Puettmann *et al. Forest Ecosystems* (2015) 2:8
DOI 10.1186/s40663-015-0031-x

Forest Ecosystems
a SpringerOpen Journal

REVIEW **Open Access**

Silvicultural alternatives to conventional even-aged forest management - what limits global adoption?

Klaus J Puettmann[1*], Scott McG Wilson[2], Susan C Baker[3], Pablo J Donoso[4], Lars Drössler[5], Girma Amente[6], Brian D Harvey[7], Thomas Knoke[8], Yuanchang Lu[9], Susanna Nocentini[10], Francis E Putz[11], Toshiya Yoshida[12] and Jürgen Bauhus[13]

Abstract

Background: The development of forestry as a scientific and management discipline over the last two centuries has mainly emphasized intensive management operations focused on increased commodity production, mostly wood. This "conventional" forest management approach has typically favored production of even-aged, single-species stands. While alternative management regimes have generally received less attention, this has been changing over the last three decades, especially in countries with developed economies. Reasons for this change include a combination of new information and concerns about the ecological consequences of intensive forestry practices and a willingness on the part of many forest owners and society to embrace a wider set of management objectives. Alternative silvicultural approaches are characterized by a set of fundamental principles, including avoidance of clearcutting, an emphasis on structural diversity and small-scale variability, deployment of mixed species with natural regeneration, and avoidance of intensive site-preparation methods.

Methods: Our compilation of the authors' experiences and perspectives from various parts of the world aims to initiate a larger discussion concerning the constraints to and the potential of adopting alternative silvicultural practices.

Results: The results suggest that a wider adoption of alternative silvicultural practices is currently hindered by a suite of ecological, economic, logistical, informational, cultural, and historical constraints. Individual contexts display their own unique combinations and relative significance of these constraints, and accordingly, targeted efforts, such as regulations and incentives, may help to overcome specific challenges.

Conclusions: In a broader context, we propose that less emphases on strict applications of principles and on stand structures might provide additional flexibility and facilitate the adoption of alternative silvicultural regimes in a broader set of circumstances. At the same time, the acceptance of alternative silvicultural systems as the "preferred or default mode of management" will necessitate and benefit from the continued development of the scientific basis and valuation of a variety of ecosystem goods and services. This publication is aimed to further the discussion in this context.

Review

Much of the history of forest science and management in the last two centuries has focused on optimizing the efficiency of commodity production, mostly of wood for timber, pulp, and fuel. Based on the notion that homogenous products are cheaper to produce and manipulate, management practices have typically led to even-aged, mono-specific or species-poor stands (Puettmann and Ek 1999, Paquette and Messier 2009, FAO 2010, West 2014). Such practices can include planting or natural regeneration, e.g., through coppice or natural or sown seed, combined with weed control and timber stand improvement practices to control species composition, tree size and quality; hereafter called "conventional" forest management. Currently, stands under conventional forest management for commodity production cover about 30% of

* Correspondence: Klaus.Puettmann@oregonstate.edu
[1]Department of Forest Ecosystems and Society, Oregon State University, Corvallis, OR 97330, USA
Full list of author information is available at the end of the article

the global forest land base (FAO 2010). At the same time, silvicultural approaches that can be viewed as alternatives to conventional management have been developed in various parts of the world, but have received less attention at a global scale (e.g., Gayer 1886, Kimmins 1992, Gustafsson et al. 2012, Lindenmayer et al. 2012). However, interest in these alternative approaches has greatly increased in many regions over the last three decades (Figures 1 and 2), particularly in countries with developed economies (Brukas and Weber 2009). Motivations for this recent development have varied across regions, but generally involve increased public scrutiny (Brunson and Steel 1994, Bliss 2000), impetus from forest certification bodies (Baker 2011), and better understanding of the implications of conventional forest management practices on biodiversity and habitat quality (Harlow et al. 1997, Manolis et al. 2000, Bauhus and Schmerbeck 2010), soils, water and nutrient cycling (Swank et al. 2001; Little et al. 2009), landscape visual quality (Ribe 1989; Paquet and Bélanger 1997), and other dimensions of natural capital and ecosystem services provision. Especially in countries with developed economies, public landowners, and, increasingly, many small private landowners do not necessarily rely on forests as their primary income source. Instead, other management goals, including recreational opportunities and landscape amenities, have gained importance (Butler and Leatherberry 2004; Hugosson and Ingemarson 2004; Urquhart and Courtney 2011).

The current variety of alternative silvicultural approaches (Figures 1 and 2) appears to have originated in two distinct contexts: in Europe and North America. Aesthetic and ecological critiques of conventional forest management during the period of 1850–1950 led to an emphasis on irregular size-class distribution and single-tree selection versus clearcuts, thus promoting the plenter forest (Plenterwald) model (Gurnaud 1882; Biolley 1901; Schütz 2002) and other “continuous cover” (Dauerwald) concepts (Möller 1923).

Other early European critiques highlighted concerns about the environmental effects of monocultures, and favored mixed-species stands (Gayer 1886). Similar concerns influenced management in other parts of the world, such as Japan (Marten 2005). Selection and shelterwood silvicultural systems suitable for the management of tropical moist forests were developed during the British and French colonial periods and were deployed in forests in India, Burma, Malaya, and West Africa until the 1960s. Technical development of these approaches has continued

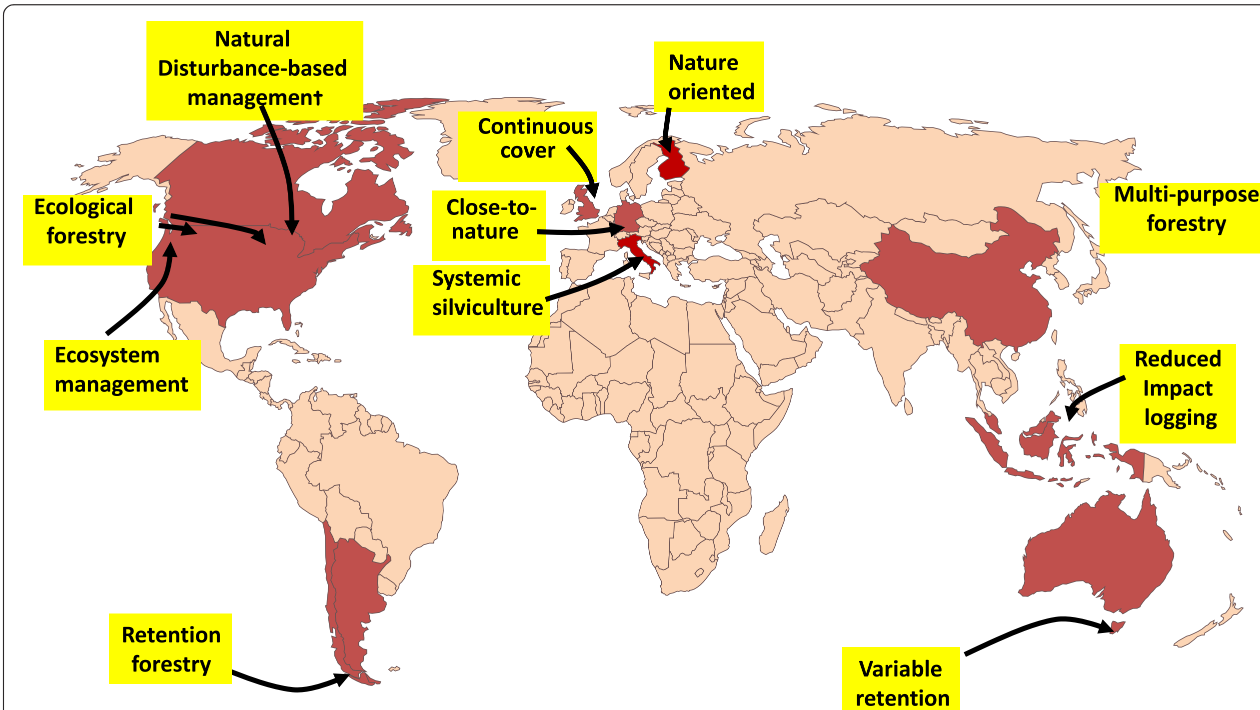

Figure 1 Examples of efforts to apply alternative silvicultural regimes. Countries with notable examples of alternative silviculture practices are in red. Associated text boxes display the common terminology used for alternative silvicultural practices in that region. *For more information about close-to-nature forestry in central Europe see Jacobsen (2001), continuous cover forestry see Mason et al. (2003), ecological forestry in the USA, see Franklin et al. (2007), ecosystem management in the USA see Kohm and Franklin (1997), multipurpose forestry in China see Lu et al. (2013), natural disturbance-based management in Canada see Bergeron et al. (2002), nature oriented forestry in Finland see Kuuluvainen (2009), reduced impact logging in southeast Asia see Putz et al. (2008), retention forestry in Chile see Donoso and Promis (2013), systemic silviculture in Italy see Ciancio and Nocentini (2011), and variable retention in Tasmania see Baker and Read (2011).

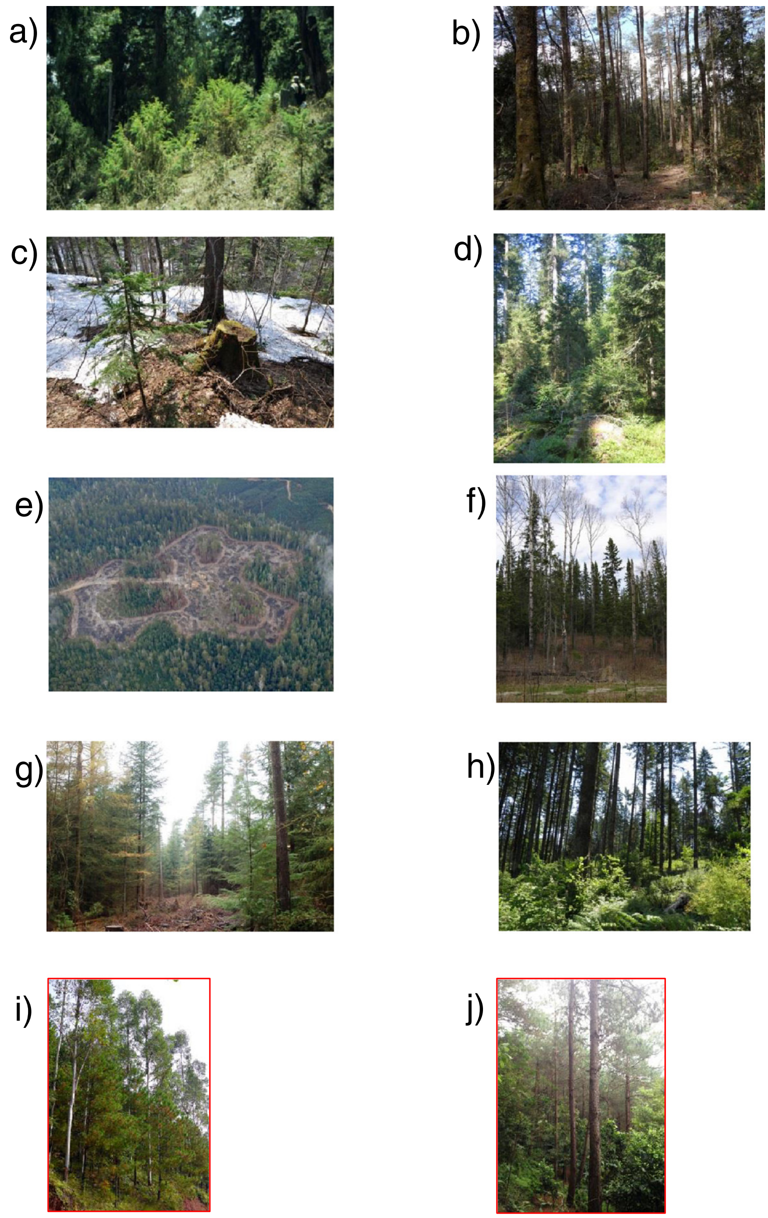

Figure 2 Examples of alternative silvicultural practices in different locations. (a) Ethiopia, natural regeneration of *Juniperus escelsa* in gaps, **(b)** Chile, recent restoration thinning in second growth *Nothofagus dombeyi* forests in Llancahue, **(c)** Japan, single tree cutting in natural *Quercus crispula* forest with *Abies sachalinensis* regeneration, **(d)** Germany, single-tree selection in mixed-species (*Abies, Picea, Fagus*) mountain forests, **(e)** Australia, aggregated retention in *Eucalyptus* forests in Tasmania, **(f)** Canada, removal of overstory *Populus tremuloides* to release and favor establishment of *Abies* and *Picea* species **(g)** England, silvicultural development in species-enriched *Pinus* and *Larix* plantations, **(h)** USA, variable density thinning with gaps and leave islands in Douglas-fir stands in Oregon, and **(i)** and **(j)** southern China, *Eucalyptus* overstory with *Pinus* underplanted between *Eucalyptus* sprouts and dominant *Pinus* overstory with *Quercus griffithii* and *Castanopsis hystrix* understory, respectively. Photo credit for **(f)** Philippe Duval, all other photos by the authors.

over recent decades, especially in Indonesia and Malaysia. The recent prominence in some European countries of Continuous Cover Forestry (e.g., UK and Ireland; Wilson 2013) and Close-to-Nature forestry (e.g., Germany, Switzerland, Slovenia, Italy) also reflects these historical influences (ProSilva 2014).

A second school of silvicultural approaches originated in the Pacific Northwest of North America under the banner of "New Forestry" (Franklin and Forman 1987) as a reaction to large-scale clearcutting in natural forest ecosystems and its impact on wildlife habitats, visual quality, and other ecosystem functions. Based on an increased understanding of how fire and other natural disturbances invariably leave patches of intact or partially affected forests in affected landscapes, this approach emphasizes the importance of residual structures and organisms (legacies), such as undisturbed vegetation patches, trees, and dead wood left behind after harvesting. These legacies are considered crucial for the speedy recovery of forest ecosystems after human-caused disturbances and thus for a continuation of ecosystem functioning and biodiversity and habitat values. Because this approach focuses on what is actually left behind after harvesting, it has spread to many regions of the world under the broad rubric of "retention forestry" (Lindenmayer et al. 2012).

A distinction between these different schools of alternative silviculture is the relative emphasis on management versus natural disturbances. For example, silviculturists in Central and Southern Europe tend to see a greater role for silvicultural interventions, reflecting the longer history of managed forests in their part of the world. By contrast, the lack of a long management history and an associated focus on natural disturbances in parts of North America and Australia are reflected in an emphasis on natural disturbance patterns as a template for alternative silviculture (Attiwill 1994; Drever et al. 2006; Long 2009). This is based on the notion that the historical range of variability in forest conditions can provide suitable guidance for management decisions (Higgs et al. 2014).

Despite their wide geographical distribution, in most contexts alternative silvicultural practices are not yet considered mainstream. They are often viewed and represented as less accepted alternatives to the conventional forest management paradigm in teaching and field practice (Puettmann et al. 2009). After long-standing arguments about alternative silvicultural systems, especially in the European literature of the last century, it appears that the debate is gaining momentum, as reflected by a number of recent summaries and overviews that discuss basic conceptual frameworks for these approaches, including complexity science (Puettmann 2011; Messier et al. 2013; Filotas et al. 2014), natural disturbance-based systems (Bergeron et al. 2002; Franklin et al. 2007), and legacies and retention (Gustafsson et al. 2012; Lindenmayer et al. 2012).

In many regions, these silvicultural alternatives to conventional forestry are enacted under a variety of social, economic, and ecological conditions and a wide array of ownership objectives, as well as legal and regulatory frameworks. While less applicable to highly intensive, short-rotation plantations (3% of the total forest area are covered by "productive plantations"; FAO 2010) and areas with the primary objective of biodiversity conservation (12%), silvicultural alternatives are most likely to be of interest on land that is designated primarily for either "commodity production" (30%), "multiple use" (24%), "soil and water protection" (8%), or "social services" (4%) (FAO 2010). These last four objectives may not be best achieved by adherence to any single management approach. Instead, a variety of local solutions have developed, including planted forests and forests that are naturally regenerated by seed or vegetative reproduction, reflecting the wide variety of ecological, economic, and social conditions and constraints of different jurisdictions. For an overview of the different efforts and discussions about labels, see Pommerening and Murphy (2004) and Evans (2006); also see Figure 1, including the notation with a list of references.

A basic distinction between conventional and alternative silvicultural approaches is the relative balance of selected values and objectives. Conventional approaches typically emphasize commodity production and view other objectives as constraints, e.g., intrinsic ecosystem values, accounting for natural processes, and maintaining species and structural diversity. In contrast, alternative silvicultural approaches place a unique set of emphases on each value. They regard all values, including non-commodity values, as a basic foundation necessary to achieve high levels and sustainable provision of ecosystem services, including product extraction (*sensu lato*) (Evans 2006).

This maturing view of forest management alternatives expresses itself in a set of five silvicultural principles (Jacobsen 2001; Schütz 2002; Mason et al. 2003; Bauhus et al. 2013):

- *Partial harvest*—use of partial harvesting and avoidance of large clearcuts
- *Natural regeneration*—where possible, preferential use of natural regeneration and native tree species
- *Structural diversity and small-scale variability*—varying management approaches across a range of spatial scales, with a special emphasis on diversity of stand structures at small scales, including single-tree and neighborhood conditions
- *Mixed species*—promotion of mixed-species stands
- *Avoidance of intensive operations*—minimization of intensive site preparation, fertilization, and weed control practices, and reliance on natural process such as self-thinning of seedlings and small saplings.

These principles correspond closely with the "low" and "medium" silvicultural intensity categories described in Duncker et al. (2012), in which management approaches are aligned along a gradient of intervention intensity.

When applying silvicultural alternatives, the focus on variability in stand structures across spatial scales typically results in an emphasis on the development and harvest of individual trees or small patches of trees. This principle may appear on the surface to be similar to selective exploitation harvesting approaches, where activities are limited to harvesting single high-value trees. However, alternative silviculture approaches, as discussed in this paper, are philosophically and practically quite distinct from such practices. In contrast to early selective exploitation, harvesting decisions in alternative silvicultural approaches are driven by an appreciation of the economic and ecological value of retained trees in terms of ensuring the continuity of ecosystem processes and functions. Thus, the application of all five principles aims to maintain or increase the growth potential of the site, conforming to traditional sustained-yield paradigms.

The potential advantages of alternative silvicultural approaches have been hailed in various dimensions, including in terms of biodiversity (Steventon et al. 1998; Fedrowitz et al. 2014), maintenance of "undeniably better resilience" (Schütz et al. 2012), general resilience (O'Hara and Ramage 2013) or, specifically, resilience to climate change (Schütz 1999a). However, limitations to specific adaptation strategies may exist; for example, the introduction of selected or improved genetic material may not be allowed or difficult to achieve in forests managed under these principles (Brang et al. 2014). Alternative approaches have also been claimed to provide other benefits compared to even-aged monocultures, albeit under specific sets of conditions. These conditions include more uniform cash-flow of harvest revenues (Knoke et al. 2001), higher income resulting from the production of high-quality wood (Hanewinkel 2002), more diverse wildlife habitats, especially for late-seral species (Hyvaerinen et al. 2006; Rosenvald and Lohmus 2008), increased wind stability of individual trees (Dvorák et al. 2001, but see Cameron 2002), and improved recreation value and public acceptance (Tönnes et al. 2004; Ribe 2005). This said, there is still much more work to be done in order to investigate and quantify the impacts under specific regional conditions (Gustafsson et al. 2010). Given these reported advantages, however, as well as the fact that many of the public and private landowners who have begun applying these principles are very satisfied with the results, "it is surprising that [alternative silvicultural approaches] are so seldom applied" (Schütz et al. 2012). In the following sections, we hope to provide a basis for a discussion about broader application of alternative silvicultural approaches and ask the following questions:

- What are the major factors that influence the decision to apply alternative silvicultural approaches?
- What is currently limiting the wider application of alternative silvicultural approaches at a global scale?
- What can be done to remove such limitations?

Methods

The authors have extensive experience dealing with research and teaching of alternative silviculture in various parts of the world. An initial collection of arguments by the authors was based on their own experience and familiarity with the relevant literature. This collection highlighted that the answers to questions about factors limiting wider application of alternative silvicultural practices vary between and within regions and between and within ownerships. To improve our insight into such highly complex decision-making environments and to better understand the decision factors, we found it useful to organize the assessment into a framework structured around the five silvicultural principles listed above (partial harvest, natural regeneration, small-scale variability in stand structures, mixed species, avoidance of intensive operations). Within these principles, we determined that the challenges to the implementation of these principles could be grouped into five categories and structured our results and discussion accordingly: ecological; economic; logistical and administrative; educational and informational; and cultural and historical. All authors repeatedly provided insights and feedback regarding the number and distinctions between the silvicultural principles and categories. At the same time, we went through repeated iterations in which the authors interacted to expand and organize the list of challenges. Thus, even though this does not comprise a systematic review of all existing literature (which would go beyond the scope of a single publication), we refined the list of challenges until we felt comfortable that all influential topics were covered in the discussion and provided a solid basis to initiate further discussions.

Results and discussion

Ecological challenges

The emphasis on continuous canopy structures (avoidance of clearcuts) typifies forests growing under natural disturbance regimes characterized by small scale disturbances, e.g., pathogen-induced mortality or mechanical damage (Lutz and Halpern 2006). In much of the world, the spatial scale of natural disturbance regimes can be represented by a J-shaped size frequency distribution, i.e., a combination of frequent small-scale and fewer large-scale disturbances (Veblen et al. 1981; Seymour and Hunter 1999; Shorohova et al. 2009; Yasuda et al. 2013). Examples of disturbances that generate these patterns include wildfires, e.g., in the western United States and Australia, or windstorms, e.g., in storm-prone regions of Western Europe (Schelhaas et al. 2003) or in the temperate forests of southern Chile (Veblen 1985). In such regions, a focus on any single silvicultural approach will only reflect a subset of patterns and dynamics found under natural conditions (Seymour and Hunter 1999). For example, region-wide applications of a management regime that focused only on continuous overstory cover would not promote conditions and patterns associated with severe, larger-scale disturbances, e.g., certain early successional habitat features. In such cases, the emphasis on smaller-scale variability in stand structure may reflect natural conditions found in individual stands, but it may not reflect the overall landscape-scale dynamics. Such concerns are currently discussed regarding the lack of early-seral habitat on federal land in the Pacific Northwest of the USA (Swanson et al. 2011; Franklin and Johnson 2012). Since natural disturbances such as fire and windstorms cannot be totally prevented or controlled in most forest landscapes, concern about the lack of selected disturbance effects may be of little practical relevance in the long run. Exceptions are situations where management artificially reduces the probability of occurrence of large-scale or stand-replacing disturbances. Examples of such situations include the application of short rotations that prevent trees from reaching heights common in older forests, and thus may reduce windthrow. Alternatively, density management aims to reduce tree stress to the remaining trees by ensuring higher light, water, and nutrient levels, and thus may limit competition related mortality (either directly due to drought or indirectly, e.g., insect related mortality due to low vigor, often found in high-density unmanaged stands (e.g., Neumann and Minko 1981). Also, fuel management may reduce the extent of large-scale fire disturbances. Hence, practices that change “natural” disturbance regimes must be carefully assessed in terms of their implications on landscape dynamics, and restoration may be required in some cases. For example, controlled burning as a restoration technique can be beneficial for threatened species in boreal forests where there has been extensive long-term fire suppression (Kouki et al. 2012).

Lack of large openings and early successional conditions in close-to-nature silvicultural systems operating with small canopy gaps can be detrimental to maintenance of light-demanding tree species in ecosystems where these species are mixed with more shade-tolerant species (e.g., Neyland et al. 2012; Bauhus et al. 2013). On the other hand, under selected conditions, such as low-density stands or species with open tree canopies, intensive management with repeated entries can facilitate survival and growth of light-demanding species, e.g., small-group uneven-aged management in Mediterranean pine forests (Ciancio et al. 1986; Barbeito et al. 2008; Calama et al. 2008). However, more often the higher mortality of light-demanding species in shady conditions and the slower responses of suppressed trees after silvicultural release can lead to an increasing dominance of shade-tolerant species (Lüpke and Hauskeller-Bullerjahn 1999; Kneeshaw et al. 2002; Drössler et al. 2013). These trends lead to concerns, as light-demanding species are often desirable in managed forests because of their fast growth rates, desirable timber properties, and dependent biodiversity components. They are also of broader interest under climate change conditions as they can be more drought tolerant than shade-tolerant species (Ninemets and Valladares 2006) and their fast initial growth rates and associated shorter rotations have the effect of reducing long-term risks.

The focus on small-scale variability in stand structure means that trees of different species and sizes grow in close proximity to each other. Such stands may have a lower probability of extensive crown fires, as they do not have continuous high density canopies. However, multi-layered stand structures can produce ideal fire ladders (Schoennagel et al. 2004), a great concern in fire-prone areas. The spread of certain pests may also be facilitated in such intimate structures, e.g., large infected trees have the potential to infect nearby regeneration through higher exposure to inocula (Reich et al. 1991; Shaw et al. 2005). Tree-species diversity tends to restrict this threat, however, by reducing host-density for any species-specific pest or pathogen. In addition, smaller trees of one species may be less vulnerable to specific hosts when hidden by taller trees of another species (Castagneyrol et al. 2014). Similar arguments for species diversity at small spatial scales can be made in regards to other perturbations, as species differ in their sensitivity to wind, herbivory, and climatic stresses, such as drought or frost periods (for example, see the mixed species discussion in the *Economic Challenges* section below).

Natural regeneration with the consequent avoidance of the need for financial investments in artificial tree regeneration works well where competitive understory vegetation is sparse. Although dense stand conditions prior to regeneration cutting can reduce the amount of understory vegetation, numerous forest types in the world have understory vegetation that is highly shade tolerant and understory species that can respond very aggressively and competitively to canopy opening, even after partial harvests (e.g. Noguchi and Yoshida 2004; Donoso and Nyland 2005; Nilsson and Wardle 2005; Bose et al. 2014; Dodson et al. 2014). In these forests, regeneration of desirable tree species (especially, but not limited to shade-intolerant species) may be poor or delayed for years or even decades (Hibbs and Bower 2001; Axelsson et al. 2014).

In summary, ecological constraints underline the imperative of allowing more flexibility in adherence to the five principles in order to provide more opportunities for broader applications of silvicultural alternatives. Based on local ecological conditions, it may be necessary to deviate or “stretch” the principles. For example, larger canopy openings or more intense weed-control practices than preferred under alternative silvicultural approaches may be necessary in selected settings to ensure regeneration of desired tree species. Finally, acknowledging the full diversity of natural disturbance and development patterns may put the role of alternative silvicultural practices in a larger perspective.

Economic challenges

Economic considerations are generally strong drivers of land-use decisions, as already made clear by Thünen's (von Thünen 1842) theory on the spatial distribution of forestry and agriculture. A strong focus on economics may not always apply to forestry, where ecological considerations, tradition, social acceptability, culture, life-style, and similar factors may dominate management decisions (Kimmins 1992) and long-term economics of decisions are not always clear. However, it is unlikely that alternative silvicultural strategies will be adopted on large scales if they are not financially compatible with economic sustainability.

Economic considerations include the expected profit, uncertainty, and flexibility of management alternatives. The outcome of such economic considerations strongly depends on the specific settings of the land ownership and the services included into the decision matrix (Amsalu et al. 2014). Any application of alternative silvicultural approaches has to be viewed in the context of other management options to consider the opportunity costs for the final silvicultural decisions appropriately. In many places, especially on larger private holdings in the tropics, subtropics, and temperate regions of the Southern Hemisphere, the context includes the economic expectations from short-rotation plantation forestry, generally with exotic tree species, and often aided by political and economic policies (e.g., Niklitschek 2007; Miller Klubock 2014). Even under optimistic expectations, alternative silvicultural approaches are unlikely to reach the short-term financial profitability of intensively managed short-rotation plantations in tropical regions or some temperate regions (Cubbage et al. 2007; Knoke and Huth 2011). In some settings, however, native tree species may compete with exotic tree species when managed in a short-rotation plantation system (Cubbage et al. 2007; Griess and Knoke 2011).

The economic picture for alternative silvicultural methods is more favorable when viewed in a longer-term context, such as typically used in temperate and boreal biomes. For example, Tahvonen et al. (2010) showed the importance of relying on natural regeneration to reduce regeneration costs as a critical criterion that allowed continuous-cover forestry to emerge as the option with the highest net present value in Finnish spruce forests, under nearly all combinations of assumptions used in the study (Note that the study assumed higher regeneration costs due to artificial regeneration in even-aged management regimes). Many other studies support the findings published by Tahvonen et al. (2010) in principle, for example Chang (1981); Haight (1987); Haight and Monserud (1990); Pukkala et al. (2010) and Hyytiäinen and Haight (2010). Another argument often presented in the discussion of economic outcomes of alternative silvicultural practices is that individual trees can be harvested at the time when they peak in terms of their economic values. This can increase the total net present value substantially in stands with an existing wide range of tree values (as determined by species, size, and wood quality) (Knoke 2012). The advantage of harvesting trees at their peak economic value - versus harvesting all trees in a stand at the same time - may be reduced or lost in stands where trees are very homogenous (also, see the discussion about harvesting costs and staffing needs). Thus, it is important to note that the economic attractiveness of alternative silviculture is conditional on the initial state in the short run (Tahvonen et al. 2010). This makes generalizations about comparisons between conventional and alternative silvicultural approaches not very useful for landowners who consider such options for a specific property. The influence of the initial state can be minimized by using a very long (at best an unlimited) time horizon in comparative economic analyses; a requirement that certainly poses additional challenges.

The economic comparison may also change towards alternative silviculture when these approaches result in an increased resilience to natural hazards, e.g., in mixed-species even-aged (Griess et al. 2012; Neuner et al. 2015) or uneven-aged stands (Hanewinkel et al. 2014). Alternative silvicultural approaches may also be more suitable for forest owners with concerns about economic risks, as the risk is lower in stands with higher resilience to disturbances and when timber harvesting is accomplished with multiple operations over time (Roessiger et al. 2013).

Finally, increased stand-level ecological stability in mixed and uneven-aged forests also enhances economic performance of forest operations through improved flexibility because harvest levels can be more easily adjusted to accommodate changes in market conditions (Knoke and Wurm 2006). Management flexibility may be of special importance in a more unpredictable future, e.g., with climate change (Jacobsen and Thorsen 2003; Wagner et al. 2014) or novel pest incidences. Consequently, major issues in economic assessments of silvicultural approaches are the relative emphases on economic risks and management and marketing flexibility.

One argument often used to promote application of single-tree selection and also for alternative silvicultural approaches is the benefit of the production of high value, i.e., large diameter and high-quality trees (e.g., "Dutch cuttings", see Schütz et al. 2012) (often in conjunction with the decreased need for non-commercial thinning operations). As markets have shifted, and in regions where much of the wood-processing industry has re-tooled to efficiently process smaller logs, large logs now may have no premium (per unit of volume), and in some cases may even have price penalties (Fitzgerald et al. 2013). This issue will vary by species and may be alleviated by sawmilling innovation in response to a higher availability of predicted assortments from alternative silviculture. In the meantime, in many regions, the theoretically higher mill recovery from larger diameter logs is often offset by the faster speed when processing homogenous (in terms of size and quality) logs, especially in high-volume sawmills. Concerns also exist about lower log quality for trees that grow in highly variable conditions throughout their lives. This variability can exhibit itself in somewhat adverse branching patterns, including large branch sizes and higher variation in juvenile wood, wood density, and growth rings (Schütz 1999b; Macdonald et al. 2010; Piispanen et al. 2014).

Harvesting costs per unit volume for similar sized trees are typically higher in partial harvesting operations, especially on steep slopes and in mixed-species stands when different species have to be sorted and marketed separately (Pausch 2005). These higher costs are partially due to reduced efficiency of logging when only small amounts are harvested in a single operation. Early adopters also may incur higher costs and time delays when hiring and training specialized logging contractors. The necessary investments into infrastructure, including the development and maintenance of road systems, may also be a financial barrier to managing alternative silviculture, especially for landowners with smaller properties. Similarly, compared to conventional approaches, the proper implementation of alternative silvicultural approaches may result in higher personnel costs due to the higher skill level required, as well as more frequent site visits to assess progress, mark trees, and develop and supervise the implementation of often more complicated management prescriptions. Another economic concern with partial harvesting may be the risk of physical damage to the retained growing stock. This issue is of special concern in difficult terrain and when large-crowned species are felled or species with little decay resistance are left behind (Nill et al. 2011).

In summary, the ability to rely on natural regeneration, the limited need for site preparation and weed-control operations, in conjunction with a higher proportion of larger, high quality trees at harvest time, are viewed as major economic advantages of alternative silvicultural approaches. Thus, ecological conditions that influence natural regeneration, such as seed production, herbivory levels, and competitive conditions in the understory are crucial factors that can determine the financial viability of alternative silvicultural approaches. Risk and flexibility considerations may also constitute strong arguments in favor of alternative silvicultural approaches. However, the economies of scale of industrialized short-rotation management may more than balance these advantages of alternative silviculture in many parts of the world in the short-term, where the production of large amounts of homogenous timber is the main aim of forestry.

Finally, ecosystem services that may be provided more efficiently in forests managed under alternative silvicultural approaches, e.g., visual quality, hydrological services, or wildlife habitat provision, are not necessarily adequately monetized or evaluated (e.g., Ribe 1999; Daniel 2001). Whether or not such values compensate for a potential loss in timber production after conversion to alternative silviculture regimes will vary with the specific situation and assumptions, e.g., soil quality and interest rates, respectively (Amsalu et al. 2014). In many situations, the application of alternative silviculture would only be economically viable through measures such as conservation payments (Cubbage et al. 2007), monetary incentives as part of forest certification efforts (Nasi et al. 2011), or direct payments for ecosystem services (Wunder 2006), such as water supply and regulation (Nahuelhual et al. 2007).

Logistical and administrative challenges

Efficient partial-harvesting operations may require highly trained loggers and specialized machinery. Both can be in scarce supply, particularly in regions where these practices are only emerging. In some areas, forest managers may be able to benefit from loggers with experience in selective harvesting in other settings, such as exploitation cuttings that selectively removed only the highest value trees. Using inexperienced loggers and unsuitable machinery that is not designed for partial harvest operations increases the probability of inadequate prescription application and harvesting damage to residual trees (Jones and Thomas 2004; Putz et al. 2008), both outcomes that can reinforce a perception that alternative silvicultural approaches are inoperable. The damage to retained trees can be very high also in regions with a longer tradition of uneven-aged forest management (Nill et al. 2011). Moreover, advanced regeneration is often cut to improve the visibility for machine operators during harvest procedures or damaged during skidding or forwarding operations (Newton and Cole 2006). In contrast, these concerns can be less prevalent in parts of the world where logging operations are not highly mechanized. For example, manual logging operations with extraction by horses or oxen can be done with relatively little damage to residual trees and regeneration (Bacardit 2014). However, there are notable exceptions, for example where logs are thrown downhill by forest workers through forests on steep slopes, as has been practiced in some parts of China (J. Bauhus, personal observations). Even in stands with little harvesting damage, sudden exposure after partial harvesting can lead to higher evaporative demands (Bladon et al. 2006) and unexpected mortality of residual tress (Yoshida et al. 2006; Aubry et al. 2009).

Health and safety considerations are always important during and after partial harvesting operations due to concerns about the stability of branches and retained trees (Schaetzl et al. 1989). The presence of dead branches or forked trunks leads to safety concerns, but can be taken into account when selecting residual trees. Past scarring, possibly during earlier harvest operations, can also provide indications of possible trunk rot and thus the likelihood of tree fall (Matlack et al. 1993). Training can also reduce workplace safety risks. For example, the injury rate dropped - rather than increased - when variable retention harvesting replaced clearcutting in coastal British Columbia, because of strong organizational focus on worker safety. In contrast, at a larger scale, forests with continuous cover are preferred because of their safety benefits for avalanche protection (Bebi et al. 2009) and protection from landslides (Dhakal and Sidle 2003; Noguchi et al. 2011).

Changing management practices to alternative silvicultural approaches requires the development of different expertise by existing staff and additional educational and training efforts (see below) or, possibly, restaffing. Applying repeated partial-harvesting operations with decisions made at the individual-tree level may initially require a larger workforce until new training programs take effect to reduce or offset the workload. Planning and monitoring processes and inventory systems may have to be modified to more efficiently consider and accurately track the development of tree and stand attributes for anticipated future treatments (Rice et al. 2014).

Alternative silvicultural benefits from continuity of ownership and supervisory management personnel who can oversee the consistent application of silvicultural prescriptions. For example, these approaches may only be feasible if concessions are agreed on beyond the scope of a single harvest to include repeated harvesting operations, and if concessionaires are held responsible for reforestation and other silvicultural operations. Especially on larger private ownerships and in areas with limited infrastructure, the supervision of logging activities is necessary to avoid unauthorized or accidental removal of higher-valued trees intended for retention. Furthermore, the higher diversity of forest conditions (e.g., tree-species combinations – literally dozens in tropical forests - and various stand structural conditions), and the associated lack of simple, standardized instructions and management protocols make it more difficult to cope with rapid turnover of staff. Even where scientific data and understanding already exist from long-term silvicultural trials, foresters often appear to heavily rely on their observations, intuition, and experience when applying alternative silvicultural approaches. Developing and fostering these skills in new personnel is challenging for forest administrators and land owners.

In summary, staffing challenges will require increased training efforts, e.g., in reduced impact logging (RIL, Tropical Forest Foundation 2008). New machinery and modification of harvesting practices may help overcome challenges when implementing alternative silvicultural practices. New technologies for planning and monitoring (e.g., GPS, GIS, remote sensing tools) will reduce the need for staff, but will require a more highly qualified workforce. Finally, the modification of contracting practices, such as involving concessions, may be necessary in many places to facilitate a transition to alternative silvicultural systems.

Informational and educational challenges

Over the last century, many educational programs in forestry schools and continuing professional education programs have focused primarily on conventional forestry practices and have often provided limited exposure to alternative management approaches such as selection systems (Schütz et al. 2012). One reason for this has been the decline in the availability of experienced silvicultural professionals to impart this knowledge. Practical examples of alternative silviculture that can be used as demonstration projects for students and practitioners are still lacking in many regions. This is true especially in countries with developing economies, following the decline of previous colonial and overseas development forestry practices. Related to the lack of practical field examples is the limited capture of traditional ecological knowledge of some indigenous communities (Berkes et al. 2000), although this is changing in some regions. For example in the Maya region of Mexico, new silvicultural systems for the regeneration of *Swietenia macrophylla* were developed as a result of collaborations among forest scientists and local communities (Menzies 2007).

The amount and type of scientific information available to support alternative silviculture reflect the bottom-up development of these approaches. In contrast to conventional forestry operations, which are based on the agricultural model or efficiency paradigm (Puettmann et al. 2009), alternative silvicultural approaches have not received the same level of attention by scientists. Studies that document the long-term response to alternative silvicultural treatments in terms of the full suite of ecosystem goods and services are lacking. Instead, in many instances, foresters adopted these approaches after observing trends in their own forests or visiting forests on which alternative silviculture had already been successfully applied. Thus, the spread of silvicultural alternatives is related to the availability of examples as well as to scientific progress. The limited awareness and utilization of scientific studies covering relevant aspects, such as the physiological basis for seedling and sapling responses to overstory removals or natural regeneration of species mixtures (Puettmann and Ammer 2006), remain a constraint in many regions, particularly in the tropics. New field installations, simulation exercises (Yasuda et al. 2013), and other research programs are currently beginning to provide valuable results (e.g., Thorpe et al. 2010; Neyland et al. 2012). At this time, organizations and forest managers may be (understandably) reluctant to take risks and accept uncertainties associated with trying out unfamiliar management approaches without being able to rely on extensive scientific literature and empirical results from field experiences. This is likely one of the major limitations for a more rapid spread of alternative silviculture.

Just as for forest managers, training opportunities are often lacking (or too expensive) for loggers to obtain information and experience with these new management systems. Successful logging operations require a workforce with a good understanding of the reasons for and basic principles behind different silvicultural treatments. Harvesting operators may also have limited access to innovative machinery and techniques suitable for partial harvesting operations that address small-scale variability in stand structure, are able to deal with a wider variety of species, tree sizes, and qualities, and are designed to protect retained trees (including natural regeneration and site and soil conditions).

Cultural and historical challenges

Schütz et al. (2012) wrote that “willingness” (defined as “readiness to do something” by Merriam-Webster 2014) is one of the main factors limiting the wider application of alternative management regimes. In addition to the reasons for the lack of “readiness” that have been discussed already, the role of strong intellectual, political, and administrative leadership is especially important in shaping public and professional opinions (Brukas and Weber 2009). The degree to which an organizational leadership champions alternative approaches influences the degree to which employees and contractors embrace and apply the practices. Strong support from upper management encourages employees and contractors to overcome operational challenges, as well as prejudices, enabling successful transition to alternative silviculture (Baker 2011). Other reasons may have a deeper, historical background. For example, the expansion of “scientific forestry” (*sensu* Oosthoek 2007; see also Lowood 1990), reflected in controlled management of homogenous, even-aged, mono-cultural plantations from central Europe at the end of the 19th century, was accepted in other countries because it fitted prominent economic ideas about control and efficiency (Lang and Pye 2001; Oosthoek 2007; Cock 2008; Puettmann et al. 2009; Sears and Pinedo-Vasquez 2011). This approach also helped to elevate forestry as an autonomous discipline at universities and research institutions, which facilitated its professional recognition by foresters and society in general. This historical development has led to several phenomena that are still influential today. The resulting expectation of simple, practical operational guidelines cannot easily be met by alternative silvicultural approaches, especially when they emphasize greater silvicultural flexibility (and outcomes) in a wide diversity of forest structures and species compositions. Moreover, the educational focus on conventional forestry has led to “imprinting” or “knowledge lock-in” in many practicing foresters who may consider only the predominant management model as acceptable. An example of this can be found in the management history of beech and black pine forests in the mountains of southern Italy, where selection felling based on traditional local knowledge and applied by private landowners during the last few centuries has been and often still is considered “irrational” by forest administrations and technicians (Ciancio et al. 2006; Nocentini 2009). Thus, the professional and public perceptions of alternative silvicultural approaches may have a major influence on the development of policies and implementation strategies (Brukas and Weber 2009).

Forest policies and practices can still be biased against continuous-forest-cover systems. For example, in Finland and Sweden, forest authorities and professionals have actively encouraged clearcut operations because selective cutting methods applied in the past led to political concerns that private forest owners were devastating their forests (Siiskonen 2007; Brukas and Weber 2009). In 1948, a group of influential Finnish researchers published a declaration against the destructive impacts of selective logging on Finland’s forests. Similarly, influential German forestry professors were successful in discrediting the “Dauerwald” (continuous-cover forests) efforts, mainly by stating concerns about the economic performance and management complexity (Pommerening and Murphy 2004). These arguments may exacerbate an existing lack of incentives or desire to switch to alternative silvicultural approaches, given that they are still brought up in current discussions of new laws and regulations.

The “search for simplicity” in silviculture is often also encouraged by staff shortages and overly complex, computerized desk-work environments, where foresters have to deal with multifarious and new, distracting aspects. The reluctance to try more complicated silvicultural prescriptions is also partly the result of highly visible failures of alternative silviculture experiences in some regions. For example, early partial-harvest trials in old-growth *Pseudotsuga menziesii* stands in the Pacific Northwest were pronounced a failure in the 1950s. As noted later by Curtis (1998), “partial cutting trials came to an abrupt end”, leading to “the consequent lack of research into alternatives to clearcutting”, which “severely handicaps current efforts to meet changing objectives and public concerns”. Similarly, “European” silvicultural systems and practices were initially implemented in Australia (and other places around the globe) without an adequate understanding of the ecological functioning of the local ecosystems (Florence 1996). For a long time, silvicultural alternatives were only applied on selected properties, which were viewed as "unique" and in some cases even belittled, making it harder for a broader set of professionals to associate themselves with these practices.

Decisions about management activities are typically the domain of landowners acting within their local ecological, social, and economic contexts. Thus, it is not enough to educate foresters and contractors; it is also necessary to convince private landowners and politicians who have decision power over public land use and policies that impact private landowners. The attitudes of these decision makers regarding alternative silvicultural regimes may be influenced by a variety of factors, including their knowledge and prioritization of desired ecosystem goods and services, as well as the anticipated revenue constraints due to size of the estate. For example, large public or investor-owned properties can afford to spatially separate the production of various forest products or ecosystem services over large areas. This allows them to homogenize portions of their forest holdings for the efficient production of selected forest products or services. In contrast, landholders who manage small and/or fragmented properties may need to obtain a variety of products from their property. In Finland, landowners with small forest land bases often obtain logs of different sizes for firewood or for construction wood and at the same time may harvest berries, mushrooms, and game (Siiskonen 2007). Similarly, in Latin America, campesinos (rural smallholders) may work under the logic of a diversified production to mitigate potential risks. For example, they collect firewood, produce charcoal, sell animals, and produce apple cider—activities that also generate income that may be complemented with off-farm income (Moorman et al. 2013). Alternative silvicultural regimes are typically more suitable in such settings where integrated land use is important because their emphasis on smaller spatial scales facilitates simultaneous production of various ecosystem goods and services (Hein et al. 2006).

The regional or national context also influences decisions about silvicultural approaches. For example, high human population densities may increase the importance of providing high-amenity recreational settings as an ecosystem service, leading to alternative silvicultural approaches that are more visually appealing (Rydberg and Falck 2000). Similarly, mountainous topographies may lead to an emphasis on protection from landslides, e.g., in Japan (Noguchi et al. 2011) and Italy (see discussion about safety above). On the other hand, a well-established and economic and politically powerful forest industry sector can influence the availability of wood processing facility and thus markets for forest products (Miller Klubock 2014). This may limit or bias market accessibility towards products (tree species, sizes, qualities) derived from industrial forest lands through conventional management, effectively reducing the value of a variety of products that could come from forests managed under alternative regimes (for example, see the above discussion about the impact of log sizes on wood value). A strong forest industry sector may also directly or indirectly influence the focus of educational and research themes according to their management interests (Benner and Sandström 2000).

A long history of forest management also means that private and public ownerships are organized and staffed to accommodate conventional approaches, making any transition more difficult. Furthermore, some of the challenges mentioned above may actually be legally embedded in forest policy and regulations. For example, well-intentioned reforestation regulations may specify acceptable tree species and required seedling densities, effectively limiting the choice of species and discouraging natural regeneration (for example, see the Oregon Forest Practices Act, Oregon Department of Forestry 2014). It should be acknowledged that not only environmental conditions, silvicultural options, and markets determine the implementation of alternative management methods, but traditions and stakeholders' views also affect ongoing political discourses (Arts et al. 2010).

Conclusions

In summary, the diversity of settings in which alternative silvicultural approaches are of interest reflects the diversity of challenges that limit their wider implementation. The range of arguments presented here suggests that ecological, economic, logistical and administrative, educational and informational, and cultural and historical challenges are all important. The relative importance of any of these challenges varies among and within geographical regions and ownerships. We suggest that these challenges can be addressed at two levels. At a lower level, each situation can be analyzed for the specific major challenges or limitations. Any such assessment of challenges benefits from viewing alternative regimes as a collection of silvicultural principles. Knowing which principle specifically is related to the major challenge in the situation at hand provides detailed insights that will facilitate discussion of whether that specific principle is necessary or can be modified or ignored, while still achieving overall management objectives. For example, foresters often will forgo natural regeneration if they foresee regeneration failures, and they will plant seedlings—even in close-to-nature forest operations. Having such detailed assessments will allow interested groups, for example landowners or politicians, to initiate efforts to implement policies, procedures, and/or incentives to help overcome these challenges. Examples could include new laws or regulations, subsidies, and scientific and educational efforts that are targeted to specific situations. Although this may be successful in individual settings, it may be an inefficient process for tackling overall problem areas.

At a broader level, our overview provides some general insights that suggest opportunities for more coordinated efforts. It appears obvious that in this context, efforts that allow foresters to take advantage of the widest possible array of silvicultural tools to accommodate a wide variety of local ecological, economic, and social conditions are especially useful. This would be facilitated by a more formal shift of alternative silvicultural approaches away from the focus on desired or acceptable stand structures, often defined as specific diameter distributions or other visual targets, such as photos or sketches of desired stand structures (Larsen and Nielsen 2007) (Figure 2). Instead, a more targeted focus on the suite of desired ecosystem goods and services will allow foresters to integrate a broader set of disturbances, stand dynamics, and successional trends into their management practices. Such a focus will allow more flexibility in the future and encourage practices to be "customized" to optimally fit specific ecological, economic, and social settings without the confining restrictions of labels.

For further progress, especially to overcome information deficits and educational, economic, cultural, and historical challenges, the spread of alternative management approaches would benefit greatly from the continued development of a scientific basis. This basis includes investigations of specific detailed ecological, social, economic, and ethical issues. In addition, developing a larger-scale scientific framework that provides more explicit linkages between basic scientific theories and principles and practical applications of alternative silvicultural approaches will also facilitate progress by allowing better coordination—including internationally—of research and educational activities. This will facilitate an understanding of the distinctions between idiosyncrasies and regularities. It also will help provide answers to questions such as whether experiences are unique to specific situations or how far experiences in one forest can be extrapolated into other settings—questions that were already at the heart of the Dauerwald discussions almost 100 years ago. Furthermore, an expanded scientific basis will be very helpful in developing a coherent and efficient educational and—maybe most important—outreach and policy agendas. Finally, great economic challenges remain for the creation of economic modeling approaches that are more biologically realistic and thus capture the ecological complexity of alternative silvicultural management approaches.

While not a formal review of all pertinent literature, the expertise represented by the authors covering a variety of regions and ecological and social settings allowed us to build a comprehensive framework to provide hypotheses and suggest opportunities to advance the implementation of alternative silvicultural regimes. However, we acknowledge that experiences in specific settings may differ or complement the ones provided by us. We hope that our arguments and such differences will provide the basis for further fruitful discussion.

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
KP initiated the work and coordinated the contributions from the co-authors. SW, SB, PD, LD, GA, BH, TK, YL, SN, FP, TY, and JB provided input into the analytical structure and contributed to writing and revising the manuscript. All authors read and approved the final manuscript.

Acknowledgements
This material is based upon work supported by the National Institute of Food and Agriculture, United States Department of Agriculture, McIntire-Stennis Funds under ID number OREZ-FES-850-P to the lead author and by the Edmund Hayes Professorship. PJ Donoso acknowledges the support from FONDECYT Grant No 1110744. Jürgen Bauhus received funding for this work from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 265171. The authors would like to acknowledge many colleagues, practitioners, and students for their contributions.

Author details
[1]Department of Forest Ecosystems and Society, Oregon State University, Corvallis, OR 97330, USA. [2]Consultant Forester and Forest Ecologist, 3 Thorngrove Crescent, Aberdeen, Scotland AB15 7FH, UK. [3]School of Biological Sciences, University of Tasmania, Private Bag 55, Hobart, TAS 7001, Australia. [4]Department of Forests and Society, Faculty of Forest Sciences and Natural Resources, Universidad Austral de Chile, Isla Teja s/n, Valdivia, Chile. [5]Southern Swedish Forest Research Centre, Swedish Agricultural University, PO Box 49, Alnarp SE-23053, Sweden. [6]Haramaya University, P. Box 138, Diredawa, Ethiopia. [7]Institut de recherche sur les forêts, Université du Québec en Abitibi-Témiscamingue, 445, Boulevard de l'Université, Rouyn--Noranda, Québec J9X 5E4, Canada. [8]Institute of Forest Management, TUM School of Life Sciences Weihenstephan, Technische Universität München, Hans-Carl-von-Carlowitz-Platz 2, Freising 85354, Germany. [9]Department of Forest Management and Statistics IFRIT, Chinese Academy of Forestry, Dongxiaofu 2, Xiangshan Road, Beijing, Haidian 100091, China. [10]Department of Agricultural, Food and Forestry Systems, University of Florence, v. S. Bonaventura 13, Florence I-50145, Italy. [11]Department of Biology, University of Florida, P.O. Box 118526, Gainesville, FL 32611-8526, USA. [12]Uryu Experimental Forest, Field Science Center for Northern Biosphere, Hokkaido University, Moshiri, Horokanai 074-0741, Japan. [13]Chair of Silviculture, Faculty of Environment and Natural Resources, University of Freiburg, Tennenbacherstr. 4, Freiburg 79085, Germany.

Received: 18 December 2014 Accepted: 18 March 2015
Published online: 09 April 2015

References
Amsalu DW, Jacobsen JB, Lundhede TH (2014) Economic assessment of use values of near-natural forestry compared with rotational forestry in Denmark. Eur J For Res 133(4):611–622

Arts B, Appelstrand M, Kleinschmit D, Pülzl H, Vissen-Hamakers I (2010) Discourses, actors and instruments in international forest governance. IUFRO World Ser 28:57–73

Attiwill PM (1994) The disturbance of forest ecosystems - the ecological basis for conservative management. Forest Ecol Manag 63:247–300

Aubry KA, Halpern CB, Peterson CE (2009) Variable-retention harvests in the Pacific Northwest: a review of short-term findings from the DEMO study. Forest Ecol Manag 258:398–408

Axelsson EP, Lundmark T, Högberg P, Nordin A (2014) Belowground competition directs spatial patterns of seedling growth in boreal pine forests in Fennoscandia. Forests 5(9):2106–2121
Bacardit P (2014) Evaluación del daño provocado por cortas de selección sobre los árboles residuales en un bosque del Tipo Forestal Siempreverde en Llancahue, provincia de Valdivia. Undergraduate Thesis, Faculty of Forest Sciences and Natural Resources, Universidad Austral de Chile, Valdivia, Chile
Baker SC (2011) Seeking a Balance Between Forestry and Biodiversity – The Role of Variable Retention Silviculture. Insights from Western USA and Canada. FWPA Project Report PG D167–0910. FWPA, Melbourne, p 60
Baker SC, Read SM (2011) Variable retention silviculture in Tasmania's wet forests: ecological rationale, adaptive management and synthesis of biodiversity benefits. Austral For 74:218–232
Barbeito I, Pardos M, Calama R, Cañellas I (2008) Effect of stand structure on Stone pine (*Pinus pinea* L.) regeneration dynamics. Forestry 81:617–629
Bauhus J, Schmerbeck J (2010) Silvicultural Options to Enhance and Use Forest Plantation Biodiversity. In: Bauhus J, van der Meer P, Kanninen M (eds) Ecosystem Goods and Services from Plantation Forests. Earthscan, London, pp 96–139
Bauhus J, Puettmann KJ, Kühne C (2013) Close-to-nature forest management in Europe: does it support complexity and adaptability of forest ecosystems? In: Messier C, Puettmann KJ, Coates KD (eds) Managing forests as complex adaptive systems: building resilience to the challenge of global change. Routledge, New York, pp 187–213
Bebi P, Kulakowski D, Rixen C (2009) Snow avalanche disturbances in forest ecosystems—state of research and implications for management. Forest Ecol Manag 257(9):1883–1892
Benner M, Sandström U (2000) Institutionalizing the triple helix: research funding and norms in the academic system. Res Policy 29:291–301
Bergeron Y, Leduc A, Harvey B, Gauthier S (2002) Natural fire regime: a guide for sustainable forest management of the Canadian boreal forest. Silva Fennica 36:81–95
Berkes F, Colding J, Folke C (2000) Rediscovery of traditional ecological knowledge as adaptive management. Ecol Appl 10:1251–1262
Biolley H (1901) Le jardinage cultural. J Forestier Suisse 52:67–104
Bladon KD, Silins U, Landhäusser SM, Lieffers VJ (2006) Differential transpiration by three boreal tree species in response to increased evaporative demand after variable retention harvesting. Ag For Meteorol 138:104–119
Bliss JC (2000) Public perceptions of clearcutting. J Forestry 98:4–9
Bose AK, Harvey BD, Brais S, Beaudet M, Leduc A (2014) Constraints to partial cutting in the boreal forest of Canada in the context of natural disturbance-based management: a review. Forestry 87(1):11–28
Brang P, Spathelf P, Larsen JB, Bauhus J, Boncina A, Chauvin C, Drössler L, Garcia-Guemes C, Heiri C, Kerr G, Lexer MJ, Mason B, Mohren F, Mühlethaler U, Nocentini S, Svoboda M (2014) Suitability of close-to-nature silviculture for adapting temperate European forests to climate change. Forestry 87(4):492–503, doi:10.1093/forestry/cpu018
Brukas V, Weber N (2009) Forest management after the economic transition—at the crossroads between German and Scandinavian traditions. For Pol Econ 11:586–592
Brunson MW, Steel BS (1994) National public attitudes toward federal rangeland management. Rangelands 16:77–81
Butler BJ, Leatherberry EC (2004) America's family forest owners. J Forestry 102:4–14
Calama R, Barbeito I, Pardos M, del Rio M, Montero G (2008) Adapting a model for even-aged *Pinus pinea* L. stands to complex multi-aged structures. Forest Ecol Manag 256:1390–1399
Cameron A (2002) Importance of early selective thinning in the development of long-term stand stability and improved log quality: a review. Forestry 75(1):25–35
Castagneyrol B, Jactel H, Vacher C, Brockerhoff EG, Koricheva J (2014) Effects of plant phylogenetic diversity on herbivory depend on herbivore specialization. J Appl Ecol 51(1):134–141
Chang SJ (1981) Determination of the optimal growing stock and cutting cycle for an uneven-aged stand. Forest Sci 27:739–744
Ciancio O, Nocentini S (2011) Biodiversity conservation and systemic silviculture: concepts and applications. Plant Biosyst 145:411–418
Ciancio O, Cutini A, Mercurio R, Veracini A (1986) Sulla struttura della pineta di pino domestico di Alberese. Annali dell'Istituto Sperimentale della Selvicoltura, Arezzo, p 17
Ciancio O, Iovino F, Menguzzato G, Nicolaci A, Nocentini S (2006) Structure and growth of a small group selection forest of Calabrian pine in Southern Italy: a hypothesis for continuous cover forestry based on traditional silviculture. Forest Ecol Manag 224:229–234
Cock AR (2008) Tropical forests in the global states system. Int Aff 84(2):315–333
Cubbage F, MacDonagh P, Sawinski J Jr, Rubilar R, Donoso PJ, Ferreira A, Hoeflich V, Morales V, Ferreira G, Balmelli G, Jacek Siry M, Báez N, Alvarez J (2007) Timber investment returns for selected plantations and native forests in South America and the Southern United States. New For 33(3):237–255
Curtis RO (1998) "Selective cutting" in Douglas-fir - History revisited. J Forestry 96:40–46
Daniel TC (2001) Whither scenic beauty? Visual landscape quality assessment in the 21st century. Landsc Urban Planning 54:267–281
Dhakal AS, Sidle RC (2003) Long-term modelling of landslides for different forest management practices. Earth Surf Proc Land 28:853–868
Dodson EK, Burton JI, Puettmann KJ (2014) Multi-scale controls on natural regeneration dynamics after partial overstory removal in Douglas-fir forests in western Oregon, USA. Forest Sci 60(5):953–961
Donoso PJ, Nyland RD (2005) Seeding density according to structure, dominance and understory cover in old-growth forest stands of the evergreen forest type in the coastal range of Chile. 2005. Rev Chil Hist Nat 78(1):51–63
Donoso PJ, Promis A (2013) Silvicultura en Bosques Nativos. Avances en la investigación en Chile, Argentina y Nueva Zelandia. Estudios en Silvicultura de Bosques Nativos, Vol. 1. Ed. Marisa Cuneo, Valdivia, Chile. p 253. https://sites.google.com/site/alvaropromis/Home/libro-silvicultura-bosques-nativos.
Drever CR, Peterson G, Messier C, Bergeron Y, Flannigan M (2006) Can forest management based on natural disturbances maintain ecological resilience? Can J For Res 36:2285–2299
Drössler L, Nilsson U, Lundqvist L (2013) Simulated transformation of even-aged Norway spruce stands to multi-layered forests: an experiment to explore the potential of tree size differentiation. Forestry 87(2):239–248, doi:10.1093/forestry/cpt037
Duncker PS, Barreiro SM, Hengeveld GM, Lind T, Mason WL, Ambrozy S, Spiecker H (2012) Classification of forest management approaches: a new conceptual framework and its applicability to European forestry. Ecol Soc 17(4):51, http://dx.doi.org/10.5751/ES-05262-170451
Dvorák L, Bachmann P, Mandallaz D (2001) Sturmschäden in ungleichförmigen Beständen. Schweiz Zeitschr Forstw 152:445–452
Evans Z (2006) What is ecological forestry?. http://www.forestguild.org/ecological_forestry/Ecological_Forestry_evans_06.pdf. Accessed 10 November 2014
FAO (Food and Agriculture Organization of the United Nations) (2010) Global forest resources assessment 2010. Food and Agriculture Organization of the United Nations, Rome
Fedrowitz K, Koricheva J, Baker DC, Lindenmayer DB, Palik B, Rosenvald R, Beese W, Franklin JF, Kouki J, Macdonald E (2014) Can retention forestry help conserve biodiversity? A meta-analysis. J Appl Ecol 51(6):1669–1679, doi:10.1111/1365-2664.12289
Filotas E, Parrott L, Burton PJ, Chazdon RL, Coates KD, Coll L, Haeussler S, Martin K, Nocentini S, Puettmann KJ, Putz FE, Simard SW, Messier C (2014) Viewing forests through the lens of complex systems science. Ecosphere 5:1, http://dx.doi.org/10.1890/ES13-00182.1
Fitzgerald SA, Oester PT, Parker R (2013) Individual tree selection (ITS) in a northeast Oregon mixed conifer forest. Extension Service, Oregon State University, Corvallis, OR, USA
Florence RG (1996) Ecology and silviculture of eucalypt forests. CSIRO, Melbourne, p 400
Franklin JF, Forman TT (1987) Creating landscape patterns by forest cutting: ecological consequences and principles. Landscape Ecol 1:5–18
Franklin JF, Johnson KN (2012) A restoration framework for federal forests in the Pacific Northwest. J Forestry 110:429–439
Franklin JF, Mitchell RJ, Palik BJ (2007) Natural disturbance and stand development principles for ecological forestry, General Technical Report NRS-19. United States Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, PA
Gayer K (1886) Der gemischte Wald, seine Begründung und Pflege, insbesondere durch Horst-und Gruppenwirtschaft. Parey Verlag, Berlin
Griess VC, Knoke T (2011) Can native tree species plantations in Panama compete with Teak plantations? An economic estimation. New For 41:13–39
Griess VC, Acevedo R, Härtl F, Staupendahl K, Knoke T (2012) Does mixing tree species enhance stand resistance against natural hazards? A case study for spruce. Forest Ecol Manag 267:284–296
Gurnaud A (1882) Le controle et le regime forestier. Rev Eaux For 21:1–23

Gustafsson L, Kouki J, Sverdrup-Thygeson A (2010) Tree retention as a conservation measure in clear-cut forests of northern Europe: a review of ecological consequences. Scand J For Res 25:295–308

Gustafsson L, Baker SC, Bauhus J, Beese WJ, Brodie A, Kouki J, Lindenmayer DB, Lõhmus A, Martínez Pastur G, Messier C, Neyland M, Palik B, Sverdrup-Thygeson A, Volney WJA, Wayne A, Franklin JF (2012) Retention forestry to maintain multifunctional forests: a world perspective. Bioscience 62:633–645

Haight R (1987) Evaluating the efficiency of even-aged and uneven-aged stand management. Forest Sci 33:116–134

Haight RG, Monserud RA (1990) Optimizing any-aged management of mixed-species stands: II. Effects of decision criteria. Forest Sci 36:125–144

Hanewinkel M (2002) Comparative economic investigations of uneven-aged and uneven-aged silvicultural systems: a critical analysis of different methods. Forestry 75:473–481

Hanewinkel M, Kuhn T, Bugmann H, Lanz A, Brang P (2014) Vulnerability of uneven-aged forests to storm damage. Forestry 87:525–534, doi:10.1093/forestry/cpu008

Harlow RF, Downing R, Van Lear D (1997) Responses of wildlife to clearcutting and associated treatments in the Eastern United States, Technical Paper no. 19. Department of Forest Resources Clemson University, Clemson, SC

Hein L, van Koppen K, De Groot RS, van Ierland EC (2006) Spatial scales, stakeholders and the valuation of ecosystem services. Ecol Econ 57(2):209–228

Hibbs DE, Bower AL (2001) Riparian forests in the Oregon Coast Range. Forest Ecol Manag 154:201–213

Higgs E, Falk DA, Guerrini A, Hall M, Harris J, Hobbs RJ, Jackson ST, Rhemtulla JM, Throop W (2014) The changing role of history in restoration ecology. Front Ecol Environ 12:499–506

Hugosson M, Ingemarson F (2004) Objectives and motivations of small-scale forest owners; theoretical modelling and qualitative assessment. Silva Fennica 38:217–231

Hyvaerinen E, Kouki J, Martikainen P (2006) Fire and green-tree retention in conservation of red-listed and rare deadwood-dependent beetles in Finnish boreal forests. Conserv Biol 20:1710–1719

Hyytiäinen K, Haight RG (2010) Evaluation of forest management systems under risk of wildfire. European J Forest Res 129:909–919

Jacobsen MK (2001) History and principles of close to nature forest management: a central European perspective. Naconex 3:56–58

Jacobsen JB, Thorsen BJ (2003) A Danish example of optimal thinning strategies in mixed-species forest under changing growth conditions caused by climate change. Forest Ecol Manag 180(1):375–388

Jones TA, Thomas SC (2004) The time course of diameter increment responses to selection harvests in *Acer saccharum*. Can J For Res 34:1525–1533

Kimmins H (1992) Balancing act: environmental issues in forestry. UBC Press, Vancouver, BC

Kneeshaw D, Williams H, Nikinmaa E, Messier C (2002) Patterns of above- and below-ground responses of understory conifer release 6 years after partial cutting. Can J For Res 32:255–265

Knoke T (2012) The economics of continuous cover forestry. In: Pukkala T, Gadow Kv (eds) Continuous cover forestry. Managing forest ecosystems Vol. 23, pp 167–193. doi:10.1007/978-94-007-2202-6_5

Knoke T, Huth A (2011) Modelling forest growth and finance: Often disregarded tools in tropical land management. In: Günter S, Weber M, Stimm B, Mosandl R (eds) Silviculture in the tropics Tropical Forestry 8, part 3, pp 129–142. doi:10.1007/978-3-642-19986-8_11. Springer Verlag, Heidelberg.

Knoke T, Wurm J (2006) Mixed forests and a flexible harvest policy: a problem for conventional risk analysis? Eur J For Res 125(3):303–315

Knoke T, Moog M, Plusczyk N (2001) On the effect of volatile stumpage prices on the economic attractiveness of a silvicultural transformation strategy. Forest Pol Econ 2(3):229–240

Kohm KA, Franklin JF (1997) Creating a forestry for the 21st century: the science of ecosystem management. Island Press, Washington, DC

Kouki J, Hyvarinen E, Lappalainen H, Martikainen P, Simila M (2012) Landscape context affects the success of habitat restoration: large-scale colonization patterns of saproxylic and fire-associated species in boreal forests. Divers Distrib 18:348–355

Kuuluvainen T (2009) Forest management and biodiversity conservation based on natural ecosystem dynamics in northern Europe: the complexity challenge. AMBIO 38:309–315

Lang C, Pye O (2001) Blinded by science: the invention of scientific forestry and its influence in the Mekong Region. Watershed 6:25–34

Larsen JB, Nielsen AB (2007) Nature-based forest management—where are we going?: laborating forest development types in and with practice. Forest Ecol Manag 238:107–117

Lindenmayer DB, Franklin JF, Lõhmus A, Baker SC, Bauhus J, Beese W, Brodie A, Kiehl B, Kouki J, Pastur GM, Messier C, Neyland M, Palik B, Sverdrup-Thygeson A, Volney J, Wayne A, Gustafsson L (2012) A major shift to the retention approach for forestry can help resolve some global forest sustainability issues. Conserv Lett 5:421–431

Little C, Lara A, McPhee J, Urrutia R (2009) Revealing the impact of forest exotic plantations on water yield in large scale watersheds in South-Central Chile. J Hydrol 374:162–170

Long JN (2009) Emulating natural disturbance regimes as a basis for forest management: a North American view. Forest Ecol Manag 257:1868–1873

Lowood HE (1990) The calculating forester: quantification, cameral science, and the emergence of scientific forestry management in Germany. In: Frängsmyr T, Heilbron JL, Rider RE (eds) The quantifying spirit in the eighteenth century. University of California Press, Berkeley, http://ark.cdlib.org/ark:/13030/ft6d5nb455/

Lu Y, Liu X, Lei X, Wang H, Hong L, Guo H (2013) Development of silvicultural models for multi-functional forest management: the systematic consideration and application in experiment center of tropical forestry, Southwestern China. In: Fehrmann L, Kleinn C (eds) Forests in climate change research and police: the role of forest management and conservation in a complex international setting. Proceedings of the 3rd International DAAD workshop. Cuvillier Verlag Goettingen, Germany.

Lüpke B, Hauskeller-Bullerjahn M (1999) Kahlschlagfreier Waldbau: wird die Eiche an den Rand gedrängt? Forst und Holz 54:363–368

Lutz JA, Halpern CB (2006) Tree mortality during early forest development: a long-term study of rates, causes, and consequences. Ecol Monogr 76:257–275

Macdonald E, Gardiner B, Mason W (2010) The effects of transformation of even-aged stands to continuous cover forestry on conifer log quality and wood properties in the UK. Forestry 83:1–16

Manolis JC, Andersen DE, Cuthbert FJ (2000) Patterns in clearcut edge and fragmentation effect studies in northern hardwood-conifer landscapes: retrospective power analysis and Minnesota results. Wildlife Soc B 28:1088–1101

Marten GG (2005) Environmental tipping points: a new paradigm for restoring ecological security. J Policy Studies 20:75–87

Mason B, Kerr G, Pommerening A, Edwards C, Hale S, Ireland D, Moore R (2003) Continuous cover forestry in British conifer forests. Forest Res Annu Rep Acc 2004:38–53

Matlack GR, Gleeson SK, Good RE (1993) Treefall in a mixed oak-pine coastal plain forest: immediate and historical causation. Ecology 82:1559–1566

Menzies NK (2007) Our forests, your ecosystem, their timber. Communities, conservation and the state in community-based forest management. Columbia University Press, New York

Merriam-Webster (2014) Merriam Webster Dictionary. http://www.merriam-webster.com/. Accessed 1 May 2014

Messier C, Puettmann KJ, Coates D (2013) Managing forests as complex adaptive systems: building resilience to the challenge of global change. Routledge, New York

Miller Klubock T (2014) La Frontera: forests and ecological conflicts in Chile's frontier territory. Duke University Press, Durham, NC

Möller A (1923) Der Dauerwaldgedanke. Erich Degreif Verlag, Oberteuringen

Moorman M, Nelson S, Moore S, Donoso P (2013) Stakeholder perspectives on adaptive co-management as a Chilean conservation management strategy. Soc Natur Resour 26:1022–1036

Nahuelhual L, Donoso PJ, Lara A, Núñez D, Oyarzún C, Neira E (2007) Valuing ecosystem services of Chilean temperate rainforests. Environ Dev Sustainabil 9:481–499

Nasi R, Putz FE, Pacheco P, Wunder S, Anta S (2011) Sustainable forest management and carbon in tropical Latin America: the case for REDD+. Forests 2:200–217

Neumann FG, Minko G (1981) The sirex wood wasp in Australian radiata pine plantations. Aust For 44:46–63

Neuner S, Albrecht A, Cullmann D, Engels F, Griess VC, Hahn A, Hanewinkel M, Härtl F, Kölling C, Staupendahl K, Knoke T (2015) Survival of Norway spruce remains higher in mixed stands under a dryer and warmer climate. Global Change Biol 21:935–946

Newton M, Cole EC (2006) Harvesting impacts on understory regeneration in two-storied Douglas-fir stands. West J Appl For 21:14–18

Neyland M, Hickey J, Read SM (2012) A synthesis of outcomes from the Warra Silvicultural Systems Trial, Tasmania, Australia: safety, timber production, economics, biodiversity, silviculture and social acceptability. Aust For 75:147–162
Niklitschek ME (2007) Trade liberalization and land use changes: explaining the expansion of afforested land in Chile. Forest Sci 53(3):385–394
Nill M, Kohnle U, Sauter U (2011) Rindenschäden mit mutmaßlichem Bezug zur Holzernte im Spiegel der Betriebsinventuren in Baden-Württemberg. Forstarchiv 9(6):216–224
Nilsson M-C, Wardle DA (2005) Understory vegetation as a forest ecosystem driver: evidence from the northern Swedish boreal forest. Front Ecol Environ 3:421–428
Ninemets Ü, Valladares F (2006) Tolerance to shade, drought, and waterlogging of temperate Northern Hemisphere trees and shrubs. Ecol Monogr 76:521–547
Nocentini S (2009) Structure and management of beech (*Fagus sylvatica* L.) forests in Italy. iForest 2:105–113, http://www.sisef.it/iforest/show.php?id=499
Noguchi M, Yoshida T (2004) Tree regeneration in partially cut conifer-hardwood mixed forests in northern Japan: roles of establishment substrate and dwarf bamboo. Forest Ecol Manag 190:335–344
Noguchi M, Okuda S, Miyamoto K, Itou T, Inagaki Y (2011) Composition, size structure and local variation of naturally regenerated broadleaved tree species in Hinoki cypress plantations: a case study in Shikoku, south-western Japan. Forestry 84:493–504
O'Hara KL, Ramage BS (2013) Silviculture in an uncertain world: utilizing multi-aged management systems to integrate disturbance. Forestry 86:401–410
Oosthoek J (2007) The colonial origins of scientific forestry in Britain. Essay in: Environmental History Resources. http://www.eh-resources.org/colonial_forestry.html. Accessed 22 February 2015.
Oregon Department of Forestry (2014) Oregon forest practices act. http://www.oregon.gov/ODF/privateforests/pages/fpareforestation.aspx. Accessed 1 May 2014
Paquet J, Bélanger L (1997) Public acceptability thresholds of clearcutting to maintain visual quality of boreal balsam fir landscapes. Forest Sci 43:46–55
Paquette A, Messier C (2009) The role of plantations in managing the world's forests in the Anthropocene. Front Ecol Environ 8:27–34
Pausch R (2005) Ein System-Ansatz zur Darstellung des Zusammenhangs zwischen Waldstruktur, Arbeitsvolumen und Kosten in naturnahen Wäldern Bayerns. Forstliche Forschungsberichte München 199
Piispanen R, Heinonen J, Valkonen S, Mäkinen H, Lundqvist S-O, Saranpää P (2014) Wood density of Norway spruce in uneven-aged stands. Can J For Res 44(2):136–144
Pommerening A, Murphy S (2004) A review of the history, definitions and methods of continuous cover forestry with special attention to afforestation and restocking. Forestry 77:27–44
ProSilva Europe (2014) ProSilva Europe: integrated forest management for resilience and sustainability across 25 countries. http://prosilvaeurope.wordpress.com. Accessed 13 August 2014
Puettmann KJ (2011) Silvicultural challenges and options in the context of global change: simple fixes and opportunities for new management approaches. J Forestry 109:321–331
Puettmann KJ, Ammer C (2006) Trends in North American and European regeneration research under the ecosystem management paradigm. Eur J For Res 126:1–9
Puettmann KJ, Ek AR (1999) Status and trends of silvicultural practices in Minnesota. North J Appl For 16:203–210
Puettmann KJ, Coates KD, Messier C (2009) A critique of silviculture: managing for complexity. Island Press, Washington, DC
Pukkala T, Lähde E, Laiho S (2010) Optimizing the structure and management of une-ven-sized stands of Finland. Forestry 83:129–142
Putz F, Sist P, Fredericksen T, Dykstra D (2008) Reduced-impact logging: challenges and opportunities. Forest Ecol Manag 256:1427–1433
Reich RM, Mielke PW Jr, Hawksworth FG (1991) Spatial analysis of ponderosa pine trees infected with dwarf mistletoe. Can J For Res 21:1808–1815
Ribe RG (1989) The aesthetics of forestry: what has empirical preference research taught us? Environ Manage 13:55–74
Ribe RG (1999) Regeneration harvests versus clearcuts: public views of the acceptability and aesthetics of Northwest Forest Plan harvests. Northw Sci 73:102–117
Ribe RG (2005) Aesthetic perceptions of green-tree retention harvests in vista views: the interaction of cut level, retention pattern and harvest shape. Landscape Urban Plan 73:277–293
Rice B, Weiskittel A, Wagner R (2014) Efficiency of alternative forest inventory methods in partially harvested stands. Eur J For Res 133:261–272
Roessiger J, Griess VC, Härtl F, Clasen C, Knoke T (2013) How economic performance of a stand increases due to decreased failure risk associated with the admixing of species. Ecol Model 255:58–69
Rosenvald R, Lohmus A (2008) For what, when, and where is green-tree retention better than clear-cutting? A review of the biodiversity aspects. Forest Ecol Manag 255:1–15
Rydberg D, Falck J (2000) Urban forestry in Sweden from a silvicultural perspective: a review. Landscape Urban Plan 47:1–18
Schaetzl RJ, Johnson DL, Burns SF, Small TW (1989) Tree uprooting: review of terminology, process, and environmental implications. Can J For Res 19:1–11
Schelhaas M, Nabuurs GJ, Schuck A (2003) Natural disturbances in the European forests in the 19th and 20th centuries. Glob Change Biol 9:1620–1633
Schoennagel T, Veblen TT, Romme WH (2004) The interaction of fire, fuels, and climate across Rocky Mountain forests. BioScience 54:661–676
Schütz J-P (1999a) Naturnaher Waldbau: gestern, heute, morgen. Schw Z Forstwes 150:1–12
Schütz J-P (1999b) Principles of functioning of mixtures in forests stands; experience of temperate central European forest conditions. In: Olsthoorn AFM, Bartelink HH, Gardiner JJ, Pretzsch H, Hekhuis HJ, Franc A (eds) Management of mixed-species forest; silviculture and economics, IBN Scientific Contribution 15. Inst. For Forestry and Nature Research, Wageningen, pp 219–234
Schütz J-P (2002) Silvicultural tools to develop irregular and diverse forest structures. Forestry 75:329–337
Schütz J-P, Pukkala T, Donoso PJ, von Gadow K (2012) Historical emergence and current application of CCF. In: Pukkala T, von Gadow K (eds) Continuous cover forestry. Springer Verlag, Dordrecht, Heidelberg, p 6
Sears RR, Pinedo-Vasquez M (2011) Forest policy reform and the organization of logging in Peruvian Amazonia. Dev Change 42:609–631
Seymour RS, Hunter ML (1999) Principles of ecological forestry. In: Hunter ML (ed) Maintaining biodiversity in forest ecosystems. Cambridge University Press, Cambridge, pp 499–524
Shaw DC, Chen J, Freeman EA, Braun DM (2005) Spatial and population characteristics of dwarf mistletoe infected trees in an old-growth Douglas-fir – western hemlock forest. Can J For Res 35:990–1001
Shorohova E, Kuuluvainen T, Kangur A, Jogiste K (2009) Natural stand structures, disturbance regimes and successional dynamics in the Eurasian boreal forests: a review with special reference to Russian studies. Ann For Sci 66:201
Siiskonen H (2007) The conflict between traditional and scientific forest management in 20th century Finland. Forest Ecol Manag 249:125–133, doi:10.1016/j.foreco.2007.03.018
Steventon JD, MacKenzie KL, Mahon TE (1998) Response of small mammals and birds to partial cutting and clearcutting in northwest British Columbia. Forest Chron 74(5):703–713
Swank W, Vose J, Elliott K (2001) Long-term hydrologic and water quality responses following commercial clearcutting of mixed hardwoods on a southern Appalachian catchment. Forest Ecol Manag 143:163–178
Swanson ME, Franklin JF, Beschta RL, Crisafulli CM, DellaSala DA, Hutto RL, Lindenmayer DB, Swanson FJ (2011) The forgotten stage of forest succession: early-successional ecosystems on forest sites. Front Ecol Environ 9:117–125
Tahvonen O, Pukkala T, Laiho O, Lähde E, Niinimäki S (2010) Optimal management of uneven-aged Norway spruce stands. Forest Ecol Manag 260:106–115
Thorpe HC, Astrup R, Trowbridge A, Coates KD (2010) Competition and tree crowns: a neighborhood analysis of three boreal tree species. Forest Ecol Manag 259:1586–1596
Tönnes S, Karjalainen E, Löfström I, Neuvonen M (2004) Scenic impacts of retention trees in clear-cutting areas. Scand J For Res 19:348–357
Tropical Forest Foundation (2008) Sustaining tropical forests with reduced impact logging. http://www.tff-indonesia.org/index.php/en/r-i-l/ril-criteria-and-indicators. Accessed 14 April 2015
Urquhart J, Courtney P (2011) Seeing the owner behind the trees: a typology of small-scale private woodland owners in England. Forest Policy Econ 13:535–544
Veblen TT (1985) Forest development in tree-fall gaps in the temperate rain forests of Chile. Natl Geogr Res 1:162–183
Veblen TT, Donoso ZC, Schlegel FM, Escobar RB (1981) Forest dynamics in south-central Chile. J Biogeogr 8:211–247
von Thünen JH (1842) Der isolierte Staat in Beziehung auf Landwirtschaft und Nationalökonomie, 2nd edn. Leopold, Rostock, Germany
Wagner S, Nocentini S, Huth F, Hoogstra-Klein M (2014) Forest management approaches for coping with the uncertainty of climate change: trade-offs in service provisioning and adaptability. Ecol Soc 19(1):32

West PW (2014) Growing plantation forests. Springer, Dordrecht, Heidelberg, London, New York
Wilson SMG (2013) Adoption of alternative silvicultural systems in Great Britain: a review. Q J Forest 100:279–293
Wunder S (2006) Are direct payments for environmental services spelling doom for sustainable forest management in the tropics. Ecol Soc 11:23
Yasuda A, Yoshida T, Miya H, Harvey BD (2013) An alternative management regime of selection cutting for sustaining stand structure of mixed forests of northern Japan: a simulation study. J For Res 18:398–406
Yoshida T, Noguchi M, Akibayashi Y, Noda M, Kadomatsu M, Sasa K (2006) Twenty years of community dynamics in a mixed conifer broad-leaved forest under a selection system in northern Japan. Can J For Res 36:1363–1375