Coping with complexity: Designing low-impact forest bioenergy systems using an adaptive forest management framework and other sustainable forest management tools¹

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ABSTRACT

Forest fuel production is a growing industry in Canada and elsewhere, as governments strive to increase energy security and find alternatives to the use of fossil fuels. While forest bioenergy can provide environmental benefits such as renewability and carbon emissions reductions, the industry can also pose environmental risks through increasing pressure on forest resources. Because large-scale forest bioenergy production is relatively new to Canada, much is still unknown about how such an industry might evolve and impact forest ecosystems. These unknowns, along with the cross-sectoral, multi-stakeholder nature of the industry, make planning for sustainable forest bioenergy systems quite challenging. In this paper, we introduce some of the challenges to creating sustainable systems, and we discuss how sustainable forest management frameworks like Adaptive Forest Management and Sustainable Forest Management Certification can help to meet these challenges. We also discuss the importance of technology transfer to ensuring that the best available knowledge forms the basis for effective standards and management plans. Sustainable forest management frameworks can help to organize, distil and communicate the growing body of research on forest bioenergy production, link policy to practice through the creation of standards, and incorporate provisions for continual learning and system adaptation, all of which are key to the long-term sustainability of the rapidly evolving forest bioenergy sector.

Key words: bioenergy, sustainable forest management frameworks, adaptive forest management, certification, standards, technology transfer

RÉSUMÉ

La production de carburant à partir des forêts constitue une industrie en croissance au Canada et ailleurs dans le monde, étant donné que les gouvernements cherchent à accroître le niveau de sécurité énergétique et à trouver des alternatives à l'utilisation des combustibles fossiles. Même si la bioénergie forestière peut comporter des bénéfices environnementaux du fait qu'elle est renouvelable et qu'elle peut réduire les émissions de carbone, l'industrie peut également engendrer des risques environnementaux suite à l'accroissement de la pression sur les ressources forestières. Compte tenu que la production à grande échelle de bioénergie forestière demeure une chose relativement nouvelle au Canada, il y a beaucoup d'inconnues entourant l'évolution de cette industrie et sur ce que seront ses impacts sur les écosystèmes forestiers. Ces inconnues, en plus de la nature intersectorielle et multi-intervenants de l'industrie, font en sorte que la planification des systèmes durables de bioénergie forestière représente tout un défi. Dans cet article, nous introduisons certains des défis reliés à la création de systèmes durables et nous discutons de la façon selon laquelle les cadres de référence d'aménagement forestier durable comme l'aménagement forestier adaptatif et la certification de l'aménagement forestier durable peuvent aider à relever ces défis. Nous discutons également de l'importance du transfert technologique dans le but d'assurer que les meilleures connaissances disponibles soient à la base des normes en vigueur et des plans d'aménagement. Les cadres de travail en aménagement forestier durable peuvent aider à organiser, distiller et diffuser la masse croissante de la recherche sur la production de bioénergie forestière, à faire le lien entre les politiques et les pratiques au moyen de la création de normes et à incorporer des mesures visant un apprentissage continu et des systèmes d'adaptation, qui sont tous des éléments clés de la durabilité à long terme du secteur en évolution rapide de la bioénergie forestière.

Mots clés : bioénergie, cadres de travail en aménagement forestier durable, aménagement forestier adaptatif, certification, normes, transfert technologique

¹This paper is based on an invited presentation made at a workshop on *The Scientific Foundation for Sustainable Forest Biomass Harvesting Guidelines and Policies*, Toronto, Ontario, 18–21 Feb. 2008.

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inherent complexities and achieve a sustainable forest bioenergy industry. We will begin with a brief introduction to some of the challenges facing sustainable forest biomass production systems. We will then discuss how the application of an Adaptive Forest Management (AFM) framework can meet these challenges. Using an AFM approach can help scientists, forest managers and other stakeholders work together to:

- effectively gather, distil and communicate volumes of relevant but largely unutilized research;
- link this research to policy and practice through the formulation of science-based standards (e.g., legislation, guidelines, criteria and indicators);
- design low-impact practices that meet these standards; and
- incorporate provisions for monitoring, assessment, learning and adaptation throughout the life of the systems created.

We also discuss ways in which sustainable forest management certification schemes might act as vehicles for delivering an AFM framework to forest fuel production and harvesting operations. Finally, we will give some attention to technology transfer, as the effectiveness of all of the tools and processes discussed in this paper is dependent upon the timely and accessible transmission of knowledge among various stakeholders.

Please note that while our focus here is on environmental aspects at the forest fuel production and harvesting stages, it is important that environmental considerations be assessed along with social and economic aspects of sustainability and within a wider analysis of the entire bioenergy supply chain.

Challenges to Creating a Sustainable Forest Bioenergy Industry in Canada

The idea of the industrial production of energy from forest biomass is a relatively new concept in Canada, despite its longer-standing prominence elsewhere. In Nordic countries, for example, industrial-scale bioenergy production for heating and electricity has been practised for many years, while in many developing countries traditional wood has been a long-standing primary source of energy. Inspired by the need to find fossil fuel alternatives, the past three decades have seen a flurry of research, projects and initiatives to test the viability of forest bioenergy production in Canada and elsewhere in the world (Luxmore 2008). The rapid expansion of interest in the forest bioenergy sector lends a sense of urgency to the need for knowledge and standards to ensure sustainability. Designing systems that will be sustainable in the long run, however, may be quite challenging. Thomas Buchholz summed up some of these challenges when he asked "how can we improve the predictive power of sustainability assessments if we do not know what the expectations to an evolving bioenergy system will be in an uncertain future and if we do not have the confidence that the complex system has been fully specified?" (Buchholz *et al.* 2007).

Introduction

In a growing, changing and globalizing world, designing systems that sustain both people and the environment is a much less simple task than it once seemed. In fact, it is often difficult to know just where to begin. John Gall, American author and systems theorist, is famously quoted as saying "a complex system that works is invariably found to have evolved from a simple system that works" (Gall 1975). In today's world, where processes and structures can be quite vast and intricate, many people who design and manage complicated systems find Gall's statement a useful place to start when trying to navigate the sea of complexities they must face. Perhaps it is also a useful place from which to begin a discussion of sustainable forest management for forest fuel production. Wood is a very basic, ancient source of energy; in early times, people gathered, chopped, sawed and burned wood to heat dwellings and cook food, governed only by the needs and actions of individuals and rarely causing large-scale damage to the forests from which they harvested. Wood energy systems were simple, and they worked. As civilizations evolved and people developed manufacturing industries fuelled by wood, larger quantities of biomass were required and forest ecosystems began to feel the stress of more intensive harvests. Now, in the 21st century, the idea of sustainably producing industrial and household energy from forest resources is more complex than ever, with high populations and greater demands presenting more challenges than ever before.

If we wish to maintain the ecological integrity and productive capacity of forests in the face of growing demands and pressures, every decision we make regarding our interventions must be supported by a variety of stakeholders and follow regulations and guidelines designed to protect the forest environment as much as possible. Whether production methods are still basic (e.g., gathering and burning wood directly) or more intricate (e.g., industrial combined heat and power production), the task of meeting the needs of today's societies without compromising our resource base is complex. In the centre of this complexity lies sustainability. How can we obtain energy from the forest without compromising forest sustainability? How can we understand the complex issues involved and distil them down to create systems that are both manageable and effective in order to achieve the goal of sustainability?

Complex systems can be managed using a number of frameworks and tools. The objective of this paper is to describe how sustainable forest management frameworks can help scientists, policy-makers and forest managers handle

Fig. 1. An illustration of the complex web of stakeholders involved in the Canadian forest bioenergy industry.

One reason it is difficult to predict how expectations of a bioenergy system will evolve is because of the multitude of stakeholders involved in the industry, each with different interests, values and concerns. Fig. 1 depicts a number of government agencies, industry players, academic institutions and public and private groups who hold a stake in bioenergy production. When designing sustainable, workable forest fuel production and harvesting systems, it is important that all stakeholders be involved right from the beginning. Facilitating communication and information exchange among various parties can, however, be a significant challenge to planning and implementation. One major obstacle to effective information sharing is the tendency for high-quality science to remain within academic circles, rather than being synthesized and packaged in an accessible format for use by policy-makers and other stakeholders. Using systematic frameworks (e.g., sustainable forest management frameworks), both to capture existing scientific knowledge and to structure further scientific inquiry, can help move science from the realm of academic interest to that of operational relevance. Furthermore, frameworks can provide an interface through which various stakeholders can interact, communicate, share and learn.

In addition to aiding in the synthesis and transmission of existing knowledge, sustainable forest management frameworks can incorporate mechanisms for continual learning. This helps managers and researchers overcome the second obstacle to the development of sustainable forest bioenergy systems: incomplete information. As Buchholz pointed out, we cannot yet be confident that we understand all of the potential impacts, positive or negative, of the different biomass production and harvesting systems currently under consideration. As with any emerging industry, it will take time, research and experience to better understand the implications of our actions and how to effectively design systems for long-term sustainability. One stepwise approach to continually increasing knowledge while improving the sustainability of operations includes the following components:

- synthesis of the best available knowledge (e.g., preliminary results from Canadian studies and experience, lessons learned from other countries, general knowledge about forest ecosystems and sustainable forest management);

- design and implementation of a number of management plans based on this knowledge;
 - monitoring and assessment of the impacts of each intervention;
 - and use of the information gained through this process to inform future research directions and management plans.
- This type of progression is known as Adaptive Forest Management (AFM), an overarching framework for SFM.

Learning by Doing: The Adaptive Forest Management Framework

Adaptive Forest Management is an approach that was developed in the 1970s by C.S. Holling as an alternative to the traditional North American view of environmental assessment as a “passive reaction to an independently developed proposal” (Holling 1978). Rather than have an independent body generate a policy or management prescription that is then reacted to if and when that policy or prescription proves inadequate, the AFM approach integrates research, planning, management and monitoring into a continuous process that encourages learning and adaptation (McAfee *et al.* 2006). The type of system adaptability fostered by AFM is critical when dealing with complex, rapidly evolving and hard-to-predict systems such as forest fuel production, conversion and use (Bormann *et al.* 2007, Buchholz *et al.* 2007).

The Adaptive Forest Management framework encompasses the steps outlined in Fig. 2.

Such a framework can help to distil and categorize existing knowledge, linking it to policy and practice. The entire process is grounded in research; at each step, scientific information is consulted, modified or generated through experience and further research to fill gaps in knowledge.

Step 1: Identify issues

The first step in an AFM framework is to identify potential issues that could affect system sustainability, based on the best

Fig. 2. Adaptive Forest Management framework. Rather than a linear progression, the AFM framework is a continuous cycle, embedded within a foundation of research and knowledge (represented by the large oval) which informs each of the six steps. It begins with the identification of issues and proceeds through the next five steps. Information gained through Step 6 (assessment) is then fed back into the system so that issues, standards and practices are revised according to the most up-to-date knowledge available.

available knowledge. Lattimore *et al.* (2009), for example, conducted an extensive review of literature on the impacts of forest fuel production and harvesting on forest ecology and identified possible changes to ecosystem attributes such as soils, water and biodiversity (see Table 1).

A significant body of research currently exists on potential impacts that should be tapped during this stage. With regard to soils, for example, a number of long-term research trials have been conducted or are ongoing to determine the effects of intensive biomass removal on the soil properties of certain sites (see Smith *et al.* 1986, 2000; Johnson and Curtis 2001; Burger 2002; Powers *et al.* 2005; Fleming *et al.* 2006; McLaughlin and Phillips 2006; Morris and Fleming 2006; Raulund-Rasmussen *et al.* 2007). Long-term studies are criti-

Table 1. Potential impacts of forest fuel production systems and harvesting on soil chemical properties (Lattimore *et al.* 2009).

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- Reduction in total capital and availability of nutrients (especially N, Ca, P and K) stored in biomass
 - Increased nutrient leaching
 - Base cation depletion leading to pH changes
 - Water balance changes leading to increases in salinity
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cal to determining impacts over more than one rotation. The knowledge gained through years of scientific research is key to identifying potential impacts; knowledge can then be modified as new information is gained through ongoing research and management experiences. Once potential issues have been identified, standards addressing these issues are developed to guide sustainable practices.

Step 2: Develop standards

Standards to guide sustainable forest biomass production and harvesting can come in a variety of forms, including policies, guidelines and best management practices, and criteria and indicators (C&I). Standards vary according to:

- their levels of specificity;
- the ways in which they are employed; and
- the roles that they play in governance of sustainable biomass production and harvesting.

Where available, policies, guidelines and C&I can be used in conjunction with each other and within a framework of Adaptive Forest Management to structure sustainable practices.

Policies

While the production and harvesting of forest biomass for bioenergy must comply with policies governing forestry, energy production and environmental protection, government policy and legislation designed specifically for this industry are rare (Roos 2002). At a national level, the United Kingdom, Germany, Belgium and the Netherlands are leading in their development of comprehensive policy frameworks to address issues of sustainable biomass and bioenergy production (Cramer *et al.* 2006, van Dam *et al.* 2006). At a supra-national level, the EU aims to have a sustainability scheme put together for all forms of bio-based energy (aside from liquid fuels, which are addressed separately) by the end of 2010 (Public

Technology Limited 2008). No legislation specific to forest bioenergy production currently exists in Canada, although a number of provincial governments are currently working to develop policies for this emerging industry. For example, the proposed forest biomass policy for New Brunswick offers general guidance for sustainability, including the stipulation that “biomass availability will be limited to the amount that can be removed from the forest floor without compromising the forest’s long-term health” (Legislative Assembly of New Brunswick 2007). Policy prescriptions usually rest at a similarly broad level, stating a general condition that must be met rather than offering more precise and measurable requirements. More detailed prescriptions can come in the form of guidelines or best management practices; these can help forest managers design their operations so that they meet broader legislative requirements.

Guidelines and best management practices

Guidelines are usually developed to address local or regional conditions and can provide a toolkit for the design and implementation of sustainable forest fuel production and harvesting operations. They are most effective when they are based on the best available science (e.g., regarding local soils, water, biodiversity and forestry practices) and presented in a logical and accessible manner for use by forest managers and practitioners. Comprehensive guidelines are not yet available in Canada, while in North America, the state of Minnesota is a leader in the development of guidelines for forest biomass harvesting. “Biomass Harvesting Guidelines for Forestlands, Brushlands and Open Lands” was published in 2007 as an addendum to an existing handbook of guidelines for site-level forest management put forth by the Minnesota Forest Resources Council (MFRC) (MFRC 2007). Knowledge of Minnesota’s unique environmental conditions was used in the development of these specific and often measurable guidelines. For example, one guideline urges managers to “avoid biomass harvesting (over and above bolewood utilization) on: ombrotrophic soils deeper than 24 inches and aspen or hardwood cover types on shallow soils (8 inches or less) over bedrock” (MFRC 2007). (Guidelines or best management practices [BMPs] also exist for Missouri, Pennsylvania and Wisconsin, and are under development for Maine: see Evans 2008; see also reviews of European policies and guidelines in Stupak *et al.* 2007 and 2008a). A number of research trials on various forest types grown in different soils show that impacts on soil physical and chemical properties can vary significantly from site to site (e.g., Smith *et al.* 1986, Federer *et al.* 1989, Briggs *et al.* 2000, McLaughlin and Phillips 2006), and even from tree species to tree species (Hacker 2008). For example, while current research seems to indicate that the effects of residue removal on soil nutrients are short-term on sites that are high quality, sites that are nutrient-poor may face long-term effects. Identifying sensitive environments and planning management accordingly is one way to avoid long-term damage. A variety of site conditions and forest types still need to be assessed across the Canadian landscape so that site-specific guidelines can be formulated wherever operations are planned (cf. Hornbeck *et al.* 1990).

Best management practices are similar to guidelines in their operability; they transform knowledge about local con-

ditions and practices into prescriptions for low-impact operations by specifying methods that reduce negative impacts on soils, water and biodiversity. Guidelines and BMPs are meant as recommendations, not as requirements; legislation can, however, require that guidelines and BMPs be followed. For example, the Minnesota State Legislature requires that logging slash be managed in compliance with the guidelines for biomass harvesting set out by the Minnesota Forest Resources Council and that available BMPs be followed (Minnesota Office of the Revisor of Statutes 2007). Having both policies and guidelines for forest fuel harvesting and production is ideal, as they serve to reinforce each other in this way.

Criteria and indicators

An important factor in achieving sustainable forest fuel production is the availability of systems to monitor and assess the effectiveness of relevant policies and guidelines. A criteria and indicators (C&I) framework, where properly implemented, can work within an AFM framework to help meet requirements for monitoring and assessment. Criteria define and describe SFM goals in broad terms, while indicators add quantitative and qualitative information about the condition of the systems being managed, helping to indicate whether or not we are on track to achieving these goals (Lewandowski and Faaij 2006). For example, Criterion 4 of the Montreal Process (applicable to all types of forest management) sets a very broad standard for protecting soils from the types of impacts outlined in Step 1 above, calling for “the conservation and maintenance of soil and water resources” (Montreal Process Working Group 2005). Related indicators add specificity and measurability to this broad goal, requiring information on, for example, the “area and percent of forest land with significantly diminished soil organic matter and/or changes in other soil chemical properties” (Montreal Process Working Group 2005).

A C&I framework can also provide a useful organizational tool when managing intricate systems; such a framework can help to “deconstruct the complex goal of sustainable ecosystem management into parameters that can be managed, planned for and monitored” (Beasley and Wright 2001). Indicators are useful in capturing and integrating information that describes the state of a system, thereby reducing complexity (Lewandowski and Faaij 2006). A C&I framework organizes these indicators so that they are paired with specific goals and logically linked (rather than just random pieces of unconnected information) for ease of use by policy-makers or forest managers (Beasley and Wright 2001). Some of the benefits of such a framework, according to Beasley and Wright (2001), include:

- an increased chance that all important aspects of a system will be covered;
- a decrease in redundancy;
- a transparent and easy-to-follow link between measured parameters and their related system elements; and
- a model through which to link the condition of the forest with sustainability goals, assisting the processes of monitoring and assessment and advancing the process of AFM.

AFM necessitates that information is continually revised and improved based on new knowledge and experiences. The C&I framework then helps to organize and transmit existing information, identify gaps in knowledge, and structure the

gathering of new information to feed back into an AFM framework. With regards to biomass harvesting, van Dam *et al.* (2006) advise the design and use of relevant C&I that are easy to understand, enforceable, quantifiable, specific, and flexible enough to be regionally adaptable (van Dam *et al.* 2006). Lattimore *et al.* (2009), for example, developed a set of generic C&I for forest fuel harvesting by screening existing sustainable forest management C&I sets and adding indicators to address areas of concern that are particularly relevant to forest fuel harvesting. Indicators such as these could be adapted to local conditions through stakeholder consultation and applied within an AFM framework. Locally relevant, science-based C&I can guide forest managers in the design and implementation of low-impact forest-fuel production and harvesting operations.

Steps 3 and 4: Design and implement practices

Environmental criteria must be incorporated from the very beginning of the planning process if sustainability goals are to be achieved (Holling 1978). At this point in the AFM process, potential environmental impacts have already been identified and standards have been developed to address these impacts. Looking back to the examples of potential impacts on soil chemical properties from Lattimore *et al.* (2009) (see Step 1, Table 1), we can begin piecing together the different steps in an AFM framework up to this point. One of the potential issues cited in Table 1 was a reduction in total capital and availability of nutrients resulting from more intensive biomass removals for bioenergy. In Minnesota, guidelines were established (Step 2) based on the best available knowledge of local conditions that might address this issue (e.g., guidelines as to which types of sites to avoid because of sensitive underlying soils [MFRC 2007]). Likewise, a number of recommendations for designing low-impact operations for the state of Wisconsin are offered by Hacker (2008), based on a review of relevant research on the effects of logging residue removal. These include, among others:

- avoiding forest bioenergy harvesting on specific soil types (e.g., shallow soils; soils with restricted rooting volumes; coarse-textured outwash sands; phosphorous-deficient soils; poorly-drained soils);
- concentrating impacts of heavy equipment;
- harvesting when soils are dry or frozen;
- using tracked vehicles;
- cutting in winter after leaves have fallen;
- leaving some logs on site; and
- lengthening rotations.

Once designed, low-impact operations can be carried out by well-trained and well-informed forest practitioners, in accordance with management plans, guidelines and best management practices. (See Hakkila 2002 for more suggestions for designing low-impact operations.)

Following the implementation stage, many non-adaptive approaches to forest management fall short. The success of management plans, policies and guidelines in achieving sustainable operations is quite often limited by a lack of adequate monitoring and assessment (McAfee *et al.* 2006). An AFM approach, on the other hand, includes these two additional steps as part of a holistic management framework; rather than just implementing management plans and reacting only when necessary, as is often the case with environmental man-

agement systems, an AFM approach actively monitors and assesses the effectiveness of management activities in achieving goals, and uses the information gained through these steps to inform future management plans.

Steps 5 and 6: Monitoring and Assessment

A famous quote attributed to the late industrialist Henry Ford (1863–1947) says that “life is a series of experiences, each of which makes us bigger...” A great deal of our personal learning comes through experience, and what we learn is often of great value. The same can be said for forest management. What we learn about systems through practical management experience can be used to help us move towards greater sustainability. The Adaptive Forest Management framework is designed so that management becomes part of the research process—new information gained through monitoring and assessment is fed back into the AFM framework (Fig. 1), helping scientists and managers expand their understanding of the systems being managed, for progressive evolution towards the most sustainable operations possible (Holling 1978, Beasley and Wright 2001). Continually learning from the successes and failures of our interventions is particularly critical when dealing with a relatively new (in the Canadian context) and rapidly evolving industry such as forest bioenergy, where impacts can currently be hard to predict.

Despite its importance, effective monitoring can be costly and difficult to implement, which is why it is not always achieved. The following are three broad categories of monitoring, which vary in their accessibility from least costly to most costly (Neary 2002):

1. implementation monitoring (are standards being properly implemented?);
2. effectiveness monitoring (are standards effective in reaching the desired goals?); and
3. validation monitoring (more-in-depth investigations of the relationships between management activities and the landscape).

The last form of monitoring is the most critical to a successful AFM approach. It need not be applied across an entire site, but at certain strategic or sensitive locations for the purposes of scientific advancement. Effectiveness monitoring and validation monitoring are easiest to assess and can be applied more broadly to gain an overall idea of whether or not goals are being met.

Under Step 2 (the formulation of standards), criteria and indicators were discussed as a framework for setting and monitoring standards. Monitoring is structured and encouraged by the use of C&I. Now that we have introduced some tools for designing, monitoring and assessing sustainable forest fuel production and harvesting systems, we will briefly discuss the use of sustainable forest management certification schemes as one possible vehicle for delivering such tools and frameworks.

Mobilizing SFM Frameworks through Forest Certification Schemes

Forest certification is a voluntary process through which qualified forest managers can attach a label to their products to indicate to consumers that they have been produced sustainably (FPAC and PWC 2008). An AFM framework (obtaining information, setting goals and standards, monitoring progress, assessing results, and adapting accordingly) is inherent within a forest certification process. Management is

assessed in relation to a set of standards (criteria and indicators) that are then monitored and assessed by an independent third party, who determines whether or not the standards have been adequately met (Lewandowski and Faaij 2006). If standards are not met, operations will need to be adapted before certification can be obtained. The price premiums that managers may fetch for offering certified products can help to offset the costs of the certification process, hence making effective monitoring and assessment more affordable. While voluntary in nature, some governments require or encourage the certification of forest biomass for bioenergy. For example, Minnesota's Biomass Power Mandate states that “The wood procurement process must utilize third-party audit certification systems to verify that applicable best management practices were utilized in the procurement of sustainably produced biomass” (Minnesota Office of the Revisor of Statutes 2007). Similarly, the Ontario government encourages forest managers to seek third-party certification (OMNR 2008).

Comprehensive forest and green energy certification standards may help to ensure that bioenergy products are sustainably produced and provide real environmental, social and economic benefits. Globally, there are no green energy certification systems in existence that cover the entire length of the forest bioenergy supply chain. Canada is a good place to begin setting appropriate standards for the certification of biomass and bioenergy because we are still in the preliminary stages of developing bioenergy policies. Lewandowski and Faaij (2006) believe that, out of all existing certification and eco-labelling schemes, those in place for sustainable forest management, such as Forest Stewardship Council (FSC) (FSC 1996) and the Programme for the Endorsement of Forest Certification (PEFC) (PEFC 2007), can be most readily applied to the bioenergy sector, or integrated into a system of certification for trade in biomass. Stupak *et al.* (2008b) and Lattimore *et al.* (2009) assessed the applicability of existing SFM certification schemes to forest biomass production and harvesting, and proposed ways to adapt such schemes to include this growing industry (Stupak *et al.* 2008b, Lattimore *et al.* 2009). Certified feedstock could then be incorporated into green energy certification programs designed to cover the whole supply chain. Used symbiotically with relevant legislation, guidelines, and best management practices, certification schemes can provide an effective means for delivering standards, monitoring practices, and encouraging continual system improvement.

From The Lab to the Field: Transmitting Knowledge

The frameworks and tools suggested in this paper can help to advance the progression towards sustainable forest fuel production and harvesting, but are only part of the picture. Equally important is the knowledge that informs these mechanisms, and the means of transmitting this knowledge among stakeholders. Good decisions are well-informed decisions. Unfortunately, journal articles and texts that hold a wealth of relevant research and information are not effective ways to communicate important science to policy-makers and other non-scientists (Holling 1978). Translating research results into user-friendly formats will help ensure that science is directly linked to practice. Some vehicles for delivering knowledge to a wide range of policy-makers and stakeholders include:

- brief and interesting summary reports;
- brochures and fact sheets;
- bulletins;

- illustrations and audiovisuals;
- websites;
- curricula; and
- workshops.

Two existing projects using interesting and interactive methods to inform landowners and other interested parties about sustainable forest bioenergy production are:

- the Encyclopedia of Southern Bioenergy, hosted by the USDA Forest Service Southern Research Station and the Southern Regional Extension (Smith and Rauscher 2007); and
- Sustainable Forestry for Bioenergy and Bio-Based Products, a Web-based learning system developed by the National Learning Centre for Private Forest and Range Owners (National Learning Centre for Private Forest and Range 2007).

The latter is a component of a training program for southern landowners that also includes workshops, fact-sheets and quizzes. Both the Encyclopedia of Southern Bioenergy and the training modules offered through the Sustainable Forestry for Bioenergy and Bio-Based Products program are designed for a southern audience in the United States. Similar resources would be helpful for different regions of Canada, to help governments, forest managers and other stakeholders understand the issues and how they can best plan for a sustainable renewable energy sector.

Conclusion

With rising demands for forest resources in Canada and around the globe, forest management systems, including those that produce and harvest forest fuel, are no longer as simple as they once were. This paper has identified a number of mechanisms based around an adaptive forest management framework and related tools and processes that can be used to structure and sustainably manage complex forest fuel production systems.

Currently, neither provincial governments nor certification schemes offer strong standards for sustainable forest fuel production and harvesting. Also lacking is comprehensive knowledge of which areas may be particularly sensitive to forest fuel operations: this knowledge is crucial to region- or site-specific guideline development. Increased research and standard development, carried out within an AFM framework, are recommended to fill in these gaps. The development of effective programs and resources to transmit knowledge among stakeholders is also critical.

There is a great deal that we do not yet know about the potential long-term effects of modern-day forest fuel production and harvesting systems, but identifying and applying what we do know to the development of standards and low-impact operations and continuing to learn through research and experience will move us in the right direction.

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