Intensive forest biomass harvesting and biodiversity in Canada: A summary of relevant issues[1]

by Shannon M. Berch[2], Dave Morris[3] and Jay Malcolm[4]

ABSTRACT

Increasing interest in renewable fuels inspired a three-day workshop in Toronto in February 2008, entitled: *The Scientific Foundation for Sustainable Forest Biomass Harvesting Guidelines and Policy*. In this paper, we summarized the biodiversity-focused content of the workshop, including potential implications of intensification of biomass removal on biodiversity, knowledge gaps identified by workshop participants, and implications for policy development. Woody debris represents an important habitat resource for a wide variety of forest organisms, and the presence and continued supply of fresh to highly decayed dead wood represents a key concern in managed forest systems. A key challenge in sustainable forests management is to determine to what extent biomass harvests can increase fibre use while sustaining biodiversity, its functions, and the broad suite of ecosystem services that it provides. For knowledge-based planning and policy development, researchers must provide complex information to policy-makers and forest managers in a clear, effective way. In particular, full life-cycle analysis of intensive forest biomass harvesting taking into account environmental consequences is needed to inform sound evidence-based policy and decision-making. In the absence of complete scientific information, forest managers and decision-makers are well-advised to proceed with caution within a well-developed adaptive management framework.

Key words: forest biomass harvesting, biodiversity, research gaps, forest policy implications

RÉSUMÉ

LL'intérêt sans cesse croissant pour des carburants renouvelables a suscité la tenue d'un atelier de trois jours à Toronto en février 2008, intitulé : *The Scientific Foundation for Sustainable Forest Biomass Harvesting Guidelines and Policy*. Nous résumons dans cet article les aspects portant sur la biodiversité abordés au cours de l'atelier, incluant les implications possibles de l'intensification de l'extraction de la biomasse au niveau de la biodiversité, les lacunes au niveau des connaissances telles qu'identifiées par les participants à l'atelier et les implications en matière de développement des politiques. Les débris ligneux constituent une source importante d'habitat pour une grande variété d'organismes forestiers et la présence et l'apport continu de bois à des stades divers de décomposition constituent un enjeu important dans les systèmes forestiers aménagés. Un défi de prime importance en aménagement forestier durable consiste à déterminer jusqu'à quel point la récolte de la biomasse peut accroître l'utilisation de la fibre tout en maintenant la biodiversité, ses fonctions et l'ensemble des services écosystémiques qu'elle assure. Pour ce qui est de la planification basée sur les connaissances acquises et de l'élaboration des politiques, les chercheurs doivent fournir des informations complexes aux législateurs et aux aménagistes forestiers de façon précise et efficace. Plus particulièrement, une analyse complète du cycle relié à la récolte de la biomasse forestière prenant en considération les conséquences environnementales, est requise pour permettre l'élaboration de politiques et la prise de décisions reposant sur des faits vérifiés. En l'absence d'informations scientifiques complètes, les aménagistes forestiers et les décideurs seraient bien avisés de procéder avec précaution à l'intérieur d'un cadre bien établi de gestion adaptative.

Mots clés : récolte de la biomasse forestière, biodiversité, manque de connaissances, implications des politiques forestières

[1]This paper is based on a presentation made at the workshop on The Scientific Foundation for Sustainable Forest Biomass Harvesting Guidelines and Policies, Toronto, Ontario 18–21 February 2008, and on discussions by workshop participants.

[2]British Columbia Ministry of Environment, P.O. Box 9536 Stn. Prov. Govt., Victoria, British Columbia V8W 9C4. Author to whom correspondence should be sent. E-Mail: Shannon.Berch@gov.bc.ca
[3]Ontario Ministry of Natural Resources, Centre for Northern Forest Ecosystem Research, c/o Lakehead University, 955 Oliver Road, Thunder Bay, Ontario P7B 5E1.
[4]Faculty of Forestry, University of Toronto, 33 Willcocks St., Toronto, Ontario M5S 3B3.


Shannon M. Berch


Dave Morris


Jay Malcolm

Introduction

To foster sharing and discussion of issues and ideas related to the environmental sustainability of forest biomass harvesting, a three-day workshop was held in Toronto, in February 2008. Entitled "The Scientific Foundation for Sustainable Forest Biomass Harvesting Guidelines and Policy," the workshop brought together scientists, government regulators, industry, and environmental non-government organizations to share what is known about the effects of biomass removals on forest ecosystems, to identify research priorities for the scientific information required for guidelines and policies, and to create synergies and reduce duplication among different agencies across Canada as they conduct work relevant to their own ecosystems and circumstances. Several papers from this workshop have already been published in *The Forestry Chronicle*, including an introduction to the workshop (Titus *et al.* 2010), information on low-impact forest bioenergy systems (Lattimore *et al.* 2010), a conservation perspective (Hesselink 2010), issues related to site productivity (Thiffault *et al.* 2010), operational and cost considerations (Ralevic *et al.* 2010), and guidelines for whole-tree harvesting in Sweden (Levin and Eriksson 2010). This paper addresses the biodiversity-focused content of the workshop.

Perspectives on biodiversity can be narrow or broad in scope (e.g., genetic, population, species, communities, or ecosystems). The workshop organizers determined that a broad and comprehensive approach was required for these discussions to help frame the range of issues and challenges, hence our working definition of biodiversity was a broad one: "The variety of life and its processes, including genes, species, communities, and ecosystems and the ecological and evolutionary processes that keep them functioning" (Noss and Cooperrider 1994). In this paper, we consider potential implications of intensification of biomass removal for biodiversity, note gaps identified by workshop participants, and examine how all of this might affect policy development.

Implications of the Intensification of Biomass Removal for Biodiversity

Forest biomass provides habitat for a diverse array of organisms, including thousands of vertebrate, invertebrate, bryophyte, lichen and fungi species. These species interact with each other and the environment to provide a diverse array of important ecosystem functions and services (Ferris and Humphrey 1999). These functions include slow release of nutrients, soil organic matter supply, contributions to soil development and productivity, energy for the heterotrophic organisms of the forest, microsites for plant establishment, disease and insect pest regulation, free-living and symbiotic nitrogen fixation, mulching, ion and moisture retention, habitats for a wide variety of species, and physical protection from erosion.

From a biodiversity perspective, the presence and continued supply of fresh to highly decayed dead wood represents a key concern in managed forest systems (Hansen *et al.* 1991, Siitonen 2001). For example, among forest-dwelling vertebrates in Ontario, an estimated 26% use tree cavities and 36% use dead wood (Naylor 1994). Siitonen (2001) estimated that of the 19 000 species of forest-dwelling organisms of Finland, some 20% to 25% were saproxylic (i.e., dependent on dead or dying wood or other organisms associated with it). Logs in later stages of decay provide highly diverse habitats and are especially important for bryophyte (moss and liverwort) diversity both at the stand and landscape levels (Cole *et al.* 2008) and many red-listed species in Europe are characteristic of these habitats (Hylander and Dynesius 2006). As logs decay, the composition of species associated with them changes; for example, Vanderwel *et al.* (2006) found that the family-level composition of insects emerging from logs changed over time and reflected changes in trophic relationships within the logs, with xylophagous insects and their predators most abundant in fresh logs and saprophages, fungivores, predators and parasitoids most abundant in highly decayed logs.

A wide variety of studies indicates that changes in woody debris supplies due to forest management, including both changes in quantities and quality (such as size) can have strong impacts on forest biodiversity (Nordén *et al.* 2004, Josefsson *et al.* 2010, Verschuyl *et al.* 2011). Such impacts are especially strong in western Europe, which has a relatively long history of intensive forest management and associated fibre removal. Effects on invertebrate and fungi communities in some cases have been profound. Large numbers of saproxylic species are now threatened; for example, logs and snags were judged to be critical factors for >60% of Sweden's 739 threatened forest invertebrate species (Berg *et al.* 1994). Similarly, of 727 forest species classified as threatened in Finland, reduction in dead wood was identified as the principal threat factor for 217 species and as one of the threat factors for 317 (43.6%; Rassi *et al.* 1992 cited by Siitonen 2001). Increasingly, certain groups of fungi and insects in Europe are becoming isolated to rare dead wood-rich stands, which, because of their small size and isolated nature, show evidence of species loss and a potential future extinction debt (e.g., Økland 1994, Penttilä *et al.* 2006, Berglund and Jonsson 2008). Although forest management is a much more recent phenomenon in North America, dead wood supply also has been found to correlate with abundances and richness of insects and fungi (e.g., Clarkson and Mills 1994, Gomez *et al.* 2003) and certain specialized and/or rare wood-inhabiting species are more common in old growth than managed forests (Spence *et al.* 1996, Desponts *et al.* 2002). In boreal mixedwoods of Alberta, Work *et al.* (2004) determined that although percent cover of moss and forbs were most important in determining ground beetle species assemblages, stands with <43 m^3 ha^{-1} dead wood differed from stands with more dead wood. In poplar stands, rove beetles were found to be closely associated with old and mature forests and dead wood (Buddle *et al.* 2006). In central Ontario, Vanderwel *et al.* (2006) found that fungivorous insects emerging from logs were most abundant in logs surrounded by high volumes of dead wood. Given this evidence of the sensitivity of many species to the quality and quantity of dead wood, the question we face in Canada is whether forest biomass harvesting could result in the kinds of depletions evident in Europe and, if so, what policies and practices are needed to avoid this outcome.

Fine woody materials, such as branches and twigs, and non-woody foliage are also important habitats and may also serve as a bioenergy source when slash-bundling systems are used. In southern Sweden, Nordén *et al.* (2004) examined fungi fruiting on fine and coarse dead wood (using a 10-cm diameter limit) in a temperate broadleaf forest and determined that 75% of ascomycetes and 50% of red-list species were found on fine dead wood. Fungal endophytes that live within plant leaves and twigs are ubiquitous and diverse (Saikkonen 2007) and can be very habitat-specific; for example, leaves of birch and alder have been found to host entirely different communities of fungal endophytes than twigs of the same plants (Sieber *et al.* 1991, Barengo *et al* 2000). Sherwood and Carroll (1974) documented 25 microfungi fruiting on needles and twigs from just a few Douglas-fir trees. Camacho *et al* (1997) sequenced over 100 fungi taxa isolated from asymptomatic spruce needles. It is clear that there is much to learn about the biodiversity of foliar and fine-wood inhabitants; at the same time, one wonders if forest biomass harvesting could ever be sufficiently intense to threaten biodiversity associated with these finer substrates.

The use of culture-independent molecular approaches is finding species, genera, and even subphyla of previously unknown fungi in insects, forest canopies, plant roots, plant leaves, and soil (Porter *et al.* 2008, Schmidt *et al.* 2008). Fischer (2008) sampled fungal species from 60 lightly and heavily decayed logs in boreal northeastern Ontario and recorded 304 species from DNA-based sampling, but only 116 species from fruiting body samples of an even larger sample of logs (the 60 plus an additional 90). Interestingly, the two samples overlapped relatively little: only 14 species were in common to both sampling methods. When attempting to monitor the impacts of intensive biomass removals on fungi, the monitoring of fruiting bodies evidently tells only part of the story.

Catastrophic disturbances such as epidemics and forest fires can transform virtually all living trees in affected stands into dead wood (Siitonen 2001). For example, Morris *et al.* (unpublished data[5]) estimated that nearly 140 Mg ha^{-1} (70 m^3 ha^{-1}) of dead wood (standing dead + downed woody debris) remained following stand-replacing wildfires in boreal conifer stands. After 40 years, this amount declined due to wood decomposition processes to approximately 40 Mg ha^{-1} (18 m^3 ha^{-1}). In Fennoscandia, fire disturbance and its episodic, large inputs of dead wood have almost been eliminated (see Siitonen 2001 for references). In British Columbia fire suppression seems to have decreased the annual area burned, although fires have by no means been eliminated. The number of reported forest fires increased from the 1920 to 1960 period (average of about 1600 annually) to the present (about 2300 annually since the 1960s), although they burn only half the area (170 000 ha yr^{-1} versus 80 000 ha yr^{-1}, respectively) (John Parminter, Researcher Emeritus, BC Ministry of Forests and Range, unpublished data). Research suggests that disturbance-based systems are ecologically resilient, but just how resilient they are to anthropogenic disturbances is not fully understood (Bunnell and Houde 2010). Management policies may assist in this regard, e.g. Ontario's Natural Disturbance Pattern Emulation guide requires the retention of trees and recommends leaving dead wood to reflect the structure that might have been left following a natural disturbance (OMNR 2001). Continued research and incorporation of research findings into decision-making is needed to manage forest biomass removals at levels safely below those that might surpass inherent ecosystem resilience (Joe Churcher, Ontario Ministry of Natural Resources, personal communication, September 2010).

Intensive forest biomass harvesting may lead to decline in habitat levels essential for sustaining biodiversity. In southern Fennoscandia, for instance, average volume of dead wood in old-growth forests was 60 m^3 ha^{-1} to 90 m^3 ha^{-1}, similar in mature forests, and higher following disturbance, but only 2 m^3 ha^{-1} to 10 m^3 ha^{-1} in managed forest lands; even managed stands over 140 years since harvest average only 15.9 m^3 ha^{-1} (Siitonen 2001). In Ontario, Hunt *et al.* (2010) estimated standing and downed dead wood in young (10 to 14 years old) jack pine and black spruce plantations to be 2 m^3 ha^{-1} to 5 m^3 ha^{-1} (4–10 Mg ha^{-1}) compared to 42 m^3 ha^{-1} to 78 m^3 ha^{-1} (96–178 Mg ha^{-1}) in similarly aged post-wildfire stands (Wang *et al.* 2003). Forest habitats such as decayed wood, proximity to decayed wood, and humps and depressions arising from wind-throw were significantly reduced in Scots pine-dominated forests in Fennoscandia that had been heavily utilized since the 16th century in comparison to relatively natural forests (Kuuluvainen and Laiho 2004). Even lighter-touch forest operations, such as selective logging in the boreal forest of eastern Finland (Sippola *et al.* 2001) resulted in over 40% less volume of dead wood compared to natural forests, with particular depletion of relatively intact logs (decay classes 1 to 3). Similar results were found in Sweden where selective forest logging (22 to 26 stems per ha) a century earlier resulted in a reduced number of decaying logs relative to uncut stands (Josefsson *et al* 2010). Whole tree harvesting can reduce site productivity relative to stem-only harvesting on nutrient-poor sites (Wei *et al* 2000, Walmsley *et al* 2009) and removal of slash also reduces habitat, alters microclimate, and reduces local biodiversity (Janowiak and Webster 2010).

Currently in Canada, some above-ground biomass typically is retained on site following whole-tree harvesting oper-

[5]Morris, D.M., L. Edgington and D.R. Duckert. 2006. Carbon and nitrogen dynamics associated with post-wildfire stand development for jack pine-dominated sites in northwestern Ontario. (Abstract). In Soil Sci. Soc. Am. 2006 Annual Meeting, Nov. 12–16, 2006, Indianapolis, Indiana.

ations, including non-commercial stems and species and other residual material. For example, Ralevic *et al.* (2010) reported that following full-tree harvesting operations in Ontario, 41% to 59% (94–225 m^3 ha^{-1} or 41.2–99.1 odt ha^{-1}) of total above-ground biomass remained on site following harvesting in boreal mixedwoods and 25% (53 m^3 ha^{-1} or 25.3 odt ha^{-1}) following harvesting in a black spruce stand. Of this, 9% to 17% and 7%, respectively, was in roadside residue piles after recovery for energy generation rather than being on the cutblock (no data were provided on the size, species and decay class of remaining material). In British Columbia, monitoring of sites harvested during 1998 to 2004 found coarse woody debris volumes after harvesting that were comparable to unharvested reference stands, but noticeably lower density of pieces >10 m long (BCMFR 2008). As a result, the Chief Forester released guidance to raise the level of awareness around the need for increased dead wood planning and management before and during harvest operations with a focus on improving dead wood quality, especially as it relates to piece size (Densmore 2010).

Recently, a number of jurisdictions have developed guidelines specific to biomass harvesting operations. In 2008, Sweden developed a directive with recommendations for maintaining insect habitat, the extraction of logging residues, and ash recycling, including limiting ash use on sensitive sites. (Skogsstyrelsen 2008). With respect to biodiversity, the directive recommends retention of rarer tree species and 20% of logging residues (branches and tops) and dead wood >10 cm in diameter. Nevertheless, efficient biomass harvesting operations in Sweden are now removing as much as 90% of total logging residue (Gustaf Egnell, Swedish University of Agricultural Sciences, personal communication, August 2010). Minnesota's 2007 biomass harvesting guidelines also recommend retention of 20% of tops and branches (MFRC 2007). In contrast, Titus *et al.* (2009) suggest that 50% on-site retention of tops and branches produced might be prudent given soils, biodiversity and water quality concerns. Bunnell and Houde (2010) recommend that 50% of naturally occurring amounts of down wood be sustained in managed landscapes (averaged across cutblocks) to allow for retention levels that emulate those of unmanaged landscapes. It is, however, much more difficult to manage dead wood at the landscape level than at the site level because a landscape may include different land owners and different logging companies.

The challenge in the part of Canada where forest utilization is not as intensive as in Fennoscandia, and where most forest operations on publicly owned forests are still harvesting natural forests, is determining to what extent biomass harvests can increase fibre use while sustaining biodiversity, its functions, and the broad suite of ecosystem services that it provides. In parts of eastern Canada, such as Nova Scotia, that more closely parallel the long history of forest utilization of Fennoscandia, the future of biomass harvesting is controversial. Recently, the Nova Scotia Forest Panel of Expertise provided two reports, one stating that the province's forests are already vastly modified and would benefit from an ecologically based, multi-aged forest management approach with little or no biomass harvesting (Forest Panel of Expertise 2010a), and the other that the economy of Nova Scotia could benefit from biomass harvesting under specific biomass guidelines (Forest Panel of Expertise 2010b).

Key Knowledge Gaps Identified by Workshop Participants

Intensification of forest harvesting for biomass is a relatively new subject in Canada. There has been a limited number of journal publications specific to biomass removal effects on biodiversity to date, particularly when compared to plantations or focused on coarse woody debris (Fig. 1; see also Appendix 1). In addition, the state of knowledge in Canada appears to be different than that in Fennoscandia (Fig. 2). For example, emphasis in Canadian biodiversity research relevant to the biomass removal question has focused more on bird and mammal responses, whereas Fennoscandian research has focused more on fungi. To date, there has also been a greater focus in Fennoscandia on biomass and woody debris-related research than in Canada (Fig. 2).

Given the complexity of forest biodiversity, and the overall lack of research specific to biomass harvesting, workshop participants were asked to highlight gaps in our knowledge and how these might translate into challenges for sustainable forest management in Canada, especially in light of the increased fibre utilization that is possible with biomass harvesting. These gaps are summarized below.

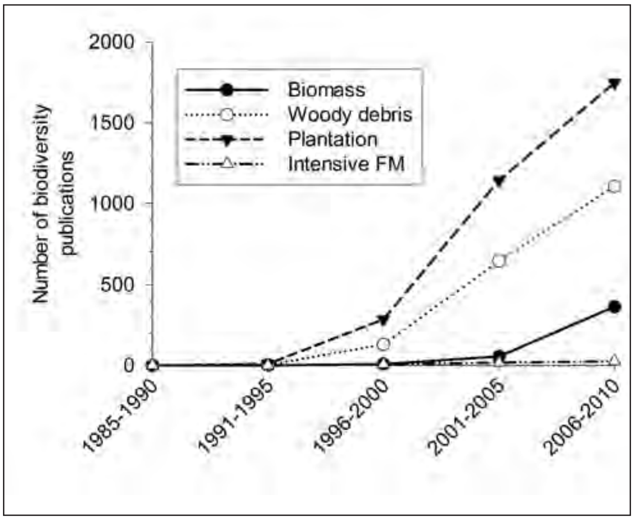

Fig. 1. Number of biodiversity-related publications in Canada and Fennoscandia over time and by subject area. Data are from Web of Science searches undertaken in September of 2010; see Appendix 1 for search terms.

Complexity and Thresholds

Important habitat attributes

To adequately protect biodiversity, it is essential to know which habitat attributes are important and how they respond to increased levels of biomass removal. Habitat attributes, including elements such as vertical complexity, horizontal patchiness, plant species composition, tree size, and a variety of characteristics of dead wood among others, contribute to maintaining biodiversity at the stand scale (McComb 2008). It seems reasonable to expect, based on experience elsewhere, that intensive biomass harvesting in contrast to traditional timber-focused operations can leave sites with relatively low levels of dead wood and slash. The fact that many species at risk in northern Europe are saproxylic indicates that long-

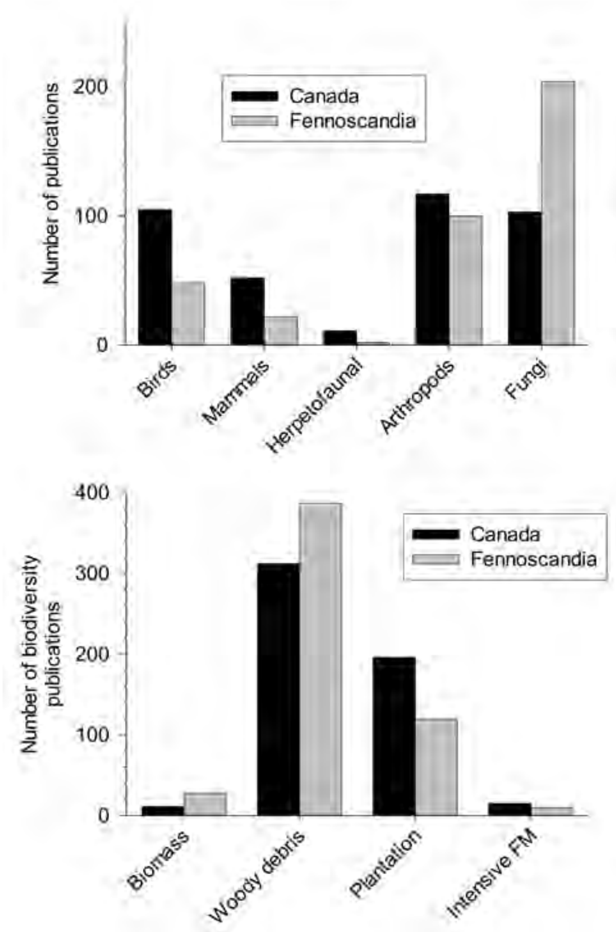

Fig. 2. As Fig. 1 except that number of publications are shown for two regions (Canada and Fennoscandia) by taxon (top) and subject area (bottom). In the upper figure, the search included only the four subject areas. See Appendix 1 for search terms.

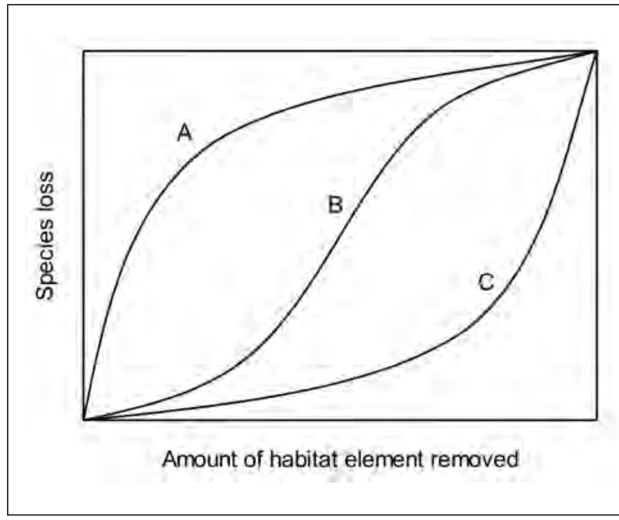

Fig. 3. Hypothetical species loss in response to increased removal of a dead wood-associated element type.

term, intensive removal of biomass can dramatically alter forest ecosystems. Fig. 3 illustrates three hypothetical responses to increased biomass removal that are illustrative of the potential impacts of the removal of a specific habitat element. Curve C, for example, would suggest a considerable amount of resiliency and resistance to change over a wide range of removals, whereas curve A illustrates a highly sensitive system even at low levels of removals. The third curve (B) illustrates some level of resiliency, but abrupt ecological change once a particular removal threshold is reached, as illustrated by Huggett 2005, Groffman *et al*. 2006, and others. Although critical threshold levels can be predicted from modelling approaches, empirical support is limited or lacking (Homan *et al*. 2004). An associated problem is the definition of habitat types: Ranius and Jonsson (2007) note that if habitat is too broadly defined, then clear threshold relationships are unlikely to be observed because communities are actually responding to different aspects of the habitat (e.g., standing dead wood vs. heavily decayed deciduous logs). Well-designed, long-term research is required to empirically derive these response curves for specific habitat elements and to define appropriate threshold levels of biomass removal that are sufficient to maintain biodiversity in specific ecosystems over the long term.

Particularly complex, both spatially and temporally, is the relationship between biomass removal, population viability and species persistence, and the ecological services that biodiversity provides. Currently in Canada, operational biomass harvesting methods and direction largely targets unmarketable and unmerchantable trees or parts of trees, including branches and tops (e.g., roadside debris) (e.g., OMNR 2008). These methods typically retain >25% of the total aboveground biomass on site (Ralevic *et al*. 2010). The situation, however, is not the same in other countries. For example, in Sweden a combination of pricing and skilled equipment operators has resulted in removals that routinely are up to 90% to 95% of logging slash, and in some cases also include the removal of stumps (Gustaf Egnell, Swedish University of Agricultural Sciences, pers. comm., August 2010). One might predict that as biomass removal becomes more locally intense and pervasive across the landscape, increasing effects can be expected, from local reductions in populations, to endangerment of species, to impairment of ecological services. Relatively more is known about the biodiversity values of coarse than about fine dead wood. Clearly, there are species that use fine dead wood such as branches and twigs as habitat, but what is less clear is whether these species and this habitat is more or less sensitive to biomass harvesting than coarse dead wood and associated species and whether forest management and biomass harvesting result in more or less being retained relative to natural disturbances, for example.

Population viability

For species intimately linked to dead wood, population viability analysis can be used to estimate the sensitivity of a population to extinction or extirpation given different intensities of biomass removal at a range of spatial and temporal scales. Each species is different and much work needs to be done to determine which are most likely to be negatively affected by intensification of biomass removals. If this work supports the concept of keystone species that can represent larger communities, then population viability analysis of these keystone species could be used to assess sensitivity of guilds or communities.

It has been suggested that there is a considerable amount of ecological (functional) redundancy in forest systems, particularly at the lower trophic levels (Moretti and Legg 2009). This redundancy, in turn, represents the foundation for ecosystem resilience and stability (Gordon *et al.* 2001). Within the context of biomass harvesting, a key question to ask with respect to impacts on biodiversity is: "which kinds, and what amounts, of biological simplification lead most readily to significant or irreversible changes in the inherent structure and function of an ecosystem" (Walker 1992).

Indicators

Keystone species, as mentioned above, might be useful for the study and monitoring of more complex communities, but much research will be needed to determine how useful this approach will be and which species are useful keystones. Walker (1992) suggests an alternative approach to the species-based approach, based on the use of functional groups of organisms defined according to ecosystem processes. The coarse filter approach to management and monitoring involves representation of ecological land units within the historical range of variability based upon natural disturbance regimes. This approach could allow for some intensive biomass harvesting within the landscape as long as other parts of the landscape cover the rest of the natural range and maintain viable populations. Another approach to management and monitoring is the use of structures such as retained green trees or green tree patches and coarse dead wood as proxies for diversity, predicated on there being research supporting the link between these structural elements and biodiversity. Another research need is to understand better the implications of particular harvest practices and retention levels for future habitat supply, especially over the long term (one or more rotations). For example, management of dead wood supply is a relatively complex problem because of inputs from a variety of sources over time, including disturbance events and stand development. In addition, wood decay is a dynamic process, with the habitat value and amount of woody debris changing as the wood decays.

Biodiversity at Different Scales

Spatial scales of diversity

For biomass harvesting, impacts of management are most meaningful in a landscape context. This is perhaps best illustrated by the recent experience in Fennoscandia, where the use of small areas with high dead wood supply (and other natural forest features) that are interspersed across the landscape has been suggested as a strategy to maintain dead wood-dependent taxa (Ranius and Kindvall 2006, Berglund and Jonsson 2008). However, unless such areas are big enough and/or interconnected enough to maintain viable populations and their processes over time, eventual loss of taxa from individual islands of habitat, and across the landscape as a whole, can be expected (the so-called extinction debt [Tilman *et al.* 2002]). Such a debt appears to have been incurred in Sweden (Berglund and Jonsson 2008). A critical question is to determine how landscapes can be managed for social values and economic returns, but still be sustainable from an environmental and biodiversity context (e.g., Ranius and Kindvall 2006, Rompré *et al.* 2010).

Temporal scales of diversity

For practical reasons, more research on the effects of harvesting on biodiversity occurs over the short term than the long term. Because the consequences of habitat loss and biodiversity decline due to intense biomass harvesting will become manifest only after time, we need to utilize our long-term research installations, where possible, to ask biodiversity questions that may not have been the original focus of their design. Such considerations also highlight the potential utility of management as an experimental tool to learn about a system and about the assumptions upon which management is based (adaptive resource management sensu Holling 1978, Walters 1986, Lee 1993, and others).

Biodiversity/productivity links

A clear focus of concern among workshop participants was the implications of biofuel harvesting for site productivity. For example, several jurisdictions have suggested that biomass harvesting should be restricted on nutrient-poor sites. A number of participants noted that biodiversity itself is part and parcel of site productivity and that there are various ways of looking at this relationship. For instance, while simplified stands such as plantations may produce more timber or woody biomass than natural stands (e.g., Morris *et al.* 2011), they do so at the cost of reduced biodiversity (Hunt *et al.* 2005). But, from an economic perspective, failure to sustain biodiversity may incur economic costs over the long term to replace the attendant loss of the ecological (and economically valuable) services that biodiversity provides. An obvious example is competition and/or predation that keep populations of economically harmful species low. There are huge challenges in designing research that incorporates all the complexities and inter-relatedness of productivity and biodiversity through time, space, and scale. Equally, there are challenges in making clear to society the costs and benefits of managing for narrowly focused productivity (timber or woody biomass) versus managing more broadly for ecosystems that can supply a full range of ecological services.

Lessons from Other Countries

The centuries-long Nordic experience with intensive forest biomass removal and its impacts on biodiversity provides us with very useful information for Canada. Compared to Canadian forests, Nordic forests now have less dead wood and a high number of rare and endangered species that are dependent on dead wood. For Canadians to learn from the experience of others, it would be very useful for this body of knowledge to be critically reviewed and examined for parallels to our situation. In some cases (e.g., Imbeau *et al.* 2001 on bird fauna), red-listed taxa in Europe also occur in Canada (or very closely related taxa), begging the question as to whether such taxa can serve as early-warning indicators in Canada.

Operational Scale Planning and Policy

Biodiversity is only one of the components of policy development and operations planning; social, economic, and other environmental considerations are also key. For knowledge-based planning and policy development, researchers must provide complex information to policy-makers and forest managers in a clear, effective way. This will recognize that knowledge is context-specific and may not exist in one source, individual or publication, but may be the product of groups of people, experiences, or some structured process of discovery such as scenarios or narratives. Full life-cycle analysis of intensive forest biomass harvesting taking into account all environmental and social consequences is needed to inform sound evidence-based policy and decision-making.

Triad approach

Land-use planning with a triad approach (Hunter and Calhoun 1996) divides the operational land base into three levels of management intensity: intensive management, extensive management, and protected areas. Intensive management, such as short-rotation cropping, could be carried out close to mills thus minimizing haul distances. Where parts of the resource landbase are managed intensively, productivity is optimized through inputs (e.g., wood ash, fertilizer) and biodiversity may be reduced in order to channel potential productivity into the crop trees. In extensive forest management areas, tools for predicting site suitability for intensive forest biomass harvesting need to take into account productivity, operational and biodiversity issues in addition to the social decisions. There are risks with the triad approach, for instance because it may also reduce flexibility available to decision-makers and managers. To obtain benefits from our forest lands, specific operations should be carried out on the sites best suited to them, with the realization that such sites also may be critical for biodiversity. Improved mapping of high-value biodiversity areas and sensitive soils might permit the development of SFM that includes intensive biomass harvesting. Whether the triad approach is economically feasible in the Canadian north temperate and boreal climates remains to be determined.

Fire hazard reduction, regeneration of fire-exclusion overgrown forests

In fire-regenerated ecosystems, the forest fire dynamic as altered by management has contributed to the current patterns of biodiversity and forest condition. Useful research might be carried out into whether well-planned biomass harvesting may be substituted for natural fires to reduce fire risk in urban/rural interfaces and to re-establish biotic communities and stands that existed before industrial forest management.

Meaningful monitoring

It is challenging to design monitoring approaches that address biodiversity because so many species, scales, and processes are involved. Well-designed planning systems will focus on the desired future forest condition including structural and functional diversity and spatial and temporal scales. Meaningful monitoring of the impacts of biomass harvesting on biodiversity may have to rely on the use of proxies, umbrella species, indicator species, and keystones that are relevant to the natural disturbance regime and are feasible to monitor reliably and at reasonable cost. Monitoring should include specific objectives and thresholds that trigger policy or operational change within an adaptive management framework (Bell *et al.* 2008, Lattimore *et al.* 2010).

Conclusions

Clearly, biomass harvesting alters forest structure and biodiversity, even more than a century after the relatively light touch of selective timber harvesting, and it stands to reason that more intensive utilization of woody forest biomass leads to greater loss of dead wood and increased threats to associated taxa. It is also clear that much remains to be done to fully understand the role of dead wood, fine woody materials, and foliage and their associated biodiversity in forest ecosystems, including their functional role in productivity. We are especially ignorant of the roles and sensitivities of small and microscopic species. The funding of collaborations between existing, relevant long-term research projects and experts in different groups of organisms and their functions could help fill some of these information gaps.

However, politicians and forest managers are faced with making decisions now about forest biomass harvesting and with balancing environmental values with socio-economic values during this decision-making. Given the urgency that scientists and foresters face in providing sound scientific guidance to decision-makers, we believe that there are basic principles upon which this guidance can be based even though the details will need to vary by ecosystem and the land-use decisions will result from how environmental, economic and social risks and values are weighed.

After summarizing many of the issues related to biomass harvesting and sustainability, Janowiak and Webster (2010) concluded with a list of guiding principles for biomass management, including adapting management to site conditions, retaining organic legacies for soil productivity, retaining dead wood and structural heterogeneity for biodiversity, evaluating the role of fertilization and wood ash recycling, and using biomass harvest as a tool for ecosystem restoration.

To these, we add the following suggestions for consideration by policy-makers:

- Alternate intensity of biomass removal on the same site through time. If forest biomass is intensively harvested from a site, ensure that harvest at the end of the next rotation on that site is not intensive by leaving slash and large amounts of dead wood spread on site, combined with green tree retention to provide a supply of dead wood over the long term.
- Emulate natural-disturbance type landscape pattern. In a fire-disturbance landscape, one approach is to manage for an area intensively harvested that is comparable to the area that has been historically severely burned, an area bole-only harvested comparable to the area that was moderately burned, and an area on extended rotation comparable to that lightly or unburned. Extend the rotation to the range of age of the oldest stands in the landscape.
- Use structural attributes (e.g., quantity, quality, species composition, age of fine and coarse dead wood) as proxies for biodiversity. We cannot measure all aspects of biodiversity in each proposed cutblock or in a monitoring program, but we can use expert knowledge to select keystone attributes for conservation of habitat and consequently for species in an adaptive management approach. This is the approach used by the Forest and Range Evaluation Program in British Columbia for stand-level biodiversity monitoring (Province of British Columbia 2009).

- Identify and monitor key indicator taxa. Ultimately, the sustainability of biomass harvesting must be judged by the long-term viability of species themselves.

In closing, we propose that better ways of informing decision-makers, forestry practitioners and the general public of the issues related to forest biomass harvesting and biodiversity need to be found so that even in the absence of complete knowledge, there can be broader and more comprehensive discussion of these issue so that decisions are well-informed and balanced. Data-sharing, synthesis of information from diverse sources, and interpretation within the Canadian context of data from beyond our borders could fill some of our information gaps. Finally, it is important to recognize that in the absence of complete scientific information, forest managers and decision makers are well-advised to proceed with caution within a well-developed adaptive resource management framework.

Acknowledgements

The authors would like to thank Dan Puddister, Wayne Bell, Bill Chapman, Ian Thompson, and Steve Newmaster for their input/expertise in putting together the presentation entitled: *An overview of Canadian research on biomass removals and biodiversity* presented at The Scientific Foundation for Sustainable Forest Biomass Harvesting Guidelines and Policy workshop held in Toronto on February 18–21, 2008. In addition, the authors are grateful for the thoughtful comments and suggestions made by Dan Puddister, Ian Thompson, Bill Chapman and Brian Titus on an earlier version of this manuscript.

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Appendix 1. Search terms used in Web of Science searches to create Fig. 1 and Fig. 2.

TAXON
Bird = (bird* OR avian)
Mammal = (mammal*)
Herpetofauna = (amphibian* OR herpetofauna)
Arthropod = (insect* OR arthropod* OR arachnid*)
Fungi = (fung*)
Biodiversity = the above plus (biodiversity OR vertebrate*)

SUBJECT AREA
Biomass = (biofuel* OR “biomass harvesting” OR “biomass removal*”)
Woody debris = (“woody debris” OR “dead wood” OR snag* OR “downed wood”)
Plantation = (plantation*)
Intensive FM = (“intensive silviculture” OR “intensive forest management”)

REGION
Canada = (Canada OR Newfoundland OR Labrador OR “Prince Edward Island” OR “Nova Scotia” or “New Brunswick” OR Quebec OR Ontario OR Manitoba OR Saskatchewan OR Alberta OR “British Columbia” OR Yukon OR “Northwest Territories” OR Nunavut)
Fennoscandia = (Fennoscandia OR Norway OR Finland OR Sweden)