Guidelines for Sustainable Forest Biomass Production – Challenges in view of an emerging bioeconomy

Viktor J. Bruckman, Alexander Evans,
Heljä-Sisko Helmisaari, Inge Stupak and Brian Titus

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Managing Editor:
Viktor J. Bruckman

Layout: Karin Windsteig

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Editorial office:
Commission for Interdisciplinary Ecological Studies , OeAW, Dr. Ignaz Seipel-Platz 2, 1010 Vienna
E-mail: viktor.bruckman@oeaw.ac.at, +43 1 51581 3200

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Introduction

Viktor J. Bruckman

Forests provide essential goods and services for humankind and forest products were of great importance in the development and prosperity of many civilizations. This distinct dependency becomes especially clear when considering examples of where degradation of forests ultimately paved the way for the fall of established empires. A growing population combined with increased demands for wood, especially for mining activities and the need for thermal energy, led to regional wood shortages in central Europe as early as the late medieval period. The problem continued and soon became an issue in most mountainous forests because of the constantly increasing demand for wood. The fate of lowland forests was no different. The conversion of forest to agricultural land and large-scale clear-cutting to produce primarily fuelwood and charcoal were among the primary causes for the loss and degradation of these forests.

Hans Carl von Carlowitz, a German tax accountant and mining administrator, realized early in the eighteenth century that the unbridled and ongoing exploitation of forests and woodlands would threaten not only the mining industry itself, but also the livelihood of the wider population. He was responsible for maintaining a continual wood supply for the flourishing industry that also included smelting of ores. In his book "Sylvicultura oeconomica" (Fig. 1), he defines solutions for restoration of degraded land, mainly by afforestation with common woody forest species. He also coined the term "sustainability", which is now ubiquitous and used in a range of disciplines. However, the original meaning proposed by Carlowitz was grounded on purely economic considerations and was defined as silvicultural practices that ensured constant wood supplies. One of the main thoughts behind this concept is that sustaining wood production is the most economic and safest option compared to others, such as expensive and time-consuming restoration activities (e.g. planting trees) that become necessary if forests are cleared. Moreover, the success of restoration is not guaranteed, especially if organic matter and nutrients are lost because of erosion and microbial oxidation.


Mit GOtt!
SYLVICVLTVRA OECONOMICA,
Oder
Haußwirthliche Nachricht und Naturmäßige
Anweisung
Zur
Wilden Baum-Zucht,
Nebst
Gründlicher Darstellung/
Wie zu förderst durch Göttliches Benedeyen dem allenthalben und insgemein einreissenden
Grossen Holtz-Mangel/
Vermittelst Säe-Pflantz- und Verletzung vielerhand Bäume zu prospiciren/
auch also durch Anfug und Wiedermachs des so wohl guten und schleunig anwachsend, als andern genüchtigen und nöthigsten Holtzes, auch öde und abgetriebene Holtz-Länderey, Plätze und Oerte widerum Holtzreich, nützlich und brauchbar zu machen; Bevorab von Saam-Bäumen und wie der wilde Baum-Saamen zu sammlen, der Grund und Boden zum Säen zuzubereiten, solche Saat zu bemerckelligen, auch der junge Anfug und Wiedermachs zuhedachten. Dabeyden das sogenannte lebendige, hier Schlag- an Ober- und Unter-Holtz aufzubeutzen und zu vermuthen, welchen beygefügt die Arten des Tangel- und Laub-Holtzes, ingleichen deren Eigenschaften und was besagtes Holtz für Saamen trage, auch wie man mit fremdden Baum-Gewächsen sich zu verhalten, ferner, wie das Holtz zu fällen, zu verkohlen, zu äschern und sonst zu nutzen.
Alles zu nothdürfftiger Versorgung des Hauß-Bau-Brau-Berg- und Schmeltz-Wesens/
und wie eine immerwährende Holtz-Nutzung, Land und Leuten/ auch jedem Hauß-Wirthe zumschätzbaren grossen Aufnehmen/ pfleglich und füglich zu erziehlen und einzuführen.
Worbey zugleich eine gründliche Nachricht von den in Churfl. Sächs. Landen
Gefundenen Torff
Dessen Natürliche Beschaffenheit/ grossen Nutzen/ Gebrauch und nützlichen Verkohlung.
Aus Liebe zu Beförderung des algemeinen Wesens beschrieben
Von
Hannß Carl von Carlowitz/
Königl. Pohl. und Churfl. Sächs. Cammer-Rath und Ober-Berg-Hauptmann.
Mit Königl. Pohl. und Churfürstl. Sächs. allergnädigsten PRIVILEGIO.
LEIPZIG/
verlegts Johann Friedrich Braun 1713.

Figure 1: Title page of "Sylvicultura oeconomica"
Image credits: FVA/Weidner

Nearly 300 years later, the forest sector went through periods of increased demands, such as during the early industrial revolution, and periods where forests and woodlands were able to recover, such as in post-war periods, and once use of fossil fuels increased and hence use of fuelwood decreased. However, foresters worldwide are facing the same challenge as before: to manage forests sustainably. There are a multitude of reasons for doing so which differ regionally, from increasing demands because of promotion of biomass for energy generation or for industrial processes, to changes in demography and impacts of climate change and associated demands of certain criteria for maintaining resilience and the conservation of biodiversity. The key message remains constant, however, even though the significance of other ecosystem functions has broadened recently, mainly because of increasing understanding of natural processes and their links resulting from environmental research.

Global change will ultimately affect the way forests will be managed in the future, and demand structures and environmental conditions may be altered as a consequence of climate change. It is incumbent on forest managers to ensure sustainable production by applying suitable silvicultural measures. In traditional forestry operations, which are typically characterized by long rotation periods of > 80 years and stem-only extractions, harvesting operations are likely to have little effect on nutrient balances under normal stand conditions. If management strategies tend towards shorter rotations and/or extraction of tree components other than stems, nutrients might become a limiting factor, in the absence of proper counter-measures, site degradation might take place.

Forest biomass harvesting guidelines are a tool that can be applied to help ensure sustainability, even under regimes where increasing amounts of biomass and formerly untouched tree components are extracted. Guidelines apply simple proxies and use clear instructions for harvesting operations, making them useful tools for both machine operators and forest managers. The intention is to provide additional information based on the latest scientific knowledge; guidelines should thus not be seen as static but, on the contrary, subject to constant revision and local adaptation. Guidelines should help in the promotion of the forestry biomass sector and the use of wood for a range of purposes now and in future generations, while taking into consideration the maintenance of other essential forest goods and services.

A current project on the evaluation of international guidelines and guideline development was initiated at a workshop sponsored by the OECD Cooperative Research Programme (CRP), held on 3rd of July, 2012 at the EUROSOIL congress in Bari, Italy, and convened by Prof. Heljä-Sisko Helmisaari (University of Helsinki) and Dr. Elena Vanguelova (Forestry Commission, UK). In 2015, the board of the International Union of Forest Research Organizations (IUFRO) approved a proposal for the Task Force "Sustainable Forest Biomass Network (SFBN)", later renamed to Forest Biomass Network (FBN), where the evaluation and development of harvesting guidelines was set as one of three main priorities in the working agenda. The task force consists of 15 members from 13 countries, who are dedicated experts in relevant aspects of forest biomass. The Commissions for Interdisciplinary Ecological Studies (KIOES) and the Climate and Air Quality Commission of the Austrian Academy of Sciences (OeAW) jointly organized a workshop with the SFBN task force entitled "Guidelines for Sustainable Forest Biomass Production – Challenges in view of an emerging bioeconomy", held in Vienna on the 11th of September, 2017. The workshop aim was to discuss further guideline development and the integration of guidelines with existing governance tools, such as certification schemes. The outcome of the discussions will be published and manuscripts are currently in preparation. The aim of the current report is to provide the context, an executive summary in English and German, and a collection of recent literature, which covers various important aspects around guideline development. The collection selected by the authors of this issue of KIOES Opinions provides an overview of existing literature and current trends.

The IUFRO Task Force Forest Biomass Network and the Commission for Interdisciplinary Ecological Studies (KIOES) thanks the workshop participants for their valuable inputs and discussions. Most ideas and concepts presented in this summary and in future reports germinated in the various discussions and sessions held during the workshop.

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Guidelines for Sustainable Forest Biomass Production – Challenges in view of an emerging bioeconomy: Executive summary

Viktor J. Bruckman[a], Alexander Evans[b], Heljä-Sisko Helmisaari[c], Inge Stupak[d], and Brian Titus[e] [1]

[a] Austrian Academy of Sciences (OeAW), Vienna, Austria, viktor.bruckman@oeaw.ac.at (corresponding)
[b] Forest Stewards Guild, Madison, WI, USA
[c] University of Helsinki, Helsinki, Finland
[d] University of Copenhagen, Copenhagen, Denmark
[e] Natural Resources Canada, Canadian Forest Service, Canada

Definition and context

Forest biomass harvesting guidelines (hereafter referred to as "guidelines") are science-based site-specific good practise recommendations or regulations (sometimes referred to as "Best-Management Practices") to be implemented during harvesting operations. These guidelines are designed to reduce negative impacts of biomass harvesting on ecosystem processes and services within the context of sustainable forest management (SFM).

Global change has led to dramatic impacts on natural ecosystems that provide the natural resources and services essential for human well-being. The rising atmospheric concentration of CO_2 from combustion of fossil fuels is an important driver behind an ongoing transition from a fossil-based economy towards a bioeconomy. Consequently, an increasing demand for biomass from forestry and agriculture implies a need for increasing intensification of ecosystem management, which increases the risk that the impacts of disturbances move in a less sustainable direction. Guidelines can be helpful tools for ensuring that the SFM objective of ecological sustainability is still being met. In general, guidelines are based on and work in concert with existing SFM regulations or recommendations, with details applicable at a management level. This may include consideration of alternative indicators if they differ among SFM regulations or specifications but are supported by the latest scientific evidence. Although new markets for bioenergy from wood have motivated the creation of guidelines, it is forest management practices and not the end-use of harvested biomass that is the important driver because a growing suite of forest products in addition to bioenergy can be derived from this same biomass feedstock.

Objectives

The objective of guidelines is therefore to provide site management recommendations based on the latest scientific knowledge and stakeholder involvement, but locally adapted so that forest operators can meet sustainability standards within their current context. In general, avoiding or minimizing negative impacts on forest ecosystems helps ensure that the same quality and quantity of monetary land value and provi-

[1] Authors appear in alphabetical order
This document represents a summary of the workshop "Guidelines for Sustainable Forest Biomass Production – Challenges in view of an emerging bioeconomy" held at the Austrian Academy of Sciences on 11th of September, 2017, organized by the Commission for Interdisciplinary Ecological Studies (KIOES), the Climate and Air Quality Commission and the Task Force "Sustainable Forest Biomass Network (SFBN)" of the International Union of Forest Research Organizations (IUFRO). See https://www.oeaw.ac.at/kioes/aktivitaeten/detail/article/guidelines-for-sustainable-forest-biomass-production/ for more details. Date of publication: 30th of October, 2017.

sion of natural resources and services will continue into the future. Furthermore, careful consideration of the wider implications of guideline development can ensure that they aid policy integration with superordinate national or transnational policies, which may be otherwise overlooked if the focus is solely on local forest management issues. An additional key objective of guidelines should therefore be the translation and simplification of complex SFM issues so that they can be applied operationally using clear, concise and practical local recommendations based on proxies that are also relevant to the intricacies of the total governance context for products made from stemwood and other biomass components. For example, a guideline recommending leaving harvesting residuals on site from a defined number of trees per unit area represents use of a simple proxy for addressing far more complex relations with biodiversity, nutrient retention, organic matter cycling and ultimately with carbon sequestration. In terms of bioeconomy development and the associated increased use of biomass, guidelines that are well-integrated with certification and national/transnational trade policies would be helpful in generating trust and promoting consumer and social acceptance of goods and services delivered through a bioeconomy framework.

Aspirations

Guidelines need to be simple, user-friendly, easily monitored, and framed within existing SFM regulations or recommendations if they are to be accepted and implemented locally by forest operators. Strategies for communicating the objectives of guidelines and the general concepts underpinning their development need to be developed carefully, for example through educational activities, so that the additional value to forest managers is highlighted. Guidelines need to acknowledge that ecological conditions change and science gaps still exist, and hence an adaptive management approach needs to be adopted to take into consideration future changes in conditions and increases in scientific and operational knowledge. In terms of vertical policy integration, guidelines must comply with superordinate regulations and it would be beneficial if they align with similar frameworks, such as certification schemes. Guideline development needs to include forest managers, policy-makers, appropriate forest authorities, scientific experts, and other stakeholders such as NGOs and relevant interest groups.

Summary

The aim of forest biomass harvesting guidelines is to provide a useful, simple and yet effective framework within existing SFM regulations or recommendations for ensuring ecologically sustainable practices at the forest management and operational level, taking into account economic conditions. Although based on the latest scientific knowledge, guidelines must be subject to ongoing revisions and updates because knowledge and experience increases over time. Guidelines are designed to avoid or reduce undesirable impacts on natural ecosystems and therefore ensure the quality and quantity of services and resources for further generations, and stable incomes for forest owners. National and transnational regulations must be considered during guideline development and translated into simple, forest practice-oriented recommendations. The implementation of guidelines can help to generate consumer awareness and trust, and therefore reduce barriers to the use of new forest products made from biomass that mitigate the effects of climate change through displacement of products made from fossil fuels.

Acknowledgements

We thank the organizers for their strong support, in particular the Commission for Interdisciplinary Ecological Studies (KIOES), Austrian Academy of Sciences (OeAW) for providing funds. We further acknowledge the valuable Inputs from speakers and poster presenters that led to this workshop summary: Simon Armstrong, Georg Greutter, Uwe Häußermann, Robert Jandl, Klaus Katzensteiner, Florian Kraxner, Johannes Schima, Josef Spitzer and Tiina Törmänen.

Leitlinien für eine nachhaltige forstliche Biomasseproduktion – Herausforderungen hinsichtlich jüngster bioökonomischer Entwicklungen: Kurzfassung[2]

Definition und Kontext

Richtlinien zur Ernte von Waldbiomasse (nachfolgend als „Leitlinien" bezeichnet) sind wissenschaftsbasierte, standortsspezifische und praxisbewährte Empfehlungen oder Vorgaben (manchmal auch als „Best Management Practices" bezeichnet), die bei der Holzernte implementiert werden. Leitlinien werden zur Minimierung negativer Auswirkungen von Erntemaßnahmen auf ökosystemare Prozesse und Dienstleistungen innerhalb des Kontextes eines nachhaltigen Waldmanagements (SFM) eingesetzt.

Der globale Wandel hat zu dramatischen Auswirkungen auf Ökosysteme geführt, die für das menschliche Wohlbefinden essenzielle natürliche Ressourcen und Services bereitstellen. Die steigende atmosphärische CO_2-Konzentration aus der Verwertung von fossilen Rohstoffen ist ein Hauptgrund für den stetigen Übergang von einer fossilbasierten hin zur Bioökonomie. Eine dadurch zu erwartende verstärkte Nachfrage an Biomasse bei gleichbleibenden Produktionsflächen führt zu einer Intensivierung der Landnutzung, was im Kontext der Nachhaltigkeit auch zu einem vermehrten Risiko für negative Auswirkungen auf diese Systeme führen kann. Leitlinien können wirksame Instrumente zur Sicherstellung einer ökosystemaren Nachhaltigkeit im Sinne des SFM sein. Grundsätzlich basieren Leitlinien auf existierenden Nachhaltigkeitskriterien und SFM-Vorgaben und ergänzen bzw. präzisieren diese auf Managementebene. Das kann die Berücksichtigung alternativer Indikatoren beinhalten, wenn unterschiedliche SFM-Vorgaben hinsichtlich ähnlicher Parameter variieren, aber jene alternativer Indikatoren durch rezente wissenschaftliche Erkenntnisse als zuverlässiger identifiziert wurden. Obwohl in letzter Zeit neue Märkte für Bioenergie aus Holz den Entwurf zahlreicher Leitlinien initiiert haben, sind doch die waldbaulichen Maßnahmen und die Holzernte und weniger die Nutzung des Rohstoffes an sich auschlaggebend, weil ein wachsender Anteil dieser für unterschiedlichste industrielle Prozesse Verwendung finden kann.

Ziele

Leitlinien bezwecken daher die Bereitstellung von Bewirtschaftungsvorschlägen basierend auf neuesten wissenschaftlichen Erkenntnissen und der Berücksichtigung von den Bedürfnissen und Vorstellungen unterschiedlicher Interessensgruppen (Eigentümer, Behörden, etc.). Diese sollen den lokalen Bedingungen angepasst sein, damit Nachhaltigkeitskriterien auf Bewirtschaftungsebene durch einfache Anweisungen implementiert werden können. Grundsätzlich bezweckt die Minimierung von negativen Auswirkungen auf Waldökosysteme eine kontinuierliche und fortwährende Bereitstellung von natürlichen Ressourcen, sowie den Erhalt des Grundwertes und die Stabilität hinsichtlich sich ändernden Umweltbedingungen. Darüber hinaus kann eine Berücksichtigung der regionalen Implikationen von Leitlinien die Berücksichtigung von übergeordneten nationalen und internationalen politischen Vorgaben und Rahmenbedingungen ermöglichen, die ansonsten bei einem Fokus auf regionale Themen leicht übersehen werden. Ein weiteres Ziel ist die Übersetzung und Vereinfachung komplexer SFM-Vorgaben, so dass diese klar und verständlich formuliert sind und praktikabel im betrieblichen Ablauf umgesetzt werden können. Die Basis sollen stellvertretende, einfach zu erfassende Parameter sein, welche die Rahmenbedingungen von Vorgaben für die Produktion von Stammholz und anderen Biomassekompartimenten wiederspiegeln. Zum Beispiel ist eine Leitlinie, die den Verbleib von Ernteabfällen von einer definierten Anzahl von Bäumen pro Flächeneinheit festlegt, stellvertretend für weitaus komplexere Zusammenhänge mit Biodiversität, Nährstoffversorgung, Haushalt von organischem Material und in letzter Konsequenz mit der Speicherung von Kohlenstoff. Leitlinien, die sehr gut mit Zertifizierungsmechanismen und nationalen bzw. internationalen Handelsvorgaben integriert sind, können im Sinne einer bioökonomischen Entwicklung und der damit zu erwartenden verstärkten Nutzung von Biomasse dazu beitragen, dass Vertrauen generiert und Akzep-

[2] This part represents the German translation of the executive summary

tanz für Güter und Dienstleistungen im bioökonomischen Kontext gesteigert wird.

Ansprüche

Leitlinien müssen einfach aufgebaut, benutzerfreundlich, die Implementierung leicht zu überwachen, sowie innerhalb von bereits existierenden SFM-Regularien angesiedelt sein um diese z.B. zu konkretisieren und/oder zu ergänzen. Nur klare und einfach handhabbare Leitlinien haben Chance auf Akzeptanz und Berücksichtigung in betrieblichen Abläufen bei Holzerntemaßnahmen. Strategien zur Kommunikation der Ziele von Leitlinien und die generellen zugrundeliegenden Konzepte müssen mit Bedacht entwickelt werden, etwa durch zusätzliche aufklärende Aktivitäten, damit der konkrete Mehrwert für die Betriebsführung erkannt wird. Leitlinien müssen aber berücksichtigen, dass sich ökologische Rahmenbedingungen ändern, und dass es nach wie vor Wissenslücken gibt, daher soll im Sinne von adaptivem Management auf zukünftige Entwicklungen, sowie auf neu generiertes Wissen flexibel Rücksicht genommen werden können. Eine Integration von Leitlinien in übergeordnete Vorgaben erscheint sinnvoll, speziell dann, wenn es Übereinstimmungen bzw. Ergänzungen zu verwandten Regularien gibt, wie z.B. mit Zertifizierungsschemata. Generell sollen zur Entwicklung von Leitlinien Forstbehörden, Waldeigentümer und für die Bewirtschaftung zuständige Personen, Experten aus Wissenschaft und Forschung und weitere relevante Interessensgruppen, wie z.B. NGO's, eingebunden werden.

Zusammenfassung

Das Ziel von Leitlinien für eine nachhaltige forstliche Biomasseproduktion ist es, ein nützliches, einfaches und dennoch effektives Werkzeug innerhalb der SFM-Vorgaben oder Empfehlungen zur Verfügung zu stellen um ökologisch nachhaltige Verfahren bei der Holzernte zu gewährleisten, die auch ökonomische Gesichtspunkte berücksichtigen. Obwohl diese auf aktuellen wissenschaftlichen Ergebnissen beruhen, müssen Leitlinien laufend überarbeitet werden, da sich der Kenntnisstand und die Rahmenbedingungen, sowie die Erfahrungen mit der Implementierung ständig ändern bzw. zunehmen. Mit Leitlinien sollen negative Auswirkungen auf natürliche Ökosysteme verhindert bzw. minimiert werden, um dadurch die Qualität, aber auch die Quantität von ökosystemaren Dienstleistungen und Ressourcen für kommende Generationen zu erhalten und damit auch zukünftig stabile zukünftige Einkommen generieren zu können. Nationale und internationale Vorgaben sollen bei der Entwicklung von Leitlinien berücksichtigt, und relevante Inhalte aus diesen Regelwerken ggf. in einfache, praxisorientierte Anweisungen übersetzt werden. Die Implementierung von Leitlinien kann beim Verbraucher zur Bewusstseins- und Vertrauensbildung beitragen und dadurch helfen etwaige Vorbehalte gegenüber neuen Produkten, die auf Biomasse basieren, und die durch den Ersatz von fossilbasierten Rohstoffen zum Umweltschutz beitragen, abzubauen.

Danksagung

Wir danken den Organisatoren für ihre besondere Unterstützung, speziell der Kommission für Interdisziplinäre Ökologische Studien (KIÖS) der Österreichischen Akademie der Wissenschaften (ÖAW) für die finanzielle Unterstützung. Wir bedanken uns auch für die vielen wertvollen Inputs der Diskussionsteilnehmerinnen und Diskussionsteilnehmer, die wesentlich zu dieser Zusammenfassung beigetragen haben: Simon Armstrong, Georg Greutter, Uwe Häußermann, Robert Jandl, Klaus Katzensteiner, Florian Kraxner, Johannes Schima, Josef Spitzer and Tiina Törmänen.

Literature

This section provides useful literature that we found essential and representative for further reading. The references are sorted according to their publication date within three distinct groups: Reviews of guidelines, guidelines development and testing, Harmonisation and General sustainability issues. The collection is comprised of reviews, meta-studies and case examples to provide a good overview that provide the rationale for guidelines development.

Reviews of guidelines, guidelines development and testing

2016

Fritts, S., Moorman, C., Grodsky, S., Hazel, D., Homyack, J., Farrell, C., and Castleberry, S. "Do Biomass Harvesting Guidelines Influence Herpetofauna Following Harvests of Logging Residues for Renewable Energy?", *Ecological Applications,* 26(3), 926–39, 2016.

DOI: https://doi.org/10.1890/14-2078

Abstract: Forests are a major supplier of renewable energy; however, gleaning logging residues for use as woody biomass feedstock could negatively alter habitat for species dependent on downed wood. Biomass Harvesting Guidelines (BHGs) recommend retaining a portion of woody biomass on the forest floor following harvest. Despite BHGs being developed to help ensure ecological sustainability, their contribution to biodiversity has not been evaluated experimentally at operational scales. We compared herpetofauanal evenness, diversity, and richness and abundance of Anaxyrus terrestris and Gastrophryne carolinensis among six treatments that varied in volume and spatial arrangement of woody biomass retained after clearcutting loblolly pine (Pinus taeda) plantations in North Carolina, USA (n = 4), 2011–2014 and Georgia (n = 4), USA 2011–2013. Treatments were: (1) biomass harvest with no BHGs, (2) 15 % retention with biomass clustered, (3) 15 % retention with biomass dispersed, (4) 30 % retention with biomass clustered, (5) 30 % retention with biomass dispersed, and (6) no biomass harvest. We captured individuals with drift fence arrays and compared evenness, diversity, and richness metrics among treatments with repeated-measure, linear mixed-effects models. We determined predictors of A. terrestris and G. carolinensis abundances using a priori candidate N-mixture models with woody biomass volume, vegetation structure, and groundcover composition as covariates. We had 206 captures of 25 reptile species and 8710 captures of 17 amphibian species during 53 690 trap nights. Herpetofauna diversity, evenness, and richness were similar among treatments. A. terrestris abundance was negatively related to volume of retained woody biomass in treatment units in North Carolina in 2013. G. carolinensis abundance was positively related with volume of retained woody debris in treatment units in Georgia in 2012. Other relationships between A. terrestris and G. carolinensis abundances and habitat metrics were weak or absent. The lack of consistent community or population responses suggests the addition of a woody biomass harvest to a clearcut in pine plantations does not impact herpetofauna use of Coastal Plain loblolly plantations in the southeastern United States. We recommend additional research to examine relationships between woody biomass harvesting and rarer species or amphibians with high desiccation risk, particularly in other regions and harvesting systems.

2014

Fritts, S.R., Moorman, C.E., Hazel, D.W., and Jackson, B.D. "Biomass Harvesting Guidelines Affect Downed Woody Debris Retention", *Biomass and Bioenergy,* 70, 382–91, 2014.

DOI: https://doi.org/10.1016/j.biombioe.2014.08.010

Abstract: Our objective was to determine if a retention area-based Biomass Harvesting Guideline (BHG) strategy maintained desired volumes of downed woody debris (DWD) following woody biomass harvests. We implemented six randomly-assigned treatments in four clearcuts in loblolly pine plantations in the Coastal Plain physiographic region of North Carolina during 2010–2011: 1) woody biomass harvest with no BHGs (NOBHG); 2) 15 % retention with woody biomass dispersed (15DISP); 3) 15 % retention with woody debris clustered (15CLUS); 4) 30 % retention with woody biomass dispersed (30DISP); 5) 30 % retention with woody biomass clustered (30CLUS); and 6) no woody biomass harvest (i.e., clearcut only; NOBIOHARV). Prior to harvesting, we flagged 15 % or 30 % of the treatment area to serve as woody biomass retention sources for the four BHG treatments, and all woody biomass from the flagged area were retained and distributed across that entire treatment area. We examined effects of treatments on: 1) fraction estimated volume of pre-harvest standing volume (total and woody biomass) retained as residual DWD; and 2) fraction retained DWD in treatments 2–5 relative to retained DWD in the NOBHGS and NOBIOHARV treatments. Adding a woody biomass harvest reduced volume of residual DWD by 81 % in NOBHG compared to NOBIOHARV. Estimates based on the second metric were most similar to target retentions with retention percentages at 18.8 % in 15CLUS, 14.1 % in 15DISP, 39.0 % in 30CLUS, and 38.0 % in 30DISP. Treatments resulted in retention of DWD fractions approximate to those prescribed, suggesting BHGs can be implemented successfully in an operational setting.

2013

Evans, A.M., Perschel, R.T., and Kittler, B.A. "Overview of Forest Biomass Harvesting Guidelines", *Journal of Sustainable Forestry,* 32(1–2), 89–107, 2013.

DOI: https://doi.org/10.1080/10549811.2011.651786

Abstract: Growing interest in bioenergy has motivated the development guidelines for the harvest and retention of forest biomass. In general, wood that would have been left on-site under traditional harvest conditions may be removed in a biomass harvest, which can mean a reduction of dead wood and other ecological effects. Recently developed biomass harvesting guidelines cover topics such as dead wood, wildlife and biodiversity, water quality and riparian zones, soil productivity, silviculture, and disturbance. This article reviews the commonalities of current guidelines and provides insights for future efforts to ensure sustainability of biomass harvests.

Extended Report: Evans, A.M., Perschel, R.T., and Kittler, B.A. "Revised Assessment of Biomass Harvesting and Retention Guidelines", Forest Guild [Online], http://www.forestguild.org/publications/research/2009/biomass_guidelines.pdf, 2010 (Accessed 09.02.2018).

Nisbet, R. "Development of forest bioenergy guidelines for soil and water protection – experience from the UK", In H.-S. Helmisaari and E. Vanguelova (eds), *Proceedings of the workshop W6.1 Forest bioenergy and soil sustainability.* EUROSOIL Congress, July 2–6, 2012, Bari, Italy, 31–35 [Online], http://www.helsinki.fi/forestsciences/eurosoil/index.html and http://www.oecd.org/agriculture/crp, 2013 (Accessed 03.04.2018).

Abstract: The UK has a target for 15 % of its energy consumption to be from renewable sources by 2020. Delivering this target is expected to increase the demand for biomass feedstocks in the heat and power sectors. Two potential sources attracting increased attention in recent years are the production of forest energy crops and the harvesting of wood fuel. Energy crop systems such as short rotation forestry (SRF) and short rotation coppice (SRC) have the potential to deliver greater volumes of biomass from the same land area than shorter biomass crops. An added advantage is that they are suitable for growing on lower-grade agricultural land, previously forested land or reclaimed land, reducing competition with food crops on better quality soils. The harvesting of wood fuel from existing woodlands and forests includes bringing under-managed woodlands into productive management and the harvesting of forest residues and tree stumps.

2012

Berch, S.M., Bulmer, C., Curran, M., Finvers, M., and Titus, B. "Provincial Government Standards, Criteria, and Indicators for Sustainable Harvest of Forest Biomass in British Columbia: Soil and Biodiversity", *International Journal of Forest Engineering*, 23(1), 33–37, 2012.

DOI: https://doi.org/10.1080/14942119.2012.10739958

Abstract: Sustainable forest management (SFM) is a cornerstone of forest management, whether the resulting forest products are destined for the manufacturing sector or for the emerging bioenergy feedstock market. In British Columbia, research on the environmental effects of forest management has generated scientific knowledge that has informed two linked areas of government responsibility:

1. a comprehensive set of science-based regulations and policies to ensure soil and water conservation, and
2. a monitoring program to ensure the effectiveness of these regulations and policies.

An increasing amount of biomass is being harvested from British Columbia's forests as a feedstock for bioenergy, and these removals have the potential to incrementally increase machine traffic and organic matter removals from forest sites, compared to harvesting operations focused solely on roundwood for timber or pulp. To the extent that existing standards support SFM, they may be sufficient for ensuring that biomass harvesting is also sustainable. Regardless of the new challenges created by intensive harvesting practices, the principles of soil and biodiversity conservation remain the same. The current framework for BC's SFM policy is reviewed to examine whether it addresses the major sustainability issues that are likely to arise in the province if intensive biomass harvesting becomes more prevalent. We conclude that intensification of biomass removals will require us to keep focused on stand and landscape sensitivity to coarse woody debris removals and biodiversity requirements, nutrient removals, and cumulative soil disturbance.

Fielding, D., Cubbage, F., Peterson, M.N., Hazel, D., Gugelmann, B., and Moorman, C. "Opinions of Forest Managers, Loggers, and Forest Landowners in North Carolina Regarding Biomass Harvesting Guidelines", *International Journal of Forestry Research,* 2012(256141), 2012.

DOI: https://doi.org/10.1155/2012/256141

Abstract: Woody biomass has been identified as an important renewable energy source capable of offsetting fossil fuel use. The potential environmental impacts associated with using woody biomass for energy have spurred development of biomass harvesting guidelines (BHGs) in some states and proposals for BHGs in others. We examined stakeholder opinions about BHGs through 60 semistructured interviews with key participants in the North Carolina, USA, forest business sector—forest managers, loggers, and forest landowners. Respondents generally opposed requirements for new BHGs because guidelines added to best management practices (BMPs). Most respondents believed North Carolina's current BMPs have been successful and sufficient in protecting forest health; biomass harvesting is only an additional component to harvesting with little or no modification to conventional harvesting operations; and scientific research does not support claims that biomass harvesting negatively impacts soil, water quality, timber productivity, or wildlife habitat. Some respondents recognized possible benefits from the implementation of BHGs, which included reduced site preparation costs and increases in proactive forest management, soil quality, and wildlife habitat. Some scientific literature suggests that biomass harvests may have adverse site impacts that require amelioration. The results suggest BHGs will need to be better justified for practitioners based on the scientific literature or linked to demand from new profitable uses or subsidies to offset stakeholder perceptions that they create unnecessary costs.

2011

Abbas, D., Current, D., Phillips, M., Rossman, R., Hoganson, H., and Brooks, K.N. "Guidelines for Harvesting Forest Biomass for Energy: A Synthesis of Environmental Considerations", *Biomass and Bioenergy*, 35(11), 4538–4546, 2011.

DOI: https://doi.org/10.1016/j.biombioe.2011.06.029

Abstract: Interest in the utilization of forest biomass for energy is growing. A search into existing forest biomass harvesting and regeneration guidelines was carried out to identify how biomass energy can be environmentally sustainable. Findings have shown that there are only a few guidelines that specifically address harvesting and regenerating biomass for bioenergy or other bio-based products. Of these few, there are guidelines developed for dedicated energy plantations such as the Scottish Agricultural College guidelines, as well as some Finnish and Swedish guidelines recommending management practices for both timber and biomass extraction. Most of the existing small woody material guidelines emphasize the retention, disposal, redistribution, burning and mulching of biomass material on-site in a more detailed manner than forest and timber management guidelines. This study synthesizes and classifies existing biomass-related guidelines based on an in-depth literature review of existing guidelines in Europe and North America involved with biomass energy harvesting. Biomass guidelines are classified according to those applicable to systems producing biomass commercially for energy versus those that are applicable to systems managing this material for non-commercial purposes. Biomass guidelines are analyzed with respect to how they address issues of sustainability related to soil, water and habitat. Recommendations are offered for developing guidelines for biomass harvesting.

Gerow, T. "Lessons Learned on the Revision of the North Carolina Forestry Bmp Manual", North Carolina Forest Service [Online], http://ncforestservice.gov/water_quality/pdf/LessonsLearnedNCBMPRevision.pdf, 2011 (Accessed 09.02.2018).

Abstract: Forestry best management practices (BMPs) are measures that should be implemented to protect water quality from nonpoint sources of pollution and promote the conservation of soil resources. Forestry BMPs are site-specific, voluntary recommendations and are widely recognized as the primary accepted methodology to help forestry/silvicultural activities: (1) Achieve compliance with water quality standards, (2) Promote soil conservation, and (3) Sustainably harvest forest products. Each state has the flexibility to develop, adopt, and monitor implementation of forestry BMPs that are suited to the specific attributes associated with that state. A periodic review and/or revision of forestry BMPs should be done to maintain relevancy of the recommendations and to incorporate new or additional practices that are deemed worthwhile to accomplish that state's goals or objectives. In addition, a periodic review allows for the replacement or removal of out-dated or ineffective BMPs.

McGown, K. "Existing State Woody Biomass Harvesting Guidelines", In W. Stewart, R.F. Powers, K. McGown, L. Chiono and T. Chuang Berkeley (eds), *Potential positive and negative environmental impacts of increased woody biomass use for California.* Department of Environmental Science, Policy, and Management, University of California [Online], http://www.energy.ca.gov/2011publications/CEC-500-2011-036/CEC-500-2011-036.pdf, 2011 (Accessed 09.02.2018).

Puddister, D., Dominy, S.W.J., Baker, J.A., Morris, D.M., Maure, J., Rice, J.A., Jones, T.A., et al. "Opportunities and Challenges for Ontario's Forest Bioeconomy", *The Forestry Chronicle*, 87(04), 468–77, 2011.

DOI: https://doi.org/10.5558/tfc2011-045

Abstract: Ontario's forest sector is undergoing a significant shift owing to declining markets for traditional products; this shift is further exacerbated by a cyclical industry downturn. These factors are leading to extensive job losses in Ontario's north as well as rural community upheaval. Governments are striving to reverse these effects by stimulating new industries focused on using forest biofibre for products such as fuel for energy, specialty chemicals, and polymers. In light of these new demands, provincial and federal policy and science experts are examining the range of potential forest biomass utilization opportunities in terms of their long-term implications for sustainability, role in an emerging bioeconomy, and the possible influences of, for example, a changing climate and technological advances. Current research and broad-scale monitoring projects are helping to answer several important questions in the ecological, economic, policy, resource supply, and technological realms, while new questions must be continually addressed. In this paper, we describe the legislative, policy, and administrative context in which the sustainable biofibre industry may exist. We argue that social, economic, and environmental goals for a sustainable forest biofibre industry in Ontario can best be achieved by adhering to the principles of adaptive management. Market forces and third-party certification, which can influence the biofibre sector, are also discussed.

2010

Benjamin, J.G., (ed.) "*Woody Biomass Retention Guidelines. Considerations and Recommendations for Retaining Woody Biomass on Timber Harvest Sites in Maine*", Maine Agricultural and Forest Experiment Station, University of Maine, Miscellaneous Publication 761 [Online], https://forestbioproducts.umaine.edu/wp-content/uploads/sites/202/2010/10/Woody-Biomass-Retention-Guidelines-2010.pdf, 2010 (Accessed 09.02.2018).

Janowiak, M.K., and Webster, C.R. "Promoting Ecological Sustainability in Woody Biomass Harvesting", *Journal of Forestry,* 108(1), 16–23, 2010.

URL: http://www.ingentaconnect.com/content/saf/jof/2010/00000108/00000001/art00006

Abstract: Enthusiasm for the use of forest biomass as an energy resource is growing as a result of increased energy costs and a desire to reduce the greenhouse gas emissions responsible for climate change. Although the opportunity exists for forests to have a significant role in the development and use of bioenergy technologies, justifiable concerns regarding the long-term sustainability of using forest-based energy feedstocks have emerged. In this article, we review the state of our knowledge regarding the impacts of intensive forestry with respect to issues relevant to bioenergy production, including soil and site productivity, hydrologic quality, and biodiversity. We then present guiding principles intended to aid with sustainable forest management decisions.

Levin, R., and Eriksson, H. "Good-Practice Guidelines for Whole-Tree Harvesting in Sweden: Moving Science into Policy", *The Forestry Chronicle*, 86(1), 51–56, 2010.

DOI: https://doi.org/10.5558/tfc86051-1

Abstract: Concerns over climate change, peak oil and energy security have prompted countries such as Sweden to develop policies that promote alternative energy sources, including forest-based bioenergy. Sweden is at the forefront of research and development on forest-based bioenergy and has employed a model of science-based policy development to implement bioenergy production systems. In response to environmental concerns over whole-tree harvesting for bioenergy in Sweden, a number of government-funded research programs on forest-derived bioenergy have been undertaken with the intent of generating knowledge about the effects of whole-tree harvesting, ash recycling and bioenergy-related silvicultural practices on ecological

systems and values such as soil, nutrient balances, water, biodiversity, greenhouse gas balances and recreation. Sweden developed a series of recommendations and good-practice guidelines for whole tree harvesting starting in 1986 and ending with the most recent revision in 2008. These guidelines and regulations are based on various scientific studies and include prescriptions and mandates to minimize environmental damage caused by whole tree harvesting for bioenergy. From the beginning, the process of developing effective guidelines and regulations governing whole tree harvesting in Sweden has been informed by science. Guidelines and regulations govern the areas of site productivity, utilization of recycled wood ash, biodiversity and physical damage to trees and soils. Overall, Sweden's experience demonstrates the way in which science can be used to inform guidelines and policies.

2009

Fernholz, K., Bratkovich, S., Bowyer, J., and Lindburg, A. "Energy from Woody Biomass: A Review of Harvesting Guidelines and a Discussion of Related Challenges", Dovetail Partners, Inc. [Online], http://www.pinchot.org/uploads/download?fileId=488, 2009 (Accessed 09.02.2018).

Abstract: Biomass harvesting and associated energy, fuel and chemical products offer significant opportunities for economic development, fossil fuel independence, community self-reliance, and job creation. Biomass harvesting could also help in responding to ecological challenges including insect and disease threats, storm events and natural disasters, wildfire and fuel loading concerns, and goals of achieving more effective management of young forests to support longerlived species and higher valued products. However, biomass harvesting raises significant social concerns about esthetics and potential conflicts with other forest values and benefits. The development of biomass harvesting guidelines is one response to these concerns, but there are several other challenges to consider in the development of woody biomass opportunities. Careful monitoring and precautionary guidelines as well other policy and planning actions are needed to ensure that energy investments, including bio-energy initiatives, do not negatively impact biodiversity, soil productivity and ecosystem health in the United States and other parts of the world.

2008

Stupak, I., Asikainen, A., Röser, D., Pasanen, K. "Review of recommendations for forest energy harvesting and wood ash recycling", In D. Röser, A. Asikainen, K. Raulund-Rasmussen and I. Stupak (eds) *Sustainable Use of Forest Biomass for Energy – A Synthesis With Focus on the Nordic and Baltic Region*. Managing Forest Ecosystems, vol. 12. Dordrecht: Springer, 29–78, 2008.

DOI: https://doi.org/10.1007/978-1-4020-5054-1_7

Abstract: In other chapters of this book, different economic, environmental and social aspects of forest fuel harvesting and wood ash recycling are treated and recommendations are given. However, national recommendations have already been elaborated by authorities in Sweden, Finland, Denmark and Lithuania, and other recommendations and information materials have been elaborated by different national or international groups with varying degree of stakeholder involvement. Synthesis information on these issues is also being provided by internet homepages such as www. aboutbioenergy.info by IEA Bioenergy Task 29, and computer models. The existing recommendations and information materials cover a wide range of topics including economic, ecological, environmental, social, technical and practical aspects for the whole forest fuel chain, ranging from available and potential resources, silviculture and production in the forest, harvesting technology, processing, handling, storage and transport to fuel quality, combustion technology, and emissions from the energy plant. In addition, waste production, wood ash recycling to the forest and institutional and participatory aspects are covered.

2007

Stupak, I., Asikainen, A., Jonsell, M., Karltun, E., Lunnan, A., Mizaraitė, D., Pasanen, K., et al. "Sustainable Utilisation of Forest Biomass for Energy – Possibilities and Problems: Policy, Legislation, Certification, and Recommendations and Guidelines in the Nordic, Baltic, and Other European Countries", *Biomass and Bioenergy*, 31(10), 666–84, 2007.

DOI: https://doi.org/10.1016/j.biombioe.2007.06.012

Abstract: The substitution of biomass for fossil fuels in energy consumption is a measure to mitigate global warming, as well as having other advantages. Political action plans for increased use exist at both European and national levels. This paper briefly reviews the contents of recommendations, guidelines, and other synthesis publications on sustainable use of forest biomass for energy. Topics are listed and an overview of advantages, disadvantages, and trade-offs between them is given, from the viewpoint of society in general and the forestry and energy sectors in particular. For the Nordic and Baltic countries, the paper also identifies the extent to which wood for energy is included in forest legislation and forest certification standards under the "Programme for the Endorsement of Forest Certification" (PEFC) and the "Forest Stewardship Council" (FSC) schemes. Energy and forest policies at EU and national levels, and European PEFC forest standards are analysed. With respect to energy policies, the utilisation of wood for energy is generally supported in forest policies, but forest legislation is seldom used as a direct tool to encourage the utilisation of wood for energy. Regulations sometimes restrict use for environmental reasons. Forest certification standards include indicators directly related to the utilisation of wood for energy under several criteria, with most occurrences found under environmental criteria. Roles and problems in relation to policy, legislation, certification standards, recommendations and guidelines, and science are discussed.

Harmonisation

2017

Abrams, J., Becker, D., Kudrna, J., and Moseley, C. "Does Policy Matter? The Role of Policy Systems in Forest Bioenergy Development in the United States", *Forest Policy and Economics,* 75, 41–48, 2017.

DOI: https://doi.org/10.1016/j.forpol.2016.12.007

Abstract: Public policies play a key role in supporting systems of innovation in the woody biomass energy sector. Although hundreds of biomass promotion policies have been enacted at state and national levels in the United States, the effectiveness of these various policies – individually and as a policy system – remains unclear. Here we draw upon a survey of biomass producers and users at various supply-chain steps to explore whether and how individual policies and the larger policy system influence innovation and decision-making. We find that individual policies were considered influential in a small but substantial proportion of significant changes made to operations, with disbursement, tax, and regulatory policies seen as the most influential. A relatively small proportion of respondents were willing or able to describe policy effects across multiple supply-chain steps; those who did described variably effective biomass support policies, largely at the state level, conflicting with federal regulatory policies that were seen as creating additional costs and uncertainties. These results suggest that the biomass policy system in the United States may not be well designed to support innovation, particularly due to conflicts between biomass promotion policies and other forest, environmental, or energy policies.

Mai-Moulin, T., Armstrong, S., van Dam, J., and Junginger, M. "Toward a Harmonization of National Sustainability Requirements and Criteria for Solid Biomass", *Biofuels, Bioproducts and Biorefining*, 1–17, 2017.

DOI: http://dx.doi.org/10.1002/bbb.1822

Abstract: This paper compares national sustainability support schemes and sustainability requirements in four countries that import solid biomass for heat and power generation: Belgium, Denmark, the UK, and the Netherlands. The paper also reviews voluntary certification schemes for solid biomass that may be used to demonstrate sustainability compliance. In the absence of mandatory EU criteria for solid biomass, different national support schemes and sustainability requirements may present barriers to trade. This paper identifies some possibilities for harmonization and provides suggestions for policymakers for the improvement and alignment of national sustainability requirements. Ultimately the paper suggests establishing a harmonized certification scheme in the short term based on legislative requirements in the four countries and in voluntary initiatives. The proposed harmonized certification scheme may also reduce both implementation costs and complexity for biomass suppliers and generators. In the long term, the paper recommends binding criteria on sustainability requirements for solid biomass at EU level.

2016

Stupak, I., Joudrey, J., Smith, C.T., Pelkmans, L., Chum, H., Cowie, A., Englund, O., Goh, C.S., and Junginger, M. "A Global Survey of Stakeholder Views and Experiences for Systems Needed to Effectively and Efficiently Govern Sustainability of Bioenergy", *Wiley Interdisciplinary Reviews: Energy and Environment*, 5(1), 89–118, 2016.

DOI: https://doi.org/10.1002/wene.166

Abstract: Different governance mechanisms have emerged to ensure biomass and bioenergy sustainability amidst a myriad of related public and private regulations that have existed for decades. We conducted a global survey with 59 questions which examined 192 stakeholders' views and experiences related to (1) the multi-leveled governance to which they are subjected, (2) the impacts of that governance on bioenergy production and trade, and (3) the most urgent areas for improvement of certification schemes. The survey revealed significant support along the whole supply chain for new legislation which uses market-based certification schemes to demonstrate compliance (co-regulation). Some respondents did not see a need for new regulation, and meta-standards is a promising approach for bridging divergent views, especially if other proof than certification will be an option. Most respondents had so far experienced positive or neutral changes to their bioenergy production or trade after the introduction of new sustainability governance. Legislative requirements and a green business profile were important motivations for getting certified, while lack of market advantages, administrative complexity and costs all were barriers of varying importance. A need to include, e.g., regular standard revision and dealing with conflicting criteria was identified by respondents associated with bioenergy schemes. Respondents associated with forestry schemes saw less need for revisions, but some were interested in supply chain sustainability criteria. Significant differences among schemes suggest it is crucial in the future to examine the tradeoffs between certification costs, schemes' inclusiveness, the quality of their substantive and procedural rules, and the subsequent effectiveness on-the-ground.

2015

Bosch, R., van de Pol, M., and Philp, J. "Policy: Define Biomass Sustainability", *Nature,* 523(7562), 526–27, 2015.

DOI: http://dx.doi.org/10.1038/523526a

2011

van Dam, J., and Junginger, M. "Striving to Further Harmonization of Sustainability Criteria for Bioenergy in Europe: Recommendations from a Stakeholder Questionnaire", *Energy Policy,* 39(7), 4051–66, 2011.

DOI: https://doi.org/10.1016/j.enpol.2011.03.022

Abstract: This questionnaire analyzed the ongoing development of sustainability criteria for solid and liquid bioenergy in the European Union and further actions needed to come to a harmonization of certification systems, based on EU stakeholder views. The questionnaire, online from February to August 2009, received 473 responses collected from 25 EU member countries and 9 non-European countries; 285 could be used for further processing. A large majority of all stakeholders (81%) indicated that a harmonized certification system for biomass and bioenergy is needed, albeit some limitations. Amongst them, there is agreement that (i) a criterion on 'minimization of GHG emissions' should be included in a certification system for biomass and bioenergy, (ii) criteria on optimization of energy and on water conservation are considered of high relevance, (iii) the large variety of geographical areas, crops, residues, production processes and end-uses limits development towards a harmonized certification system for sustainable biomass and bioenergy in Europe, (iv) making better use of existing certification systems and standards improves further development of a harmonized European biomass and bioenergy sustainability certification system and (v) it is important to link a European certification system to international declarations and to expand such a system to other world regions.

2010

CEPI. "Biomass Sustainability Criteria Should Be Binding and Harmonized!", Confederation of European Paper Industries [Online], http://www.cepi.org/system/files/public/documents/positionpapers/forest/2010/2010Sustainability_criteria_for_biomassl-20100301-00005-01-E.pdf, 2010 (Accessed 09.02.2018).

General sustainability issues

2018

Vance, E.D., Prisley, S.P., Schilling, E.B., Tatum, V.L., Wigley, T.B., Lucier, A.A., and Van Deusen, P.C. "Environmental Implications of Harvesting Lower-Value Biomass in Forests", *Forest Ecology and Management*, 407, 47–56, 2018.

DOI: https://doi.org/10.1016/j.foreco.2017.10.023

Abstract: Lower-value biomass (LVB) in forests constitutes non-commercial material traditionally left on site following harvesting. Emerging markets for energy and bioproducts have increased incentives to harvest and utilize this material in some cases. Removal of LVB can reduce forest health risks stemming from wildfire, diseases, and pests but has raised questions about effects on forest productivity and environmental sustainability. The status, trends, and quantities of forest biomass are most often estimated from forest inventories but socioeconomic and physical factors limit the quantity of residual biomass available for use. National forest inventory data suggest quantities of LVB are likely substantial, with annual timberland growth exceeding harvest removals in all states where data are available and unutilized dead biomass roughly half that of current harvest removals. Cost-effective transport distance and logistical factors limit the practical

availability of LVB, with in-woods chipping as part of conventional harvesting operations generally providing the greatest economic returns. Harvesting LVB removes higher quantities of nutrients from forested sites with greater potential impact on soil physical properties, soil carbon, and forest productivity than traditional, stem-only harvesting. However, global assessments show inconsistent forest productivity and soil responses and impacts across contrasting sites and soil types. Lower residue retention and changes in forest structure resulting from LVB harvesting can also influence habitat for some wildlife species. Some field studies suggest removals of downed coarse woody debris negatively impact bird diversity and abundance while other assessments suggest minimal or only temporary effects with benefits to other species, particularly those associated with early seral habitat. While LVB harvesting and residue removal have the potential to increase soil disturbance and delivery of sediment and nutrients to streams compared to traditional harvesting, best management practices demonstrated effective in protecting water quality through decades of field research should be largely applicable to practices that include LVB harvesting. Although states and other entities have developed biomass harvesting guidelines and revised certification standards that restrict or modify intensive harvesting practices, the efficacy of such guidelines is uncertain due to highly variable site limitations and responses and a lack of site-specific response data. This paper provides an overview of environmental implications and practical considerations related to harvesting LVB in forests and how they differ from harvesting of traditional, commercial biomass sources.

2017

de Jong, J., Akselsson, C., Egnell, G., Löfgren, S., and Olsson, B.A. "Realizing the Energy Potential of Forest Biomass in Sweden – How Much Is Environmentally Sustainable?", *Forest Ecology and Management,* 383, 3–16, 2017.

DOI: https://doi.org/10.1016/j.foreco.2016.06.028

Abstract: Harvesting of wood for bioenergy purpose will probably increase in importance in the future, in order to replace fossil fuel. However, the environmental impact of increased harvesting might be considerable, e.g. on soil and water chemistry, biodiversity and long-term productivity, and in this study we investigate thresholds for sustainable harvesting volumes. The study is based on scientific reviews of the impact of harvesting of logging residues (slash and stumps) on forest production, biodiversity, acidification, eutrophication and toxic substances. We define sustainability by using environmental objectives decided by the Swedish parliament (which are based on the Aichi targets), and relate the harvesting impact to these objectives within different harvesting scenarios, by using expert judgment. We demonstrate that an increase in harvesting of logging residues by 2.5 times might be sustainable. However, we also identify a number of risks and the sustainability depends on a number of requirements that should be fulfilled, such as ash-recycling. It was found that factors related to biodiversity conservation (defined in the goals 'Sustainable Forests' and 'A Rich Diversity of Plant and Animal Life') were limiting factors both for slash- and stump harvesting, and that risk of acidification (defined in the goal 'Natural Acidification Only') also limit slash harvesting. We also include harvesting of brushwood and energy wood from conservation cutting in the discussion, since these assortments might be important in the future.

2016

Scott, D.A., and Page-Dumroese, D.S. "Wood Bioenergy and Soil Productivity Research", *BioEnergy Research,* 9(2), 507–17, 2016.

DOI: https://doi.org/10.1007/s12155-016-9730-6

Abstract: Timber harvesting can cause both short- and long-term changes in forest ecosystem functions, and scientists from USDA Forest Service (USDA FS) have been studying these processes for many years. Biomass and bioenergy markets alter the amount, type, and frequency at which material is harvested, which in turn has similar yet specific impacts on sustainable productivity. The nature of some biomass energy operations provides opportunities to ameliorate or amend forest soils to sustain or improve their productive capacity, and USDA FS scientists are leading the research into these applications. Research efforts to sustain productive soils need to be verified at regional, national, and international scope, and USDA FS scientists work to advance methods for soil quality monitoring and to inform international criteria and indicators. Current and future USDA FS research ranges from detailed soil process studies to regionally important applied research and to broad scale indicator monitoring and trend analysis, all of which will enable the USA to lead in the sustainable production of woody biomass for bioenergy.

2015

Achat, D.L., Deleuze, C., Landmann, G., Pousse, N., Ranger, J., and Augusto, L. "Quantifying Consequences of Removing Harvesting Residues on Forest Soils and Tree Growth – a Meta-Analysis", *Forest Ecology and Management,* 348, 124–41, 2015.

DOI: https://doi.org/10.1016/j.foreco.2015.03.042

Abstract: Increasing attention is being paid to using modern fuelwood as a substitute for fossil energies to reduce CO_2 emissions. In this context, forest biomass, particularly harvesting residues (branches), and stumps and associated coarse roots, can be used to supply fuelwood chains. However, collecting harvesting residues can affect soil properties and trees, and these effects are still not fully understood. The main objective of the present study was to compile published data worldwide and to quantify the overall effects of removing harvesting residues on nutrient outputs, chemical and biological soil fertility and tree growth, through a meta-analysis. Our study showed that, compared with conventional stem-only harvest, removing the stem plus the harvesting residues generally increases nutrient outputs thereby leading to reduced amounts of total and available nutrients in soils and soil acidification, particularly when foliage is harvested along with the branches. Losses of available nutrients in soils could also be explained by reduced microbial activity and mineralization fluxes, which in turn, may be affected by changes in organic matter quality and environmental conditions (soil compaction, temperature and moisture). Soil fertility losses were shown to have consequences for the subsequent forest ecosystem: tree growth was reduced by 3–7 % in the short or medium term (up to 33years after harvest) in the most intensive harvests (e.g. when branches are exported with foliage). Combining all the results showed that, overall, whole-tree harvesting has negative impacts on soil properties and trees that may have an impact on the functioning of forest ecosystems. Practical measures that could be taken to mitigate the environmental consequences of removing harvesting residues are discussed.

Clarke, N., Gundersen, P., Jönsson-Belyazid, U., Kjønaas, O.J., Persson, T., Sigurdsson, B.D., Stupak, I., and Vesterdal, L. "Influence of Different Tree-Harvesting Intensities on Forest Soil Carbon Stocks in Boreal and Northern Temperate Forest Ecosystems", Forest Ecology and Management, 351, 9–19, 2015.

DOI: https://doi.org/10.1016/j.foreco.2015.04.034

Abstract: Effective forest governance measures are crucial to ensure sustainable management of forests, but so far there has been little specific focus in boreal and northern temperate forests on governance measures in relation to management effects, including harvesting effects, on soil organic carbon (SOC) stocks. This paper reviews the findings in the scientific literature concerning the effects of harvesting of different intensities on SOC stocks and fluxes in boreal and northern temperate forest ecosystems to evaluate the evidence

for significant SOC losses following biomass removal. An overview of existing governance measures related to SOC is given, followed by a discussion on how scientific findings could be incorporated in guidelines and other governance measures. The currently available information does not support firm conclusions about the long-term impact of intensified forest harvesting on SOC stocks in boreal and northern temperate forest ecosystems, which is in any case species-, site- and practice-specific. Properly conducted long-term experiments are therefore necessary to enable us to clarify the relative importance of different harvesting practices on the SOC stores, the key processes involved, and under which conditions the size of the removals becomes critical. At present, the uncertainty gap between the scientific results and the need for practically useable management guidelines and other governance measures might be bridged by expert opinions given to authorities and certification bodies.

2014

Helmisaari, H.-S., Kaarakka, L., and Olsson, B.A. "Increased Utilization of Different Tree Parts for Energy Purposes in the Nordic Countries", *Scandinavian Journal of Forest Research,* 29(4), 312–22, 2014.

DOI: https://doi.org/10.1080/02827581.2014.926097

Abstract: The review gives an overview of the increased utilization of forest biomass for energy. The emphasis is on Nordic countries, especially on Sweden and Finland with large biomass potentials and a high share of renewable energy in gross final energy consumption. The utilization and potential of forest chip sources such as logging residues, small-size tree stems and stumps that are normally not harvested in conventional harvesting are described. Environmental potential and impacts that may reduce the utilization of forest biomass are discussed based on recent publications. Finally, the review summarizes the future developments based on their relationship to policies, certifications and guidelines and forest owners' decisions.

2012

Bouget, C., Lassauce, A., and Jonsell, M. "Effects of Fuelwood Harvesting on Biodiversity—a Review Focused on the Situation in Europe ", *Canadian Journal of Forest Research,* 42(8), 1421–32, 2012.

DOI: https://doi.org/10.1139/x2012-078

Abstract: A continually increasing demand for energy and concerns about climate change, greenhouse gas emissions and peak oil have prompted countries to develop policies that promote renewable energy including forest-based bioenergy. In Europe, fuelwood-driven changes in forestry are likely to impact habitat conditions for forest biodiversity. We conducted a systematic literature overview based on 88 papers to synthesize research findings and gaps in knowledge. At the stand scale, but also on a landscape scale, deadwood availability and profile are altered by several practices: whole-tree harvesting and postharvest recovery of logging residues and stumps, for instance. Large-scale fuelwood removal may, on a landscape scale, jeopardize the amounts and diversity of substrate that saproxylic organisms require as food and habitat. Besides, bioenergy-related forest practices also affect nonsaproxylic biodiversity through physical (e.g., soil compaction and disturbance) and chemical changes in soil properties associated with fuelwood removal and increased machine traffic. Moreover, the extended density of internal edges threatens interior forest species populations. Important effects differ substantially between boreal and nemoral forests because of contrasts in management systems, structure of forest ownership, and ecological properties. Developing relevant operational guidelines to partially mitigate ecological damage on biodiversity should be based on our compiled cautionary statements but require further large-scale and long-term research.

2011

Riffell, S., Verschuyl, J., Miller, D., and Wigley, T.B. "Biofuel Harvests, Coarse Woody Debris, and Biodiversity – a Meta-Analysis", *Forest Ecology and Management,* 261(4), 878–87, 2011.

DOI: https://doi.org/10.1016/j.foreco.2010.12.021

Abstract: Forest harvest operations often produce large amounts of harvest residue which typically becomes fine (foliage, small limbs and trees) and coarse woody debris (snags and downed logs). If removed at harvest, residual biomass has potential to be a local energy source and to produce marketable biofuel feedstock. But, CWD in particular serves critical life-history functions (e.g., breeding, foraging, basking) for a variety of organisms. Unfortunately, little is known about how forest biodiversity would respond to large scale remo-val of harvest residues. We calculated 745 biodiversity effect sizes from 26 studies involving manipulations of CWD (i.e., removed or added downed woody debris and/or snags). Diversity and abundance of both cavity- and open-nesting birds were substantially and consistently lower in treatments with lower amounts of downed CWD and/or standing snags, as was biomass of invertebrates. However, cumulative effect sizes for other taxa were not as large, were based on fewer studies, and varied among manipulation types. Little is currently known about biodiversity response to harvest of fine woody debris. Predicting the effects of bio-mass harvests on forest biodiversity is uncertain at best until more is known about how operational harvests actually change fine and coarse woody debris levels over long time periods. Pilot biomass harvests report post-harvest changes in CWD levels much smaller than the experimental changes involved in the studies we analyzed. Thus, operational biomass harvests may not change CWD levels enough to appreciably influ-ence forest biodiversity, especially when following biomass harvest guidelines that require leaving a portion of harvest residues. Multi-scale studies can help reduce this uncertainty by investigating how biodiversity responses scale from the small scale of manipulative experiments (i.e., 10-ha plots) to operational forest ma-nagement and how biodiversity response to CWD levels might vary at different spatial and temporal scales and in different landscape contexts.

Stupak, I., Lattimore, B., Titus, B.D., and Tattersall Smith, C. "Criteria and Indicators for Sustainable Forest Fuel Production and Harvesting: A review of Current Standards for Sustainable Forest Management", *Biomass and Bioenergy*, 35(8), 3287–308, 2011.

DOI: https://doi.org/10.1016/j.biombioe.2010.11.032

Abstract: Forest biomass is increasingly being considered as a source of sustainable energy. It is crucial, however, that this biomass be grown and harvested in a sustainable manner. International processes and certification systems have been developed to ensure sustainable forest management (SFM) in general, but it is important to consider if they adequately address specific impacts of intensified production and harvesting methods related to forest fuels. To explore how existing SFM frameworks address sustainable forest fuel production, criteria and indicators (C&I) from 10 different international processes and organizations and 157 international, national and sub-national forest management certification standards under the Forest Stewardship Council (FSC) and the Programme for the Endorsement of Forest Certification (PEFC) were reviewed. International processes include indicators that require identification or reporting of availability, harvested amounts, value, or share in energy consumption of forest fuels. Forest certification standards address several specific woodfuel issues, but not always in a consistent manner. It seems that developed countries more frequently address environmental consequences of harvesting residues or whole trees on soil fertility and biodiversity, while developing countries more frequently address social issues, such as local people's access to firewood and working conditions in charcoal production. Based on findings, options to improve SFM standards for sustainable forest fuel production are discussed. These options include clarification of terminology, systematic inclusion of important management impacts unique to forest fuel production, coordination of efforts with other related governance processes, including tools promoting sustainability at more integrated levels, such as landscape, supply chain and global levels.

Thiffault, E., Hannam, K.D., Paré, D., Titus, B.D., Hazlett, P.W., Maynard, D.G., and Brais, S. "Effects of Forest Biomass Harvesting on Soil Productivity in Boreal and Temperate Forests – a Review", *Environmental Reviews,* 19, 278–309, 2011.

DOI: https://doi.org/10.1139/a11-009

Abstract: Concerns about climate change and the desire to develop a domestic, renewable energy source are increasing the interest in forest biomass extraction, especially in the form of logging residues, i.e., tree tops and branches. We reviewed the literature to determine the site and soil conditions under which removal of logging residues along with the stem (i.e., whole-tree harvesting), especially at clearcut, results in negative impacts on soil productivity compared with conventional stem-only harvesting in boreal and temperate forests. Negative impacts of biomass harvesting on soil nutrient pools (e.g., nitrogen, phosphorus and base cations) and soil acid-base status are more frequent in the forest floor than in the mineral soil. In the first years post-harvest, however, biomass harvesting has the greatest potential to influence tree survival and growth, either positively or negatively, through its effects on microclimate and competing vegetation. Later in the rotation, impaired nitrogen and (or) phosphorus nutrition on whole-tree harvested sites has been shown to reduce tree growth for at least 20 years in some stands. Biomass removal can also reduce the concentrations of base cations in soils and foliage, but this has not, to date, been shown to affect tree productivity. There are no consistent, unequivocal and universal effects of forest biomass harvesting on soil productivity. However, climate and microclimate, mineral soil texture and organic C content, the capacity of the soil to provide base cations and phosphorus, and tree species autecology appear to be critical determinants of site sensitivity to biomass harvesting. Rigorous, long-term experiments that follow stand development through a rotation will facilitate the identification of categories of site or stand conditions under which negative impacts of biomass harvesting are likely.

2009

Lattimore, B., Smith, C.T., Titus, B.D., Stupak, I., and Egnell, G. "Environmental Factors in Woodfuel Production: Opportunities, Risks, and Criteria and Indicators for Sustainable Practices", *Biomass and Bioenergy,* 33(10), 1321–42, 2009.

DOI: https://doi.org/10.1016/j.biombioe.2009.06.005

Abstract: Bioenergy from sustainably managed forest ecosystems could provide a renewable, carbon-neutral source of energy in many nations and communities throughout the world. In order for forest bioenergy to be an ecologically sustainable fuel source, woodfuel procurement systems must not adversely impact forest ecosystems or the environment. Sustainable forest management (SFM) certification schemes are one mechanism for applying standards and monitoring regimes to forest management systems to ensure ecological sustainability. This paper provides a global review of the main environmental risks to forest ecosystems that can arise from household- to industrial-scale woodfuel production systems, including forest soil quality and site productivity, water resources, biodiversity and carbon budgets. A set of regionally adaptable principles, criteria, indicators and verifiers of sustainable forest management were developed, based on criteria and indicators from existing internationally recognized certification frameworks and scientific literature and tailored to address issues relevant to producing and harvesting forest bioenergy feedstocks. A variable monitoring approach and a three-tiered certification approach are proposed as two methods for enabling the adoption of certification and associated monitoring requirements across a wide range of forest operations in regions with widely differing levels of development. The importance of the Adaptive Forest Management framework inherent in certification systems to ensuring the efficacy and continual improvement in woodfuel sustainability is stressed. The proposed principles, criteria, indicators and verifiers can be adapted to local conditions and incorporated into existing sustainable forest management and green energy certification

schemes, as well as other criteria and indicator frameworks, to ensure the environmental sustainability of woodfuel production systems.

2008

Röser, D. *Sustainable Use of Forest Biomass for Energy: A Synthesis with Focus on the Baltic and Nordic Region*. Managing Forest Ecosystems. Dordrecht, The Netherlands: Springer, 2008.

DOI: https://doi.org/10.1007/978-1-4020-5054-1

Abstract: With the large-scale utilization of forest biomass for energy still in its infancy, there is an urgent need to understand the short- and long-term consequences of intensive forest biomass harvesting – both on the forest ecosystem and on forest economics. Sustainable Use of Forest Biomass for Energy draws on the vast body of knowledge of forest ecology and management in the Nordic-Baltic region, with the aim of bridging the gap between scientific knowledge and general principles on the one hand, and more concrete practical forest management and policy development on the other. The focus on the Nordic and Baltic countries makes it possible to compare two groups of countries in Europe which have similar ecological conditions, but substantial differences in both their economic frameworks and, consequently, their need to overcome barriers to increased use of forest biomass for energy. In this ground-breaking book, Nordic and Baltic scientists from ecological, economic, social, and technological disciplines join forces to synthesize current knowledge, generate new data, describe cases, and create a solid basis for the future development of management recommendations for forest energy harvesting and wood ash recycling. Providing tools and information for improved evaluation the real sustainability of a given management regime, this book is indispensable reading for forest scientists and managers, forest extension, forest and energy policy makers and the energy sector.

2002

Richardson, J. *Bioenergy from Sustainable Forestry: Guiding Principles and Practice*. Forestry Sciences. Dordrecht; Boston: Kluwer Academic, 2002.

DOI: https://doi.org/10.1007/0-306-47519-7

Abstract: Bioenergy from Sustainable Forestry synthesizes information needed to design or implement sustainable forest management systems for production of biomass for energy in conjunction with other forest products. It is organized around the criteria for sustainable forest management: productivity, environment, social issues, economics, and legal and institutional framework. More than 25 international experts from 10 countries have brought together available ecological, physical, operational, social and economic information and identified gaps in knowledge related to biomass production and harvesting systems. This is the first time that such comprehensive information has been brought together under one cover, using an integrated, holistic approach. Guiding principles and state of the art knowledge are emphasized. The book will enable forest resource managers and planners to evaluate the ability of specific forest regions to sustainably meet bioenergy production demands.

Author biographies

Viktor J. Bruckman is employed at the Austrian Academy of Sciences and lecturer at the University of Natural Resources and Life Sciences (BOKU). His research focus is on carbon in forest ecosystems, as well as renewable energy in general and climate change mitigation/adaptation. He is board member of the division Energy Resources and the Environment of the European Geosciences Union and member of the working group on biochar of the national advisory board for soil protection and fertility. He co-chairs the Task Force "Forest Biomass Network (FBN)" of the International Union of Forest Research Organizations (IUFRO).
E-mail: viktor.bruckman@oeaw.ac.at

Alexander Evans is Executive Director of the Forest Stewards Guild. For eleven years previous to his current role, he directed the Guild's research programs. His research supports on-the-ground implementation of ecological forestry including and sustainability of forest bioenergy. Other research has looked at the spread of non-native forest pests and the effective of fuel reduction treatments on wildfire and carbon. Dr. Evans is involved in local collaborative efforts to improve forest management as a board member of Southwest Fire Science Consortium. He received his PhD from the Yale School of Forestry and Environmental Studies after working as a cartographer and spatial analyst with the US Geological Survey.
E-mail: zander@forestguild.org

Heljä-Sisko Helmisaari is Professor in Forest Soil Science at the Department of Forest Sciences at the University of Helsinki, Finland. She is an expert on biogeochemistry, concentrating on carbon and nutrient dynamics in forest ecosystems. Many of her projects have been large ecosystem-level studies on environmental gradients or with experimental manipulations. Her present research projects concentrate on ecosystem aboveground – belowground interactions and the sustainability of forest bioenergy, which has also been a topic of several international and national seminars organized by her. Prof. Helmisaari has published more than 100 research papers and book chapters.

E-mail: helja-sisko.helmisaari@helsinki.fi

Inge Stupak is Associate Professor at the University of Copenhagen. She is the Danish national team leader in IEA Bioenergy Task 43 on 'Biomass feedstocks for Energy Markets'. Her major research contributions and research management responsibilities have been focused on the environmental impacts of woody biomass production, including forest and short rotation crops, and sustainability governance of bioenergy. She is currently involved in analyses of governance systems and complexes to ensure sustainability of biomass for energy and other end uses. She is also involved in national forest soil inventory, and work on the effects of land use and land use change on soil carbon. Previous work also include field experiments to determine the effects of mineral and organic fertilizer application on yield and nutrient cycling in forest and short rotation coppice systems. Inge has also participated in teams providing technical assistance to the EU for evaluations of sustainability requirements and schemes to promote biomass sustainability, and to the Danish Energy Agency for an evaluation of the sustainability of imported woodfuels.
E-mail: ism@ign.ku.dk

Brian Titus is a research scientist with the Canadian Forest Service of Natural Resources Canada. His work centres on the environmental sustainability of increased biomass removal from forests, especially impacts on nutrient cycling and site productivity, which began with his Ph.D. studies in the early 1980s on the earliest biomass removal trial in the U.K. He also works on incorporation of ecological sustainability considerations into biomass inventories, and application of knowledge in sustainability criteria and guidelines. He co-led several national CFS projects in bioenergy, and was on the steering committee of a recent multi-disciplinary and multi-national Pan-American project on bioenergy.
E-mail: brian.titus@canada.ca