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Retention Forestry to Maintain Multifunctional Forests: A World Perspective

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The majority of the world's forests are used for multiple purposes, which often include the potentially conflicting goals of timber production and biodiversity conservation. A scientifically validated management approach that can reduce such conflicts is retention forestry, an approach modeled on natural processes, which emerged in the last 25 years as an alternative to clearcutting. A portion of the original stand is left unlogged to maintain the continuity of structural and compositional diversity. We detail retention forestry's ecological role, review its current practices, and summarize the large research base on the subject. Retention forestry is applicable to all forest biomes, complements conservation in reserves, and represents bottom-up conservation through forest manager involvement. A research challenge is to identify thresholds for retention amounts to achieve desired outcomes. We define key issues for future development and link retention forestry with land-zoning allocation at various scales, expanding its uses to forest restoration and the management of uneven-age forests.

Keywords: biodiversity, ecology, conservation, forestry

Forests cover approximately 30% of the world's land surface; harbor most of the global terrestrial biodiversity; and provide critical ecosystem services, such as climate regulation and protection of soil and water resources (FAO 2010). The different and often contradictory societal expectations for forests have led to many conflicts over their use (Freer-Smith and Carnus 2008). In many parts of the world, this has resulted in allocating forest areas either to conservation or to fiber production in intensively managed plantations. However, forest reserves and plantations currently constitute only about 11% and less than 4% of the world's forest area, respectively (Del Lungo et al. 2006, FAO 2010). Although the proportions of both plantations and reserves are likely to increase (Bauhus et al. 2010), most of the global forest estate will continue to play a multifunctional role, in which attempts are made to balance human commodity needs with the production of other goods and services (Thompson et al. 2011), including the habitat needs of forest-dependent organisms (Lindenmayer and Franklin 2002). More than 2 billion hectares of the world's forests (around 55% of all forest area) are managed as production forests or used to extract multiple values (FAO 2010). Most private and public forest owners will need to manage forests to supply ecosystem services simultaneously with the production of revenue from forest products to help pay for that management.

One of the most controversial issues in the management of multifunctional forests around the world has been the simplification of forest structure and composition as a part of intensive wood production (Puettmann et al. 2009). The type and intensity of disturbances that occur under industrial forestry can deviate dramatically from those of natural disturbance processes (Lindenmayer and Franklin 2002). In fact, the traditional industrial approach to forest management is very much akin to a conventional agricultural model, in which simplification is the goal (Smith et al. 1997). The resulting lack of complexity in managed stands and across forest landscapes feeds back through ecosystem processes and carries high risks of reducing several key environmental services (e.g., Thompson et al. 2011).

A new forest-management model—retention forestry—was introduced in northwestern North America about

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25 years ago as a response to the rapid ongoing transformation and simplification of forests and to the need to better integrate wood production and biodiversity (Franklin 1989). Retention forestry spread rapidly and was adapted to conditions in various regions of the world. Retention forestry (or the *retention approach*—terms used interchangeably in this article) has until recently largely been used as a replacement for clearcutting, but the concept of structural retention as a part of management is increasingly incorporated into other silvicultural systems, such as selection systems widely applied in tropical and temperate forests (Nyland 2002, Mitchell RJ et al. 2006, Sheil et al. 2010).

One revolutionary aspect of this new way of planning, managing, and harvesting forests is the primary focus on the type and quantity of forest structures that are left behind, which contrasts with the traditional silvicultural focus on what is being harvested (Franklin et al. 1997). Retention forestry is highly adaptable, with great variation in application, including the pattern and amount of retention, which reflects differences in the management objectives and forest types, as well as in the social and policy context. However, the basic requirement of retention forestry is the provision for continuity in structural, functional, and compositional elements from the preharvest to the postharvest forest. Today, there is extensive practical experience with the retention approach all over the world. Large-scale research initiatives have been undertaken on several continents to evaluate its effectiveness in achieving multifunctional goals, especially those related to biodiversity conservation.

Here, we present a global overview of the evolving practice of retention forestry and summarize the ecological principles and theories that underpin the approach. In particular, we emphasize its foundation in emulating natural disturbance patterns and processes, which makes retention forestry generally applicable to different forest types and management goals and distinguishes it from traditional forestry models. We provide a summary of the current scientific knowledge base, including several large-scale experiments designed to evaluate ecological responses. Using examples from boreal, temperate, and tropical regions, we illustrate how the retention approach is currently practiced and how it relates to land-tenure and -policy frameworks. Important factors driving the large variation in practices are discussed, including landscape contexts and forest history. We also highlight the role of retention forestry in forest preservation, as well as in restoration, and reflect on how the wide range in quantity of retained forest structures may affect ecological outcomes. Finally, we discuss future prospects in a world in which there will be increasing demands for the ecosystem services derived from forests.

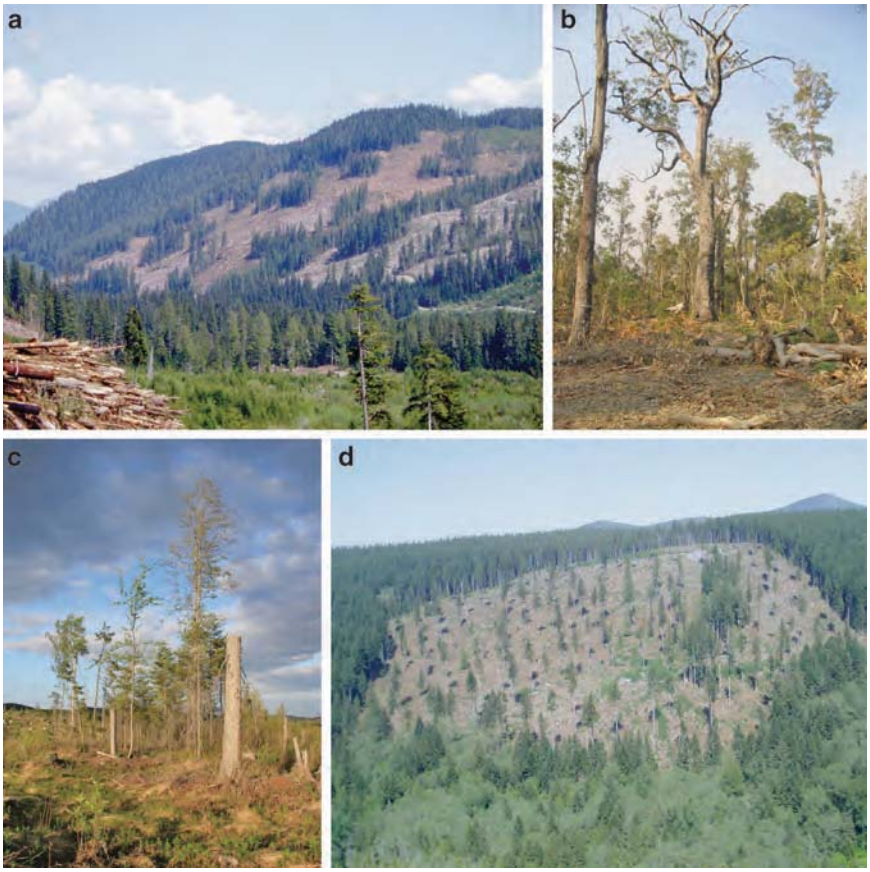

Figure 1. Photos illustrating retention forestry in different parts of the world. The common feature is a long-term and planned retention of biological legacies, including dispersed and aggregated trees, over forest generations with the aim of maintaining biodiversity and ecosystem functions. The levels and designs of this approach, which has been practiced for more than 20 years, differ considerably depending on ecological conditions, policy settings, and social contexts. (a) Group retention in coastal British Columbia, Canada. Photograph: William J. Beese. (b) Tree and habitat retention in a gap release treatment in Jarrah Forest, Western Australia. Photograph: Deirdre Maher. (c) Small aggregate and created dead wood in boreal Sweden. Photograph: Lena Gustafsson. (d) Dispersed retention in Washington State. Photograph: Cassandra Koerner.

Definition and objectives of the retention approach

The unifying feature of retention forestry is that during harvest, important structures and organisms are intentionally retained on site for the long term (figure 1). Maintenance of some structures and organisms from the preharvest forest ecosystem has several specific objectives, including (a) maintaining and enhancing the supply of ecosystem services and the provisioning of biodiversity (e.g., MA 2005); (b) increasing public acceptance of forest harvesting and the options for future forest use (e.g., McDermott et al. 2010); (c) enriching the structure and composition of the postharvest forest (e.g., Franklin et al. 1997); (d) achieving temporal and spatial continuity of key habitat elements and processes, including those needed by both early- and late-successional specialist species (e.g., Bauhus et al. 2009, Gustafsson et al. 2010); (e) maintaining connectivity in the managed forest landscape (e.g., Kouki et al. 2001); (f) minimizing the off-site impacts of harvesting, such as on aquatic systems (e.g., Clinton 2011); and (g) improving the aesthetics of harvested forests (e.g., Shelby et al. 2005).

A wide array of terminology is associated with retention forestry. *Variable retention* is extensively used for practices in North America, Latin America, and Australia. Current applications use the terms *aggregated* or *group retention* and *dispersed retention* to indicate different spatial distributions of retained structures. Retention forestry is intimately linked to the concept of *biological legacies* (*sensu* Franklin et al. 2000), which refers to preharvest structures, such as dead and living trees, but also to species from different taxonomic groups, and emphasizes the importance of a continuous supply of such resources over forest generations. We define *retention forestry* as an approach to forest management based on the long-term retention of structures and organisms, such as live and dead trees and small areas of intact forest, at the time of harvest. The aim is to achieve a level of continuity in forest structure, composition, and complexity that promotes biodiversity and sustains ecological functions at different spatial scales. Approaches and levels of retention, which take account of natural disturbance dynamics, differ depending on local context, but the practice is justified for all types of silvicultural systems and forests.

The necessary area or volume to retain within stands will vary with and should be adapted to local conditions, but we suggest 5%–10% as a strict minimum, and considerably more is often likely to be needed to achieve the desired ecological objectives. In addition, retention should be well distributed across the landscape to facilitate the dispersal of organisms.

Ecological foundation and role

Sound forest management relies on ecological principles and theories (Puettmann et al. 2009). Especially relevant to retention forestry are the concepts of *niche*, *disturbance*, *diversity–stability relationships*, and *resilience* (table 1). These are intimately linked to the structural and compositional diversity of forests. In terms of biodiversity, *island-biogeography theory* and later developments of the principles of *metapopulation dynamics* additionally highlight the importance of habitat area and proximity to recolonization sources, which retention forestry enhances, in contrast to clearcut harvesting.

The retention approach has emerged from the recognition that even intense natural disturbances leave biological legacies and spatial heterogeneity in the new forest, which contrasts with the simple and homogeneous environment that is often the outcome of traditional harvesting practices, particularly clearcutting (Franklin et al. 2000). Although large-scale disturbances (e.g., fire, wind, extensive pest outbreaks) in intact forest landscapes kill trees and modify ecosystem functioning, many biological legacies, such as standing dead trees; downed tree boles; and live mature and regenerating trees, plants, fungi, and animals, persist from the predisturbance forest. Biological legacies are also functionally important in forest landscapes characterized by small gap-phase disturbances and long-term continuity in the tree layer. Therefore, lessons from natural disturbances can be applied to a multitude of forest ecosystems, regardless of the scale and intensity of their disturbance regimes (Puettmann et al. 2009).

Retention forestry prescriptions can vary in a multitude of ways with large variations in the types, amounts, and spatial distribution of retained trees and intact forest patches to achieve different ecological outcomes (figure 2). The primary goal is to provide continuity in ecosystem structure, function, and composition between forest generations. Legacies, such as large old trees and dead trees, are structural elements that take a long time to develop and are therefore otherwise generally rare in

Table 1. Some important ecological concepts and theories of relevance to retention forestry.

Concepts and theories	Link to retention forestry
Niche (Elton 1927)	Each species occupies an ecological zone or habitat within which it can outcompete other species; retention recognizes this by providing a rich diversity of habitats within the postharvest stand.
Disturbance (Picket and White 1985)	Disturbance is an integrated and important component of ecosystem dynamics. Retention forestry creates disturbance, and in emulating natural disturbance patterns, it sustains biodiversity and ecosystem processes.
Diversity–stability (Ives and Carpenter 2007)	Studies demonstrate positive diversity–stability relationships, although they are complex and remain to be better understood. In the face of uncertainty, the safest policy is to maintain as much diversity as possible, which is the philosophy behind the retention approach.
Resilience (Holling 1973)	Fundamental to the concept of resilience is that changes in ecological processes at one scale can affect processes at other scales. Retention forestry acts at the stand level, complementing conservation actions at higher scale levels.
Island biogeography (MacArthur and Wilson 1967)	The theory predicts that species number increases with the size of habitat and with increasing proximity to dispersal sources. Retaining structures at harvest increases the area of suitable habitats as well as their distribution at the landscape level and thus enhances diversity.

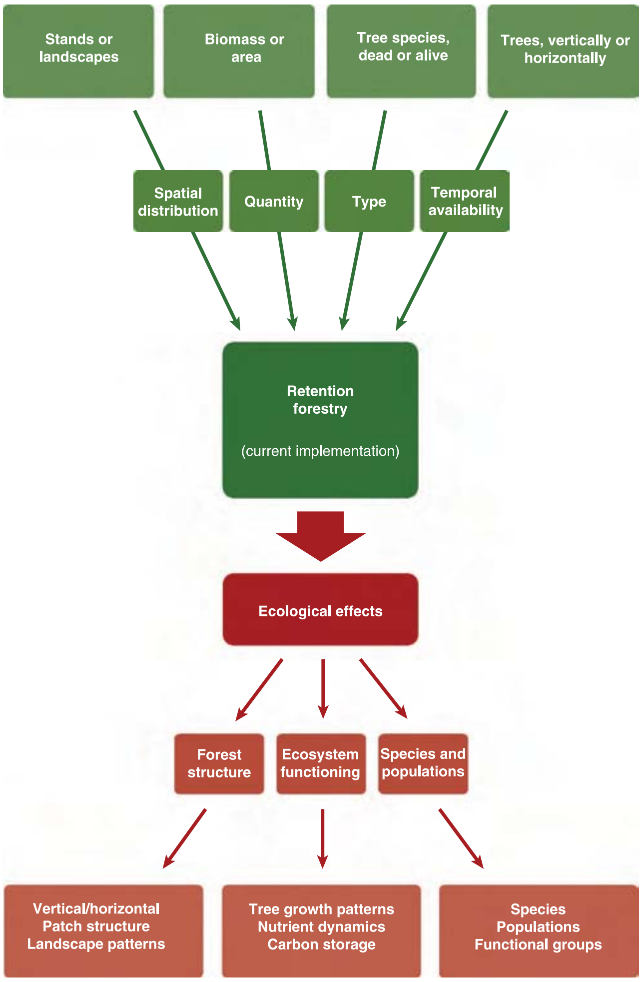

Figure 2. A main element in retention forestry is the retention of trees and forest patches at the time of logging to maintain continuity in structural diversity while at the same time permitting an economic return. Retention forestry practices in managed forest ecosystems may vary in the amount of retention, the type of retention, and the spatial and temporal availability of the retained trees (the upper part of the figure). Retained forest elements have a multitude of ecological effects (the lower part of the figure), but the magnitude and significance of these effects are determined by the details of the implementation. The figure was drawn by Berrit Kiehl (berrit.kiehl@allmacs.de).

intensively managed forests, where trees are comparatively young when they reach maturity for economic purposes and are cut. For species and populations, the retention approach facilitates the maintenance of habitat for epiphytic plants, wood-inhabiting insects and fungi, and many other organisms (for reviews, see Rosenvald and Lõhmus 2008, Gustafsson et al. 2010). Thus, retention provides a "lifeboat" for species through the regeneration phase of forest development. By improving the connectivity of habitats within the managed landscape, the recolonization and dispersal of organisms are enhanced in the harvested compartments (e.g., Chan-McLeod and Moy 2007). The maintenance of ecosystem function is another fundamental role of the retention approach. For instance, key structural legacies and small forest patches can be important for retaining carbon, nutrients, and moisture on sites after disturbance; may improve regeneration by reducing the effects of extreme climatic events; and are important for sustaining soil organisms and mycorrhizal fungi (e.g., Martikainen et al. 2006, Outerbridge and Trofymow 2009, Siira-Pietikäinen and Haimi 2009).

Origin and development

Adjustment of the prevailing regeneration harvesting practices through the retention of biological legacies from the preceding stands began 20–30 years ago in boreal and temperate regions throughout the world but most prominently in North America. The approach has spread rapidly and retention forestry is implemented in all major biomes today.

Boreal and temperate regions. Retention forestry originated in the Pacific Northwest (northwest United States, southwest Canada) in the 1980s, promoted under the terms *new forestry* and *green-tree retention*. The Clayoquot Scientific Panel introduced the term *variable retention* and was instrumental in raising the profile of the approach in this region. Private forestry companies instituted retention forestry practices to address marketplace demands. By the end of the 1990s, retention forestry was an established practice in this region and was specified in policy or regulations (e.g., in California, Oregon, and Washington in the United states and in British Columbia in Canada). The concept found its way to the eastern United States and the rest of Canada by the early 1990s and was beginning to be studied and applied formally by the late 1990s. In Canada's prairie provinces (Alberta, Saskatchewan, Manitoba) and the province of Quebec, the Sustainable Forest Management Network led efforts to develop practices emulating natural disturbances.

The retention approach spread to Chile and Argentina in the late 1990s when forestry companies in Tierra del Fuego utilized expertise from northwestern North America to implement an ecological forestry approach in *Nothofagus* forests.

In Australia, various states required explicit habitat provisions for wildlife during timber harvest by the 1970s, and since that time, the levels of retention required within harvested forests have increased. For example, application of retention harvesting has recently expanded in Tasmania, although it has been used only experimentally in the state of Victoria.

Sweden, Finland, and Norway were the first European countries to introduce the retention approach. During the 1980s and 1990s, legislation and forest-management guidelines in all three countries were revised to incorporate environmental concerns into harvest operations. In the three Baltic states, the retention approach was mainly adopted from Sweden, Finland, and Norway, developing from the late 1990s and onward. In Germany, where clearcutting is now uncommon and selection and shelterwood systems prevail, the deliberate retention of old and habitat trees and dead wood is a recent phenomenon that began to be formally applied in public forests about 10 years ago.

Tropics. The prevailing sustainable harvesting method in natural tropical forests is selective logging, and new approaches designed as a result of increased environmental concern have been developed during the last few decades under the term *reduced impact logging* (RIL) and sometimes *low-impact logging.* So far, the main focus of RIL has been on maintaining growing stock and securing tree regeneration and on soil and water quality (Putz et al. 2008). Although the proportion of tropical production forests under sustainable management is estimated to be less than 10% (Blaser et al. 2011), RIL is today an established and well-known concept in tropical forestry in Africa, Asia, and America. The emphasis on incorporating biodiversity concerns is increasing, including the retention of biological legacies as a part of harvesting operations (Meijaard et al. 2005, Dykstra 2012), and examples of such practices are accumulating (Sheil et al. 2010).

Current application

The extent to which retention forestry is practiced differs substantially between and within countries (see supplemental table S1, available online at *http://dx.doi.org/10.1525/bio.2012.62.7.6*). It is applied in harvest operations on all forestland in countries such as Finland, Norway, and Sweden. Examples of countries and regions embracing this approach on more than 50% of their forestland include the Baltic states; Germany; and the Canadian provinces of Alberta, British Columbia, and Ontario. In the United States, it is applied to varying degrees on all federal lands and on a variety of land ownerships in the eastern United States. In Latin America, retention forestry is so far formally practiced by only a few forestry companies in southern Argentina. All Australian states have some wildlife-management rules, and there are requirements for retaining habitat trees in different forest types across the country.

Retention levels and arrangement. Retention levels, in terms of the area or wood volume retained, can range more than fortyfold, varying from sometimes as low as 1%–3% of the harvested volume in Finland to more than 30% in some state forests in Tasmania (see table S1) and more than 40% in forests managed by some First Nations (the governments of Canadian indigenous peoples) on Vancouver Island, British Columbia, in Canada. Differences are also large within regions; for instance, in Alberta, retention levels may vary between 1% and 15%. There is a tendency to retain higher amounts in the western United States, in western Canada, and in parts of Australia than in Europe, the eastern United States, and eastern Canada. Spatial design can take almost any form, from evenly distributed individual trees to patches of intact forest of diverse shapes and sizes; dispersed and aggregated retention are often applied together in a harvest unit (figure 1). The most common expressions of retention level are the number of trees and the aboveground timber volume per hectare in the case of dispersed retention or the percentage of the harvest area in the case of aggregates. Specific requirements for trees to be retained often include the minimum diameter and tree species preferences.

In some regions, guidelines about the proximity of harvested areas to retained structures or patches are employed. This is done to ensure that the retained forest elements are well distributed in the harvest unit to serve as a source population for recolonization and to ameliorate microclimatic conditions (e.g., Mitchell SJ and Beese 2002, Baker and Read 2011).

Although retention forestry in the strict sense has not yet been applied in tropical forests, there are examples of retention components within RIL in Malaysia and Ecuador (Blaser et al. 2011) and in Cameroon (Ezzine de Blas and Pérez 2008). Examples of retention actions to promote biodiversity include some timber concessions in Indonesian Borneo, in which wildlife corridors, food trees, and nesting trees are demarcated and saved. In the Republic of the Congo, there are also attempts to retain habitats of importance to large mammals such as gorillas and chimpanzees in some forest operations (figure 3, table 2).

Links to land tenure. In some regions, individual forestry companies have often taken a lead role in instigating, developing, and tailoring the retention approach. For instance, MacMillan Bloedel was a pioneer in British Columbia, Canada, and Stora Skog AB was in Sweden. Current examples of forestry companies with a strong commitment to this approach are Western Forest Products in British Columbia and Daishowa Marubeni International in Alberta, Canada. Together, these companies manage more than 5 million hectares of forestland using this approach (figure 3, table 2). State and federal forest agencies have also been important in the development and implementation of retention forestry, as on public lands in the states of Washington, Minnesota, and Wisconsin in the United States and in Western Australia, New South Wales, and Tasmania in Australia. Similar prescriptions and retention models are applied on all productive forestland, irrespective of ownership in Finland, Norway, Sweden, the Baltic states, and Germany.

Policy instruments. Third-party certification, which is intended to provide credible evidence of sustainable forest management (McDermott et al. 2010), has been a strong driver in the adoption of retention forestry. Forest certification standards often require the use of retention approaches in their evaluations of sustainability. Examples include the Forest Stewardship Council (FSC) and the Program for the Endorsement of Forest Certification (PEFC). FSC certification has been particularly important in encouraging the

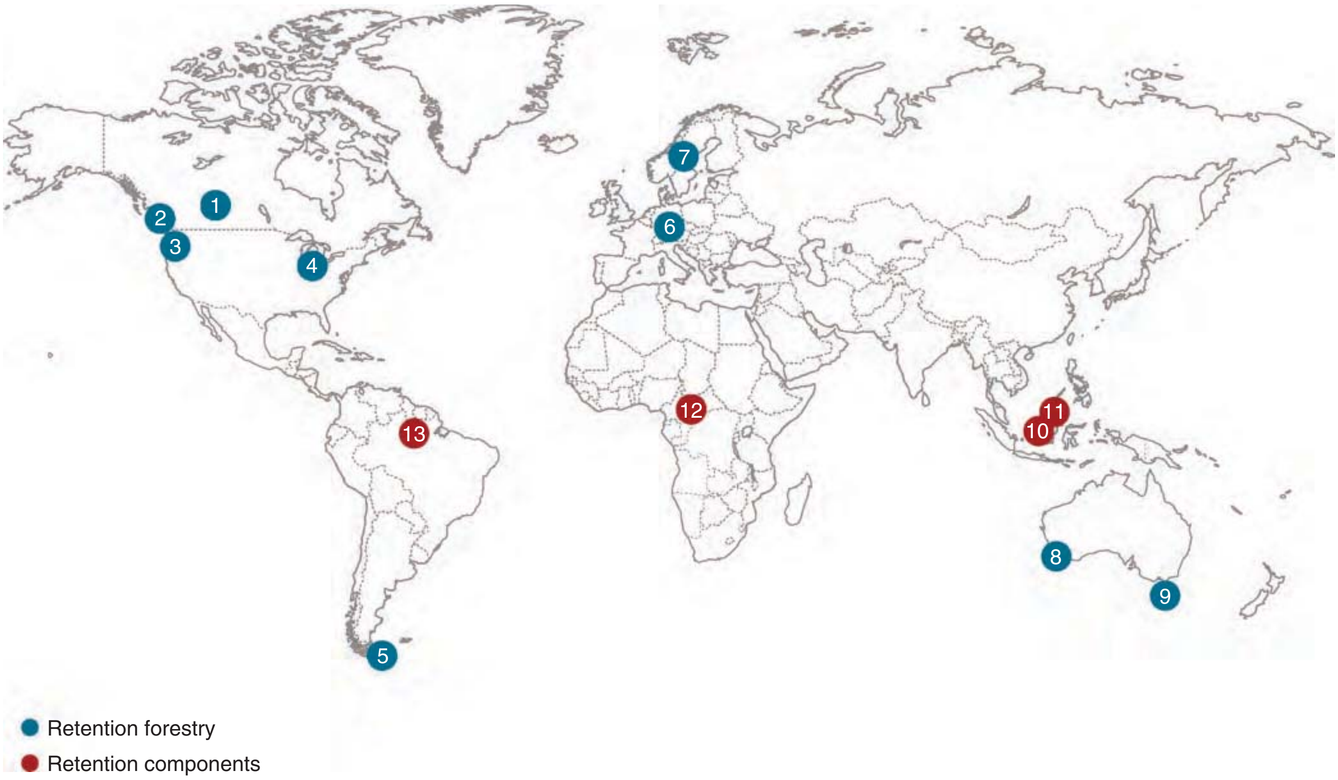

Figure 3. Examples of how the retention approach is applied in different forest biomes of the world, selected to show the flexibility toward scale level, logging system, land tenure, and policy framework. Full implementation of retention forestry is presently confined to temperate and boreal regions (the blue dots), whereas components of the retention approach can be found in the tropics (the red dots)—for instance, in efforts toward reduced impact logging. More information is given in table 2 and in supplemental table S2 (available online at http://dx.doi.org/10.1525/bio.2012.62.7.6*). The figure was drawn by Berrit Kiehl (berrit.kiehl@allmacs.de).*

incorporation of biodiversity considerations in tropical logging (Sheil et al. 2010). More than 80% of certified tropical forests are large tracts that are managed by the private sector (ITTO 2008).

Legal policy instruments are also important for the adoption of retention harvesting and include legislation at the national or state level (e.g., the 2005 Forestry Act in Norway and its amendments), contractual agreements between government entities (e.g., the Tasmanian Community Forest Agreement), and state forest-practice rules (e.g., in many US states, in the provinces of Ontario and British Columbia in Canada, and in Germany). There are no current examples of retention forestry involving government subsidies, so the loss of revenue from the retention of potential harvestable trees is carried by the forest owner or the contractor conducting harvests. However, in some countries, such as Germany and Finland, private forest owners may be compensated for their conservation efforts through contractual agreements. Nevertheless, there might be economic incentives for landowners, since higher prices are sometimes offered for certified timber, and it can also provide access to markets that demand responsibly produced forest products (Auld et al. 2008).

Research on retention harvesting

Many of the ecological principles that underpin retention practices have been validated in the extensive research that has been conducted on the retention approach and its ecological effects during the past 20 years. Two reviews summarize ecological responses: Rosenvald and Lõhmus (2008) on green-tree retention in Europe and North America and Gustafsson and colleagues (2010) on both living and dead trees in northern Europe. Different levels and patterns of retention are being investigated in several large, replicated long-term experiments; numerous taxa and structural and biophysical variables are being considered in these studies (figure 4, table 3). Two of these experiments have been summarized: Aubrey and colleagues (2009) described the DEMO (Demonstration of Ecosystem Management Options) experiment in Washington and Oregon, and Baker and Read (2011) described the Warra silviculture systems trial experiment in Tasmania, Australia.

More aboveground species are maintained, at least in the short term, in stands with retained structures than in stands that are cut using conventional methods (Work et al. 2003, Hyvärinen et al. 2005, Atwell et al. 2008, Aubry et al. 2009). Retention has been shown to be particularly successful for epiphytic lichens and small ground-dwelling animals

Table 2. Examples of application of retention forestry and incorporation of retention components shown in figure 3.

Example	Geographical location
1. Daishowa Marubeni International forestry company	Alberta, Canada
2. Western Forest Products	Coastal British Columbia, Canada
3. State trust lands	Washington State, USA
4. State of Minnesota	Minnesota, USA
5. Kareken sawmill (PRODIN S.R.L)	Tierra del Fuego, Argentina
6. State forest	Baden-Württemberg, Germany
7. All private and public forestland	Sweden
8. State forest	Western Australia
9. State forest	Tasmania, Australia
10. Deramakot Commercial Forest Reserve (state owned)	Sabah, Malaysia
11. High conservation values within Forest Stewardship Council certification, Alas Kusuma Group and Suka Jaya Makmur	Kalimantan, Indonesia
12. Buffer Zone Project	Republic of the Congo
13. Precious woods	Amazonas, Brazil

Note: More information is given in supplemental table S2 (available online at *http://dx.doi.org/10.1525/bio.2012.62.7.6*).

(Rosenvald and Lõhmus 2008). A similar effect has been observed belowground—for example, for soil fauna (e.g., Martikainen et al. 2006, Siira-Pietikäinen and Haimi 2009) and ectomycorrhiza (Outerbridge and Trofymow 2009). Studies have shown, however, that the ability to maintain species on site (the lifeboat function) does vary with the type, level, and pattern of retention (e.g., Aubry et al. 2009). Higher retention levels increase habitat suitability for many species and also promote structural diversity (Work et al. 2003, Hyvärinen et al. 2005, Aubry et al. 2009). Some highly sensitive or area-demanding species may have requirements that cannot be met at the scale of harvesting and retention units, which emphasizes the need to integrate site-level conservation planning with larger reserves in the managed landscape.

The spatial arrangement of retention has been found to affect the ability of a site to sustain forest properties and functions. In some studies, aggregates have been found to have advantages over dispersed trees for maintaining much—but not all—biodiversity (e.g., Baker and Read 2011). The important role of structural retention in maintaining source populations for species recolonization of nearby harvested areas has been demonstrated (e.g., Huggard and Vyse 2002, Tabor et al. 2007); however, edge effects may limit this capability for some highly sensitive forest species (Aubry et al. 2009).

Many but not all natural structures and their associated organisms may be maintained through retention, according to studies in forest ecosystems in which retention harvesting was compared with natural disturbances (e.g., Hutto 2006). For example, retention patches have been found to have somewhat different species composition than patches that have been spared by natural disturbances (e.g., unburned patches found in otherwise burned areas; Gandhi et al. 2001, Martikainen et al. 2006).

Important considerations for current and future application

Although retention forestry is an established practice in many countries, it is still in its infancy as a silvicultural system. For future application, it will be important to learn from best practices but also to critically evaluate and improve designs applied in different parts of the world. Retention forestry also needs to be incorporated into larger contexts and combined with other land uses in planning processes tailored to local and regional conditions.

Retention forestry and land zoning. The partitioning between the three main forest-use categories of reserves, multifunctional forests, and plantations is a broadscale planning issue that warrants increased attention in the future. Zoning models may be one future approach to apply in boreal and temperate forest landscapes and attempts are emerging, such as the TRIAD approach (Hunter and Calhoun 1996). In this model, intensified forestry on a small portion of the land is compensated for by increasing the area set aside for conservation and by implementing ecosystem management that includes retention forestry (Messier et al. 2009). The efficiency in implementation of such instruments is likely to be strongly linked to land tenure, with a larger probability of success in publicly owned lands for which the decision processes are comparatively easy than in lands with diverse ownerships and small land holdings (Ranius and Roberge 2011). Parallels can be drawn to conventional agricultural land use, which is currently intensively debated, especially in the tropics (e.g., Phalan et al. 2011). Studies in agricultural systems point in different directions regarding the efficiency of zoning models, embracing the different categories of high-intensity agriculture, wildlife-friendly agriculture (the equivalent of retention forestry), and land for conservation (Ewers et al. 2009).

The importance of landscape context and spatial scales. The traditional approach to biodiversity conservation has been to protect relatively large areas with a minimum of human intervention, and the forest area designated for conservation has increased steadily over time (FAO 2010). Retention forestry, in contrast, is a stand-level conservation approach, and trees and forest patches left unharvested can be considered *set-asides*, although at a much more local spatial scale than large reserves and national parks. The biological legacies at the level of the harvest unit or stand resemble the structures in forests subjected to natural disturbance dynamics at a similar spatial scale. Tree retention may lead to faster ecological recovery of logged and regenerating areas

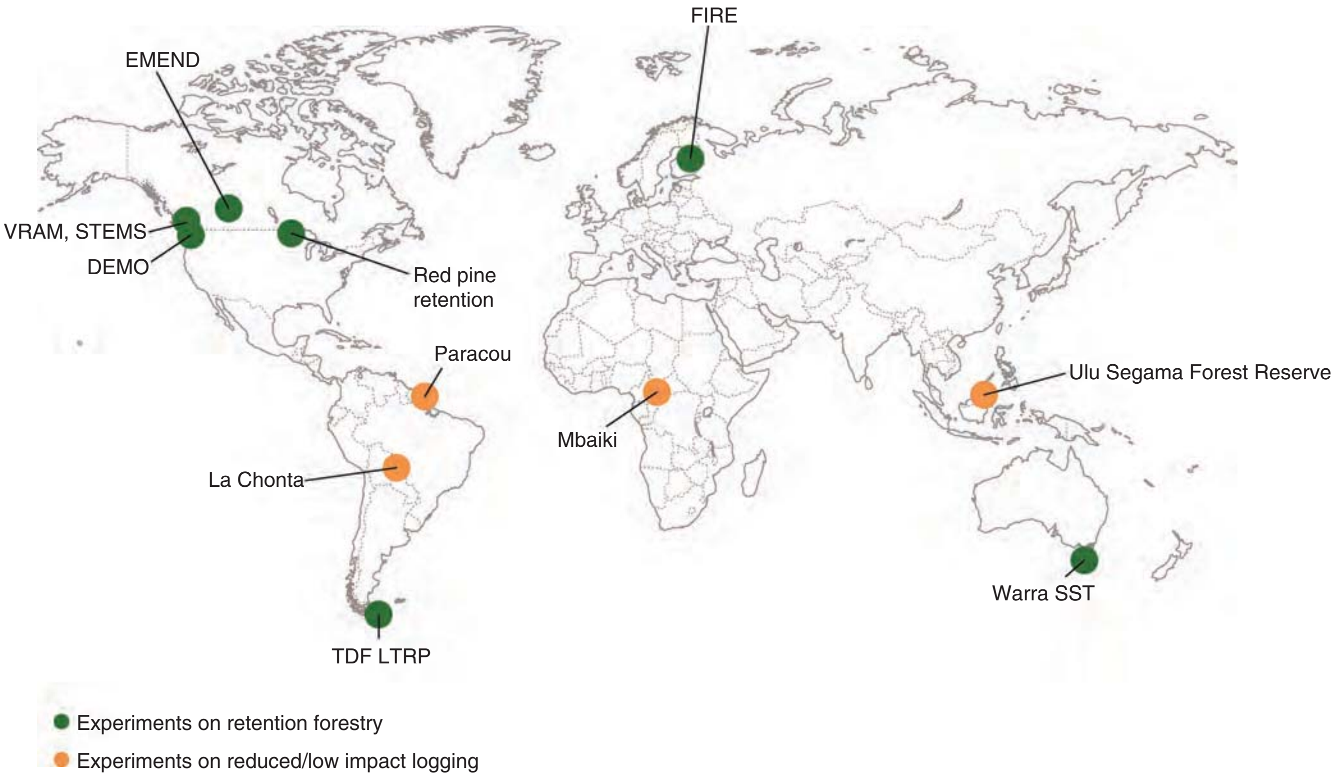

Figure 4. Large research experiments on retention forestry (boreal and temperate regions, green dots), and reduced impact logging or low-impact logging experiments (tropics, orange dots). The experiments in boreal and temperate regions have been set up to study ecological responses, including biodiversity, tree regeneration, and yield, and effects on biogeochemistry and microclimate. They include treatments that vary regarding retention levels or spatial pattern. The experiments in the tropics are mostly directed toward effects on tree regeneration, growth, carbon stocks, and damage to stands and soils, but biodiversity is also studied. Treatments vary regarding the numbers of trees harvested per hectare and their diameters, preharvest treatment such as liana cutting, and logging methods (e.g., winching, directional felling). More information is given in table 3 and supplemental table S3 (available online at **http://dx.doi.org/10.1525/bio.2012.62.7.6*****). Abbreviations: DEMO, Demonstration of Ecosystem Management Options; EMEND, Ecosystem Management Emulating Natural Disturbance; SST, silviculture systems trial; STEMS, Silviculture Treatments for Ecosystem Management in the Sayward; TDF LTRP, Tierra del Fuego Long Term Research Plots; VRAM, Variable Retention Adaptive Management. FIRE (http://joyx.joensuu.fi/~jkouki/project_fire.htm) is a large-scale experimental facility for exploring fire and harvest effects on forest biodiversity and succession, created by Jari Kouki of the University of Eastern Finland, in Joensuu, and his research team. The figure was drawn by Berrit Kiehl (berrit.kiehl@allmacs.de).***

through the spread and colonization of species from retained aggregates (e.g., Huggard and Vyse 2002). One of the largest benefits, which is unique to the stand level, is the large spatial coverage. Species composition varies over the landscape, and some species are confined to certain areas. By retaining patches within every harvest unit, the biological legacies and mature forest fragments important to many species will be spread over the entire landscape. Compared with the establishment of a few large reserves restricted to parts of the landscape, the probability of capturing the whole or at least a large part of the species pool will be higher.

The optimal allocation of conservation areas among various scales is not a trivial exercise, since the amounts, individual sizes, shapes, and spatial locations of reserves may vary substantially, which creates complex causal relationships. Ecological science has addressed the question of how large reserves should be and how many reserves are needed to conserve biodiversity since the formulation of the theory of island biogeography (MacArthur and Wilson 1967), but a clear answer has yet to emerge. Conservation actions at different scale levels have different ecological functions that complement each other, and it is also clear that the retention approach can never replace the need for large reserves. There are species (e.g., the woodland caribou in the boreal forest of Canada; Schneider et al. 2010) and ecological processes (e.g., fire regimes; Lindenmayer et al. 2011) that depend on extensive and continuous reserves.

In the future, new planning instruments are needed to identify optimal mixes of conservation areas of different sizes, like retention patches, small set-asides and large reserves, as well as their spatial configuration. The ideal partitioning of such types will vary strongly with the goal

Table 3. Large research experiments on retention forestry (boreal and temperate regions), and reduced impact logging or low-impact logging experiments (tropics) shown in figure 4.

Experiment	Country or state	Biome	Factors investigated (selection)
DEMO (Demonstration of Ecosystem Management Options)	Washington and Oregon, USA	Temperate	Vegetation, mycorrhizal fungi, physical environment, public perception
EMEND (Ecosystem Management Emulating Natural Disturbance)	Alberta, Canada	Boreal	Vertebrates, arthropods, biogeochemical cycling, socioeconomics
FIRE[a]	Finland	Boreal	Living or dead trees, bryophytes, soil fauna, small mammals
La Chonta	Bolivia	Tropical	Tree regeneration, recovery of mahogany (*Swietenia macrophylla*)
Mbaïki	Central African Republic	Tropical	Carbon stock, flora diversity
Paracou	French Guyana	Tropical	Carbon stock, functional traits (understory, seedling morphology, seed mass)
Red pine retention	Minnesota, USA	Temperate	Vascular plants, songbirds, disease, productivity
STEMS (Silviculture Treatments for Ecosystem Management in the Sayward)	British Columbia, Canada	Temperate	Forest growth, soil processes, tree damage, wind damage
TDF LTRP (Tierra del Fuego Long Term Research Plots)	South Patagonia, Argentina	Temperate	Regeneration, microclimate, nitrogen cycling, biodiversity
Ulu Segama	Sabah, Malaysia	Tropical	Trees, palms, vine biomass, soil disturbance
VRAM (Variable Retention Adaptive Management)	British Columbia, Canada	Temperate	Forest structure, growth and regeneration, birds, wind damage
Warra silviculture systems trial	Tasmania, Australia	Temperate	Plants, forest regeneration, insects, economics, social acceptability

Note: More information is given in supplemental table S3 (available online at *http://dx.doi.org/10.1525/bio.2012.62.7.6*).

[a] FIRE (*http://joyx.joensuu.fi/~jkouki/project_fire.htm*) is a large-scale experimental facility for exploring fire and harvest effects on forest biodiversity and succession, created by Jari Kouki of the University of Eastern Finland, in Joensuu, and his research team.

for the conservation area network (e.g., the type of biodiversity being targeted). For instance, if the aim is to promote species dependent on continuous areas of old growth (e.g., three-toed woodpecker in boreal regions; Imbeau and Desrochers 2002), high connectivity will be essential, which implies that retention may best be used to connect larger patches. However, if the aim is to preserve flora and fauna connected to the often transient open habitats created by disturbance events (e.g., rare fire-associated dead-wood beetle fauna; Kouki et al. 2012), a dispersed pattern can be very efficient to reach these goals. This is no small matter, since open habitats with legacies created through natural disturbances often have the highest levels of biodiversity of any type of forested landscapes (e.g., Swanson et al. 2011).

Some researchers have proposed that management interventions for conservation have their greatest relative effects in landscapes with intermediate amounts of remaining natural vegetation (Pardini et al. 2010), whereas others suggest that they have more pronounced effects in structurally simple landscapes (Kleijn et al. 2011). Our overview from different parts of the world suggests that retention forestry has benefits in landscapes with widely varying land-use histories. In heavily transformed landscapes with small amounts of structurally diverse forest remaining, such as parts of northern Europe, it is unlikely that restoration through retention will enable the recovery of all specialist species adapted to natural forest conditions, because the dispersal distances from source populations may be too large (Kouki et al. 2012). Retention, however, may be a way to increase population sizes and to increase the possibilities of long-term survival. However, in landscapes with large amounts of high-quality forest remaining, such as in some parts of boreal North America, retention forestry may safeguard almost all of the flora and fauna associated with intact forest landscapes.

Retention as a restoration tool. Retention forestry is a way to conserve the structural, functional, and compositional diversity of forest ecosystems for the future in settings in which complex and diverse forests are being harvested for the first time, as is often the case in Canada, Tasmania, and Argentina. However, the retention approach is also an excellent tool for the restoration of impoverished or degraded forest ecosystems. Examples include parts of northern Europe and the eastern and southern United States, where intensive forestry over centuries has depleted biological legacies and where there are few trees more than 100 years old. In such areas, even if the retained trees are comparatively young, long-term retention will contribute to more structurally diverse landscapes with a successive increase in the number of old trees and tree-derived structures. One restoration example is the conversion from plantations of common pine species (e.g., *Pinus elliottii* Engelm.) to the biologically very rich but rare forests of longleaf pine (*Pinus palustris* Miller) in the southeastern United States (Kirkman et al. 2007). By leaving some mature plantation pine trees at harvest, hardwood regeneration that otherwise hampers the establishment of longleaf pine seedlings is prevented, and fuel for subsequent prescribed fires is also provided. Another example is the creation of dead wood by the deliberate cutting of stumps several meters above the ground, as is implemented in Sweden (figure 1c) with documented positive effects (e.g., on beetles; Gustafsson et al. 2010). Actions to promote dead wood are less necessary in primary landscapes on other continents where this substrate is still abundant and needs only to be retained and supplemented by the periodic death of retention trees, not artificially created through management practices.

Amount of retention. It is very likely that there are retention amounts below which the survival of certain species within the managed stand is not assured. We suggested earlier, on the basis of expert opinion, that a strict minimum amount of 5%–10% is needed to achieve a positive ecological response, and considerably higher levels are often needed. Strong benefits for biodiversity from higher retention levels are evident from analyses of some of the existing experiments (e.g., Aubry et al. 2009) and are also indicated in initial meta-analyses (Rosenvald and Lõhmus 2008). Nevertheless, more explicit approaches are urgently needed to identify possible thresholds and their variability with target organisms and with forest and landscape types. Although we argue strongly against very low retention levels, we are also aware that leaving any level of retention as legacies is better than leaving none. In forest landscapes heavily disturbed by humans, leaving even a few live trees per hectare will in time contribute to an increase in the number of old-tree individuals and in the amount of dead wood.

As it is currently practiced, the selection of what to retain is made with varied precision, and retention guidelines vary in detail on which habitat types and biological legacies are prioritized. With increasing knowledge about forest types and their associated biodiversity, the potential for higher specificity will increase. Until then, in many instances, selection is rather coarse grained, although the level of detail often increases with decreasing retention amounts. Future important development includes designing retention levels that can scale up to the landscape in order to match specific goals set for biodiversity and ecosystem function.

We have identified in our review a pattern of lower retention levels in areas with a long history of industrial forestry and transformed natural forests (e.g., northern Europe; see table S1). Regions with substantial remaining areas of natural forest, such as Canada, usually have much higher retention levels. There may be several reasons for the lower levels in areas with a long history of intensive forest harvesting, including expectations of both industry and the general society as a result of past practices and market demands and also because of investments made by forest owners. Nevertheless, the concerned societies need to assess whether existing retention levels are actually achieving the desired ecological or cultural objectives and to determine what adjustments need to be made.

Determining whether conserved forest areas, such as riparian buffers, can be considered retention patches within harvest units or whether they should alternatively be considered landscape-level reserves within forest production landscapes will depend on the context. In areas in which logging units cover hundreds of hectares (as in parts of Canada), it is common to leave numerous aggregates of several hectares in a single harvest unit. Where harvest units cover only a few hectares (as in Fennoscandia and the Baltic states), leaving large aggregates within harvested areas is not feasible. Instead, in such areas, very small aggregates or dispersed individual trees are retained during harvesting and combined with larger reserve patches between stands as part of special planning processes (e.g., woodland key habitats).

Whether riparian zones or other buffers are included in retention accounting is another example in which practices may differ among countries and regions or even among management organizations within a region. Furthermore, in our data compilation (table S1), the figures for some regions are based on monitoring, whereas others are based on prescriptions and recommendations. This means that cross-jurisdictional comparisons of retention levels need to be made with caution.

The involvement of forest managers in conservation. Retention forestry represents a bottom-up conservation approach, since forest owners or forest license holders are ultimately responsible for retention strategies and generally bear the costs of such actions. Furthermore, within a broad policy context, local managers and field staff may make specific decisions on retention. Other types of conservation-oriented reserves are typically organized and implemented by governmental agencies. A positive aspect to this bottom-up approach is that it may stimulate an interest in biodiversity and conservation among forest managers and also encourages innovation in the development and improvement of retention designs. On the negative side, there is no guarantee that the retained structures will be preserved over the long term, contrary to those in government-established reserves (although such areas may also become degraded; e.g., Curran et al. 2004). Nongovernmental approaches to forest governance that have emerged during the recent decades—most clearly expressed in certification initiatives (e.g., McDermott et al. 2010)—could provide assurances regarding the retention approaches in private and community forests.

Application in different silvicultural systems. The retention approach is equally applicable to uneven- or even-age silvicultural systems or to high or low rates of wood extraction (Bauhus et al. 2009); that is, the importance of the continuity of biological legacies over forest generations has universal generality. Therefore, the potential is large for expanding retention forestry beyond the areas in which traditional clearcutting practices first stimulated its implementation and in which it is still most commonly used to areas in which selection systems have traditionally been applied. In our overview, we have included examples of areas in which extraction rates range from only 20%–30% (humid tropical forests) to 50% (partial logging in southern Patagonia, Argentina) and, finally, to more than 90% (boreal Europe). Although clearcutting is traditionally viewed as having the most negative impacts on biodiversity and the environment (e.g., McDermott et al. 2010), traditional selection systems also drastically reduce diversity in forests, such as by decreasing the amounts of old and dead trees (Angers et al. 2005, Mitchell RJ et al. 2006, Kenefic and Nyland 2007). Therefore, the emergence of retention practices in selectively harvested forests is encouraging, such as in the southeastern United States (Mitchell RJ et al. 2006) and in Germany (see table S1). The increasing incorporation of retention approaches in tropical forest harvesting is also likely to be accelerated through certification systems. We emphasize that retention in selection systems should largely target large and old live and dead trees, as well as rare species.

Key knowledge gaps. Many important research challenges remain for retention forestry in addition to the analysis of possible thresholds for ecological responses. Expanding our knowledge of the effects of retention harvesting on ecosystem functions, such as the hydrologic regime and nutrient dynamics, is among the most urgent. This includes a better understanding of belowground structures; processes; and organisms, such as mycorrhizal fungi, decomposers, and other functional groups. Such knowledge is needed in order to quantify the effects of retention forestry on various key ecosystem processes and thereby to develop a more comprehensive understanding of this relatively novel forestry system. Such insights are also required to evaluate the tradeoffs of various retention strategies among economic, social, and ecological benefits and to develop approaches that can optimize these benefits.

The development of planning systems and decision-support tools is also essential. Managers need better instruments to locate retention in relation to other conservation areas and also to select the types and amounts of retention that optimally achieve preset goals and that adapt to prevailing disturbance dynamics. The modeling of future landscapes with different types and levels of retention—while considering global change issues—and how this affects biodiversity and ecosystem functioning in the long term is also a key future research area.

There is also a need to extend research on the retention approach from clearcutting to selection systems and other forms of uneven-age silviculture, such as those practiced in the tropics. The retention models for the most intensive harvesting practices (e.g., stump, biofuel harvesting, and wood-fiber plantations) also need to be evaluated.

Conclusions

Although forest composition, structure, and dynamics vary among different forest types around the globe, the goals for the sustainable management of forests and the basic ecological principles guiding their use are the same. Timber harvesting or any other extraction of biomass should not reduce the possibilities for the future long-term provision of biodiversity and other ecosystem services. In this article, we have provided a review of an approach to management—retention forestry—that is highly adapted to the sustainable management of forests for environmental, economic, and cultural objectives. The strength of retention forestry is that it rests on more than 25 years of scientific experimentation and practical application throughout the world. It is also adaptable to emerging forest-operation systems such as harvesting for bioenergy or managing forests for carbon storage. Important challenges remain to further develop retention forestry to identify quantitative relationships—including thresholds—between levels and patterns of retention and specific ecosystem functions and organisms. On the basis of current evidence, applying retention forestry over the long term will create more structurally and compositionally diverse forest ecosystems that will offer society a broader array of ecosystem services and management options.

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