NCASI White Paper

WP-20-04

IMPACT. SCIENCE. SOLUTIONS.

The Contribution of Managed Forests in Canada to Biodiversity: How Forest Management Plays an Active Role

NCASI WHITE PAPER
JUNE 5, 2020

Prepared by
Kevin A. Solarik, Ph.D.
Kirsten Vice
Montréal, Québec, Canada

For more information about this report, contact:

Dr. Kevin A. Solarik
Director of Forestry Research, Canada & Northeastern/Northcentral U.S.
NCASI Canadian Office
2000 McGill College Ave, 6th Floor, Montréal, QC, H3A 3H3
(514) 907-3153
ksolarik@ncasi.org

Kirsten Vice
Vice President, Sustainability & Climate and Canadian Operations
NCASI Canadian Office
2000 McGill College Ave, 6th Floor, Montréal, QC, H3A 3H3
(514) 907-3145
kvice@ncasi.org

For more information about NCASI publications, contact:

Publication Coordinator
NCASI
1513 Walnut Street, Suite 200
Cary, NC 27511
(919) 941-6400
publications@ncasi.org

Cite this report as:

NCASI. 2020. The Contribution of Managed Forests in Canada to Biodiversity: How Forest Management plays an Active Role. White Paper (WP-20-04). Cary, NC: National Council for Air and Stream Improvement, Inc

About this report:

This white paper examines the interactions between active forest management and biodiversity in Canada, exploring practices that are currently used by the forest sector in designing harvesting plans to mitigate potential long-term effects on biodiversity conservation. Knowledge gaps that may help orient future research and activities in this area of study are also provided.

About NCASI:

NCASI (National Council for Air and Stream Improvement, Inc.) is a non-profit environmental research organization that seeks to create credible scientific information to address the environmental information needs of the forest products industry in North America. NCASI conducts surveys, performs field measurements, undertakes scientific research, and sponsors research by universities and others to document the environmental performance of industry facility operations and forest management, and to gain insight into opportunities for further improvement in meeting sustainability goals.

THE CONTRIBUTION OF MANAGED FORESTS IN CANADA TO BIODIVERSITY: HOW FOREST MANAGEMENT PLAYS AN ACTIVE ROLE

SUMMARY

Forest management influences biodiversity at multiple scales, from the harvested area up to the broader landscape. Decades of research and monitoring within actively managed forests have greatly improved our understanding of how biodiversity responds to contemporary, sustainable forest management. Management tools and practices are used by land managers to consider a wide range of species responses, along with site and landscape variability, to help improve or maintain biodiversity across multiple species within forested ecosystems. A managed forest landscape contains a variety of stand structures and ages, forest types, and set-asides (e.g., buffers, mature forests) that provide habitat for a variety of terrestrial and aquatic species. In Canada, federal, provincial, and territorial regulations, voluntary best management practices, and third-party forest certification programs guide active forest management and have led to advances in expertise, technology, and implementation of strategies to minimize the potential negative effects of forest management on ecosystem services, while helping the industry better understand potential trade-offs and opportunities for synergies. In addition, these advances have helped the industry identify opportunities for enhancing biodiversity through active forest management.

KEYWORDS

Biodiversity, Canada, Certification, Conservation, Forest Management, Regulations

TABLE OF CONTENTS

THE CONTRIBUTION OF MANAGED FORESTS IN CANADA TO BIODIVERSITY: HOW FOREST MANAGEMENT PLAYS AN ACTIVE ROLE

1.0 INTRODUCTION

Forest management influences biodiversity at multiple scales (e.g., microsite, stand, regional, landscape). Decades of research and monitoring within actively managed forests have greatly improved our understanding of how biodiversity responds to contemporary, sustainable forest management. Local and regional species composition, site characteristics (including both abiotic and biotic conditions), and the specific metrics selected to quantify biodiversity responses to forest management provide context to better understand these responses. Forest lands face increasing pressure from natural disturbances (e.g., fire, insect outbreaks, drought), alternative land uses, and climate change, making it ever more important to understand the relationships between activities such as sustainable forest management and conservation of biological diversity. Federal, provincial, and territorial polices and regulations, voluntary best management practices, and third-party forest certification programs guide sustainable forest management and have led to advances in expertise, technology, and implementation of strategies to minimize potential negative effects of forest management on ecosystem services, while enabling the forest sector to better understand potential trade-offs and opportunities for synergies. Research continues to enhance our knowledge regarding biodiversity needs, and thus there are constant refinements of approaches to forest management as a means to manage for meeting those needs.

2.0 BIODIVERSITY

Biodiversity is a highly debated, abstract concept that, when measured, is often associated with a high degree of uncertainty and, as a result, contributes to the difficulty in demonstrating its management and/or conservation. Biodiversity has been extensively defined, with over 90 attempts to do so within the peer-reviewed published literature (NCASI 2011). In its purest and simplest form:

> “biodiversity includes all organisms, species, and populations; the genetic variation among these; and all their complex assemblages of communities and ecosystems. It also refers to the interrelatedness of genes, species, and ecosystems and their interactions with the environment.”
>
> Ecological Society of America

Because of such a broad definition, there is little consistency across the array of biodiversity metrics related to forest management when they are applied for conservation (Guynn et al. 2004). This factor also makes it difficult for a resource manager to use this definition for management guidance. To begin to think about managing biodiversity based on this definition, it is probably easiest (and most appropriate) to recognize this concept at four primary scales (in increasing spatial scale):

1. Genetic diversity within a species [Genetic]
2. Species diversity in a given area [Species]
3. Ecosystem diversity, accounting for the diversity of ecological processes and vegetation associations (e.g., forest types) in a region or given area [Ecosystem]
4. Landscape diversity, the spatial heterogeneity within a broader region [Landscape]

Keeping with the notion of scale, Noss and Cooperrider (1994) provide a more effective working definition of biodiversity:

> *"The variety of life and its processes, including genes, species, communities, and ecosystems and the ecological and evolutionary processes that keep them functioning."*

Managing the forest for such variability across scales has proven, and probably will continue to prove, to be a daunting task, and could increase the likelihood of failure, particularly if not all scales are simultaneously considered during implementation and monitoring (over both short and long terms) of a harvesting management plan. The most effective path for forest managers to maintain biodiversity at multiple scales is through maintaining ecosystem function across landscapes.

Conserving biodiversity is also influenced by the value humans place on it as a concept, which can be grouped into two broad categories: intrinsic and anthropocentric. Intrinsic value suggests that biodiversity must be conserved irrespective of its present or future use to benefit humanity, and rests on species' inherent right to exist and the role biodiversity plays in contributing to ecosystem function. Anthropocentric value refers to those that are directly or indirectly beneficial to humans (NCASI 2011). The mix between intrinsic and societal values placed on biodiversity often drive conservation and management goals.

3.0 CANADIAN FOREST

3.1 Forested Areas and Biodiversity

Global estimates show that more than half the world's known terrestrial plant and animal species resides in forests (Hassan et al. 2005). Worldwide, forests cover approximately 3999 million hectares (ha) across four major biomes: tropical, subtropical, temperate, and boreal (FAO 2015). In North America, 723 million ha are forested; 347 million ha (48%) are in Canada, which is primarily composed of boreal forest (67.8%) (NRCan 2020). Two-thirds of Canada's approximately 80,000 identified species are forest-dwelling. Canadian forests can be quite diverse, with 212 tree species (157 native and 55 exotic) comprising its composition and where, for example, the boreal contains over 300 bird species (NRCan 2020).

3.2 Ownership, Economics, and Ecosystem Services

Forest ownership across Canada varies by jurisdiction. Most practices relative to forestry occur within forests that are publicly owned (91.4%, ~317.2 million ha), with constitutional ownership and management by individual provinces (76.6%, ~265.8 million ha), and territorial governments (12.9%, ~44.8 million ha). Relatively little of Canada's forestland is privately (6.2%, ~21.5 million ha) or indigenously owned (2.0%, 6.9 million ha) (NRCan 2020).

It is estimated that each year, wood extraction from forests results in a gross value of US$110 billion globally, which contributes to a forest sector valued at over US$606 billion and employing approximately 12.7 million people (FAO 2015). In North America, forest products are essential to the global market and Canada is among the world's most forested countries (Siry et al. 2018). The forest industry in Canada contributes $25.8 billion to the national gross domestic product and employs over 240,000 people (NRCan 2020).

Forests provide four categories of ecosystem services: provision (e.g., wood, pulp, bioenergy); regulation (e.g., carbon storage, clean water, soil fertility); support (e.g., habitat for species, genetic diversity); and cultural (e.g., recreation, indigenous, social) (IPBES 2018). Although wood production is the primary objective for many landowners, and forest sector companies in particular, the forest products sector strives to operate sustainably, including conservation of biological diversity.

3.3 Regulations and Certification

In much of the world, public interest has held that biodiversity should be conserved, with national and international legislation and treaties aimed at protecting and reducing biodiversity loss (e.g., the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), 1979; the Canadian Species At Risk Act (SARA), 2002; and the US Endangered Species Act (ESA), 1973). One standard method adopted by many countries to meet the goals of maintaining biodiversity is to identify and conserve species at risk, with the objective of ultimately maintaining functional populations. To accomplish this, many countries and jurisdictions have adopted policies to conserve species using various ranking, tracking, and management tools and guidelines (NCASI 2013). In Canada, forest managers operating on Crown land (i.e., land owned by the provincial or federal government) are required to consider species presence, landscape representation, special or significant ecological values, and many other factors in their forest management plans, either through legislative imperative, forest management certification programs, or best management practices (NCASI 2011). Provincial forest management guidelines are designed to ensure conservation of rare, sensitive, and "at-risk" species, riparian systems, and water quality and quantity. When a species at risk is present in a managed area, forest managers must adhere to species-specific management guidelines designed through recovery strategies and action plans. Overall, the Canadian forest management regulatory system is considered one of the most robust and comprehensive in the world (Cashore and McDermott 2004).

In addition to governmental regulatory frameworks, voluntary third-party forest certification systems such as the Canadian Standards Association (CSA), Forest Stewardship Council (FSC), and Sustainable Forestry Initiative® (SFI) promote and evaluate achievement of responsible forest stewardship and conservation of biological diversity on the managed land via various indicators and criteria. Forest management planning in Canada generally requires an assessment of species presence and richness on a landscape prior to harvesting, and both provincial regulations/guidelines and forest certification standards require providing sufficient habitat for all native species (SFI 2015, Principle 4; FSC 2015, Principal 6; CSA 2016, Criterion 1). Further, many companies use monitoring to ensure that practices are meeting various biodiversity objectives and, where they are failing, adjustments are made in an adaptive management framework (Houde et al. 2005).

CANADA'S FOREST CERTIFICATION AND PROTECTED AREAS

Certification (FPAC 2020):

- 47% of Canada's forested area is certified (168 million ha)
    - Canadian Standards Association (CSC): 12,948,094ha
    - Forest Stewardship Council (FSC): 49,961,807 ha
    - Sustainable Forestry Initiative® (SFI): 124,163,964 ha

Protected Areas (IUCN Categories): 10.5% (Wulder et al. 2018)

Areas under sustainable forest management are not recognized as permanently 'protected' under the current IUCN classification in North America, where interpretation of the classifications tends toward 'legislated' as the primary criterion (CCEA 2008). In contrast, areas under sustainable forest management in Europe are interpreted as protected under IUCN classification (NCASI 2011). Because of the interrelated nature of conservation criteria, forest managers address them collectively, and when assessing progress towards conservation objectives may choose to focus on quantitative measures that have a strong ecological/ environmental nature (NCASI 2011). Managers also commonly face the need to make trade-offs when considering multiple criteria because management to enhance habitat for one species may diminish habitat for another (e.g., early-seral vs. late-seral species). In Canada the regions of highest biological diversity occur in the southern latitudes (Venier et al. 2014); however, they also coincide with areas of the most anthropogenic pressures (e.g., urban development), which further emphasizes the critical role of forest management outside these regions.

4.0 FOREST MANAGEMENT

Forests managed primarily for forest harvest provide habitat for many forest-dwelling species where economic returns are not the primary objective, and the value of managed forests in contributing to and maintaining the diversity of a wide array of aquatic and terrestrial species has been well documented in the literature (e.g., Miller et al. 2009; Demarais et al. 2017; Beese et al. 2019). Many forests in North America are subject to large-scale natural disturbances (e.g., insect outbreaks, blowdown, fire), which create a landscape consisting of a mosaic of age classes and successional stages, very much like a managed forest landscape that typically includes unmanaged parcels or reserves mixed in with managed stands (e.g., Bergeron et al. 2002; Gauthier et al. 2004, 2009). In general, forest management practices implemented in Canada are being designed to remain within the range of natural variability on a landscape (Beese et al. 2019), which in the case of management within the boreal forest is frequently dependent on large-scale natural disturbances (Bergeron et al. 2002; Bergeron 2004). As a result, forest management regimes are increasingly being designed to emulate (to the extent possible) these natural disturbance patterns, both in intensity and design, to maintain native biodiversity levels (e.g., Spence 2001). Furthermore, many forest management plans are designed to support the proportion and total surface area of stand types found before harvest, with a specific intention of maintaining the proportion and total area of age class structure that would be found in the same landscape with a large-scale natural disturbance (Neave and Neave 2005; NCASI 2011). Acting as both an art and a science, the challenge lies in doing so based on a robust scientific platform and in a socially acceptable manner that can be economically maintained (Weber and Stocks 1998; Davis et al. 2001; Wyatt et al 2011). Although a small subset of species depend on older forest stands for either a portion of their life (associated with a specific life history event) or their entire life (e.g., closed-canopy specialists, some lichens and herbaceous plants) and can be negatively affected by forest management, there have been no directly-documented species extinctions caused by forest activities, despite over two centuries of commercial harvesting in North America.

4.1 Dual Forest and Species Management

Although forestry companies manage forests under obligatory governmental policies and third-party forest certification standards, creativity in harvesting design can offer considerable flexibility within a management area and can lead to a range of spatial harvesting patterns and intensities acting together to conserve multiple species within the forest at once (Spence 2001; Lindenmeyer et al. 2012). All types of disturbance (natural or anthropogenic) alter the forest and its properties (e.g., age, structure, microclimate) to some extent. As a result, disturbances may subsequently alter species composition. Unlike natural disturbances, however, forest management can implement practices based on the best available scientific information to minimize potentially harmful impacts to aquatic and terrestrial resources caused by tree harvesting operations over both the short and long terms.

Further, when possible (and appropriate), forest management practices can improve post-harvest forest conditions for biodiversity by incorporating strategies that integrate specific provisions that maintain the ecological niche-space(s) of individual or groups of species (e.g., interior forest patches, standing dead wood), or that maintain core areas for specific species of conservation concern (e.g., northern spotted owls or woodland caribou, NCASI 2009, 2020). Historically, maintaining large tracts of unharvested forest was believed to be the best way to promote conservation of multiple species (Lindenmayer and Franklin 2002), and much less focus was made on re-establishing or maintaining biodiversity within harvested areas (McAfee et al. 2006). This older "set-aside" conservation strategy relied on a static view of forested ecosystems and largely ignored the importance of disturbance, which is known to free up resources and increase biodiversity to varying extents across forests of North America (Hansen et al. 1991). More recently, however, forest managers are actively managing to maintain (and increase when possible) regional biodiversity by ensuring that necessary site-specific characteristics are present across the landscape rather than in set-asides only. It is believed the resulting landscape will provide the best opportunity for a sustainable supply of wood products combined with fostering conservation of a broad suite of both early- and late-seral species (Lindenmayer and Franklin 2002).

CANADIAN FOREST MANAGEMENT BY THE NUMBERS

- Primary Forest: (59.3%), Other naturally regenerated forests (36.1%), and planted forests (4.5%) (Siry et al. 2018)
- Nearly 60% of the forested area in Canada is under a forest management plan (Siry et al. 2018)
- Each year, 0.2% (755,884 ha) of Canada's forest area is harvested (NRCan 2020)
- Each year, only 0.01% (35,385 ha) is lost to deforestation – Forestry being responsible for 4% of this total (1,415 ha) (NRCan 2020)
- 40% of the boreal forest is under some form of forest management; the remaining 60% is too remote, less productive, and harvesting is either economically or operationally not feasible (Venier et al. 2014)
- The volume of wood harvested in 2017 (in millions of m^3): 155.2 (well below the estimated sustainable wood supply level* of 219.6 million m^3) (NRCan 2020)

**"Sustainable wood supply refers to the volume of timber that can be harvested from federal, provincial, territorial, and private lands while meeting environmental, economic, and social objectives."* (NRCan 2020).

At a broad scale, coarse-filter[1] approaches within harvest and regeneration guidelines are used to emulate natural disturbance, maintain ecological processes, and conserve species diversity across space and time (Spence 2001; Gustafsson et al. 2012; Fedrowitz et al. 2014). Within these approaches, two levels of planning are used to achieve these objectives. Long-term and landscape-scale forest management plans are developed to maintain native cover and habitat types and to conserve genetic diversity. Stand-level harvest and forest renewal plans are developed to contribute cumulatively to landscape biodiversity objectives by providing variable disturbance size classes, maintaining aggregated and dispersed forest patches, and maintaining varying amounts of snags and downed woody material within harvest areas (NCASI 2011).

4.2 The Forest Management Matrix

Collectively, ~90% of the global terrestrial land base is found within a “semi-natural” environment, where landscapes are a combination of commodity production and conservation (NCASI 2011). Management tools and practices used by land managers consider a wide range of species responses, site and landscape variability, and political and jurisdictional regulations. For simplicity’s sake, some of the common forest management strategies being implemented around the globe are briefly highlighted herein: planted forests; agroforestry; clearcutting; selection and retention systems; conventional selective logging; and protecting riparian zones and sensitive ecological areas. Although within each of these strategies there is significant variation in application, intensity, design, and influence on biodiversity response, each requires an intimate understanding of the strategy’s contribution to conservation of biodiversity prior to implementation (and after possible changes over time), which will also vary considerably among sites (Gustaffsson et al. 2012; Lindenmayer et al. 2012; Fedrowitz et al. 2014). In addition to understanding a management practice, forest managers must have an awareness of the biological system and potential contributing factors affecting its biodiversity response (see Contributing Factors box). A more general, simplified way of understanding the potential response of biodiversity to forest management is to consider ecological groups of taxa (i.e., open-condition specialist, closed-canopy specialist, or generalist) along with the proportion of retained forest (Figure 1).

---

[1] **Coarse filter** refers to management of landscapes through a set or network of protected areas combined with management practices that emulate and conserve the natural system within the natural range of variation. Typically, a coarse-filer approach is applied to an area identified as being of high conservation value that may include a high number of endemic species. In contrast, a **fine-filter** approach manages at the local or individual species scale, or for a particular ecosystem or features that may not be adequately protected or conserved (i.e., ‘caught’) using a coarse-filer approach.

CONTRIBUTING FACTORS LIKELY TO INFLUENCE BIODIVERSITY RESPONSE TO FOREST MANAGEMENT

Biodiversity

- Metric(s) selected
- Scale of measure (i.e., species, stand, landscape) (alpha-, beta-, gamma-)

Forest Harvesting Strategy:

- Management goal(s)
- Extent and intensity
- Frequency and time of since disturbance (natural and anthropogenic)
- Design and pattern (aggregated, dispersed, combination of both)

Species and Community-Specific:

- Prey/predator dynamics
- Genetics
- Life-history strategies
- Habitat requirements
- Food web structures
- Adaptability/resilience to disturbance (both natural and anthropogenic origins)
- Regional species pool (intra- and interspecies interactions)

Other

- Local and regional climate
- Inherent properties of the ecosystem in which species typically reside

Forest

- Landscape, stand, and site characteristics, and productivity
- Species composition

Variability in any of the above responses may also occur within the same region. For example, variation within the same taxonomic group (i.e., body size, mobility, life-history traits, and diet), habitat structure and community, site history (e.g., natural and anthropogenic disturbance(s) regime), and climatic (micro and macro) conditions, land-use changes (e.g., urban development, resource extraction)

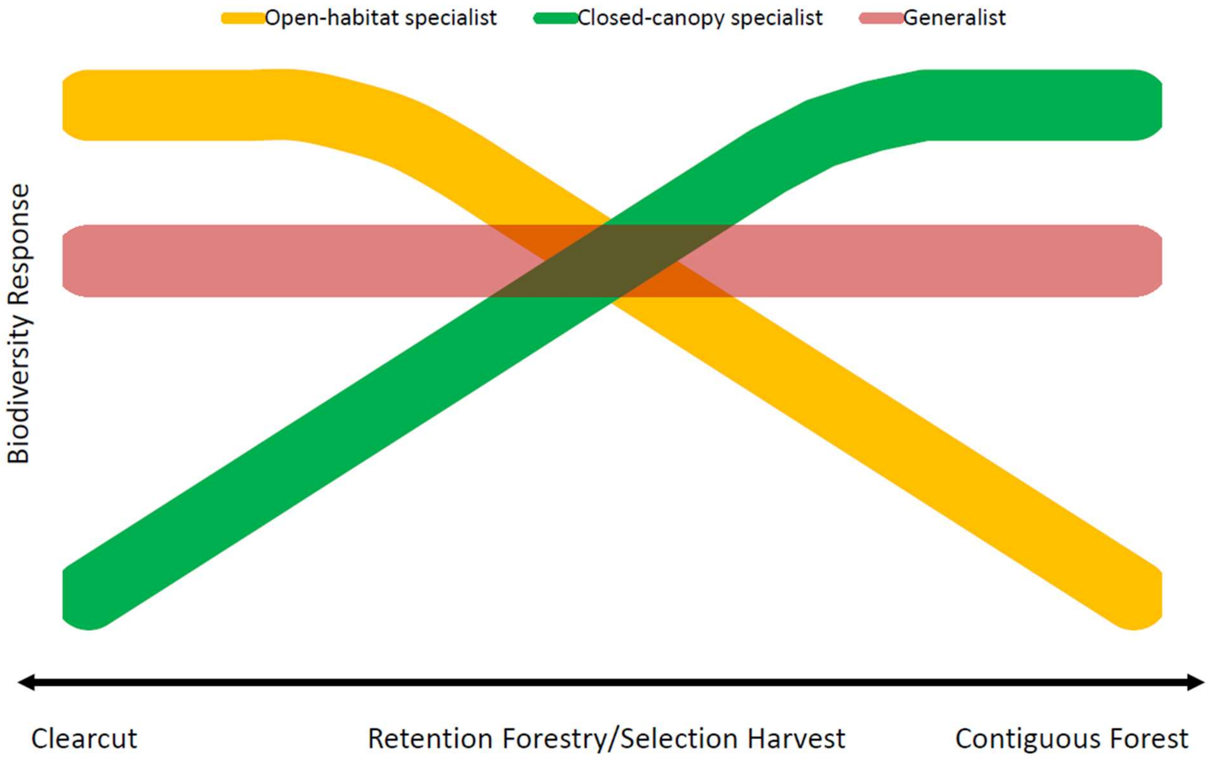

Figure 1. Range of Potential Biodiversity Responses for Different Ecological Groups of Taxa (open-condition specialists, closed-canopy specialists, generalists) to Tree Retention Intensity; response curves (and associated variability; thickness of the curve) are schematically drawn, different response curves and shapes are possible and dependent on various factors [adapted from Fedrowitz et al. 2014]

In the last few decades, it has become increasingly clear that a reserve-only management strategy can be inadequate for effectively conserving biodiversity (Lindenmayer and Franklin 2002). As a result, a new forest management model (commonly referred to as retention forestry) was introduced and has provided an opportunity to balance wood production and biodiversity conservation (e.g., Franklin 1989; Spence 2001; Gustafsson et al. 2012). However, costs associated with planning and harvesting can increase when using this approach (Phillips 2004). Retaining elements (living or dead) within a managed forest is designed to help conserve biological diversity at the stand level through ‘life-boating’ species and ecological processes that will improve ecosystem function. This is done through increasing the structural heterogeneity of the stand, improving connectivity, and offering a potential ‘middle ground’ that could be used by both open-condition and closed-canopy species specialists, all while minimizing potential effects of harvesting disturbance on a landscape (Lindenmayer et al. 2012; Baker et al. 2013). As a result, retained structures have contributed to conserving biodiversity for many forest-dwelling taxa that rely, or are dependent on, older forest characteristics and require landscape connectivity to ease their mobility (acting as stepping stones) throughout the landscape (Gustafsson et al. 2012; Lindenmayer et al. 2012; Fedrowitz et al. 2014; Demarais et al. 2017).

4.3 Biodiversity Response

Although forest management influences biodiversity response in many taxa (Demarais et al. 2017; Beese et al. 2019), the relative magnitude of impact will probably depend on several factors (see Contributing Factors box). Ultimately, a clear understanding of the driving mechanism(s), spatial scales, and responses (species- and ecosystem-level) to forestry practices will provide a more robust basis to assist forest ecologists and managers in designing effective practices to minimize potential impacts on forest-dwelling species for which forest management may be negative (Baker et al. 2013).

To date, most scientific research investigating species response to forest management has been primarily focused on birds, amphibians, and small mammals. Individual flora and fauna have unique responses to forest harvesting that reflect their habitat requirements (Rosenvald and Lõhmus 2008; Vanderwel et al. 2009). Because closed-canopy species (i.e., late-successional) depend on older, contiguous forests, harvesting has the potential to affect them more than open-condition specialists (i.e., early-successional). Open-condition species have very different habitat requirements and often rely on recently-disturbed forests (e.g., increases in resources and regeneration niches, Swanson et al. 2011). Generalist species should profit equally from either closed-canopy or open conditions. For example, coyotes (considered by many to be a generalist) benefit from open areas for improved forage and hunting or will use closed canopies to avoid deep snow during winter months to improve mobility (Thibault and Ouellet 2005; Boisjoly et al. 2010). Some species (e.g., birds) may require a mix of both early- and late-seral stages or conditions based on certain life history stages (fledgling vs. adult birds, nesting cover vs. foraging areas, etc.), and as a result show an overall neutral response to thinning (Verschuyl et al. 2011). Further, some species responses are driven by factors other than the harvesting practice *per se* (e.g., richness and abundance of amphibians have been positively correlated with stand age; Kroll et al. 2008) and must also be considered.

Typically, but not always, species that are highly mobile are less affected by forest thinning practices (Greene et al. 2016). For example, bird species richness has been repeatedly shown to be maintained (or not significantly changed) after forest thinning (see citations within Demarais et al. 2017). With clearcut harvesting, bird response can be quite variable (Baker and Lacki 1997; Duguay et al. 2000; Gram et al. 2003), but reducing the size of a harvested area and increasing retention patch sizes can positively affect richness and improve or maintain diversity through increased connectivity (Demarais et al. 2017). In contrast, some species may be negatively affected by smaller patch sizes that result from reducing the size of harvest units. Retaining structures (aggregated patches, dispersed, or a combination of both) will probably improve habitat connectivity and facilitate mobility of forest-dwelling species, resulting in an increased likelihood of meeting habitat requirements (e.g., gathering food) (Huggard and Bunnell 2007). If the proper precautions are not made for closed-canopy specialists, populations can be limited or even reduced (Powell and Babbitt 2015). For example, less mobile species (e.g., gastropods such as snails, slugs) have been particularly sensitive to a disturbance occurring within the forest understory, where these taxa are often used as indicators for monitoring biodiversity but can persist within retained patches post-harvest (Ovaska and Sopuck 2003). Arthropods (e.g., insects) have also shown tolerance for retention harvesting systems, where they are maintained in cut blocks (Pinzon et al, 2016; Lee et al. 2017). Further, many mosses, lichens, and fungi can also benefit from retention forestry (Rosenvald and Lõhmus 2008; Perhans et al, 2009; Kantvilas et al. 2015).

Providing the middle ground through retention harvesting has been shown to positively affect small mammal richness and abundance (Constantine et al. 2015). Retaining structural elements can be beneficial for certain species (e.g., snowshoe hare), as they provide protection from predators and offer early-seral forage (Ferron et al. 1998; Holbrook et al. 2017). Further, rodent assemblages have also been shown to respond positively to the presence of residual patches adjacent to unharvested patches (Constantine et al. 2004), and a number of recent research syntheses found that mammal diversity and overall response were positive or neutral to several types of harvesting (Zwolak 2009; Chaudhary et al. 2016). Dispersed retention, for example, can facilitate movement for many species by providing increased connectivity across the managed landscape (Franklin et al. 1997). While dispersed retention can be beneficial to some taxa, its effectiveness appears to be dependent on the levels of retention (Aubrey et al. 2009). Conversely, aggregated retention patterns (patches) can provide mature remnants that can 'lifeboat' these species while the forest recovers (Franklin et al. 2018). Retaining aggregated patches within a harvested stand can be an effective approach in maintaining the full complement of features (e.g., stand sturcture, complexity, nesting sites) that may be required for late-successtional species (Gustafsson et al. 2012, Baker et al. 2017). More studies are needed to provide further insight into which design is more effective for species recovery following harvest. However, combining spatial patterns (aggregated and dispersed residuals) within a harvesting area has been an increasingly attractive strategy for conservation of biodiversity (Pinzon et al. 2016; Lee et al. 2017; Franklin et al. 2018).

For sessile species (plants, trees, mosses, lichens, fungi), forest management directly manipulates their environment and therefore can produce a much higher magnitude of response (either positive or negative). Because forests are generally most biodiverse at their successional extremes (i.e., young forests to older forests, Demarais et al. 2017), removing portions of a closed-canopy forest can positively rejuvenate biodiversity of the forest understory. As a result of increased light, nutrients, and moisture reaching the forest floor, an influx of early-successional species generally begin to fill the disturbed space and often result in higher understory diversity (Hart and Chen 2006; Duguid and Ashton 2013; Franklin et al. 2018). Further, exposing the forest floor through passive (e.g., skidding trees, post-fire) or active site preparation techniques can improve tree seedling recruitment (Solarik et al. 2010), and eventually those retained trees will contribute to the coarse woody debris pool that will improve soil fertility and recruitment in the future (Solarik et al. 2012; Hämäläinen et al. 2016).

5.0 GOING FORWARD

5.1 How Much Forest Should be Retained to Conserve Biodiversity?

The short answer to how much forest should be retained to conserve biodiversity is, it depends. It depends on site productivity and history, disturbance regime, dominant and co-dominant tree species composition, and area requirements for the habitat of the late-seral species in a given region. Regardless of the considerable variability that exists with and between regions, some researchers have recommended that at least 5 to 10% of the original basal area would be required to maintain ecosystem function and processes (Gustafsson et al. 2012), while others have advocated for a minimum of 15 to 20% to maintain biodiversity in the immediate future (Work et al. 2004; Aubry et al. 2009). Variations in recommendations can probably be attributed to the high degree of variability across the landscape and the species-specific responses that were measured in past studies (Bunnell and Dunsworth 2009). In general, increases in the number of retained trees positively affects forest-dependent small mammals, birds, plants, and invertebrates (Fedrowitz et al. 2014). Mammals that depend on large tracts of contiguous, closed-canopy forest are expected to use stands harvested to high retention levels (70%); however, studies on large mammals are generally lacking (Vanderwel et al. 2009). The optimal approach and design for structural enrichment of younger, developing stands may be a combination of both grouped and dispersed retention that ensures the highest likelihood of conserving biodiversity (Lindenmayer and Franklin 2002; Aubry et al. 2009; Pinzon 2016; Franklin et al. 2018).

5.2 What Remains Unknown?

Research continues to enhance our knowledge regarding biodiversity needs and thus there is a constant refinement of approaches to forest management as a means of increasing the capacity to manage for those needs. Further investigation of forest recovery times and species-specific responses to varying degrees and patterns of harvesting are required–and in a wider range of forest conditions. Identifying the appropriate mix of intensive management vs. retention forestry for each biophysical region is also not well understood and will require particular attention in future research. Finally, the quantity and quality of retained forest elements need further analysis and monitoring of species responses over longer time scales; most studies to date investigating species responses to forest harvesting and management have occurred within a decade of a disturbance (Solarik et al. 2012; Fedrowitz et al. 2014).

6.0 CONCLUSIONS

Globally, the active conservation of biodiversity and forest area through use of protected areas has increased 2% since 1990, while the area of primary forest has remained stable over the same time period (FAO 2015). At the same time, there is growing recognition of the role land managers can play in enhancing the ways in which use of forest resources can be undertaken in a manner consistent with contributing to long-term biodiversity conservation. These are promising trends, as resource land managers are becoming much more aware that forests must be managed with the intention of conserving (and improving the landscape for) biodiversity. Climate change dynamics, natural disturbance frequency and severity, invasive species, and resource demands all provide potential stressors on forests and forest biodiversity. In response, forest management will have to continue to confront this uncertainty and solutions will be at a premium, probably resulting in landscapes being ideally managed for increased complexity and resilience (Messier et al. 2013). Where landscapes lack early successional forests, management practices can provide these conditions, especially given that some of these species are experiencing dramatic long-term declines (King and Schlossberg 2013; Demarais et al. 2017).

Active forest management can help reduce the severity and likelihood of large-scale natural disturbances (e.g., fire and insect outbreaks), which have been projected to increase in both intensity and frequency (Hanes et al. 2018).

Ensuring that habitat requirements for all species are attained at the smaller stand scale is an unattainable objective for any management strategy–and yet, success can be achieved by viewing this issue at a landscape scale. A more holistic approach to biodiversity conservation provides a mosaic of different forest conditions and characteristics across the landscape that will allow a suite of species to benefit, rather than simply a selective sub-sample. In practice, this is quite difficult to attain. However, active forest management practices continue to be designed and refined to assist in the long-term viability that supports both closed-canopy and open-condition specialists (Gusafsson et al. 2012; Fedrowitz et al. 2014).

LITERATURE CITED

Aubry, K.B., Halpern, C.B., and Peterson, C.E. 2009. Variable-retention harvests in the Pacific Northwest: a review of short-term findings from the DEMO study. *Forest Ecology and Management* 258(4):398-408. https://doi.org/10.1016/j.foreco.2009.03.013.

Baker, M.D., and Lacki, M.J. 1997. Short-term changes in bird communities in response to silvicultural prescriptions. *Forest Ecology and Management* 96(1-2):27-36. https://doi.org/10.1016/S0378-1127(97)00052-2.

Baker, S.C., Grove, S.J, Wardlaw, T.J., McElwee, D.J., Neyland, M.G., Scott, R.E., and Read, S.M. 2017. Monitoring the implementation of variable retention silviculture in wet eucalypt forest: a key element of successful adaptive management. *Forest Ecology and Management* 394:27-41. https://doi.org/10.1016/j.foreco.2017.03.013.

Baker, S.C., Spies, T.A., Wardlaw, T.J., Balmer, J., Franklin, J.F., and Jordan, G.J. 2013. The harvested side of edges: effect of retained forests on the re-establishment of biodiversity in adjacent harvested areas. *Forest Ecology and Management* 302:107-121. https://doi.org/10.1016/j.foreco.2013.03.024.

Beese, W.J., Deal, J., Dunsworth, B.G., Mitchell, S.J., and Philpott T.J. 2019. Two decades of variable retention in British Columbia: a review of its implementation and effectiveness for biodiversity conservation. *Ecological Processes* 8: 33. https://doi.org/10.1186/s13717-019-0181-9.

Bergeron, Y. 2004. Is regulated even-aged management the right strategy for the Canadian boreal forest? *Forestry Chronicle* 80:458-480. https://doi.org/10.5558/tfc80458-4.

Bergeron, Y., Leduc, A., Harvey, B., and Gauthier, S. 2002. Natural fire regime: a guide for sustainable forest management in the Canadian boreal forest. *Silva Fennica* 36:81-95. https://doi.org/10.14214/sf.553.

Boisjoly, D., Ouellet, J.-P., and Courtois, R. 2010. Coyote habitat selection and management implications for the Gaspésie caribou. *Journal of Wildlife Management* 74(1):3-11. https://doi.org/10.2193/2008-149.

Bunnell F.L., and Dunsworth, G.B. (eds.). 2009. *Forestry and Biodiversity: Learning How to Sustain Biodiversity in Managed Forests*. Vancouver, BC: UBC Press.

Cashore, B.W., and McDermott, C. 2004. *Global Environmental Forest Policies: Canada as a Constant Case Comparison of Select Forest Practice Regulations*. Ottawa, ON: International Forest Resources.

CCEA. 2008. *Canadian Guidebook for the Application of IUCN Protected Areas Categories*. CCEA Occasional Paper No. 18. Ottawa, ON: Canadian Council for Ecological Areas Secretariat.

Chaudhary, A., Burivalova, Z., Koh, L.P., and Hellweg, S. 2016. Impact of forest management on species richness: meta-analysis and economic trade-offs. *Scientific Reports* 6:23954. https://doi.org/10.1038/srep23954.

Constantine, N., Campbell, T.A., Baughman, W.M., Harrington, T.B., Chapman, B.R., and Miller, K.V. 2004. Effects of clearcutting with corridor retention on abundance, richness, and diversity of small mammals in the Coastal Plain of South Carolina, USA. *Forest Ecology and Management* 202(1-3):293-300. https://doi.org/10.1016/j.foreco.2004.07.036.

Constantine, N.L., Claire, E., Campbell, T., Baughman, W.M., and Miller, K.V. 2015. Small mammal distributions relative to southern pine plantations. *Southern Journal of Applied Forestry* 29(3):148-151. https://doi.org/10.1093/sjaf/29.3.148.

CSA. 2016. *Sustainable Forest Management*. CAN/CSA-Z809-16. Mississauga, ON: Canadian Standards Association.

Davis, L.S., Johnson, K.N., Bettinger, P.S., and Howard, P.E. 2001. Forest Management to Sustain Ecological, Economic and Social Values. New York: McGraw Hill. 804 pp.

Demarais, S., Verschuyl, J.P., Roloff, G.J., Miller, D.A., and Wigley, T.B. 2017. Tamm review: Terrestrial vertebrate biodiversity and intensive forest management in the U.S. *Forest Ecology and Management* 385:308-330. https://doi.org/10.1016/j.foreco.2016.10.006.

Duguay, J.P., Wood, P.B., and Miller, G.W. 2000. Effects of timber harvests on invertebrate biomass and avian nest success. *Wildlife Society Bulletin* 28(4):1123-1131. https://doi.org/10.2307/3783873.

Duguid, M.C., and Ashton, M.S. 2013. A meta-analysis of the effect of forest management for timber on understory plant species diversity in temperate forests. *Forest Ecology and Management* 303:81-90. https://doi.org/10.1016/j.foreco.2013.04.009.

Ecological Society of America (ESA). *Biodiversity*. https://www.esa.org/esa/wp-content/uploads/2012/12/biodiversity.pdf [June 1, 2020].

FAO. 2015. Global Forest Resources Assessment 2015 – How Are the World's Forests Changing? Rome, Italy: Food and Agricultural Organization of the United Nations. [http://www.fao.org/3/a-i4793e.pdf].

Fedrowitz, K., Koricheva, J., Baker, S.C., Lindenmayer, D.B., Palik, B., Rosenvald, R., Beese, W., Franklin, J.F., Kouki, J., Macdonald, E., Messier, C., Sverdrup-Thygeson, A., and Gustafsson, L. 2014. Can retention forestry help conserve biodiversity? A meta-analysis. *Journal of Applied Ecology* 51(6):1669-1679. https://doi.org/10.1111/1365-2664.12289.

Ferron, J., Potvin, F., and Dussault, C. 1998. Short-term effects of logging on snowshoe hares in the boreal forest. *Canadian Journal of Forest Research* 28(9):1335-1343. https://doi.org/10.1139/x98-113.

FPAC. 2020. *Forest Management Certification in Canada. 2019 Year-End Status Report Canada*. Ottawa, ON: Forest Products Association of Canada. http://certificationcanada.org/wp-content/uploads/2020/03/2019-Yearend-SFM-Certification-Detailed-Report.pdf.

Franklin, C.M.A., Macdonald, S.E., and Nielsen, S.E. 2018. Combining aggregated and dispersed tree retention harvesting for conservation of vascular plant communities. *Ecological Applications* 287(7):1830-1840. https://doi.org/10.1002/eap.1774.

Franklin, J.F. 1989. Towards a new forestry. *American Forests* 95:37-44.

Franklin, J.F., Berg, D.R., Thornburgh, D.A., and Tappeiner, J.C. 1997. Alternative silvicultural approaches to timber harvesting: variable retention harvest systems. 111-139 in Kohm, K.A., and Franklin, J.F. (eds.). *Creating a Forestry for the 21st Century: The Science of Ecosystem Management*. Washington, DC: Island Press.

FSC. 2015. *FSC Principles and Criteria for Forest Stewardship*. FSC-STD-01-01 (Version 5-2) EN. Bonn, Germany: Forest Stewardship Council.

Gauthier, S., Nguyen, T., Bergeron, Y., Leduc, A., Drapeau, P., and Grondin, P. 2004. Developing forest management strategies based on fire regimes in north-western Quebec. 219-229 in Perera, A., Buse, L.J., and Weber, M.G. (eds.). *Emulating Natural Forest Landscape Disturbances: Concepts and Applications*. New York: Columbia University Press. https://doi.org/10.7312/pere12916-021.

Gauthier, S., Vaillancourt, M.A., Kneeshaw, D.D., Drapeau, P., De Grandpré L., and Paré, D. 2009. Forest ecosystem management: origins and foundations. 15-37 in Gauthier, S., Vaillancourt, M.-A., Leduc, A., De Grandpré, L., Kneeshaw, D., Morin, H., Drapeau, P., and Bergeron, Y. (eds.). *Ecosystem Management in the Boreal Forest*. Université du Québec, Montréal.

Gram, W.K., Porneluzi, P., Clawson, R.L., Faaborg, J., and Richter, S.C. 2003. Effects of experimental forest management on density and nesting success of bird species in Missouri

Ozark forests. *Conservation Biology* 17(5):1324-1337. https://doi.org/10.1046/j.1523-1739.2003.02171.x.

Greene, R.E., Iglay, R.B., Evans, K.O., Miller, D.A., Wigley, T.B., and Riffell, S.K. 2016. A meta-analysis of biodiversity responses to management of southeastern pine forests–opportunities for open pine conservation. *Forest Ecology and Management* 360:30-39. https://doi.org/10.1016/j.foreco.2015.10.007.

Gustafsson, L., Baker, S.C., Bauhus, J., Beese, W.J., Brodie, A., Kouki, J., Lindenmayer, D.B., Lõhmus, A., Martínez Pastur, G., Messier, C., Neyland, M., Palik, B., Sverdrup-Thygeson, A., Volney, W.J.A., Wayne, A., and Franklin, J.F. 2012. Retention forestry to maintain multifunctional forests: a world perspective. *Bioscience* 62(7):633-645. https://doi.org/10.1525/bio.2012.62.7.6.

Guynn, D.C., Guynn, S.T., Layton, P.A., and Wigley, T.B. 2004. Biodiversity metrics in sustainable forestry certification programs. *Journal of Forestry* 102(3):46-52. https://doi.org/10.1093/jof/102.3.46.

Hämäläinen, A., Hujo, M., Heikkala, O., Junninen, K., and Kouki, J. 2016. Retention tree characteristics have major influence on the post-harvest tree mortality and availability of coarse woody debris in clear-cut areas. *Forest Ecology and Management* 369:66-73. https://doi.org/10.1016/j.foreco.2016.03.037.

Hanes, C.C., Wang, X., Jain, P., Parisien, M.-A., Little, J.M., and Flannigan, M.D. 2018. Fire regime changes in Canada over the last half century. *Canadian Journal of Forest Research* 49(3):256-269. https://doi.org/10.1139/cjfr-2018-0293.

Hansen, A.J., Spies, T.A., Swanson, F.J., and Ohmann, J.L. 1991. Conserving biodiversity in managed forests. *BioScience* 41(6):382-392. https://doi.org/10.2307/1311745.

Hart, S.A., and Chen, H.Y.H. 2006. Understory vegetation dynamics of North American boreal forests. *Critical Reviews in Plant Sciences* 25(4):381-397. https://doi.org/10.1080/07352680600819286.

Hassan, R.M., Scholes, R.J., and Ash, N. (eds.). 2005. *Ecosystems and human well-being: current state and trends, vol. 1: Findings of the Condition and Trends Working Group of the Millenium Ecosystem Assessment*. Millenium Ecosystem Assessment Series. Washington, DC: Island Press.

Holbrook, J.D., Squires, J.R., Olson, L.E., DeCesare, N.J., and Lawrence, R.L. 2017. Understanding and predicting habitat for wildlife conservation: the case of Canada lynx at the range periphery. *Ecosphere* 8(9):e01939. https://doi.org/10.1002/ecs2.1939.

Houde, I., Bunnell, F.L., and Leech, S. 2005. Assessing success at achieving biodiversity objectives in managed forests. *BC Journal of Ecosystems and Management* 6(2):17-28.

Huggard, D.J., and Bunnell, F.L. 2007. *Stand-level retention and forest birds: a synthesis of studies*. Vancouver, BC: University of British Columbia, Centre for Applied Conservation Research.

IPBES. 2018. *Summary for policymakers of the regional assessment report on biodiversity and ecosystem services for the Americas of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. Rice, J., Seixas, C.S., Zaccagnini, M.E., Bedoya-Gaitán, M., Valderrama, N., Anderson, C.B., Arroyo, M.T.K., Bustamante, M., Cavender-Bares, J., Diaz-de-Leon, A., Fennessy, S., García Márquez, J.R., Garcia, K., Helmer, E.H., Herrera, B., Klatt, B., Ometo, J.P., Rodríguez Osuna, V., Scarano, F.R., Schill, S., and Farinaci, J.S. (eds.). Bonn, Germany: Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. 41 pp.

Kantvilas, G., Jarman, S.J., and Minchin, P.R. 2015). Early impacts of disturbance on lichens, mosses and liverworts in Tasmania's wet eucalypt production forests. *Australian Forestry* 78(2):92-107. https://doi.org/10.1080/00049158.2015.1053025.

King, D.I., and Schlossberg, S. 2013. Synthesis of the conservation of the early successional stages in forests of eastern North America. *Forest Ecology and Management* 324:186-195. https://doi.org/10.1016/j.foreco.2013.12.001.

Kroll, A.J., Risenhoover, K., McBride, T., Beach, E., Kernohan, B.J., Light, J., and Bach, J. 2008. Factors influencing stream occupancy and detection probability parameters of stream-associated amphibians in commercial forests of Oregon and Washington, USA. *Forest Ecology and Management* 255:3726-3735. https://doi.org/10.1016/j.foreco.2008.03.005.

Lee, S.-I., Spence, J.R., and Langor, D.W. 2017. Combinations of aggregated and dispersed retention improve conservation of saproxylic beetles in boreal white spruce stands. *Forest Ecology and Management* 385:116-126. https://doi.org/10.1016/j.foreco.2016.11.032.

Lindenmayer, D.B., and Franklin, J.F. 2002. *Conserving Forest Biodiversity. A Comprehensive Multiscaled Approach*. Washington, DC: Island Press.

Lindenmayer, D.B., Franklin, J.F., Lõhmus, A., Baker, S.C., Bauhus, J., Beese, W, Brodie, A., Kiehll, B., Kouki, J., Martinez Pastur, G., Messier, C., Neyland, M., Palik, B., Sverdrup-Thygeson, A., Volney, W.J.A., Wayne, A., and Gustafsson, L. 2012. A major shift to the retention approach for forestry can help resolve some global forest sustainability issues. *Conservation Letters* 5(6):421-431. https://doi.org/10.1111/j.1755-263X.2012.00257.x.

McAfee, B.J., Malouin, C., and Fletcher, N. 2006. Achieving forest biodiversity outcomes across scales, jurisdictions and sectors with cycles of adaptive management integrated through criteria and indicators. *Forestry Chronicle* 82(3):321-334. https://doi.org/10.5558/tfc82321-3.

Messier, C., Puettmann, K.J., and Coates, D.K. (eds.). 2013. *Managing Forests as Complex Adaptive Systems: Building Resilience to the Challenge of Global Change*. New York: Routlegde.

Miller, D.A., Wigley, T.B., Miller, K.V. (2009). Managed forests and conservation of terrestrial biodiversity in the southern United States. Journal of Forestry, 107(4), 197-203. https://doi.org/10.1093/jof/107.4.197

NCASI. 2009. *Wildlife response to stand-level structural retention practices in the boreal forest*. Technical Bulletin No. 964. Research Triangle Park, NC: National Council for Air and Stream Improvement.

NCASI. 2011. *The role of forest management in maintaining conservation values*. Technical Bulletin No. 983. Research Triangle Park, NC: National Council for Air and Stream Improvement, Inc.

NCASI. 2013. *A review of the history and scientific basis of species at risk assessments in Canada*. Technical Bulletin No. 1005. Research Triangle Park, NC: National Council for Air and Stream Improvement, Inc.

NCASI. 2020. *Current state of knowledge and research on woodland caribou in Canada*. Technical Bulletin No. 1066. Cary, NC: National Council for Air and Stream Improvement, Inc.

Neave, D., and Neave, E. 2005. A web of conservation lands across Canada's forest. In *Conservation Lands – Integrating Conservation and Sustainable Management in Canada's Forests*. ISBN 0-662-39510-7. Cat. No. Fo94-1/2005E. Ottawa, ON: Natural Resources Canada.

Noss, R.F., and Cooperrider, A.Y. 1994. *Saving Nature's Legacy*. Washington, DC: Island Press.

NRCan. 2020. *The state of Canada's forests: annual report 2019*. Ottawa, ON: Natural Resources Canada. 80 pp. https://www.nrcan.gc.ca/our-natural-resources/forests-forestry/state-canadas-forests-report/16496.

Ovaska, K., and Sopuck, L. 2003. *Gastropod pilot study for adaptive management*. Report #4. Weyerhaeuser BC Coast Group Forest Project Technical Project Summary.

Perhans, K., Appelgren, L., Jonsson, F., Nordin, U., Söderström, B., and Gustafsson, L. 2009. Retention patches as potential refugia for bryophytes and lichens in managed forest landscapes. *Biological Conservation* 142(5):1125-1133. https://doi.org/10.1016/j.biocon.2008.12.033.

Phillips, E. 2004. Harvesting to emulate natural disturbance: EMEND harvesting costs and productivity. *Advantage–FERIC* 5:36.

Pinzon, J., Spence, J.R., Langor, D.W., and Shorthouse, D.P. 2016. Ten-year responses of ground-dwelling spiders to retention harvest in the boreal forest. *Ecological Applications* 26(8):2581-2599. https://doi.org/10.1002/eap.1387.

Powell, J.S.V., and Babbitt, K.J. 2015. Despite buffers, experimental forest clearcuts impact amphibian body size and biomass. *PLoS One* 10:e0143505. https://doi.org/10.1371/journal.pone.0143505.

Rosenvald, R., and Lõhmus, A. 2008. For what, when, and where is green-tree retention better than clear-cutting? A review of the biodiversity aspects. *Forest Ecology and Management* 255:1-15. https://doi.org/10.1016/j.foreco.2007.09.016.

SFI. 2015. *SFI 2015-2019 Standards and Rules*. Washington, DC: Sustainable Forestry Initiative. https://www.sfiprogram.org/wp-content/uploads/2015_2019StandardsandRules_web_Feb_2017-1.pdf.

Siry, J.P., Cubbage, F.W., Potter, K.M., and McGinley, K. 2018. Current perspectives on sustainable forest management: North America. *Current Forestry Reports* 4(3):138-149. https://doi.org/10.1007/s40725-018-0079-2.

Solarik, K.A., Lieffers, V.J., Volney, W.J., Pelletier, R., and Spence, J.R. 2010. Seed tree density, variable retention and stand composition influence recruitment of white spruce in boreal mixedwood forests. *Canadian Journal of Forest Research* 40(9):1821-1832. https://doi.org/10.1139/X10-125.

Solarik, K.A., Volney, W.J.A., Lieffers, V.J., Spence, J.R., and Hamann, A. 2012. Factors affecting white spruce and aspen survival after partial harvest. *Journal of Applied Ecology* 49(1):145-154. https://doi.org/10.1111/j.1365-2664.2011.02089.x.

Spence, J.R. 2001. The new boreal forestry: adjusting timber management to accommodate biodiversity. *Trends in Ecology and Evolution* 16(11):591-593. https://doi.org/10.1016/S0169-5347(01)02335-7.

Swanson, M.E., Franklin, J.F., Beschta, R.L., Crisafulli, C.M., DellaSala, D.A., Hutto, R.L., Lindenmayer, D.B., and Swanson, F.J. 2011. The forgotten stage of forest succession: early-successional ecosystems on forest sites. *Frontiers in Ecology and the Environment* 9(2):117-125. https://doi.org/10.1890/090157.

Thibault, I., and Ouellet, J.-P. 2005. Hunting behaviour of eastern coyotes in relation to vegetation cover, snow conditions, and hare distribution. *Ecoscience* 12(4):466-475. https://doi.org/10.2980/i1195-6860-12-4-466.1.

Vanderwel, M.C., Mills, S.C., and Malcolm, J.R. 2009. Effects of partial harvesting on vertebrate species associated with late-successional forests in Ontario's boreal region. *Forestry Chronicle* 85(1):91-104. https://doi.org/10.5558/tfc85091-1.

Venier, L.A., Thompson, I., Fleming, R., Malcolm, J., Aubin, I., Trofymow, J.A. Langor, D., Sturrock, R., Patry, C., Outerbridge, R.O., Holmes, S.B., Haeussler, S., De Grandpré, L., Chen, H.Y.H., Bayne, E., Arsenault, A., and Brandt, J.P. 2014. Effects of natural resource development on the terrestrial biodiversity of Canadian boreal forests. *Environmental Reviews* 22(4):457-490. https://doi.org/10.1139/er-2013-0075.

Verschuyl, J.P., Riffell, S., Miller, D.A., and Wigley, T.B. 2011. Biodiversity response to intensive biomass production from forest thinning in North American forests–a meta-analysis. *Forest Ecology and Management* 261:221-232. https://doi.org/10.1016/j.foreco.2010.10.010.

Weber, M.G., and Stocks, B.J. 1998. Forest fire and sustainability in the boreal forests of Canada. *Ambio* 27(7):545-550.

Work, T.T., Shorthouse, D.P., Spence, J.R., Volney, W.J.A., and Langor, D. 2004. Stand composition and structure of the boreal mixedwood and epigaeic arthropods of the Ecosystem Management Emulating Natural Disturbance (EMEND) landbase in Northwestern Alberta. *Canadian Journal of Forest Research* 34(2):417-430. https://doi.org/10.1139/x03-238.

Wulder, M.A., Cardille, J.A., White, J.C., and Rayfield, B. 2018. Context and opportunities for expanding protected areas in Canada. *Land* 7(4):137. https://doi.org/10.3390/land7040137.

Wyatt, S., Rousseau, M.-H.., Nadeau, S., Thiffault, N., and Guay, L. 2011. Social concerns, risk and the acceptability of forest vegetation management alternatives: insights for managers. *Forestry Chronicle* 87(2):274-289. https://doi.org/10.5558/tfc2011-014.

Zwolak, R. 2009. A meta-analysis of the effects of wildfire, clearcutting, and partial harvest on the abundance of North American small mammals. *Forest Ecology and Management* 258(5):539-545. https://doi.org/10.1016/j.foreco.2009.05.033.