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Bioenergy and Biodiversity: Key Lessons from the Pan American Region

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Abstract Understanding how large-scale bioenergy production can affect biodiversity and ecosystems is important if society is to meet current and future sustainable development goals. A variety of bioenergy production systems have been established within different contexts throughout the Pan American region, with wide-ranging results in terms of documented and projected effects on biodiversity and ecosystems. The Pan American region is home to the majority of commercial bioenergy production and therefore the region offers a broad set of experiences and insights on both conflicts and opportunities for biodiversity and bioenergy. This paper synthesizes lessons learned focusing on experiences in Canada, the United States, and Brazil regarding the conflicts that can arise between bioenergy production and ecological conservation, and benefits that can be derived when bioenergy policies promote planning and more sustainable land-management systems. We propose a research agenda to address priority information gaps that are relevant to biodiversity concerns and related policy challenges in the Pan American region.

Keywords Biofuel · Brazil · Canada · Ecological impacts · Woody biomass · Forest residue

Introduction

Nations are examining biomass-based energy options to increase their energy security, decrease their carbon emissions, or promote rural development and exports (Tilman et al. 2009; Fargione et al. 2010; Lankoski and Ollikainen 2011; OECD/FAO 2011; Lu et al. 2012; Leal

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et al. 2013). Policies that set targets for the increased use of bioenergy, such as the transportation fuel blending requirements of the U.S.'s Renewable Fuel Standard in the 2007 Energy Independence and Security Act (US EPA 2010), have raised concerns about negative social and environmental consequences but also highlighted opportunities for improving current production practices. These concerns include the 2007–2008 spikes in world food prices, modeling projections of increased nitrogen runoff into the Gulf of Mexico, and the continued loss of habitat in important reserves for biodiversity such as Indonesia and Brazil (Donner and Kucharik 2008; Dale et al. 2010b; Gutiérrez-Vélez et al. 2011; Tscharntke et al. 2012; Lapola et al. 2014). Opportunities include the potential for bioenergy production to improve water and soil quality, enhance biodiversity and wildlife habitat conservation, contribute to food and energy security, mitigate climate change, and decrease environmental degradation associated with current practices in agriculture and forestry (Kline et al. 2009; Dale et al. 2014; Souza et al. 2015; Dale et al. 2011, 2010c, 2015).

The tension between agricultural land use and biodiversity conservation areas is relevant in bioenergy discussions, particularly if bioenergy is meant to slow the climate changes that are expected to impact biodiversity and ecosystems (Tilman et al. 2009; Tscharntke et al. 2012). Conversely, biodiversity conservation objectives can limit the land area available for biomass production (Erb et al. 2012). The "land sharing versus land sparing" debate revolves around approaches for minimizing agriculture's impact on biodiversity and ecosystem services. This is relevant to bioenergy when native forests or grasslands are impacted by the biomass supply chain (Taubert et al. 2012; Tscharntke et al. 2012; Immerzeel et al. 2014). Likewise, prescriptions for harvesting biomass for bioenergy on "marginal" land to avoid direct competition with food crops (Tilman et al. 2009; Gelfand et al. 2013) tend to encounter economic or ecological difficulties, due to low productivity and socioecological values provided by lands subjectively defined as marginal (Dale et al. 2010c; Fahd et al. 2012; Bryngelsson and Lindgren 2013; Butterbach-Bahl and Kiese 2013). Using agricultural or forestry residue (e.g., corn stover, tree slash and stumps; Tilman et al. 2009) also comes at a cost when the residues are critical for soil fertility, protecting soils against excessive erosion, and biodiversity conservation (Reijnders 2013; Victorsson and Jonsell 2013).

Current Bioenergy Production in Pan America

The Pan American region dominates global production, particularly for transportation biofuels. The United States and Brazil together produce nearly 90 % of bioethanol worldwide (Fig. 1), and almost 80 % of the total biofuel production worldwide since 2007 (Fig. 2). On average, about 40 % of US corn production from the 2011–2013 harvest seasons was processed by mills producing ethanol (two-thirds by mass) and other co-products (such as animal feed). After this allocation among co-products, the ethanol share represents about 9 million ha or 8 % of total area harvested for major US crops (2011–2013 average) and about 0.9 % of total US territory (calculations based on USDA ERS 2014). In the case of Brazil, considering the sucrose content, it is estimated that 54–57 % of sugarcane production was used for ethanol in the two most recent harvests, 2013/2014 and 2014/2015 (UDOP 2015). As the total area used with sugarcane is currently 10.2 million ha (IBGE 2015), it can be conservatively estimated that less than 6 million ha have been used for ethanol production; this area represents about 8 % of the total area used for crops and less than 1 % of the Brazilian territory.

In terms of bioenergy for heat and electricity, the United States and Canada are two of the leading wood pellet manufacturers in the world, collectively producing roughly 7.8 million tons of wood pellets in 2013 (REN21 2014). The wood pellet capacity of North America rose rapidly from roughly 1 million tons in 2003 to over 6 million tons in 2009, driven mainly by increasing exports to the European Union (EU); 4.7 million tons were exported from North America to Europe in 2013 alone (Cocchi et al. 2011; Spelter and Toth 2009; Wood Resources International LLC 2014).

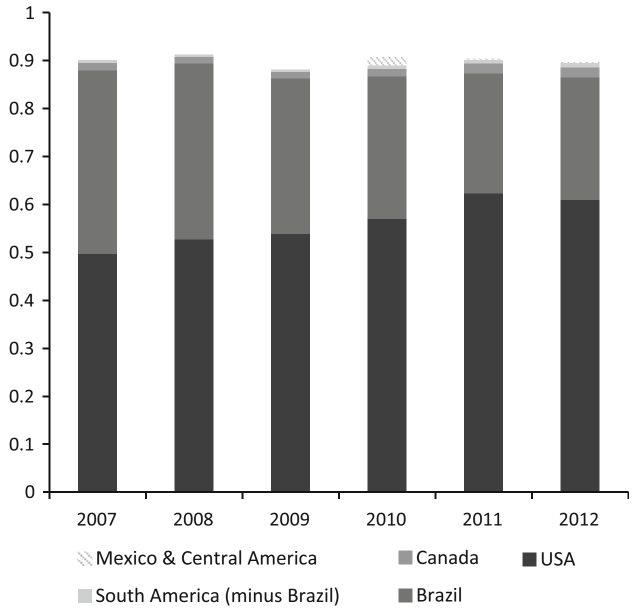

Fig. 1 Regional proportion of world bioethanol production, by volume. *Data source* Licht, cited in Renewable Fuels Association, Ethanol Industry Outlook 2008–2013 reports. Available at www.ethanolrfa.org/pages/annual-industry-outlook

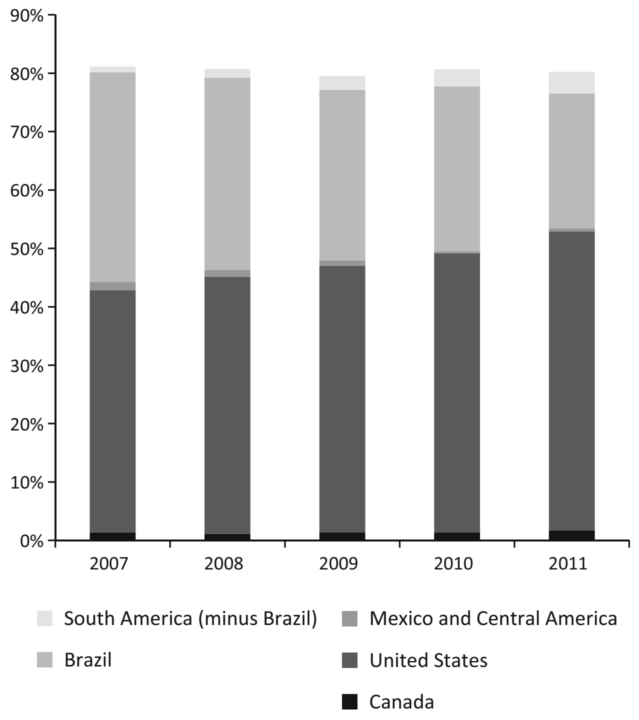

Fig. 2 Percent of total global biofuels (all types, for transport) produced regionally, by volume. *Data source* U.S. Energy Information Administration, Independent Statistics and Analysis. Available at: http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=79&pid=79&aid=1

Ecology and Land Use in Pan America

Stretching from the Canadian Arctic to the southern tip of South America, the Pan American region contains a wealth of species and habitats, many of them endemic to the Americas. Central and South America (including the Caribbean) is the most diverse region on Earth, supporting over a third of the species in most taxonomic groups (United Nations Environment Programme 2010). Climate change is a prevalent threat throughout Pan America to individual species, communities, and ecosystems, and many species are not expected to adjust to the pace of current climatic changes (Schloss et al. 2012; Grimm et al. 2013; Staudinger et al. 2013). While one justification to switch from fossil fuels to biofuels is to reduce net greenhouse gas emissions and hence slow climate change, the environmental advantages of bioenergy alternatives depend largely on whether biofuel production contributes to improved management of previously cleared and disturbed lands or causes net additional clearing and degradation on lands that would otherwise retain high conservation value (HCV) for biodiversity and carbon storage (Dale et al. 2015). Unsustainable water use from industry, agriculture, and growing urban populations is also a concern; stresses on water and habitat will be exacerbated by climate change.

The region's biodiversity suffers from deforestation driven by a complex set of interacting social, political, and economic factors. Despite ongoing pressures from development and significant losses of US forest to urban landscapes, total forest area expanded from 2004 to 2011 as US ethanol output grew fourfold (RFA 2014; US EPA 2014). From 2005 to 2011, the US Environmental Protection Agency reports that net forest area grew by an average of 525,000 ha per year, about 17 % faster than the rate observed over the prior 15 year period (based on US EPA 2014). However, forest dynamics outside of North America are quite different. The conversion of natural vegetation (forest and savanna) to agricultural production in Brazil follows, in most cases, the von Thünen land rent and Mather forest transition combined theories described by Angelsen (2007), and as shown with empirical data analysis for 1975–2006 by Barretto et al. (2013). Decisions to expand or intensify production for bioenergy are based on comprehensive management strategies that reflect land suitability (climate, soil, and topography) in order to optimize potential profitability, placing the intensively managed production into the highly suitable areas. Decisions also vary over time as they respond to evolving agricultural production systems in the area, as affected by infrastructure, services, and markets for agricultural supplies and products. Increased production to meet new bioenergy demands may occur in new regions (expansion), or replace other agricultural land use in consolidated regions (Sparovek et al. 2009). Structural threats to forests and biodiversity in Latin America have been associated with illegal land occupation, logging and clearing, corruption, and insecure land tenure rights (Bentsen and Stupak 2013).

Brazil offers an interesting case for the history of feedstock production, because industry growth was spurred by the 1970's oil crisis and associated increases in imported fuel prices (Pessoas-Jr et al. 2005). In response, the Brazilian government implemented policies to promote sugarcane alcohol as a substitute for gasoline in the transport sector (Puppim and de Oliveira 2002; Kline et al. 2008). The resulting National Alcohol Policy helped Brazil establish infrastructure including physical business and institutional and technological assets that provided the foundation for subsequent expansion in more recent years (Leal et al. 2013). Policies promoting flex-fuel vehicles were also instrumental in creating market demand for sugarcane ethanol (Kline et al. 2008) and periods of market-driven growth are associated with consolidation of the industry in more competitive regions such as the Southeast (Leal et al. 2013).

The infrastructure, markets (supply and demand), and cultural values of the producers (risk aversion, formality, and investment strategy) are different in Brazilian expansion regions compared to regions in the consolidation phase. Extensive, more informal production chains (e.g., cattle beef) which do not require highly suited land for intensive agriculture characterize agricultural land use during the expansion phase. A combination of social, political, and economic factors interact with land tenure dynamics, regulations and enforcement capacity, and government infrastructure and credit programs, to generate initially high rates of disturbance of native land cover. During this stage, cleared land is typically occupied by extensive pasture but the economic process of transition from forest to agriculture also involves extraction of resources such as timber, wildlife, minerals, wood, and charcoal; land may be cleared primarily to claim tenure rights or later payment for "improvements." Over time, extraction and extensive agricultural land use give way to the more consolidated phase as profits are increasingly based on improving land use efficiency rather than on resource extraction. Higher land prices and increased opportunities for trade and employment also support the transition to the consolidation phase and improved management practices that reduce waste and increase efficiency of land use (yields). Several dynamics act independently to influence the efficiency and profitability of the agricultural land use that is established in this period: informal governance and enforcement of environmental and labor laws; and temporary economic processes that benefit the transition to the consolidation phase. These dynamics are not formally included in the von Thünen land rent and Mather forest transition combined theories.

During the later stages of the forest transition, or consolidation phase, agricultural production intensifies in response to the following: (a) the loss of the non-agricultural extractive transitional incomes, (b) investments in infrastructure such as roads, bridges, and communities and higher land values, (c) intensive technologies and more demanding and formal markets (e.g., certified markets, more intense use of mechanization and agricultural supplies such as fertilizers and chemicals), (d) increasing labor costs and use of specialized workers, and (e) land holdings are increasingly legitimized, consolidated, and brought into legal compliance with Forestry Code (the law that regulates land use) and other regulations, and this often implies the need for some forest restoration. The combination of these factors tends to reduce production on less suited land as these are dedicated to restoration and regulatory compliance. Portions of land initially cleared and maintained with fire and/or cattle to defend land claims can be allowed to return to forest, or may be required to be reforested, once legal titles are recognized during the consolidation phase.

Data aggregation and averaging over large scales or time periods tend to disguise these two trends. However, these two dynamics—land clearing transitions followed by consolidation—have been observed around the world for centuries. At the national scale, the trend in Brazil became apparent after 1996 when the total area classified as agricultural production decreased, but total production continued to increase because of productivity gains. The average national data hide the spatial distribution of two contrasting patterns that operate simultaneously: consolidation in regions where productivity increases as total agricultural area decreases; and expansion in regions where both high and low suitability land areas are cleared for extraction and extensive agricultural production, primarily based on cattle pasture (Barretto et al. 2013).

Several past modeling simulations suggested that biofuels could accelerate deforestation (Searchinger et al. 2008; Fargione et al. 2010) but inputs often reflected correlation rather than causation and the models relied on erroneous assumptions (Kline et al. 2011). Review of deforestation data in nations with large bioenergy development such as Brazil and the USA supports alternative hypotheses (Langeveld et al. 2013; Dale and Kline 2013a, b). Recent studies underscore that assumed relationships about indirect effects of biofuels on forest cover in Brazil are speculative at best, while opportunities exist to end Amazon deforestation while continuing to expand biofuel production (Nepstad et al. 2014; Woods et al. 2015).

For example, during the period of US ethanol expansion, Brazilian deforestation rates fell dramatically (Fig. 3; Brasil 2014). We do not suggest that correlation implies causation. Total area deforested or cleared is determined largely by national and local policies governing land tenure, agricultural practices, and forest conservation and management (FAO and JRC 2012; CIFOR 2014) rather than bioenergy markets (CBES 2009; Dale and Kline 2013a, b). Demographic, biophysical, climate, and governance factors—i.e., enforcement of rules of law, institutional support for social and environmental health, and monitoring—are also influential (Dale et al. 2010c; Köthke et al. 2013). The role of bioenergy must be considered in terms of its interactions with other forces driving habitat degradation and loss (Dale and Kline 2013a, b). Policies promoting bioenergy, when combined with other regulations and policies, may contribute to forest conservation by focusing investment on improved management of previously disturbed lands and placing greater emphasis on sustainability (Kline et al. 2009; Dale et al. 2014).

Case Studies

Here we examine several case studies from the Pan American region to illustrate the issues and opportunities that arise for biodiversity associated with increasing bioenergy production. Canada, the United States, and Brazil represent different climatic conditions and concerns regarding biodiversity and ecosystem impacts, and can

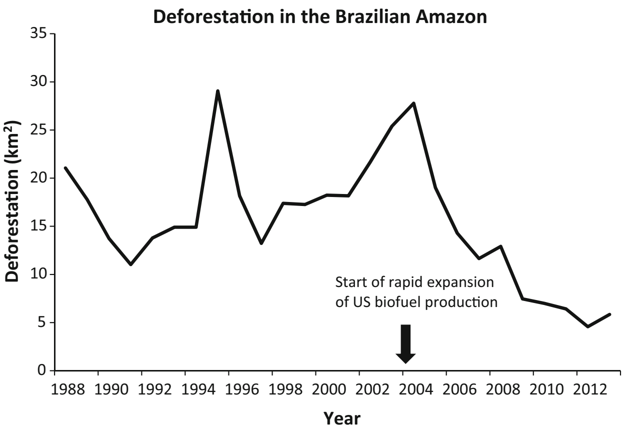

Fig. 3 Period of rapid expansion of biofuel production in Brazil and USA occurred between 2004 and 2012, coinciding with a period of forest stability or recovery in USA and dramatic reductions in deforestation in Brazil (data source: Brazil Space Agency, INPE. http://unfccc.int/files/bodies/awg/application/pdf/s1_4_brazil.pdf. Accessed 8 May 2015

therefore introduce the wide variety of positive and negative interactions of bioenergy production and environmental conservation.

Canada

The wood pellet industry in Canada produces approximately 3 million tons of wood pellets per year, of which British Columbia (BC) currently provides approximately 1,820,000 tons, or 66 % (WPAC 2013a; BC 2011). There are 11 pellet mills in BC that use feedstock that originates in the 22 million ha of public and 2 million ha of private forest land available for timber harvesting out of a total forest area of 55 million ha in the province (BC Ministry of Forests, Mines and Lands 2010; WPAC 2013a). As of 2009, BC exported 94 % of its wood pellets, mostly to Europe. 80–95 % of pellet feedstock comes from industrial residues (i.e., bark, sawdust, and shavings from the sawmill industry), also known as "process residues" in the EU Renewable Energy Directive (WPAC 2013b; Gordon Murray WPAC pers comm). The remaining 5–20 % of feedstock comes from forest harvest residues, which includes low-grade logs, tops, and branches that are typically found piled near landings and roadsides.

High-value saw timber drives forestry activities, not bioenergy markets. Only a minor portion (5–20 %) of wood pellet production is derived from low-grade logs, limbs, and tops removed from forests, and these are byproducts of traditional forest management. Lacking a market for pellets, this biomass would typically be burned on-site to reduce future fire risk and to leave site conditions conducive to replanting. It is not economical to harvest stands specifically for pellets in BC (Stennes and McBeath 2006) and capital-intensive bioenergy systems are not sustainable if they are dependent on short-term supply of salvage wood (Bogdanski et al. 2011). Thus, despite 18.1 million ha of beetle-killed trees representing a total volume of 710 million m^3 of timber (BC 2012), there is a low probability for realizing the capital investment required to collect and process pine beetle-killed wood for bioenergy. The biodiversity impacts of wood pellet production are likely to be minimal for the foreseeable future, given the reliance on sawmill residue and a minor component of roadside residues. Assuming that these two sources continue to support the chip industry, there could be slightly positive effects due to reductions in on-site burning and fire risks.

Concerns over biomass use for bioenergy in forests have centered on loss of deadwood as both snags and downed wood offer important reservoirs for biodiversity (Janowiak and Webster 2010; Berch et al. 2011; Littlefield and Keeton 2012), with not just amount but also size and decay class being important attributes (Siitonen et al. 2000). There are many forest species that are dependent on or prefer deadwood habitats including taxa from a wide range of groups including fungi, invertebrates, and vertebrates (Bunnell and Houde 2010; Riffell et al. 2011; Stockland et al. 2012). Furthermore, in Europe many endangered species are dependent on the increasingly scarce deadwood resource in forests (Berg et al. 1994; Siitonen et al. 2000). Keisker (2000) assembled a comprehensive literature summary of biodiversity dependence on dead wood for North-Central BC, demonstrating the critical nature of dead wood as habitat for 133 vertebrate species. For these reasons, current "best management practices" promote the maintenance of dead wood on harvest sites now and in the future.

Although current biomass harvest for bioenergy in BC does not result in additional loss of deadwood within stands, one concern is that higher biomass demand could change practices and reduce overall deadwood retention in the future and therefore negatively impact biodiversity. However, past practices of leaving material on sites have driven investigations of opposing concerns about excessive debris and fire hazards, and recommendations to adhere to practices to "reduce waste" on cutovers (Forest Practices Board 2010). The Research Branch of the Ministry of Forests and Range developed a "Short-term Strategy for Coarse Woody Debris Management in British Columbia's Forests" (Ministry of Forests and Range 2000) in which they recommended reducing the number and size of coarse woody debris (CWD) accumulations on roadsides and landings by leaving CWD distributed throughout the cut-block. Loggers have no incentive to move excess biomass from the cut-block to roadsides and most CWD is therefore left in cut-blocks. Putting accumulations from roadsides and landings to productive use is environmentally preferable to the current alternative of supervised burning or the earlier practices of leaving the debris piles to decay or burn unsupervised later. Moving debris piles back to cut-blocks from roadsides is likely not financially viable and involves additional environmental costs in terms of vehicle traffic, emissions, and compaction.

There are environmental protections in BC that may not exist in other forest regions because 95 % of BC forests are publicly owned and managed under the Forest and Range Practices Act (Forest and Range Practices Act (FRPA) 2004). The FRPA currently requires minimum levels of wildlife tree (FRPA 2011) and CWD retention (BC Chief Forester 2010), ensuring a future supply of dead wood to the regenerating stands. However, current evaluations suggest that there is sometimes a reduction in the coarse wood volumes in managed stands relative to uncut patches and there has been a reduction in CWD piece size in managed forests (Ministry of Forests, Lands and Natural Resource Operations 2011a, b, c). We do not have the science yet to know if current levels of deadwood in BC and elsewhere are sufficient to maintain biodiversity, or reduce it, or enhance it by reducing intensity of wildfire and increasing landscape heterogeneity. BC bases its current guidance on comparisons between cut-blocks and mature stands (Densmore 2010; B.C. Chief Forester 2010). Alternatively, some studies have examined threshold levels of deadwood required to maintain biodiversity, mostly in Europe (Work et al. 2004; Müller and Bütler 2010; Work et al. 2010; Work and Hibbert 2011). Clearly established biodiversity goals and more complete information on management requirements that best achieve those goals are needed to improve management of the public forest resource.

United States

Our discussion of the effects of biofuel policies and production on biodiversity and ecosystems in the United States is organized here under two broad themes. The first involves impacts associated with expanding production of conventional crops (corn and soybeans) for which significant historic data are available. The second involves documented and estimated impacts associated with the production of "advanced" biofuels using feedstocks such as woody wastes and residues, herbaceous and woody crops, algae, and other novel or currently non-commercial renewable resources. Given the important role of forest landscapes as habitat for biodiversity, in the latter theme we focus on forest biomass and the recent growth in production of wood pellets for energy.

Conventional Crops as Bioenergy Feedstocks

After a rapid rise from 1980 to 1985, US ethanol fuel production remained relatively stable until about 2002, when production rose as ethanol replaced the gasoline additive Methyl Tertiary Butyl Ether (MTBE) (US EIA 2014; RFA 2014; Oladosu et al. 2011). Between 2005 and 2010, US ethanol output grew rapidly again, at an average rate of 28 % per year, in response to market factors, mandates, and subsidies supported by federal Renewable Fuel Standards that were authorized in 2005 and 2007 (US EPA 2010, NRC 2011). Production for conventional biofuel feedstocks, primarily corn, soybeans and sorghum, is not differentiated from production for feed and other industrial uses, so farming practices and equipment are the same. Similar to Brazilian sugarcane ethanol, US grain ethanol and soy biodiesel offer an additional co-product market for existing producers. Biofuel production levels reflect market signals and expected profit margins when comparing biofuel products to other potential uses of the conventional feedstock. Diversifying markets and expanding the mix of co-products provide increased price stability for commodity growers and greater security for investment in improved seed, equipment, technology, and processing facilities.

Analysis of effects of current biofuels on biodiversity in the USA is based largely on data and research associated with effects of conventional agricultural systems on biodiversity. Biodiversity concerns are well documented and are the same as those for traditional US monoculture agriculture: loss of native habitat, indirect effects on food and biodiversity, and spillover effects of fertilizers, pesticides, and herbicides (Dale et al. 2010c; NRC 2011). Habitat loss remains a concern. Any production system that converts diverse habitat to a cultivated monoculture will have significant direct impacts on biodiversity (Werling et al. 2014). Furthermore, some economic modeling estimated that climate benefits are in doubt if US biofuel production causes indirect effects such as deforestation in other parts of the world (Fargione et al. 2008; Searchinger et al. 2008; Gelfand et al. 2011; Wiens et al. 2011). While coarse grain production and crop rotations can be managed to provide food and shelter for species such as grassland birds, removing indigenous vegetation to produce industrial maize monoculture for biofuel results in a net decrease in biodiversity and ecosystem functioning compared to more diversified land covers (Groom et al. 2008; Landis et al. 2008).

Practices to reduce negative impacts on biodiversity and other ecosystem services associated with conventional US agricultural systems have been promoted for decades with the support of local, state, and federal agricultural research programs (e.g., USDA NRCS 2014). There is general agreement on basic principles aimed at maintaining soil quality including soil biodiversity, increasing the efficiency of production systems and minimizing negative effects from pesticides, herbicides, fertilizers, and land disturbance. Research questions include those related to emerging technologies, genetic crop improvements, and how to achieve ecosystem service goals through systems that incentivize the use of better practices.

Advanced Biofuels from Cellulosic Crops and Residues

The outlook for biodiversity and ecosystems improves if bioenergy feedstock transitions from large-scale, monoculture grain systems to more diverse systems based on wastes and advanced perennial crops such as switchgrass and woody biomass (Williams et al. 2009; Fargione et al. 2010; Immerzeel et al. 2014). Using perennial crops on marginal agricultural land can diversify landscapes, contribute positively to the mitigation of greenhouse gas emissions (Gelfand et al. 2011), and provide habitat to support biodiversity (Wiens et al. 2011; Dale et al. 2010c). Biodiversity benefits depend upon the current context including threats, opportunities and conservation goals for the area and the degree to which management for inclusion of bioenergy crops contributes to or conflicts with these goals (Efroymson et al. 2012). Changes at the landscape scale and whether habitat heterogeneity is preserved at the site scale are also relevant factors for biodiversity (Williams et al. 2009; Fargione et al. 2010; Wiens et al. 2011). Biodiversity issues for advanced biofuels depend on production scenarios, reference cases, and model assumptions for indirect effects (Kline et al. 2011). The potential tradeoffs between the production efficiency of perennial monocultures, planting polycultures to mimic natural habitat heterogeneity, and management of native prairies and forests for sustainable harvests and residues, also influence analysis of impact on biodiversity and ecosystem services (Tilman et al. 2006; Groom et al. 2008; Flaspohler and Webster 2011; Fletcher et al. 2011; Berger et al. 2013; Werling et al. 2014).

Effects on biodiversity depend on the biomass crop and how it fits within the contextual landscape (Alguacil et al. 2012; Stoms et al. 2012; Efroymson et al. 2012). Proposed second-generation feedstocks such as switchgrass are more structurally similar to a tall grass prairie than corn and may provide critical stopover and foraging habitat for birds, and refugia for valuable pollinators and predators of crop pests, e.g., biological pest control (Landis et al. 2008; Isaacs et al. 2009; Fletcher et al. 2011; Meehan et al. 2012; Robertson et al. 2010, 2012, 2013; Werling et al. 2014). Many perennials such as switchgrass are deep-rooted and promote soil health and microbial biodiversity. Fewer studies have examined the potential for short rotation woody crops such as poplar or willow to support biodiversity (Flaspohler and Webster 2011; Fletcher et al. 2011). However, integrating them into current monoculture landscapes is expected to be beneficial (DOE 2014; Dale et al. 2014). Some proposed second-generation bioenergy crops such as eucalypts, Miscanthus, and canary reed grass which have raised concerns about potential invasiveness which merit study and monitoring (Raghu et al. 2006; Fargione et al. 2010; Witt 2010). Lewis and Porter (2014) suggest that biomass productivity goals can be achieved while minimizing invasion risks through a combination of voluntary standards, crop selection guidelines, and incentives to promote crops appropriate for the location.

Some researchers have proposed that biomass production areas be established to mimic the structural and botanical heterogeneity and functionality of target systems, such as one where flora and fauna biodiversity is maximized (Tilman et al. 2006; Myers et al. 2012). Biomass sourced from diverse prairie plantings may support greater bird and insect diversity including pollinators (Meehan et al. 2010; Myers et al. 2012; Werling et al. 2014). However, these benefits depend on landscape-scale patterns that thoughtfully integrate land management and harvesting for bioenergy with surrounding ecosystems (Engel et al. 2012; Robertson et al. 2012; Werling et al. 2014). Most management interventions favor some taxonomic groups over others (Stanley and Stout 2013), underscoring the importance of place-based analysis and planning that begin with understanding local concerns and priority targets for biodiversity conservation and other ecosystem services. Lack of incentives and market demand are the primary impediments to incorporating more biodiversity-friendly perennial biomass crops in current agricultural landscapes. Contracts with clear specifications and fair prices can promote adoption of new crops with biodiversity benefits, as demonstrated by the East Tennessee switchgrass program (Parish et al. 2012; Mitchell et al. 2014). However, lacking sustained market demand, about half of the 5200 acres initially planted in switchgrass in East Tennessee has been converted back to row-crops (Esther Parish ORNL, pers. comm.; Daily Times 2013).

Woody Biomass for Energy

In the Southeast US (the SE), forest industries have been an important part of economic activity and employment for a century (USDA Forest Service 2012). Similar to the BC case, bioenergy products are generated from the residues associated with traditional harvests for saw timber and pulp because it is not currently economical to harvest forests stands specifically for bioenergy alone. Contrary to the BC case, nearly all productive forest lands in the SE are privately owned and therefore subject to sale and conversion to other uses. Initially, these lands were cleared for plantation agriculture including rice and cotton. Past trends and US Forest Service analyses indicate that the greatest threats to SE forest biodiversity are the loss of forest due to conversion to other uses, principally suburban expansion with roads, housing, and commercial buildings (Wear and Greis 2012; USDA Forest Service 2012). If there are no incentives to maintain productive forests on private lands, investment in forest management will decline, resulting in more pests, lower site productivity, and more extreme fire events. Lack of forest product markets could also result in some current timber lands reverting to agriculture. Local research suggests that active forest management, including thinning and prescribed burns, is important to maintain SE forest biodiversity (NC State Forest Service 2014; Mitchell and Duncan 2009).

While SE forest lands stretch from the coastal plain through the piedmont region and into the Appalachian Mountains, most commercial activity for bioenergy is associated with residues from pine management on the coastal plain. The concentration of natural and industrial capital—forests, saw mills, skilled labor, and infrastructure—combined with nearby access to deep-water ports, have given the SE a major role in the recent growth of a bioenergy export market based on wood pellets (Lamers et al. 2013). One recent report suggests that residues from privately managed pine forests in the SE are one of the more promising sources of biomass in terms of compliance with stringent new sustainability requirements (Voegele 2014).

Brazil

The case of Brazilian agriculture demonstrates several agricultural land use patterns occurring simultaneously and with contrasting effects. The rates of expansion of new croplands are strongly influenced by public investments and the terms and availability of credit for clearing and preparing new land for production (Brasil 2010). Regarding the main bioenergy crops (sugarcane, soy, palm, and eucalyptus):

(i) Sugarcane is established in more consolidated agricultural regions and thus is linked to intensification and land sparing rather than the expansion areas;
(ii) Soy, the main feedstock for the national biodiesel blend, is correlated with agricultural expansion in the northeast Cerrado region (a savanna biome) and the transition of pasture areas to crop in the Amazon region;
(iii) Palm oil expansion in the Amazon region is replacing former pasture areas with support of government programs (Villela et al. 2014); and
(iv) *Eucalyptus*, primarily an industrial feedstock for pulp, fiber, and paper, and secondary markets for structural wood products and charcoal for the steel industry (Gonçalves et al. 2013), represents a potential future bioenergy feedstock in the form of wood chips or pellets. Eucalyptus is grown across the southern half of the country, in both expansion and consolidation regions.

The dynamic interactions of crops in expansion and consolidation regions differ in terms of their expected effects on biodiversity. They act distinctly in specific geographic locations and their primary drivers can vary. To estimate effects, we need modeling tools that are sensitive to the drivers, the demands, the physical suitability, and whether they occur in the expansion or consolidation phase. One research gap is to develop dynamic agriculture land use models that can reflect future technological demands and guide current policy decisions to shape land suitability demands of the foreseen future, rather than being driven by the short transitional phase of land conversion. Furthermore, improved assessments to identify and demarcate areas of high value to society for conservation and biodiversity need to be completed and translated into policy frameworks and public data sets such as that maintained by the Research Program on Biodiversity Characterization, Conservation, Restoration and Sustainable Use (BIOTA www.biota.org.br). We focus on sugarcane and palm oil to evaluate the impacts of biofuel production on biodiversity and ecosystem services in Brazil's largest and biologically important biomes: the Cerrado and the Amazon, respectively.

Brazilian Sugarcane

The ethanol production from sugarcane in Brazil provides a suitable example of the synergies between the concerns for biodiversity most frequently raised by scientists, non-governmental organizations, and the main certification schemes regarding biofuels sustainability. Although Brazil has raised sugarcane for over 500 years, the recent focus on sustainability and biodiversity conservation is explained by the growing interest in assuring that Brazilian ethanol can reach international markets. As in most regions, biodiversity loss is driven by human activities (MEA 2005) and the most important driver has been habitat loss from land cover and use changes (Sala et al. 2000; Pereira et al. 2012). Other concerns with expansion of agricultural activities include the introduction of exotic species and the large-scale use of fertilizers which can contribute to eutrophication and agrochemicals. These concerns are particularly acute in areas that are considered hotspots of biodiversity loss, such as the Atlantic Forest and Cerrado in Brazil. The central region in Brazil is an agricultural frontier where a substantial share of recent sugarcane and other crop expansion have occurred at the expense of the Cerrado. From 2000 to 2011, about 20 % of the agricultural expansion was in the Central region and Goiás is already the second largest sugarcane producer in the country (MAPA 2013). In response to concerns about loss of forests and indirect effects of sugarcane expansion, Brazil's government implemented agro-ecological zoning (AEZ) for sugarcane that focuses on utilization of extensive pastures and grasslands (Embrapa 2010). The AEZ for sugarcane puts many areas "off-limits" for sugarcane: the Amazon and other forest areas, current row crop production areas, fields with slopes that prohibit mechanized harvest, and land with environmental restrictions under other regulations and laws such as the Forest Code. Government credit and support is not available for expansion outside the zoned areas. The AEZ does not prohibit sugarcane expansion in Cerrado regions that are otherwise well-suited for sugarcane.

Brazilian Palm Oil

The Brazilian government has enacted political measures to support different sources for biodiesel, aiming to minimize social and environmental impacts and promote rural development. Oil from palm oil plantations has the potential to be a major contributor to future biodiesel production. Recent expansion has focused in the State of Pará, driven by government incentives. The experiences to date along with government targets for growth and land use zoning, can provide insights about potential effects of future palm expansion on biodiversity. Despite representing a small percentage of global palm oil production, Brazil has followed the global trend and doubled its production area during the period 2001–2009, from 46,000 ha to around 109,000 ha (Fig. 4, FAO 2013). Government scenarios and targets project major expansion over the next 5 years. To avoid palm oil expansion into Amazon forested areas, Brazil's AEZ limits palm oil production to degraded lands without environmental legal restrictions, and the removal of native vegetation for planting palm oil crop is forbidden. This recent restriction reduced the area suitable for oil palm by 70 %, from 2.3–0.7 million km^2 or the equivalent of about 14 % of the Legal Amazon region (Brasil 2010; Embrapa 2010). However, not all suitable areas fall within the Legal Amazon.

The palm oil sector is of interest to policy makers because it can incorporate smaller, family-level farms along with large-scale production schemes. Palm production is perceived to offer highly desirable income security through: (1) high yield potential; (2) lower production cost than other crops; (3) the permanent nature of the crop; and (4) less labor-intensive management requirements which allow families to maintain other agricultural activities.

With roughly 60,000 ha, the State of Pará is the main producer of oil palm in Brazil, representing 83 % of national production. The Pará palm oil region maintains significant fragments of native Amazonian tropical rainforest and is part of the Belém Endemism Center for biodiversity. Although this region is the most suitable for palm oil (Brazil 2010), it is also the most endangered area of the Brazilian Amazon: 70 % of the forests have already been cleared (Conservation International 2011) and urban development pressure is increasing.

As with any other single crop, it is difficult to quantify the extent to which palm oil has been the cause of deforestation. A lack of accurate data on forest degradation processes over time, subjective definitions of secondary forest, and classification of large areas of former pasture as "degraded land" create challenges for analysis, as do the complex historic interactions among social, political, and economic drivers of deforestation. Some palm oil producers have replaced primary forest with palm oil plantations, allowing them to profit from timber sales and recoup the costs of initiating palm oil plantations until it becomes profitable (Butler and Laurance 2009; Nahum and Malcher 2012; Backhouse 2013). However, these appear to be isolated cases. Furthermore, palm plantation projects are increasingly scrutinized due to large-scale deforestation in South East Asia (Boons and Mendoza 2010; Janssen and Rutz 2011). International pressure has led major producers in Brazil to seek certification. Thus, for both palm and sugarcane production, standards for more

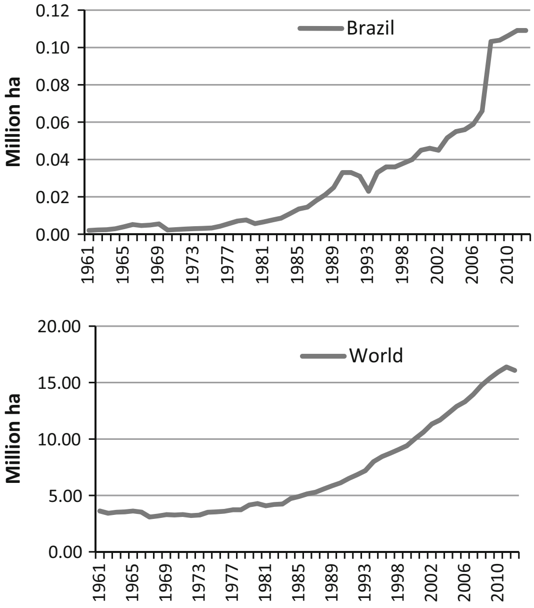

Fig. 4 Hectares of palm oil in Brazil (*top*) and globally (*bottom*). Source (FAO 2013)—modified by authors

sustainable production driven by bioenergy are having an influence on long-established industries regardless of whether production is for energy or other uses. The influence of recent palm oil industry developments on deforestation and loss of biodiversity in the State of Pará can provide a case study that merits further monitoring and research (Wilkinson and Herrera 2010).

Bioenergy Production Guidelines and Ecological Protection

The prevalence of guidelines regarding the minimization of bioenergy production impacts on biodiversity and ecosystems reflects the immense value that these ecological assets represent. For example, to qualify as a renewable fuel in the EU, production must be certified also to not cause destruction of HCV habitat for biodiversity. Exports from the Pan American region to the EU must meet these standards. The Roundtable for Sustainable Biomaterials (2010) include five (out of 12) principles directly or indirectly linked to biodiversity and ecosystems: greenhouse gas emissions, conservation, soil (maintenance or restoration of soil) health, water (addressing quality and quantity of both surface and groundwater), and air pollution. The Conservation principle contains five criteria, addressing biodiversity and ecosystem conservation, the creation or protection of buffer zones and habitat corridors, and the prevention of invasive species.

Emerging standards for market access to Europe and elsewhere have instigated new efforts to identify and protect areas of HCV as part of certification processes and recommended practices for bioenergy project planning (Kissinger 2013; Kretschmer et al. 2013; ISCC 2011; RSB 2010; Brown et al. 2013). Many certification schemes, standards and government policies for bioenergy development now include requirements to identify and protect HCV areas. For example, Van Dam (2010) identified 14 biomass certification schemes that explicitly included HCV in 2009. Neugarten and Savy (2012) reviewed 19 HCV approaches issued by national governments including six in the Americas. Another study found over a dozen standards and purchasing policies that were applying HCV approaches (Proforest 2010). The intent of HCV language in the standards, certification schemes and policies reviewed in these studies is to promote systematic analysis, identification and protection of areas of HCV. While approaches vary in clarity and effectiveness, several studies highlight the potential benefits to biodiversity when bioenergy projects employ HCV approaches, particularly when compared to alternative agriculture and forest production systems and conventional energy resource extraction practices (Kline et al. 2009; Dale et al. 2010a, b; Scarlat and Dallemand 2011; Parish et al. 2013; Dale et al. 2014).

Oliveira (2013) analyzed the rationale of biodiversity monitoring programs in Brazil and assessed how biodiversity has been addressed by the main biofuel certification schemes. We combine this work with an extensive literature review regarding the impacts of agricultural activities on biodiversity and use sustainability indicators suggested by Dennison (2011). Three certification schemes recognized by the European Commission were considered for this purpose—Roundtable on Sustainable Biomaterials (RSB), International Sustainability and Carbon Certification (ISCC) and Bonsucro (sugarcane)—which are among the most successful initiatives in this regard. Table 1 summarizes a comparison between the concerns for biodiversity preservation and the coverage of these certification schemes. We note that efforts to certify palm oil in Brazil are based on the Roundtable for Sustainable Palm Oil (RSPO), which we did not specifically include in this analysis. RSPO aims to achieve similar principles of sustainability as the three other schemes. Small land holders in areas zoned for palm oil production rarely have documented land title, which is required for certification, thus limiting their participation in these schemes. Table 2 presents an assessment on how the current practices in Brazil could facilitate the certification process for sugarcane and palm oil.

In sum, the main potential impacts of large-scale biofuels production on biodiversity have been addressed by the sustainability certification schemes. RSB appears to include more detailed requirements than the other two schemes; it is the only one with specifications for preserving riparian areas, ecological corridors, and buffer zones. ISCC is worldwide the most commonly used scheme for biofuels and has been developed mainly to address the requirements of EU-RED. Bonsucro has the most specific focus on certified production of sugar from sugarcane and is adapted for ethanol certification; some aspects (such as the protection of threatened species and maintenance of ecological corridors and riparian areas) must be addressed in the context of the management plans of the economic operator.

Biofuel certification schemes address the main biodiversity concerns due to agricultural activities in two different ways. First, based on the precautionary principle, biomass production is restricted in risky areas. Second, the schemes demand specific actions for minimizing relevant impacts. As far as land use change and biodiversity protection are concerned, Brazil has a set of laws and regulations that could facilitate biofuels certification, as most criteria and indicators are related to legal or regulatory demands. These include initiatives such as AEZ laws, the Forestry Code and a set of protected areas and conservation units in which agricultural activities cannot occur. Considering the legal apparatus, the current stage of agricultural

Table 1 How certification schemes address biodiversity concerns due to biofuels production

Aspect	Comments on potential impacts of biofuels on biodiversity (from Dennison 2011)	Aspect considered by certification schemes
Protection of sensitive areas; no production in land with high biodiversity values	Raw materials for biofuels should not be produced in sensitive areas. The high conservation value (HCV) concepts are often used for defining such areas. This is definitely an aspect to be considered regarding biofuels production	The EU-RED (Europa 2014) mentions areas where biomass production should not occur (the so called "no-go" areas). These areas are addressed by RSB. ISCC explicitly mentions the areas specified in the EU-RED (HCVs, native grasslands, peatlands). Bonsucro requires producers to avoid activities in areas of critical biodiversity
Economic activities in protected areas	Activity may occur in protected areas under specific conditions (e.g., to support conservation management, adopting adequate management practices) making this relevant to biofuels	For bioenergy, this is mainly related to forestry activities. RSB and ISCC mention cases in which production is allowed and, in case of Bonsucro, protected areas are simply off limits
Adoption of sustainable agricultural practices	Is an important aspect related to biomass production. Criteria and indicators in certification standards are considered adequate for biofuels	The aspect is addressed in all three certification schemes for biofuels, but with more details by ISCC. Bonsucro sets thresholds for the application of fertilizers, herbicides and pesticides
Threatened species	One of the main concerns regarding agricultural activities is the impacts on rare and threatened species. Relevant to biofuels	All three certification schemes state that production shall not put into risk rare, threatened, endangered and legally protected species
Invasive species	This is one of the main concerns regarding large-scale biofuels production. Impacts should be avoided or minimized	The issue is specifically mentioned as an RSB criterion. In Bonsucro the issue is to be addressed in the context of management plans
Ecosystem services	Is one of the main concerns of bioenergy production, but Dennison (2011) considered this issue to be only moderately relevant for biofuels	Ecosystem Services is specifically addressed by RSB and Bonsucro, but is not explicit in ISCC

Sources adapted from Dennison (2011), ISCC (2011), Bonsucro (2011) and RSB (2011)

practices, and the fact that the bulk of the production is in areas that were converted a long time ago, at least some Brazilian biofuel production can be certified.

Current certification programs vary widely in quality and the more comprehensive schemes have limited enrollment. Only 18 certificates have been issued by RSB as of January 2015 (RSB 2015), while worldwide less than 10 % of the ethanol production from sugarcane was certified by Bonsucro (Bonsucro 2015). As noted in the recent SCOPE assessment of bioenergy, more work is needed to improve the extent and effectiveness of certification programs (Endres et al. 2015). In addition, certification cannot be expected to replace the need for local governance, environmental regulations, and enforcement. However, certification programs can be one tool to facilitate broad stakeholder participation and to increase the degree of ownership in both the goals and the outcomes.

Lessons Learned and Research Priorities

The experiences with bioenergy production in Canada, the US, and Brazil suggest that there are opportunities to improve how bioenergy project developments can benefit biodiversity. Top-down regulations or incentives can steer bioenergy production away from sensitive, diverse areas. In a review of 53 studies on the biodiversity impacts of bioenergy production, Immerzeel et al. (2014) found that neutral or positive benefits of bioenergy production were far more common in temperate regions, while most of the impacts observed in tropical regions were negative. Much of this disparity may be due to legal and economic drivers, rather than biological differences. Neither certified production nor law enforcement are assurances of sustainable production where effective enforcement of laws is weak. Market instruments such as certification schemes would be crucial to foster the adoption of good practices, to avoid biofuel production in risky areas, and promote actions for recovering biodiversity. The adoption of certification schemes is already a very new process and a proper assessment of impacts is not yet possible. However, bioenergy production must be paired with production from other renewable sources and with energy conservation efforts; meeting current energy demand from biomass sources alone is not feasible.

While commercial bioenergy production currently dominates in the region, small-scale, local community bioenergy projects can be designed to address priority natural resource management concerns (although their ability to meet national and international demand is

Table 2 Comparison among three certification schemes for biofuels in Brazil

Topic	RSB	ISCC	Bonsucro (sugarcane)	Comments related to sugarcane ethanol production in Brazil	Comments related to palm oil production in Brazil
Principle related to biodiversity	Biofuel operations shall avoid negative impacts on biodiversity, ecosystems and conservation values	Biomass shall not be produced in high biodiversity or high carbon stocks lands. HCV areas should be protected	Actively manage biodiversity and ecosystem services	Significant share of Brazilian production meets ISCC and Bonsucro principles; traditional sugar areas could comply with RSB more readily than other areas	Industrial scale, legal palm oil production in Brazil is being developed in coordination with the RSPO, applying principles similar to ISCC
Issues addressed by criteria	Conservation Values; Ecosystem services Buffer zones Ecological corridors Invasive species	HCV Highly biodiverse grasslands High carbon stocks Peatlands	Assessment of impacts on biodiversity and ecosystem services Mitigation measures	Bonsucro's criteria can be met without difficulty for sugarcane. Any activity in the sensitive areas defined in ISCC would need attention. Compliance with some of RSB's criteria may require more studies and adoption of specific plans for zoning and management, e.g., for Buffer zones, Ecological corridors and Invasive species	
No-go areas	Addressed—certain specificities applied	Indirectly addressed	Not addressed	In Brazil, the AEZ specifies areas where the production shall not occur. The Forest Code prevents planting in other areas (e.g. Riparian Areas)	A proposed law forbids the removal of native vegetation for new palm plantations (enactment expected in 2015)
HCV	Addressed/mentioned	Addressed/mentioned	Addressed/mentioned	In Brazil, the areas designed Protected Areas and Conservation Units can be understood as HCVs	
Buffer zones	Addressed	Not addressed	Addressed	They are considered in the AEZ for São Paulo state (the largest producer region), but not in the national AEZ	They are not considered in the national AEZ, but current expansion areas in Pará avoid Protected Areas and Buffer zones
Degraded lands	Use to be promoted	Not mentioned	Mentioned	There is no need to prioritize the production in such areas due to the large land availability in Brazil. However, the utilization of degraded pastures for sugarcane is an ordinary practice	The zoning (AEZ) limits production to previously degraded lands without environmental legal restrictions
Invasive species	Addressed	Mentions grasslands	Addressed	Sugarcane is a widespread crop in Brazil. Not applicable to sugarcane plantation, even in expansion areas	African Palm can be a resource for native fauna but in some areas, research is needed to address concerns about potential invasiveness
Threatened species	Addressed/mentioned	Addressed/mentioned	Addressed/mentioned	The impacts may be bigger in expansion areas, mainly in the Cerrado	Lower direct impacts since AEZ limits production to degraded lands

Sources adapted from RSB (2011), ISCC (2011) and Bonsucro (2011)

unknown). Small-scale projects, particularly those with funding to enhance stakeholder engagement and training in natural resource management, can be more readily integrated into the landscape to provide targeted, beneficial ecosystem services. For example, the FAO sponsored a series of 15 international case studies including projects in 12 countries across six regions of the globe (PAC 2009). The studies targeted purpose grown energy crops and biomass resource development projects with a focus on the impacts on rural livelihood assets including "natural capital" and biodiversity. The researchers found no significant detrimental impacts on food security or biodiversity in these small-scale projects. However, a study by the government of the Netherlands (NL Agency 2010) found that negative effects were likely in cases where non-edible oil seed crops (e.g., *Jatropha curcas*) were grown on fields that previously provided food and fodder to local communities, such as those examined in Honduras and Brazil. Thus, planning to integrate bioenergy crops into a landscape in a manner that respects community tenure rights and enhances overall productivity is important. Previous land use, intensity and scale of production, and planning for appropriate rotations and patterns of use across a landscape should be considered in planning stages. Less-edible and low-yielding plants such as *Jatropha* do not appear to be appropriate biofuel feedstock. However, they may form part of integrated land use plans as multi-purpose plants in fence rows, home gardens, and hedges where they have been employed for thousands of years in Meso-America, with uses ranging from medicinal products to animal feed (Dias et al. 2012).

The FAO case studies identified several benefits to biodiversity, as small projects took advantage of opportunities to improve the efficiency of production and use of native renewable resources, along with planting perennials such as native trees. Project investments in training and technology, and the development of good practices, enabled higher productivity and improved management and restoration of fragile landscapes subject to erosion and recurrent fire damage. The return on these investments can be measured by the value of services provided by intact and functioning forests and other habitats (FAO 2014).

For example, the Guatemala case focused on opportunities represented by over 600,000 ha of "depleted soils" on underutilized farm fields. These fields and current field margins were targeted for enhanced natural capital through investments in land management for production of bioenergy crops, specifically for oil seeds using local species commonly used in fence rows. A case study in Kenya involved training in afforestation and found that the project enhanced the natural capital endowment area and value for the community. Using indigenous tree species that were leguminous (nitrogen-fixing) helped address soil deficiencies, improved fertility, and productivity, and provided significant ecological gains without a loss in biodiversity. Further, the afforestation was thought to have benefits in water and micro-climate regulation with benefits during the dry season relative to the pre-project conditions. Several case studies involved the use of agricultural wastes and bio-residues and this raised concern about potential detrimental effects on soils. However, the studies found that the projects used wastes that were previously causing harmful effects on soils, water and air; some were being burned inefficiently or released to the environment (methane) as a means of disposal. None of the studies found that residues were diverted from soil nutrient enrichment to bioenergy to the detriment of natural capital, but in some cases residues returned to supply chain after bioenergy production for beneficial use. For example, one of the most common, marketable bioenergy byproducts was fertilizer, such as that generated from oil seed-cake in the case study in Guatemala.

Monitoring is necessary to verify what impacts bioenergy activities have on biodiversity. Utilities and pellet industries are in the process of demonstrating compliance with certification requirements recently put in place by the UK to ensure that wood pellets are sourced in a sustainable way (UK 2014; Gordon Murray, WPAC, pers. comm.; RWE 2014; Voegele 2014), which will help ensure the environmental and social license required both locally (e.g., within BC, Canada (Bunnell 2013), the US and in export markets. The Sustainable Biomass Partnership (SBP), made up of representatives from the major European Utilities and with observers from some of the wood pellet producers from Canada, the US and Europe, was formed in 2013 with a mandate to "develop the tools necessary to provide assurance that the solid biomass used for sustainable energy production by the member organizations is compliant with regulations on sustainability and biomass legality in EU Countries and that the sector is recognized as an exemplar of good practice"(Gordon Murray, WPAC, pers. comm.). This partnership has the potential to support improved monitoring and enhance protection for biodiversity beyond that required in current provincial regulations and guidelines.

Priorities for Future Research

Despite all that we know, there are still key areas that require additional investigation:

1. *Compatibility of biodiversity and bioenergy* Ensuring that human and financial resources are assigned to identify and effectively conserve areas of HCV is paramount to preserve remaining landscapes with concentrated biodiversity (Joly et al. 2015; Immerzeel et al. 2014). Bioenergy projects provide opportunities to support the mapping and protection of biodiversity in areas where this might not otherwise occur in a timely manner (Souza et al. 2015). Guidelines and indicators need to provide warnings if projects are detrimental (Endres et al. 2015). Research should help planners to foresee and mitigate context- and region-specific negative impacts and to maximize the benefits from bioenergy projects. We also need a far better

understanding of the region-specific costs and benefits related to bioenergy production on marginal land, monocultures versus native plant communities, and systems integration which obviates the debate over land sharing versus land sparing (Immerzeel et al. 2014). Research should be coordinated at the landscape or regional scale to ensure adequate heterogeneity and space for biodiversity and ecosystem functions. Researchers and planners must acknowledge that they operate in dynamic landscapes, where climate change and disturbance regimes (such as fire) will constantly rearrange biodiversity hotspots. Long-term socioeconomic changes (such as taxation on private forestlands and urbanization in the southeastern US) also impact both high biodiversity areas and suitable bioenergy areas. These dynamics will complicate the evaluation of laws and certification schemes regarding their effectiveness in preserving biodiversity and ecosystem functions.

2. *Bioenergy best practices* Research is needed that shows how management plans for bioenergy feedstock production can be designed to enhance biodiversity and ecosystem services, and establish good practice communities for continual improvement. Furthermore, the efficacy of existing sustainable bioenergy standards needs to be assessed, and the standards amended or improved where necessary. For example, levels of deadwood and habitat retention in forests need to be sufficient to maintain biodiversity. Biodiversity could be enhanced by using residues for bioenergy (e.g., by reducing intensity of wildfire and increasing landscape heterogeneity), but not at the expense of deadwood obligate species. Table 2 describes how existing certification schemes prioritize biodiversity preservation in Brazil, however monitoring and evaluation to determine the effectiveness of such schemes is currently insufficient. Laws and certification points designed to protect biodiversity have only recently been enacted so their impacts are still unknown. Guidance on how to measure the effectiveness of these standards, considering both costs and benefits, is a critical area for further investigations.
3. *Measuring ecological value* Ecosystem services and functions need to be better quantified and communicated in consistent units, which can be expressed and monitored over space and time. These measures should quantify the different values, costs, and benefits of management options that integrate bioenergy and other productive activities into mixed use landscapes. For example, intercropping bioenergy crops with natural areas at the landscape scale may increase biomass productivity, as natural areas can provide habitat for agriculturally beneficial insects (Werling et al. 2011). Assessing impacts of bioenergy production at a landscape scale may also provide a more comprehensive understanding of the positive and negative aspects of different bioenergy crops and where they are produced (Groom et al. 2008, Webster et al. 2010, Dale et al. 2011, Wiens et al. 2011, Werling et al. 2014). However, the routine comparison of bioenergy production areas to natural areas when measuring impacts on ecological values must be re-examined. Comparisons to industrial mono-crop agriculture may be more appropriate, particularly when perennial bioenergy crops (e.g., switchgrass) are planned for areas previously used for annual crops (such as corn, sugarcane, and other conventional bioenergy crops).
4. *Prioritizing bioenergy projects* Bioenergy offers the region an alternative to more dire consequences for biodiversity that are expected if fossil fuel exploitation continues (Dale et al. 2015). Research is needed to identify when and how investments in bioenergy can be most effective in preventing further disturbance by fossil energy exploration and extraction in high-value conservation areas. Some researchers believe that a priority for bioenergy development in the Americas is to determine how to improve the governance framework—policy, institutional stability and rule of law (regulations and enforcement)—in a manner that creates incentives for managing land to increase biomass productivity (Bentsen and Stupak 2013). This research would be designed to guide bioenergy developments and investments to where they can have the greatest benefits in terms of reducing the depletion of the planet's natural capital. This information could also help business and policy makers identify when and where bioenergy development can support other ecosystem management needs, such as land restoration and control or avoidance of problems with invasive species (rather than exacerbate these problems).
5. *Transdisciplinary approaches* More work is needed to illustrate how bioenergy projects can meet multiple objectives, balancing biodiversity, social welfare, and economic goals. This can be done if a transdisciplinary approach is used from the planning through monitoring phase. For example, Nackley et al. (2013) provide an example from Washington State where harvesting of biomass from invasive tree species could be used in regional bioenergy production, driving ecological restoration of sites dominated by invasives. This research area involves identifying best practices that can be applied as industries grow to larger scales of production. The assessment of which incentive structures are most effective in generating desired results—e.g., maximizing bioenergy benefits to society as documented in the recent SCOPE Report (Souza

et al. 2015)—is also essential. Done right, bioenergy production contributes to improved soils and water quality, more persistent productivity relative to inputs, reduced waste, and better resource management on lands that were previously disturbed, frequently burned, or underutilized.

6. *Indirect land use effects* Science-based causal analysis is essential to separate correlations from the true causal chains that drive loss of biodiversity and habitat. This research can clarify debates about indirect effects in specific contexts, a key step to address one of the most pressing bioenergy certification "issues around which no scientific consensus has yet been reached" (Souza et al. 2015). Such research should be pursued in coordination with others who increasingly recognize the needs for such analysis, such as the Center for International Forest Research and the Global Land Project. Furthermore, it is important to analyze actual experiences to date with consideration for indirect effects that are positive as well as negative (Endres et al. 2015). The scale at which these land use change connections occur is emerging as a critical need for more transdisciplinary research (Liu et al. 2015).
7. *Effective communication* Finally, we need pathways for scientists to improve the effectiveness of their communications regarding opportunities to conserve biodiversity (Dale et al. 2013). We need to employ social and other communication systems and ensure that research results are shared in a manner that is useful and applicable to targeted stakeholders.

Conclusions

The Pan American region provides an excellent perspective on the opportunities and challenges for the concurrent protection of biodiversity and bioenergy production. The potential complementarity between bioenergy and biodiversity conservation values can be clarified with research related to the following: (i) dynamic landscape designs which integrate more and deeper-rooted perennial crops and incorporate crop rotations, plant diversity, and other ecosystem-friendly practices into existing large, monoculture agricultural systems (Dale et al. 2011; Tilman et al. 2006, 2009; Wiens et al. 2011); (ii) incentives for improved efficiency and management of water, soils, wastes, and residues, particularly in current systems that involve biomass utilization and disposal, including extensive use of fire or decomposition to dispose of biomass (Joly et al. 2015); (iii) socially responsive projects that apply stakeholder participation procedures in small-scale bioenergy projects designed to address local priorities (Kurka and Blackwood 2013); and (iv) incentives for science-based monitoring and continual improvement for more sustainable production, including systems of indicators and better analytical techniques (e.g., that provide more consistent and useful measurements of soil qualities, nitrogen and carbon cycles; Immerzeel et al. 2014). Bioenergy has invigorated efforts to develop and apply regional sustainability certification standards that incorporate monitoring and continual improvements to conserve or enhance ecosystems services (Souza et al. 2015). Bioenergy research and investment has already generated improved oversight, scientific measurement and analysis, which in turn have supported political pressure to enact laws to protect and manage the environmental and social effects of traditional agri-business sectors such as sugarcane, maize, and palm oil. Improved practices are context-and species-specific and will necessarily evolve over time in response to changing conditions. By demonstrating how sustainable production and biodiversity conservation goals can be simultaneously achieved, bioenergy offers new tools for sustainable and dynamic landscape management.

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References

Alguacil MdM, Torrecillas E, Hernández G, Roldán A (2012) Changes in the diversity of soil arbuscular mycorrhizal fungi after cultivation for biofuel production in a Guantanamo (Cuba) tropical system. PLoS One 7(4):e34887

Angelsen A (2007). Forest Cover Change in Space and Time: Combining the von Thülen and Forest Transition Theories. World Bank Policy Research Working Paper. World Bank. 4117:43

Backhouse M (2013) A desapropriação sustentável da Amazônia. O caso de investimentos em dendê no Pará. Fair fuels? Working Paper 6. Berlin

Barretto AGOP, Berndes G, Sparovek G, Wirsenius S (2013) Agricultural intensification in Brazil and its effects on land-use patterns: an analysis of the 1975–2006 period. Glob Change Biol 19:1804–1815

B.C. Ministry of Forests, Mines and Lands (2010) The State of British Columbia's Forests, 3rd edn. Forest Practices and Investment Branch, Victoria. http://www.for.gov.bc.ca/hfp/sof/2010/SOF_2010_Web.pdf. Accessed Jan 2014

Bentsen NS, Stupak I (2013) Imported wood fuels—a regionalised review of potential sourcing and sustainability challenges. Faculty of Science, Department of Geoscience and Natural Resource Management, University of Copenhagen. http://www.ens.dk/sites/ens.dk/files/undergrund-forsyning/vedvarende-energi/bioenergi/analyse-bioenergi-danmark/bentsen_stupak_2013b.pdf. Accessed 14 July 2014

Berch S, Morris D, Malcolm J (2011) Intensive forest biomass harvesting and biodiversity in Canada: a summary of relevant issues 1. For Chron 87:478–487

Berg Å, Ehnström B, Gustafsson L, Hallingbäck T, Jonsell M, Weslien J (1994) Threatened plant, animal, and fungus species in Swedish forests: distribution and habitat associations. Especies de plantas, animales, y hongos en peligro en bosques Suecos: distribución y asociacines de hábitats. Conserv Biol 8:718–731

Berger AL, Palik B, D'Amato AW, Fraver S, Bradford JB, Nislow K, King D, Brooks RT (2013) Ecological impacts of energy-wood harvests: lessons from whole-tree harvesting and natural disturbance. J For 111:139–153

Bogdanski B, Sun L, Peter B, Stennes B (2011) Markets for forest products following a large disturbance: opportunities and challenges from the mountain pine beetle outbreak in western Canada Information Report BC-X-429

BONSUCRO (2011) Bonsucro Production Standard—version 3.0 March 2011—including Bonsucro Production Standard EU

BONSUCRO (2015) Bonsucro Production Standard—news and statistics. http://bonsucro.com/site/in-numbers/

Boons F, Mendoza A (2010) Constructing sustainable palm oil: how actors define sustainability. J Clean Prod 18:1686–1695

Brasil (2010) Programa Nacional de Produção e Uso de Biodiesel: inclusão social e desenvolvimento territorial. Ministério do Desenvolvimento Agrário, Brasilia

Brasil (2014) Statement by Brasil for the UNFCC ADP Technical Expert Meeting on land use. Policies, Practices and Technology, Bonn. http://unfccc.int/files/bodies/awg/application/pdf/statement_by_brazil.pdf. Accessed 14 July 2014

Brazilian Institute of Geography and Statics (IBGE) (2015) SIDRA/PAM Table 1612 (variable harvested area of Sugarcane in 2013) consulted April 22, 2015. http://www.sidra.ibge.gov.br/

British Columbia (BC) (2011) British Columbia's Wood Pellet Industry June 2011. http://www.pellet.org/images/WoodPelletFactsheet.pdf. Accessed Jan 2014

British Columbia (BC) (2012) Mountain pine beetle. http://www.for.gov.bc.ca/hfp/mountain_pine_beetle/facts.htm. Accessed Apr 2014

Brown E, Dudley N, Lindhe A, Muhtaman DR, Stewart C, Synnott T (eds) (2013) Common guidance for the identification of high conservation values. http://www.hcvnetwork.org/resources/folder.2006-09-29.6584228415/2013_commonguidancev5. Accessed 14 July 2014

Bryngelsson DK, Lindgren K (2013) Why large-scale bioenergy production on marginal land is unfeasible: a conceptual partial equilibrium analysis. Energy Policy 55:454–466

Bunnell F (2013) Social license in British Columbia: some implications for energy development. J Ecosyst Manag 14:1–16. http://jem.forrex.org/index.php/jem/article/viewFile/550/492. Accessed Jan 2014

Bunnell F, Houde I (2010) Down wood and biodiversity—implications to forest practices. Environ Rev 18:397–421

Butler RA, Laurance WF (2009) Is oil palm the next emerging threat to Amazon? Trop Conserv Sci 2:1–10

Butterbach-Bahl K, Kiese R (2013) Biofuel production on the margins. Nature 493:483–485

Center for International Forest Research (CIFOR) (2014) Statement prepared for the Bonn Technical Expert Meeting on land use of the UN Framework convention on climate change. http://www.cifor.org/cifor-argues-landscapes-approach-bonn-climate-change-conference/. Accessed 07 July 2014

B.C. Chief Forester (2010) Chief Forester's Guidance on Coarse Woody Debris Management. http://www.for.gov.bc.ca/ftp/HFP/external/!publish/FREP/extension/Chief%20Forester%20short%20CWD.pdf. Accessed Jan 2014

Cocchi M, Nikolaisen L, Junginger M, Goh CS, Heinimö J, Bradley D, hess R, Jacobson J, Ovard LP, Thrän D, Hennig C, Deutmeyer M, Schouwenberg PP, Marchal D (2011) Global wood pellet industry market and trade study. IEA bioenergy, task 40: sustainable international bioenergy trade. http://www.bioenergytrade.org/downloads/t40-global-wood-pellet-market-study_final.pdf

Conservation International (2011) Responsible cultivation areas for biofuels: sustainability in practice. Results from field-testing the RCA methodology in para state. http://www.conservation.org/global/celb/Documents/2011.05.04_RCA_Report_Para.pdf. Accessed 26 Dec 2013

Daily Times (2013) Hopes for Vonore biofuel refinery remain elusive. Reported by Joel Davis. The Daily Times, Maryville. http://www.thedailytimes.com/news/hopes-for-vonore-biofuel-refinery-remain-elusive/article_042e0b4c-9553-5a8c-a81a-dfa2c159063d.html. Accessed 18 Aug 2014

Dale VH, Kline KL (2013a) Issues in using landscape indicators to assess land changes. Ecol Indic 28:91–99. doi:10.1016/j.ecolind.2012.10.007

Dale VH, Kline KL (2013b) Modeling for integrating science and management. In: Brown DT, Robinson N, French H, Reed BC (eds) Land use and the carbon cycle: advances in integrated science, management, and policy. Cambridge University Press, New York

Dale BE, Bals BD, Kim S, Eranki P (2010a) Biofuels done right: land efficient animal feeds enable environmental and energy benefits. Environ Sci Technol 44:8385–8389

Dale VH, Lowrance R, Mulholland P, Robertson GP (2010b) Bioenergy sustainability at the regional scale. Ecol Soc 15(4):23. http://www.ecologyandsociety.org/vol15/iss4/art23/

Dale VH, Kline KL, Wiens J, Fargione J (2010c) Biofuels: implications for land use and biodiversity. Biofuels and Sustainability Reports, January 2010. Ecological Society of America, Washington, DC

Dale VH, Kline KL, Wright LL, Perlack RD, Downing M, Graham RL (2011) Interactions among bioenergy feedstock choices, landscape dynamics, and land use. Ecol Appl 21:1039–1054

Dale VH, Kline KL, Perla D, Lucier A (2013) Communicating about bioenergy sustainability. Environ Manag 51(2):279–290. doi:10.1007/s00267-012-0014-4

Dale BE, Anderson J, Brown R, Csonka S, Dale V, Herwick G, Jackson R, Jordan N, Kaffka S, Kline K, Lynd L, Malmstrom C, Ong R, Richard T, Taylor C, Wang M (2014) Take a closer look: biofuels can support environmental, economic and social goals. Environ Sci Technol 48:7200–7203

Dale VH, Parish ES and Kline KL (2015) Risks to global biodiversity from fossil-fuel production exceed those from biofuel production. Biofuels Bioprod Bioref 9(2):177–189

Dennison S (2011) Biofuels: biodiversity data. Winrock International. http://ec.europa.eu/energy/renewables/studies/doc/biofuels/2011_biofuels_baseline_2008.pdf

Densmore N (2010) Coarse woody debris backgrounder. Forest and Range Evaluation Program FREP Extension Note #8. http://www.for.gov.bc.ca/ftp/hfp/external/!publish/FREP/extension/FREP_Extension_Note_08.pdf. Accessed Jan 2014

Dias LAS, Missio RF, Dias DCFS (2012) Antiquity, botany, origin and domestication of Jatropha curcas (Euphorbiaceae), a plant species with potential for biodiesel production. Genet Mol Res 11:2719–2728

DOE (2014) Incorporating bioenergy into sustainable landscape designs. Summary of a workshop held in New Bern, North Carolina, on March 4–6, 2014, organized by the U.S. Department of Energy Bioenergy Technologies Office, Oak Ridge National Laboratory, Argonne National Laboratory, and the National Council for Air and Stream Improvement, Inc. (NCASI). http://web.ornl.gov/sci/ees/cbes/workshops/Landscape%20Design%20Workshop%20Summary%20-%20New%20Bern%20NC%20March%202014.pdf. Accessed 14 July 2014

Donner SD, Kucharik CJ (2008) Corn-based ethanol production compromises goal of reducing nitrogen export by the Mississippi River. Proc Natl Acad Sci USA 105:4513–4518

Embrapa (2010) ZAE Cana (Sugarcane Agricultural Zoning Cana) for 2017 and beyond. EMBRAPA. http://www.cnps.emprapa.br

Endres J, Diaz-Chavez R, Kaffka SR, Pelkmans L, Seabra JEA, Walter A (2015) Sustainability certification In: Souza GM, Victoria RL, Joly CA, Verdade M (eds) Scientific Committee on problems of the environment (SCOPE), bioenergy & sustainability: bridging the gaps. SCOPE 72, Chapter 19. Paris. ISBN: 978-2-9545557-0-6

Engel J, Huth A, Frank K (2012) Bioenergy production and Skylark (*Alauda arvensis*) population abundance—a modelling approach for the analysis of land-use change impacts and conservation options. Glob Change Biol Bioenerg 4:713–727

Erb K-H, Haberl H, Plutzar C (2012) Dependency of global primary bioenergy crop potentials in 2050 on food systems, yields, biodiversity conservation and political stability. Energy Policy 47:260–269

Europa (2014) Promotion of the use of energy from renewable sources. Text of the European Renewable Energy Directive. http://europa.eu/legislation_summaries/energy/renewable_energy/en0009_en.htm

Fahd S, Mellino S, Ulgiati S (2012) Energy cropping in marginal land: viable option or fairy tale? In: Pimental D (ed) Global economic and environmental aspects of biofuels. CRC Press, Taylor & Francis Group, Boca Raton, pp 51–96

FAO and Joint Research Centre (JRC) (2012) Global forest land-use change 1990–2005, by E.J. Lindquist, R. D'Annunzio, A. Gerrand, K. MacDicken, F. Achard, R. Beuchle, A. Brink, H.D. Eva, P. Mayaux, J. San-Miguel-Ayanz, H-J. Stibig. FAO Forestry Paper No. 169. Food and Agriculture Organization of the United Nations and European Commission Joint Research, Centre. FAO, Rome

Fargione J, Hill J, Tilman D, Polasky S, Hawthorne P (2008) Land clearing and the biofuel carbon debt. Science 319:1235–1237

Fargione J, Plevin RJ, Hill JD (2010) The ecological impact of biofuels. Annu Rev Ecol Evol S 41:351–377

Flaspohler DJ, Webster CR (2011) Plantations for bioenergy: principles for maintaining biodiversity in intensively managed forests. For Sci 57:516–524

Fletcher RJ, Robertson BA, Evans J, Doran PJ, Alavalapati JRR, Schemske DW (2011) Biodiversity conservation in the era of biofuels: risks and opportunities. Front Ecol Environ 9:161–168

Food and Agriculture Organization (FAO) (2013) FAOSTAT Online Statistical Service. http://faostat.fao.org

Food and Agriculture Organization (FAO) (2014) State of World's Forest 2014. Rome. http://www.fao.org/forestry/sofo/en/. Accessed 07 July 2014

Forest Practices Board (2010) Measuring wood waste in British Columbia: complaint investigation 080870. FPB/IRC/170, September 2010. http://www.fpb.gov.bc.ca/WorkArea/DownloadAsset.aspx?id=5499. Accessed Apr 2014

Forest and Range Practices Act (FRPA) (2004). http://www.bclaws.ca/Recon/document/ID/freeside/14_2004. Accessed Jan 2014

Forest and Range Practices Act (FRPA) (2011) Wildlife tree retention: guidance for district and licensee staff. FRPA General Bulletin Number 8. http://www.for.gov.bc.ca/ftp/HTH/external/!publish/web/frpa-admin/frpa-implementation/bulletins/frpa-general-no-8-wildlife-tree-retention-area-dec-2011.pdf. Accessed Jan 2014

Gelfand I, Zenone T, Jasrotia P, Chen J, Hamilton SK, Robertson GP (2011) Carbon debt of Conservation Reserve Program (CRP) grasslands converted to bioenergy production. Proc Natl Acad Sci USA 108:13864–13869

Gelfand I, Sahajpal R, Zhang XS, Izaurralde RC, Gross KL, Robertson GP (2013) Sustainable bioenergy production from marginal lands in the US Midwest. Nature 493:514–520

Gonçalves JLM, Alvares CA, Higa AR, Silva LD, Alfenas AC, Stahl J, Ferraz SFB, Lima WP, Brancalion PHS, Hubner A, Bouillet JPD, Laclau JP, Nouvellon Y, Epron D (2013) Integrating genetic and silvicultural strategies to minimize abiotic and biotic constraints in Brazilian eucalypt plantations. For Ecol Manag 301:6–27

Grimm NB, Chapin FS, Bierwagen B, Gonzalez P, Groffman PM, Luo YQ, Melton F, Nadelhoffer K, Pairis A, Raymond PA, Schimel J, Williamson CE (2013) The impacts of climate change on ecosystem structure and function. Front Ecol Environ 11:474–482

Groom MJ, Gray EM, Townsend PA (2008) Biofuels and biodiversity: principles for creating better policies for biofuel production. Conserv Biol 22:602–609

Gutiérrez-Vélez VH, DeFries R, Pinedo-Vásquez M, Uriarte M, Padoch C, Baethgen W, Fernandez K, Lim Y (2011) High-yield oil palm expansion spares land at the expense of forests in the Peruvian Amazon. Environ Res Lett 6:art.044029

Immerzeel DJ, Verweij PA, van der Hilst F, Faaij APC (2014) Biodiversity impacts of bioenergy crop production: a state-of-the-art review. Glob Change Biol Bioenergy 6:183–209

International Sustainability and Carbon Certification (ISCC) (2011) Sustainability requirements for the production of biomass. ISCC 202, V. 2.3-EU. http://www.iscc-system.org/en/certification-process/isccsystemdocuments/iscc-eu/

Isaacs R, Tuell J, Fiedler A, Gardiner M, Landis D (2009) Maximizing arthropod-mediated ecosystem services in agricultural landscapes: the role of native plants. Front Ecol Environ 7:196–203

Janowiak MK, Webster CR (2010) Promoting ecological sustainability in woody biomass harvesting. J For 108:16–23

Janssen R, Rutz DD (2011) Sustainability of biofuels in Latin America: risks and opportunities. Energy Policy 39:5717–5725

Joly CA, Huntley BJ, LM Verdade LM, Dale VH, Mace G, Muok B, Ravindranath NH (2015) Biofuel impacts on biodiversity and ecosystem services. In Souza GM, Joly CA (eds) Scientific Committee on problems of the environment (SCOPE) rapid assessment process on bioenergy and sustainability, Chapter 16. Paris

Keisker DG (2000) Types of wildlife trees and coarse woody debris required by wildlife of north-central British Columbia. Res. Br. Min. For. Victoria B.C. Work Paper 50/2000. http://www.for.gov.bc.ca/hfd/pubs/Docs/Wp/Wp50.htm. Accessed Jan 2014

Kissinger G (2013) Starbucks and conservation international case study. Reducing risk: landscape approaches to sustainable sourcing. EcoAgriculture Partners, on behalf of the Landscapes for People, Food and Nature Initiative, Washington, DC

Kline KL, Oladosu GA, Wolfe A, Perlack RD, Dale VH, McMahon M (2008) Biofuel feedstock assessment for selected countries. ORNL/TM-2008/026. doi:10.2172/931159. http://info.ornl.gov/sites/publications/Files/Pub9385.pdf. Accessed Mar 2015

Kline KL, Dale VH, Lee R, Leiby P (2009) In defense of biofuels, done right. Issues Sci Technol 25:75–84

Kline KL, Oladosu GA, Dale VH, McBride AC (2011) Scientific analysis is essential to assess biofuel policy effects: in response to the paper by Kim and Dale on-Indirect land-use change for biofuels: testing predictions and improving analytical methodologies. Biomass Bioenergy 35:4488–4491. doi:10.1016/j.biombioe.2011.08.011

Kretschmer B, Allen B, Tucker G (2013) A framework for land use mapping: mapping appropriate land use and reducing land use change impacts in the context of the Renewable Energy Directive. Institute for European Environmental Policy (IEEP), London

Kurka T, Blackwood D (2013) Participatory selection of sustainability criteria and indicators for bioenergy developments. Renew Sustain Energy Rev 24:92–102

Köthke M, Leischner B, Elsasser P (2013) Uniform global deforestation patterns—an empirical analysis. For Policy Econ 28:23–37

Lamers P, Marchal D, Heinimo J, Steierer F (2013) Woody biomass trade for energy. In: Junginger M, Goh CS, Faaij A (eds)

International bioenergy trade: history, status & outlook on securing sustainable bioenergy supply, demand and markets. Springer, Berlin, pp 41–64

Landis DA, Gardiner MM, van der Werf W, Swinton SM (2008) Increasing corn for biofuel production reduces biocontrol services in agricultural landscapes. Proc Natl Acad Sci USA 105:20552–20557

Langeveld H, Dixon J, van Keulen H (2013) Biofuel cropping systems: carbon, land and food. Routledge Earthscan, Abingdon. ISBN 13: 978-0-415-53953-1

Lankoski J, Ollikainen M (2011) Biofuel policies and the environment: do climate benefits warrant increased production from biofuel feedstocks? Ecol Econ 70:676–687

Lapola DM, Martinelli LA, Peres CA, Ometto JP, Ferreira ME, Nobre CA, Aguiar APD, Bustamante MMC, Cardoso MF, Costa MH, Joly CA, Leite CC, Moutinho P, Sampaio G, Strassburg BBN, Vieira ICG (2014) Pervasive transition of the Brazilian land-use system. Nat Clim Change 4:27–35

Leal MRLV, Horta Nogueira LA, Cortez LAB (2013) Land demand for ethanol production. Appl Energy 102:266–271

Lewis KC, Porter RD (2014) Global approaches to addressing biofuel-related invasive species risks and incorporation into U.S. laws and policies. Ecol Monogr 84:171–201

Littlefield CE, Keeton WS (2012) Bioenergy harvesting impacts on ecologically important stand structure and habitat characteristics. Ecol Appl 22:1892–1909

Liu J, Mooney H, Hull V, Davis SJ, Gaskell J, Hertel T, Lubchenco J, Seto KC, Gleick P, Kremen C, Li S (2015) Systems integration for global sustainability. Science 347(6225):963

Lu H, Lin B-L, Campbell DE, Sagisaka M, Ren H (2012) Biofuel vs. biodiversity? Integrated emergy and economic cost-benefit evaluation of rice-ethanol production in Japan. Energy 46:442–450

Meehan TD, Hulbert AH, Gratton C (2010) Bird communities in future bioenergy landscapes of the upper Midwest. Proc Natl Acad Sci USA 107:18533–18538

Meehan TD, Werling BP, Landis DA, Gratton C (2012) Pest-suppression potential of Midwestern landscapes under contrasting bioenergy scenarios. PLoS One 7(7):e41728

Millennium Ecosystem Assessment (MEA) (2005) Ecosystems and human well-being: synthesis. Island Press, Washington, DC

Ministry of Agriculture and Livestock (MAPA) (2013) Sugarcane production data. www.agricultura.gov.br

Ministry of Forests, Lands and Natural Resource Operations (2011a) Northern interior forest region: analysis of stand-level biodiversity sampling results in six predominant biogeocliamtic subzones. Min. For. Lands Nat. Resour. Oper For Prac Invest Br., Victoria. FREP. http://www.for.gov.bc.ca/hfp/frep/publications/reports.htm. Accessed Jan 2014

Ministry of Forests, Lands and Natural Resource Operations (2011b) Southern interior forest region: analysis of stand-level biodiversity sampling results in six predominant biogeocliamtic subzones. Min. For. Lands Nat. Resour. Oper. For. Prac. Invest. Br., Victoria, B.C. FREP. http://www.for.gov.bc.ca/hfp/frep/publications/reports.htm. Accessed Jan 2014

Ministry of Forests, Lands and Natural Resource Operations (2011c) Coastal forest region: analysis of stand-level biodiversity sampling results in six predominant biogeocliamtic subzones. Min. For. Lands Nat. Resour. Oper. For. Prac. Invest. Br., Victoria, B.C. FREP. http://www.for.gov.bc.ca/hfp/frep/publications/reports.htm. Accessed Jan 2014

Ministry of Forests and Range (2000) A short-term strategy for coarse woody debris management in British Columbia's Forests. Research Branch. http://www.for.gov.bc.ca/hre/deadwood/DTgui3.htm. Accessed Jan 2014

Mitchell RJ, Duncan SL (2009) Range of variability in southern coastal plain forests: its historical, contemporary, and future role in sustaining biodiversity. Ecol Soc 14(1):17. http://www.ecologyandsociety.org/vol14/iss1/art17/

Mitchell R, Vogel K, Schmer M (2014) Switchgrass (*Panicum virgatum*) for Biofuel Production. Extension, America's Research-based learning network. https://www.extension.org/pages/26635/switchgrass-panicum-virgatum-for-biofuel-production#.U_YeHPldWE4. Accessed 18 Aug 2014

Müller J, Bütler R (2010) A review of habitat thresholds for dead wood: a baseline for management recommendations in European forests. Eur J For Res 129:981–992

Myers MC, Hoksch BJ, Mason JT (2012) Butterfly response to floral resources during early establishment at a heterogenous prairie biomass production site in Iowa, USA. J Insect Conserv 16:457–472

Nackley LL, Lieu BH, Batalla Garcia B, Richardson JJ, Isaac E, Spies K, Rigdon S, Schwartz DT (2013) Bioenergy that supports ecological restoration. Front Ecol Environ 11:535–540

Nahum JS, Malcher ATC (2012) Dinâmicas territoriais do espaço agrário na Amazônia: a dendeicultura na microrregião de Tomé-Açu (PA). Confins 16:1–16. doi:10.4000/confins.7947

National Research Council (NRC) (2011) Renewable fuel standard: potential economic and environmental effects of U.S. biofuel policy. Committee on Economic and Environmental Impacts of Increasing Biofuels Production; National Research Council, National Academies Press, Washington, DC

Nepstad D, McGrath D, Stickler C, Alencar A, Azevedo A et al (2014) Slowing Amazon deforestation through public policy and interventions in beef and soy supply chains. Science 344(6188):1118–1123

Neugarten R, Savy CE (2012) A global review of national guidance for high conservation value. Conservation International & Africa Biodiversity Collaborative Group (ABCG). Funded by the US Agency for International Development (USAID), Washington, DC. http://pdf.usaid.gov/pdf_docs/PA00JW7M.pdf

NL Agency (2010) Jatropha Assessment. Prepared by Utrecht University (Jansk van Eijck et al.) for NL Agency, Ministry of Economic Affairs, Agriculture and Innovation, Netherlands Programmes for Sustainable Biomass. http://english.rvo.nl/sites/default/files/2013/12/Report%20Jatropha%20assessment%20-%20Copernicus%20-%20NPSB.pdf. Accessed Dec 2013

North Carolina State Forest Service (2014) North Carolina's Emerging Forest threats—management options for healthy forests. http://ncforestservice.gov/Managing_your_forest/pdf/EmergingThreatsHealthyForestMngtOptionsNC.pdf. Accessed 17 Aug 2014

OECD/FAO (2011) OECD-FAO agricultural outlook 2011–2020, chapter 3. http://www.oecd.org/site/oecd-faoagriculturaloutlook/48178823.pdf

Oladosu G, Kline K, Martinez R, Eaton L (2011) Sources of corn for ethanol production in the United States: a review and decomposition analysis of the empirical data. Biofuels Bioprod Bioref 5:640–653

Oliveira COF (2013) Biodiversity and the certification schemes for biofuels. Masters dissertation presented at University of Campinas. Campinas

Parish ES, Hilliard MR, Baskaran LM, Dale VH, Griffiths NA et al (2012) Multimetric spatial optimization of switchgrass plantings across a watershed. Biofuels Bioprod Bioref 6:58–72

Parish ES, Kline KL, Dale VH, Efroymson RA, McBride AC, Johnson TL, Hilliard MR, Bielicki JM (2013) Comparing scales of environmental effects from gasoline and ethanol production. Environ Manag 51:307–338

Pereira HM, Navarro LM, Martins IS (2012) Global biodiversity change: the bad, the good, and the unknown. Annu Rev Environ Resour 37:25–50

Pessoas-Jr A, Roberto IC, Menossi M, dos Santos RR, Ortega S, Penna TCV (2005) Perspectives on bioenergy and biotechnology in Brazil. Appl Biochem Biotechnol 121:59–70

Practical Action Consulting (PAC) (2009) Small-scale bioenergy initiatives: brief description and preliminary lessons on livelihood impacts from case studies in Asia, Latin America and Africa. Prepared for the Food and Agriculture Organization, Policy Innovation Systems for Clean Energy Security (PISCES), Rome. http://www.fao.org/bioenergy/home/en/UTH. Accessed Dec 2013

Proforest (2010) REDD+ co-benefits and the HCV concept. Annex 2. http://www.proforest.net/objects/publications/full-report. Accessed 07 July 2014

Puppim JA, de Oliveira JAP (2002) The policymaking process for creating competitive assets for the use of biomass energy: the Brazilian alcohol programme. Renew Sustain Energy Rev 6(1–2):129–140

Raghu S, Anderson RC, Daehler CC, David AS, Wiedenmann RN, Simberloff D, Mack RN (2006) Adding biofuels to the invasive species fire? Science 313:1742

Reijnders L (2013) Sustainability of soil fertility and the use of lignocellulosic crop harvest residues for the production of biofuels: a literature review. Environ Technol 34:1725–1734

Renewable Energy Policy Network (REN21) (2014) Renewables 2014 Global Status Report. http://www.ren21.net/portals/0/documents/resources/gsr/2014/gsr2014_full%20report_low%20res.pdf

Renewable Fuel Association (RFA) (2014) Renewable Fuel Association production data. http://www.ethanolrfa.org/pages/statistics. Accessed 07 July 2014

Riffell S, Verschuyl J, Miller D, Wigley TB (2011) Biofuel harvests, coarse woody debris, and biodiversity—a meta-analysis. For Ecol Manag 261:878–887

Robertson BA, Doran PJ, Loomis RL, Robertson JR, Schemske DW (2010) Perennial biomass feedstocks enhance avian diversity. Glob Change Biol Bioenergy 3:235–246

Robertson BA, Rice RA, Sillett TS, Ribic CA, Babcock BA, Landis DA, Herkert JR, Fletcher RJ Jr, Fontaine JJ, Doran PJ, Schemske DW (2012) Are agrofuels a conservation threat or opportunity for grassland birds in the United States? Condor 114:679–688

Robertson BA, Landis DA, Sillett TS, Loomis ER, Rice RA (2013) Perennial agroenergy feedstocks as en route habitat for spring migratory birds. Bioenergy Res 6:311–320

Roundtable on Sustainable Biomaterials (RSB) (2010) RSB principles & criteria for sustainable biofuel production. RSB-STD-01-001, version 2.0. http://rsb.org/pdfs/standards/11-03-08-RSB-PCs-Version-2.pdf

Roundtable on Sustainable Biomaterials (RSB) (2011) Indicators of compliance for the RSB principles & criteria. http://rsb.org/pdfs/global/11-03-08-RSB-Indicators-2-0.pdf

Roundtable on Sustainable Biomaterials (RSB) (2015) Participating operators. http://rsb.org/certification/participating-operators/

RWE npower (2014) Tilbury biomass sustainability. https://www.rwe.com/web/cms/en/1714906/rwe-npower/about-us/our-businesses/power-generation/tilbury/sustainability/. Accessed 18 Aug 2014

Sala OE, Chapin SS, Armesto JJ, Berlow E, Bloomfield J, Dirzo R, Huber-Sanwald E, Huenneke LF, Jackson RB, Kinzig A, Leemans R, Lodge DM, Mooney HA, Oesterheld M, Poff NL, Sykes MT, Walker BH, Walker M, Wall DH (2000) Global biodiversity scenarios for the year 2100. Science 287:1770–1774

Scarlat N, Dallemand JF (2011) Recent developments of biofuels/bioenergy sustainability certification: a global overview. Energy Policy 39:1630–1646

Schloss CA, Nunez TA, Lawler JJ (2012) Dispersal will limit ability of mammals to track climate change in the Western Hemisphere. Proc Natl Acad Sci USA 109:8606–8611

Searchinger T, Heimlich R, Houghton RA, Fengxia D, Elobeid A, Gabiosa J, Tokgoz S, Hayes D, Yu TH (2008) Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change. Science 319:1238–1240

Siitonen J, Martikainen P, Punttila P, Rauh J (2000) Coarse woody debris and stand characteristics in mature managed and old-growth boreal mesic forests in southern Finland. For Ecol Manag 128:211–225

Souza GM, Victoria RL, Joly CA and Verdade M, editors (2015) Scientific Committee on Problems of the Environment (SCOPE) Report: *Bioenergy & Sustainability: bridging the gaps*. SCOPE 72. Paris, France and Sao Paulo, Brazil. ISBN: 978-2-9545557-0-6

Sparovek G, Barretto A, Berndes G, Martins S, Maule R (2009) Environmental, land-use and economic implications of Brazilian sugarcane expansion 1996–2006. Mitig Adapt Strat Glob Change 14:285–298

Spelter H, Toth D (2009) North America's wood pellet sector. USDA Forest Service, Forest Products Laboratory, Research Paper FPL-RP-656, Madison

Stanley DA, Stout JC (2013) Quantifying the impacts of bioenergy crops on pollinating insect abundance and diversity: a field-scale evaluation reveals taxon-specific responses. J Appl Ecol 50:335–344

Staudinger MD, Carter SL, Cross MS, Dubois NS, Duffy JE, Enquist C, Griffis R, Hellmann JJ, Lawler JJ, O'Leary J, Morrison SA, Sneddon L, Stein BA, Thompson LM, Turner W (2013) Biodiversity in a changing climate: a synthesis of current and projected trends in the US. Front Ecol Environ 11:465–473

Stennes B, McBeath A (2006) Bioenergy options for woody feedstock: are trees killed by mountain pine beetle in British Columbia a viable bioenergy resource? Natural Resources Canada, Pacific Forestry Centre Information Report BC-X-405. http://cfs.nrcan.gc.ca/pubwarehouse/pdfs/26537.pdf

Stockland JN, Siitonen J, Jonsson BG (2012) Biodiversity in dead wood. Cambridge University Press, Cambridge

Stoms DM, Davis FW, Jenner MW, Nogeire TM, Kaffka SR (2012) Modeling wildlife and other trade-offs with biofuel crop production. Glob Change Biol Bioenergy 4:330–341

Taubert F, Frank K, Huth A (2012) A review of grassland models in the biofuel context. Ecol Model 245:84–93

Tilman D, Hill J, Lehman C (2006) Carbon-negative biofuels from low-input high diversity grassland biomass. Science 314:1598–1600

Tilman D, Socolow R, Foley JA, Hill J, Larson E, Lynd L, Pacala S, Reilly J, Searchinger T, Somerville C, Williams R (2009) Beneficial biofuels—the food, energy and environment trilemma. Science 325:270–271

Tscharntke T, Clough Y, Wanger TC, Jackson L, Motzke I, Perfecto I, Vandermeer J, Whitbread A (2012) Global food security, biodiversity conservation and the future of agricultural intensification. Biol Conserv 151:53–59

UDOP (2015) Brazil Bioenergy Producers Union, Table: Análise Comparativa do Desempenho das Safras 2014/2015 e 2013/2014. http://www.udop.com.br/. Dados Acumulados 22 Apr 2015

United Kingdom (UK) (2014) The Government of the United Kingdom, Department of Energy & Climate Change. Press release: biomass calculator launched. https://www.gov.uk/government/news/biomass-calculator-launched. Accessed 18 Aug

United Nations Environment Programme (2010) State of Biodiversity in Latin America and the Caribbean. UNEP Regional Office for Latin America and the Caribbean (ROLAC), Ciudad de Panamá. http://www.cbd.int/gbo/gbo3/doc/StateOfBiodiversity-LatinAmerica.pdf

US Department of Agriculture Economic Research Service (USDA ERS) (2014) United States Department of Agriculture Economic Research Service, Agriculture baseline database. http://www.ers.usda.gov/data-products/. Accessed 07 July

US Energy Information Administration (EIA) (2014) United States Energy Information Administration, Monthly Energy Review

July 2014. http://www.eia.gov/totalenergy/data/monthly/pdf/sec10_7.pdf. Accessed 14 July 2014

US Environmental Protection Agency (US EPA) (2010) Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis. Contract No.: EPA-420-R-10-006. US Environmental Protection Agency, Washington, DC

U.S. Environmental Protection Agency (US EPA) (2014) Inventory of U.S. greenhouse gas emissions and sinks: 1990–2012. EPA-430-R-14-003 (April 2014). US Environmental Protection Agency, Washington, DC

USDA Forest Service (2012) Future of America's Forest and Rangelands: Forest Service 2010 Resources Planning Act Assessment. Gen. Tech. Rep. WO-87. USDA Forest Service, Washington, DC

USDA National Resources Conservation Service (NRCS) (2014) Landscape initiatives—conservation beyond boundaries. http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/initiatives/. Accessed 18 Aug 2014

Van Dam J (2010), Background document for IEA Bioenergy Task 40. Global efforts on certification of bioenergy towards an integrated approach based on sustainable land use planning (full 330 page report; short version published in Journal of Renewable and Sustainable Energy Reviews). http://www.bioenergytrade.org/downloads/overviewcertificationsystemsfinalapril2010.pdf. Accessed Mar 2015

Victorsson J, Jonsell M (2013) Ecological traps and habitat loss, stump extraction and its effects on saproxylic beetles. For Ecol Manag 290:22–29

Villela A, D'Alembert BJ, Rosa LP, Freitas MV (2014) Status and prospects of oil palm in the Brazilian Amazon. Biomass Bioenergy 67:270–278

Voegele E (2014) U.K. DECC model confirms GHG benefits of North American pellets. Biomass Magazine (July 24, 2014). http://www.theusipa.org/wood-pellet-periodical. Accessed 18 Aug 2014

Wear DN, Greis JG (2012) The Southern Forest Futures Project: summary report. Gen. Tech. Rep. SRS-GTR-168. USDA-Forest Service, Southern Research Station, Asheville

Webster CR, Flaspohler DJ, Jackson RD, Meehan TD, Gratton C (2010) Diversity, productivity and landscape-level effects in North American grasslands managed for biomass production. Biofuels 1:451–461

Werling BP, Meehan TD, Gratton C, Landis DA (2011) Influence of habitat and landscape perenniality on insect natural enemies in three candidate biofuel crops. Biol Control 59:304–312

Werling BP, Dickson TL, Isaacs R, Gaines H, Gratton C, Gross KL, Liere H, Malmstrom CM, Meehan TD, Ruan LL, Robertson BA, Robertson GP, Schmidt TM, Schrotenboer AC, Teal TK, Wilson JK, Landis DA (2014) Perennial grasslands enhance biodiversity and multiple ecosystem services in bioenergy landscapes. Proc Natl Acad Sci USA 111:1652–1657

Wiens J, Fargione J, Hill J (2011) Biofuels and biodiversity. Ecol Appl 21:1085–1095

Wilkinson J, Herrera S (2010) Biofuels in Brazil: debates and impacts. J Peasant Stud 37:749–768

Williams PRD, Inman D, Aden A, Heath GA (2009) Environmental and sustainability factors associated with next-generation biofuels in the U.S.: what do we really know? Environ Sci Technol 43:4763–4775

Witt ABR (2010) Biofuels and invasive species from an African perspective—a review. Glob Change Biol Bioenergy 2:321–329

Wood Pellet Association of Canada (WPAC) (2013a) Wood Pellet Association of Canada website. http://www.pellet.org/production/production. Accessed Jan 2014

Wood Pellet Association of Canada (WPAC) (2013b) British Columbia's Wood pellets sustainability fact sheet. http://www.canadianbiomassmagazine.ca/images/BC-biomass.pdf. Accessed Jan 2014

Wood Resources International LLC (2014) North American wood pellet exports to Europe double in 2 years. Biomass Magazine, 24 April 2014. http://biomassmagazine.com/articles/10311/north-american-wood-pellet-exports-to-europe-double-in-2-years

Woods J, Lynd LR, Laser M, Batistella M, de Castro D, Kline KL, Faaij A (2015) Land and bioenergy. In: Souza GM, Victoria RL, Joly CA, Verdade M (eds) Scientific Committee on Problems of the Environment (SCOPE), Bioenergy & sustainability: bridging the gaps, Chapter 9. SCOPE 72, Paris. ISBN: 978-2-9545557-0-6

Work TT, Hibbert A (2011) Estimating species loss of saproxylic insects under scenarios of reduced coarse woody material in eastern boreal forests. Ecosphere 2:art41

Work TT, Shorthouse DP, Spence JR, Volney WJA, Langor D (2004) Stand composition and structure of the boreal mixedwood and epigaeic arthropods of the ecosystem management emulating natural disturbance (EMEND) landbase in northwestern Alberta. Can J For Res 34:417–430

Work TT, Jacobs JM et al (2010) High levels of green-tree retention are required to preserve ground beetle biodiversity in boreal mixedwood forests. Ecol Appl 20:741–751