but Champion and Seth (1968) report the conspicuous absence of *P. roxburghii* forests on the southern exposition of the outer Himalayan ranges due to the high humidity and excessive heat. However, according to Troup (1921), *P. roxburghii* can establish on the southern slopes depending on the soil quality, insolation, denudation, undergrowth, associated species and other factors although its performance is much better on the northern slope.

Pine forests are known for their ability to withstand the frequent forest fires in the region. The thick basal bark (>3 cm) of mature *P. roxburghii* trees enables them to prevent complete cambial mortality while facing ground fires. Additionally, self-pruning of lower branches reduces the likelihood of fire spreading to the canopy (Brown et al. 2011). The ability to withstand forest fire is believed to be

Table 1 Ecological characteristics of pine and oak species of the central Himalaya (Troup 1921; Singh and Singh 1992; Semwal and Mehta 1996; Jina et al. 2011; Singh 2014)

Characteristic	*Pinus roxburghii*	*Quercus* sp.
Successional stage	Early	Mid to late
Leaf longevity	Almost 1 year of leaf longevity, deciduous tendency during spring	Mostly evergreen with one-year leaf span
Light requirement	Strong light demanding species	Shade tolerant in early years of establishment
Soil quality tolerance	Can establish on coarse dry soils	Requires relatively fertile, well-drained soil
Fire tolerance	Mature trees can survive surface fires. The seedlings, although most resistant to fire as compared to other Himalayan species, are vulnerable to high fire frequencies and intensity	Not fire resistant. (Personal observation: Mature trees can survive low intensity fires)
Frost resistance	Frost hardy	Frost hardy

one of the primary reasons behind the large spread of the species in the Himalayas (Semwal and Mehta 1996).

Depending on the local environmental conditions, pine trees can start bearing fertile seeds as early as 30–40 years of age (Troup 1921). Owing to their light weight pine seeds easily dispersed by wind (Sinha 2002; Troup 1921). According to Troup (1921), seedlings of *P. roxburghii* need light and get suppressed under the canopy of broad-leaved species. Seedlings are also frost hardy and drought resistant, however, they are unable to survive in dry regions exposed to the sun for long hours in a day. Excessive soil moisture and bad drainage may also result in the mortality of *P. roxburghii* seedlings. According to its ecological traits, it is safe to say that *Pinus roxburghii* is a pioneer species and therefore likely to be one of the first species to colonize an open or recently disturbed area.

Quercus (Oak) is a very large genus, of great ecological and economic importance, with more than 300 species known worldwide, out of which around 35 species are known to occur in the Indian Himalaya (Troup 1921; Singh and Rawat 2012a). *Quercus leucotrichophora* (banj), *Quercus floribunda* (tilonj/moru), *Quercus lanuginosa* (rianj) and *Quercus semecarpifolia* (kharsu) are the commonly occurring oak species in the Central Himalaya between 1500 and 3000 m elevations (Champion and Seth 1968; Singh and Rawat 2012b).

According to Upreti et al. (1985), oak forests of the Central Himalaya thrive well on slightly acidic, nitrogen and phosphorus rich, brown sandy loam, especially in low elevations. The nitrogen concentration in the soils of the oak forests varies within the same forest and is invariably higher on mesic hill slopes than on drier slopes (Upreti et al. 1985). All oak species of the Central Himalaya are evergreen (Singh 2014), frost hardy (Upreti et al. 1985) and shade tolerant in their initial regenerating stage (Thadani and Ashton 1995). According to Thadani and Ashton (1995), oak seedlings are able to survive in shaded areas by allocating more nutrients for leaf and shoot growth, than for roots, supporting the photosynthetic tissue in low light regimes. Such saplings can survive for some time but eventually die under the shade of a dense tree canopy (Thadani and Ashton 1995).

However, the shade-tolerating capability of oak is much higher than of pine (Thadani and Ashton 1995). Fire, grazing, cutting, and other forms of anthropogenic disturbances in the forests have shown clear negative influences on the growth and establishment of the oak species in the central Himalayan region (Singh and Rawat 2010; Makino 2011; Singh and Rawat 2012b; Singh et al. 2014). Oak's ecological requirements indicate that it is a late successional species in the Himalayan context.

Pine and oak successional dynamics

The successional dynamics of pine and oak forests begins from the pioneering pine community establishing on grasslands and open areas that are, in due time, replaced by a mixed pine and oak community, eventually culminating into a late successional dense oak forest (Fig. 3). These changes are significantly regulated by disturbances acting on the ecosystem, which can cause changes in the successional process: for example, excessive lopping in a dense oak forest will lead to the opening of canopies to create an open oak forest.

Grasslands and open areas Warm temperate grasslands of Central Himalaya are characterised by extensively grassy slopes with intermittent shrub growth. These regions are often a result of large-scale disturbances like landslides or clear cuts. Chronic anthropogenic disturbances like grazing and fire aid in maintaining these areas in the grassland stage (Rawat 1998) with very limited regeneration of light-demanding pioneer species in some regions.

Pine forests The ecological features and limited nutrient requirements of pioneering pine species (Table 1) enable them to establish in the grasslands and open areas. Over time, pine forests, in the absence of disturbances, make the local site conditions conducive for the establishment of late successional species like oak under its canopy (Joshi and Tewari 2011; Sheffer 2012). However, continuous anthropogenic disturbances like fire and grazing can arrest succession to maintain a pine-dominated vegetation community, with no regeneration of late successional species (Singh and Singh 1992; Singh 1993; Khera et al. 2001).

Furthermore, forests fires have a major role in arresting the successional dynamics in pine-dominated regions. Low-intensity surface fires are an annual occurrence in the region (Pant and Tewari 2013). Fires are most commonly found in pine forests where needles provide highly flammable fuel. They are either accidental or deliberately put by the local population to enhance the growth of fodder grasses in the forests (Kumar et al. 2013). They influence the moisture regime in the soil and the water availability, which has a severe impact on the species regeneration (Gupta 1978; Kumar et al. 2013). Oak seedlings are extremely vulnerable to fire and cannot survive in fire-prone forests, one of the reasons why oak fails to establish in pine- dominated regions (Upreti et al. 1985; Singh and Singh 1986).

Another reason why oak and associated species in pine forests fail to regenerate is livestock grazing and browsing. Oak saplings are grazed by wild as well as domesticated herbivores, which retard their growth and development) giving way for other species less sensitive to disturbance (Gupta 1978; Thadani and Ashton 1995; Khera et al. 2001). Continuously grazed saplings never fully establish as trees but are rather present in a bush or mat-shaped formation in the forest (personal observation).

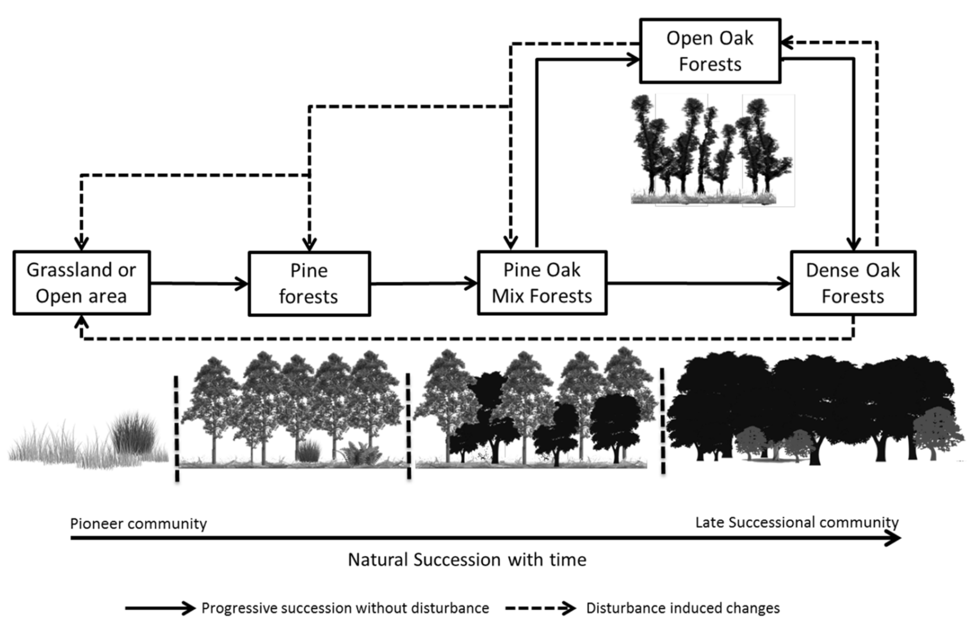
In addition to anthropogenic disturbances, other factors influencing the establishment of oak species in a pine-dominated forest include slow microbial immobilization of nitrogen in decomposing leaf litter of *P. roxburghii* (Singh et al. 1984), lack of seed sources, predation of acorns by birds and small animals (Thadani and Ashton 1995; Singh and Rawat 2010) and acorn infestation by insects like *Dicranognathus nebulosus* and *Calandra glandium* (Thadani and Ashton 1995).

Pine and oak mixed forests In a scenario where oak trees manage to establish in a pine forest, resisting all forms of disturbances, we can expect to have a mixed forest with roughly an equal proportion of pine and oak species in the stand. Such a forest represents a mid-successional stage between the pure pine pioneer forests and the late successional community of oak (Singh and Singh 1992) (Fig. 3).

Grazing and fire are the two main disturbances in the pine and oak forests; in addition, lopping of oak trees for fodder has a major influence on the vegetation dynamics (Gupta 1978; Singh and Singh 1992; Kumar et al. 2009; Arya and Ram 2011; Joshi et al. 2013).

Like every other stage of succession, the type and intensity of disturbances determines potential regeneration and movement in successional sequence in the mixed forest. In the absence of lopping, grazing and fire a pine and oak mixed forest can potentially develop into a late

Fig. 3 The dynamic of pine and oak forests in the Himalaya representing a probable successional sequence in regions with similar site conditions, as well as a representation of disturbance induced changes in the forests



successional dense oak forest (Fig. 3). Whereas in the presence of disturbances like lopping (which creates gaps in the canopy), the forest can move a step backward in the successional sequence, to form a pine-dominated forest community. Heavily lopped oak trees fail to provide the shade essential for establishment of oaks in the forests and therefore support the establishment of light-demanding pine species in the understory, a step back from progressive succession towards a late successional community. In a third scenario, removal of Pine from a mixed forest can potentially be converted to an open oak forest, which when left alone has the possibility to mature into a dense oak forest (Fig. 3).

Oak forests A dense oak forest with a closed canopy harbours rich undergrowth of late-successional species including tree species like *Rhododendron arboreum, Lyonia ovalifolia,* and *Cornus macrohylla* etc. (Dhaila et al. 1995). These forests are rich in biodiversity and believed to be the final stage of succession in the region. Anthropogenic disturbances and chronic small-scale removal of biomass for fuel and fodder from these forests often causes them to convert into open oak forests (Fig. 3). With light reaching the forest floor in a disturbed open oak forest, reestablishment of pine and other associated light-demanding species is a possibility (Gupta 1978), resulting in a mixed pine and oak community (Fig. 3).

Ecosystem services from pine and oak forests

The forests of Central Himalaya provide a multitude of ecosystem services on which the local population as well as the larger population of the Indo-Gangetic plains depends (Semwal et al. 2007; Joshi and Negi 2011; Ma et al. 2012). The ES provided at each stage of succession, leading to the oak forests, vary in kind and quantity. The following sections describe ecosystem services provided at every successional stage.

Services from grasslands and open areas In comparison to forested landscapes, grasslands are often not considered as valuable in terms ecosystem services. However, they are highly valued as fodder grounds for grazing cattle in the post-monsoon season (personal observation). Additionally, there are a few grasses and herbs that are used by the local population as vegetables and for medicinal purposes (personal observation). Furthermore, open scrub areas have limited capacity to prevent soil erosion following heavy rainfall as compared to the forested areas (Jain et al. 2001). There are no studies available of other services procured from these ecosystems in the Himalayan context.

Services from pine forests Pine forests, provide a multitude of provisioning services to the local population including, fodder, fuel wood, and timber. The openness of the pine canopy in addition to the frequent burning in the pine forest understory, results in good herbaceous growth under the canopy, which serves as fodder for domestic herbivores (Semwal et al. 2007). Arya et al. (2011) in a study on fodder sources from pine and oak forests of the Himalayas document 42 species that are used as fodder from in the central Himalayan forests. Pine forests contribute 25 of these species; however, 11 of them are common with the oak forests. Some of the commonly occurring fodder plants in the pine forests are *Themeda arundinacea, Brachiaria villosa, Andropogon munroi, Ficus sp.,* and *Butea monosperma* (Arya et al. 2011).

Even though oak species are commonly preferred as fuel wood, the use of pine is not completely absent. Singh et al. (2010) classify *Pinus roxburghii* as fair-quality fuel wood based on community surveys in the Kedarnath Wildlife Sanctuary. In the mid-altitude central Himalaya, between 1000 and 2000 m, Pine is frequently used as a fuel source (Bhatt and Sachan 2004; Kala 2004). Pine bark, traditionally known as *"chilla",* is a common lighting source in the absence of kerosene oil (Kala 2004). Pine bark, because of its ability to light for a longer duration as compared to other local species, is the preferred fuel source by small-scale blacksmiths for melting metal (Kala 2004; Semwal et al. 2007).

Pine wood forms high-quality timber with economic value and was heavily utilized for construction of railways in India during the early 1900s (Singh and Singh 1992; Tucker 1982; Negi et al. 1997). Even though timber extraction and logging has been banned for the last few decades to prevent degradation of mountain ecosystems (Singh and Singh 1992; Semwal et al. 2007), small-scale timber extraction and utilization of dead or naturally felled trees is permitted for the local people (Singh et al. 2010).

In addition to fodder, fuel, and timber, resin is an important non-timber forest product (NTFP) from *P. roxburghii* trees. The commercially valuable resin from pine trees can only be extracted by the state forest department and provides no direct benefit to the local people (Kala 2004; Semwal et al. 2007; Negi et al. 2011). Kala (2004) lists a few more products derived from pine forest: pine seeds are edible and are also used by the local people to manufacture edible oil. The pine needles are used for livestock bedding. Pine cones are sold as decorative items at tourist destinations in the hills, which yields some additional income for local people.

Pine is perceived to be of relatively low importance in terms of services like air purification, erosion control, rainfall interception, and soil-quality enhancement, as compared to oak forests (Joshi and Negi 2011).

High sediment output and surface flow rates in pure pine forests are responsible for the low soil nutrients and fertility in pine-dominated forests (Pathak et al. 1984). Furthermore, the litter decomposition rate, which is directly related to soil fertility, is the slowest for *chir* pine forests in the Himalaya (0.126% per day) but it is comparable to tropical pine species (Singh and Singh 1992). The C: N ratio of leaf litter is fairly high for pine species leading to their low decomposition rates and to an increase in the vulnerability of the ecosystem to fire incidences due to available fuel load (Singh and Singh 1992).

Frequent fires create a soil moisture imbalance, consequently giving pine species a competitive advantage over other species in the region (Gupta 1978; Singh 1993). Therefore, a co-dependent relationship between disturbances, lowered soil moisture, and pine establishment can be observed in this ecosystem. Chronic fires in the region also result in low plant diversity in pine forests (Sinha 2002), as fire inhibits the establishment of shrubs and other trees species under the pine canopy and selects for fire-resistant species in the ground vegetation.

In terms of carbon accumulation, potential pine forests show a higher value than open areas and mixed forests. However, the net carbon accumulation in pure pine forests (7.17 t C h^{-1} y^{-1}) is relatively low as compared to pure oak forests (Singh and Singh 1992). Last but not the least, the cultural services from pine are exemplified by its use in rituals and mention in the local folklore in addition to its role in recreation and tourism (Kala 2004).

Services from pine and oak mixed forests The provisioning services that can be obtained from a pine and oak mixed forest are basically the sum of those from pure pine and pure oak forests, just varying in quantity depending on the availability.

Plant diversity in the mixed forests however, is much higher as compared to the pioneering pine or late successional oak forests (Singh and Singh 1992; Upreti et al. 1985). In terms of carbon sequestration potential, mixed forests perform rather poorly with the lowest values for net carbon accumulation (6.83 t C h^{-1} $year^{-1}$) when compared to pure pine and oak forests (Singh and Singh 1992).

For all other services—like maintenance of hydrological cycles, soil fertility, and formation etc. it can be expected that mixed forests have values in between pure pine and pure oak forests.

Services from oak forests Late successional oak forests are the most valued by local people in terms of ecosystem services they provide. There are a number of provisioning services from oak, the most common among them being fuel wood and fodder, obtained via lopping of oak trees. Excessive lopping can result in conversion of a dense forest to an open forest, which is a less healthy ecosystem as compared to the dense oak forests but fundamentally provides the same provisioning ecosystem services.

Oak foliage is the preferred fodder species (Awasthi et al. 2003; Makino 2011; Singh and Rawat 2012b) and lopping of oak trees for fodder is one of the most exhaustive interactions between people and the forests that severely effects the growth and development of the trees (Makino 2011). Other than oak itself there are a number of other associated species in oak forests that are desirable sources of fodder like *Desmodium coccinum, D. elegans, Carpinus viminea, Fraxinus micrantha, Symplocus chinensis,* and *Litsea polyantha* (Arya et al. 2011).

In addition to fodder, fuel wood is a major provisioning service from oak forests. In the Himalayan region, a majority of the local population relies on fuel wood as an energy source to varying degrees depending on their socio-economic status as well as the availability of resources (Singh et al. 2010; Khuman et al. 2011). Fuel-wood extraction is practiced throughout the year to meet cooking, water heating, space heating and lighting needs (Singh et al. 2010; Singh and Rawat 2012b). With increasing tourism, there has been a staggering rise in the fuel-wood demand from *dhabas* (small scale local restaurants) in the central Himalaya, adding to the pressure on oak forests (Bhatt and Sachan 2004; Singh et al. 2010).

Non-Timber Forest Products (NTFPs) are another group of commercially important ecosystem product that the locals use (Kala 2004; Semwal et al. 2007; Joshi and Negi 2011; Negi et al. 2011; Rijal et al. 2011). NTFPs include fruits, seeds, nuts, resin, latex, mushrooms, honey, medicinal and aromatic plants etc. (Kala 2004; Semwal et al. 2007; Negi et al. 2011; Rijal et al. 2011; Saha and Sundriyal 2012). Additionally, leaves from *Quercus semecarpifolia* (Khasru Oak), found in altitudes higher than 2000 m, are used for manufacture of *tussar* silk or non-mulberry silk (Semwal et al. 2007).

Since the cost involved in collection of NTFPs is minimal, the sale of these products can contribute significantly to the monthly income of the rural households (Negi et al. 2011; Rijal et al. 2011; Saha and Sundriyal 2012). Most of the medicinal and aromatic plants of the Central Himalaya are endemic or endangered and hence their extraction and sale are strictly banned by the government under the Convention on International Trade in Endangered Species (CITES) (Semwal et al. 2007). According to Negi et al. (2011) sustainable harvest of wild edible species for sale can bring about significant improvement in the socio-economic status of the local population.

Stakeholder perception of regulating services from oak forests is rather positive with respect to services like air purification, soil fertility, rainfall infiltration, and erosion control (Joshi and Negi 2011) which is also concurred by scientific literature (Singh and Singh 1992; Semwal et al. 2007; Moktan 2014; Singh et al. 2014). Various studies show a positive relationship between oak forests and the soil and water conservation (Haigh et al. 1988; Eriksson et al. 2009; Sheikh and Kumar 2010; Jina et al. 2011; Kumar et al. 2013).

Oak forests are associated with better quality and abundance of spring water and their depletion is resulting in drying up of the springs in many areas (Sheikh and Kumar 2010; Arya and Ram 2011). Oak forests have good infiltration capacity, which is supported by work done by Pandey et al. (1984). The authors found low values of mineral losses through surface flow and sediment output after precipitation in oak forests as compared to pine forests.

Plant diversity in oak forests varies with the disturbance regimes. According to Upreti et al. (1985), disturbed oak forests show significantly low shrub diversity as compared to an undisturbed *Q. leucotrichophora* forest.

The net carbon accumulation in the oak forests (9.68 t C h^{-1} $year^{-1}$) is higher than any other forest type in the region (Singh and Singh 1992), however, studies have shown a strong correlation between the disturbance regimes and the amount of carbon sequestered (Semwal et al. 2007; Singh et al. 2010; Verma et al. 2012). According to Semwal et al. (2007), the amount of carbon sequestered in highly disturbed areas is much less compared to undisturbed areas; healthy forests sequester carbon at a much higher rate (5–9 t C h^{-1} $year^{-1}$) than poor quality forests (1.5-3 t C h^{-1} $year^{-1}$). Therefore, with increasing human disturbance and lopping in oak forests, the carbon uptake ability is likely to be weakened.

Ecosystem services: trade-offs with vegetation dynamics

Even with increasing importance given to ecosystem services in current scientific and policy discussions on natural resource management, structural integration of ecosystem services into landscape management is still lacking (De Groot et al. 2010). The interdependencies and trade-offs between vegetation formation and provision of ecosystem services need to be highlighted carefully when looking at ecologically sensitive areas like the Himalayas where local livelihoods are closely linked to the natural landscapes. Unsystematic management in the form of resource extraction practices (like grazing, lopping, cutting, and fire) in the region have maintained the present arrested stages of forest succession. However, with such a management system in place, the optimal flow of ES can not be achieved.

As the vegetation community shifts from the pioneering to late successional stage, in the central Himalayan mid-montane forests, there is a considerable increase in the variety and amount of ecosystem services, including provisioning services like fuel and fodder, and regulating services like water and soil conservation (Semwal et al. 2007). Even though trade-offs in ecosystem services occur between the successional stages, it is clear that oak forests are the most suitable vegetation type from both an ecological and economic point of view.

Primary forest succession on the warm temperate grasslands towards a pioneering forest community is beneficial for all ecosystem services, including soil stability, carbon sequestration, and hydrological balance (Table 2). The forest species colonizing open grasslands is most likely to be pine under the present disturbance regime. However, other early successional species like *Alnus nepalensis, Populus ciliate,* and *Coriaria nepalensis* (Singh 2007), are likely to hold a significant proportion of the vegetation community in the absence of human impact. Pioneer species have a stronger ability to establish on open grasslands compared to oak. Pine is the most abundant pioneer species in the mid-montane central Himalayan forests (Singh 1993); however, the perception of pine in the region is often negative (Singh 1993; Sinha 2002). It is therefore important to acknowledge the role of pine as a pioneer species that creates conditions conducive for the establishment of late successional oak species, provided that the disturbances are removed.

The next successional phase, the transition of a pine forest into a mixed pine and oak forest, is inhibited due to high fire frequency and grazing in pine forests. Elimination of these disturbances would support the development of a mix forest community with an increasing proportion of late successional oak species. Additionally, the ecosystem services supply also increases, including greater availability of provisioning, supporting, and regulating ecosystem services (see Table 2).

The only loss would be resin obtained from pine trees, which is an important source of revenue for the state forest department (Joshi and Negi 2011) and potentially timber. Pine trees yield good-quality timber and a change from pine to pine and oak forests would also mean a loss in available timber. However, due to the tree-felling ban in Himalayan forests above 1000 m, timber is not a major revenue source for the state (Joshi and Negi 2011).

Moving further in the successional sequence toward a pure oak forest, a significant increase in both tangible and intangible ecosystem services can be observed (Table 2). Other than resin and timber, there are no losses involved when moving from a mixed forest to a pure oak one. Oak forests are not only preferred by the local population they are also known to be valuable for enhancing the hydrological balance, biodiversity, soil fertility, nutrient cycling, and carbon sequestration potential (Singh 2007; Måren

Table 2 Relative values for the provision of ecosystem services of different successional stages of oak forest in mid elevations of the Central Himalayas

Ecosystem services		Vegetation types				
		Grasslands/open area	Pine forests	Pine oak mix forests	Open oak forests	Dense oak forests
Provisioning	Fuel wood	0	+	++	+++	+++
	Fodder	++	++	+++	+++	+++
	Fertilizer (litter bedding)	0	0	+	+++	+++
	Timber	0	+++	++	+	+
	Fruits and berries	++	+	+	+++	+++
	Resin	0	+++	+	0	0
	Vegetables	++	+	+	++	+++
	Flowers	0	0	++	++	+++
	Medicinal herbs	+	+	++	++	+++
Regulating	Rainfall interception	+	++	++	++	+++
	Air purification	0	+	++	++	+++
	Water Regulation	0	+	++	++	+++
	Soil fertility	+	+	++	++	+++
	Erosion control	+	++	+++	++	+++
Supporting	Plant diversity	+	+	+++	++	+++
	Nutrient Cycling	+	+	N/A	N/A	+++
	Carbon sequestration	+	+++	+++	+++	+++
	Soil formation	+	++	N/A	N/A	+++
Cultural	Aesthetics	+*	+++*	+++*	+*	+++*
	Recreational	+*	+++*	++ *	+*	+++*
	Spiritual and Religious	+*	+++*	++ *	++ *	+++*

Notes: Ascending sequence of importance: 0 = nil, + = low, ++ = medium, +++ = high, N/A = information not available). (Singh and Singh 1992; Kala 2004; Negi and Agrawal 2006; Semwal et al. 2007; Singh et al. 2010; Joshi and Negi 2011; Singh and Thadani 2013; Singh et al. 2014) (*Personal observations)

et al. 2013; Singh et al. 2014). Therefore, supporting regeneration of oak in early successional stages would not only enhance the future supply of ecosystem services but by increasing the area under oak forest we would also reduce the anthropogenic pressure on the current oak forests.

Conclusion

Despite the increasing importance of the ecosystem services concept, there is no comprehensive study that links ecosystem service supply from forests with the dynamic nature of the forest ecosystems. Our study highlights the dynamic nature of pine and oak ecosystems of the Himalayas, concluding that anthropogenic disturbances often act the primary catalyst for these changes. There are significant differences in the amount and kind of ecosystem services that the people obtain from pine and oak forests and the intermediate stages of succession. Valuation of ecosystem services at each level of forest succession would enable future researchers to provide accurate estimates about the potential benefits that can be obtained from the forests and thus help in determining the management regime that needs to be followed. Integrating ecological modelling techniques with remote sensing and GIS-based applications will make it possible to predict potential vegetation communities that are likely to develop in an undisturbed forest or in forests under varying management regimes. This information in turn can be used to find the ecological and economic value of forests that are likely to develop in this region in the future. Appropriate forest management strategies can only be developed when there is complete understanding about forest dynamics and the driving factors; this is one region where there is ample scope for further research. Re-establishment and supported growth of oak species in association with the local population should be the foremost focus of the forest managers. Additionally, there is an urgent need to understand the role of controlled fires in supporting ecosystem services like fodder availability, which are crucial for the pastoral communities. Trade-offs between ES of global (biodiversity and carbon) and local importance (fuel wood and fodder) have to be examined in order to have effective conservation and management plans. This raises the demand for intensive wide-ranging research work focussed on ecosystem services trade-offs in the near future.

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