

Biofuel Impacts on Biodiversity and Ecosystem Services

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Highlights

- Biodiversity resources are unevenly distributed across the globe. As a consequence of the asymmetrical geographic distribution of species, any consideration of the impacts of biofuels on biodiversity is likely to be biome, site and context specific. Land transformation is the most serious threat to biodiversity, and the rapid expansion of biofuels crops, most especially sugarcane and palm oil in the tropics, is currently the most serious of these concerns. Thus effects of biofuel feedstock production on biodiversity and ecosystem services are context specific, and location-specific management of biofuel feedstock production systems should be implemented to maintain biodiversity and ecosystem services.
- Few positive influences on biodiversity and ecosystem services result from biofuels development. Such positive outcomes are of limited spatial and taxonomic scale. Biofuels-mediated improvements can occur when already degraded lands are rehabilitated with non-native feedstocks, but such changes in habitat structure and ecosystem function support few and mostly common species of native flora and fauna. Even the limited evidence of perennial grass crops favoring certain bird species indicates the requirement of special management regimes.
- Trade-offs between biofuels and environmental resources are inevitable. The mitigation of climate change via reducing GHG emissions through a transition to low carbon energy systems such as selected biofuels offers a logical trade-off, as long as the design of expanded biofuel production avoids areas of special biodiversity concerns or embeds new production areas within a sustainable matrix of natural and transformed ecosystems.
- Available land resources exceed the projected needs for biodiversity conservation in terms of both the Convention on Biological Diversity target of Protected Area system expansion to 17% of the global terrestrial area and biofuels expansion to several fold current production levels.
- Sustainable biofuels and biodiversity management requires cross-sectoral integrated planning and regular monitoring of selected, cost effective and policy relevant indicators. Cost effective, landscape-level biodiversity indicators are in development but await application over most of the developing world.

Summary

As with all land transformation activities, effects on biodiversity and ecosystem services of producing feedstocks for biofuel are highly variable and context specific. Advances toward more sustainable biofuel production benefit from a system's perspective, recognizing spatial heterogeneity and scale, landscape-design principles, and addressing the influences of context, such as the particular products and their distribution, policy background, stakeholder values, location, temporal influences, and baseline conditions. Deploying biofuels in a manner to reduce effects on biodiversity and associated ecosystem services can only be done with planning, monitoring, and appropriate governance. The effects of biofuels can be avoided or reduced by conservation of priority biodiversity areas, recognizing the context specific effects of biofuels, and adopting location-specific management of production systems. Developing those management strategies takes time and effort.

16.1 Introduction

Biofuels can provide answers to current global energy and economic crises - both as a sustainable energy source and through promoting economic development, especially in rural areas of developing countries. Dependence on non-renewable fossil fuels as well as environmental concerns related to air pollution and greenhouse gas effects contributing to global warming and climate change have stimulated interests of policy makers and industry to promote bioenergy as part of energy security and climate change mitigation strategies. However, expansion of the feedstock production for biofuels has been controversial due to potential adverse side effects on natural ecosystems and the services they provide (Gasparatos et al. 2011). Ecosystem services are the benefits that humans derive from ecosystems (Mace et al. 2012) and offer a useful way to assess effects associated with biodiversity and energy use and its implications (see Highlights). There is lack of agreement on the degree to which biofuels both provide positive ecosystem services (e.g., fuel, climate regulation) and compromise other ecosystem services (e.g., biodiversity, food) (e.g., SCOPE 2009; Fischer et al. 2009).

Enhancing ecosystem services via biofuels can be achieved by location-specific design of bioenergy systems. If not well planned, the establishment of biofuel crops may result in environmental impacts (e.g., alterations in habitat or biodiversity quality, changes in soil and air quality, changes in water quality and quantity, productivity changes, and local introduction or elimination of species (McBride et al. 2011) as well as changes in social and economic interactions and outcomes (Koh and Ghazoul 2008; Wilcove and Koh 2010; Dale et al. 2013b). Such effects should be evaluated by scientists and policy makers in order to increase positive outcomes and reduce negative impacts of biofuel production. When produced in a sustainable and equitable manner, biofuels can increase energy self-sufficiency and support rural development as well as reduce

deforestation (Amigun et al. 2011) and greenhouse gas (GHG) emissions compared to fossil fuels (Muok et al. 2010). The challenge is to identify appropriate management practices and incentives. In addition, environmental monitoring programs should be established across fuel sheds in order to understand environmental effects of biofuel operations and to guide adaptive management.

There are four means by which terrestrial feedstock production can be increased: expansion of land area used to grow biomass, increases in crop yields, use of wastes and residues as feedstocks, and increases in system efficiency. This chapter deals largely with the effects of expansion of the land area planted to biofuel feedstocks, which has the largest impact on biodiversity. The chapter also focuses on proactive solutions that avoid or reduce impacts and enhance benefits. It does not consider feedstock production in aquatic systems (e.g., algal based biofuels) or feedstock and fuel transport, fuel production and end use of the fuel.

16.2 Key Findings

SCOPE's first Rapid Assessment on Biofuels and the Environment (SCOPE 2009) concluded that "environmental consequences of biofuels depend on what crop materials are used, where and how these feedstocks are grown, how the biofuel is produced and used, and how much is produced and used. Effects on the environment are both positive and negative" (Howarth et al. 2009). This 2014 SCOPE assessment concurs with that general statement and offers options whereby the negative effects of biofuel production on biodiversity and ecosystem services can be avoided or reduced and positive effects enhanced by attention to three guiding principles:

- Identification and conservation of priority biodiversity areas are paramount;
- Effects of biofuel feedstock production on biodiversity and ecosystem services are context specific; and,
- Location-specific management of biofuel feedstock production systems should be implemented to maintain biodiversity and ecosystem services.

This chapter considers these guiding principles independently even though they are clearly related (e.g., conservation areas must be established within particular contexts, and both conservation areas and their adjacent lands should be managed appropriately).

16.2.1 Identification and Conservation of Priority Biodiversity Areas are Paramount

Biodiversity is the basis for ecosystem services and the foundation for sustainable development. It plays fundamental roles in maintaining and enhancing the wellbeing of the world's 7 billion people, rich and poor, rural and urban (UNEP 2009). Expansion of

any human activities is the most serious threat to biodiversity, and the rapid expansion of biofuel crops raises a serious concern but also can address some problems. The maps in Figure 16.1 depict areas on the Earth of greatest biodiversity concern and where biofuel feedstocks are likely to overlap them.

Preserving biodiversity hotspots is of paramount importance. Conservation is particularly important in the moist tropics, for loss of primary tropical forests is the greatest threat to biodiversity (Gibson et al. 2011). The global network of nearly 133,000 protected areas covers 25.8 million km², approximately 12% of the terrestrial surface (Butchart et al. 2010), an order of magnitude larger than the area currently occupied by biofuel crops. Even so, the network of protected areas does not adequately represent biodiversity, areas of cultural importance, or all ecosystems of value. Maintaining the existing protected areas and establishing new ones require systematic and science-based conservation planning (Margules and Pressey 2000) and effective management and governance (Sodhi et al. 2013) to ensure sustainable and persistent matrices of biodiversity corridors and ecosystem service linkages.

16.2.1.1 Effects of Feedstock Production on Biodiversity and Ecosystem Services are Context Specific

The effects of feedstock production on biodiversity are specific to the biome, site conditions and characteristics of the production system. Context considerations include the particular fuel production and distribution system, policies, stakeholders and their values, and baseline soil, water, air, biodiversity and ecosystem conditions (Efroymson et al. 2013). For example, changes in greenhouse gas emissions relate to feedstock type and soil conditions as well as prior and current management practices (e.g., Castanheira and Freire 2013).

There are contexts in which well-designed deployment of biofuels enhances biodiversity and ecosystem services and other systems where biofuels reduce biodiversity and the benefits of ecosystem services. For example, biofuel-mediated improvements occur where degraded lands are rehabilitated with native or non-invasive, non-native feedstocks, and detriments occur where areas of high diversity value are converted to monocultures of a feedstock that eliminates native species or critical habitats. The challenge is to figure out how to deploy biofuels in a way that maintains or enhances biodiversity and ecosystem services. Effective deployment is facilitated by governance systems that support conservation of resources, protection of rare species, and enhancement of ecosystem services.

Environmental effects of biofuels should be considered in relation to energy and land-use practices that occur in the absence of their use. The displacement of fossil fuel use can reduce soil subsidence (Morton et al. 2006) and land-use changes associated with exploration and extraction of fossil fuels (Finer and Orta-Martinez 2010) that impact biodiversity. Furthermore, risk of environmental catastrophes that affect biodiversity is much less for biofuels than for fossil fuels, which involve exploration and extraction in relatively untouched environments such as deep seas and arctic regions (Chilingar and Endres 2005; Parish et al. 2013; Butt et al. 2013).

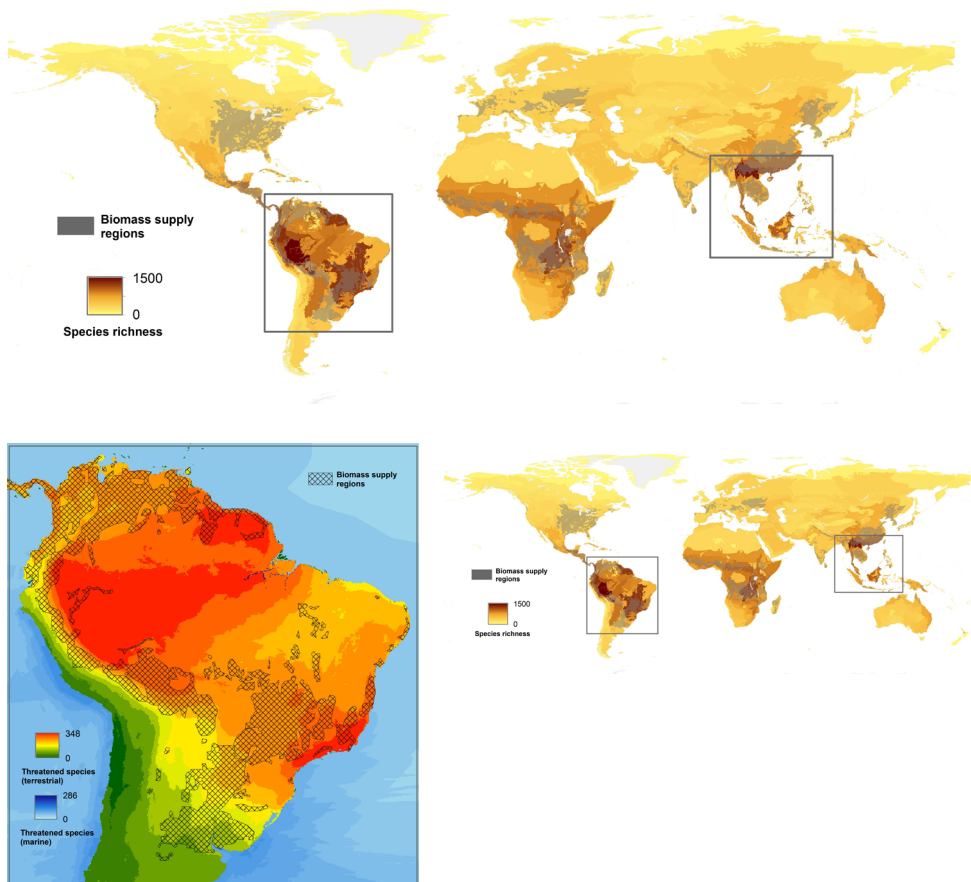


Figure 16.1. Terrestrial species distribution (number of species per ecoregion) compared with distribution of projected biofuel feedstock production areas circa 2030 (from Dale et al. in review). (a) Global area projected for near-term use of biomass resource areas for energy production compared to richness of terrestrial mammals, reptiles, amphibians, marine mammals and birds. Biofuels generated from the land areas shown offer the opportunity to replace 50% of the estimated worldwide demand for liquid transportation fuel by 2030. The species richness data was created by Butt et al. (2013) from the number of different species present in each ecoregion from the World Wildlife Fund's (WWF's) Wildfinder Database (<http://worldwildlife.org/pages/wildfinder>), WWF Terrestrial Ecoregions of the World (TEOW) polygons, and the 2012 IUCN Red List of Threatened Species datasets (<http://www.iucnredlist.org/>). The background map depicts point estimate counts of threatened species ranges at the center of each 0.1° grid cell. Details are shown for potential biomass production areas across a portion of (b) South America and (c) Southeast Asia where many threatened terrestrial and marine species may be affected. These same areas might see improvements in biodiversity conditions given proper resource management for sustainable biofuels production.

16.2.1.2 Location-Specific Management of Feedstock Production Systems should be Implemented to Maintain Biodiversity and Ecosystem Services

While the biofuel industry can build on established good practices in forestry, agriculture, transport logistics, and refinery establishment and operation, some aspects of feedstock production and acquisition are unique. For example, collection of agriculture and forest residues as feedstock requires attention to other ecosystem services. Well-managed feedstock production systems should include environmentally sensitive, science-based planning for resource use such as integrated land management, buffers, intercropping, and appropriate application of fertilizers, herbicides and pesticides. Tradeoffs between environmental resources and energy production and use are inevitable and should be considered in developing management plans. For example, a monoculture can sequester carbon and increase biofuel production but might reduce or eliminate indigenous diversity if the feedstock species becomes invasive. Effects of increased energy crop cultivation on biodiversity depend on landscape structure, and impacts can often be tolerated if a minimum level of crop-type heterogeneity is retained (Engel et al. 2012). Adoption of more sustainable agricultural practices entails defining goals for sustainability within the particular context, developing easily measured indicators of sustainability and monitoring them over time, moving toward integrated agricultural systems, and offering incentives or imposing regulations to affect the behavior of land owners (Dale et al. 2013a; Verdade et al. 2014b; see also Chapter 13, this volume).

16.2.2 Biofuel Feedstock Production Interactions with Biodiversity

The choice of feedstock and its location and management is the first step in the biofuel supply system and has great implications for environmental effects. The use of crop, forest and urban wastes does not require any new land area. Residue removal can be done so as to reduce environmental impacts (e.g., Muth et al. 2012), and it supports the benefits of using biofuels to displace fossil fuels.

16.2.2.1 Impacts of Land-Use Change and Production Intensification

The expansion of feedstock production has been based on land-use change (LUC) or management intensification. These changes can occur in relatively undisturbed ecosystems (Fitzherbert et al. 2008), crop or managed forest lands (Scharlemann and Laurance 2008), or degraded lands (Plieninger and Gaertner 2011). Direct loss of biodiversity occurs if there is a concurrent loss of wildlife habitat. Where feedstocks for biofuels are planted in pristine landscapes, biodiversity losses exceed positive impacts of biofuels production on biodiversity. However, benefits to biodiversity can

occur where feedstocks are planted on degraded land (see Table 16.1 and Harrison and Berenbaum 2013; Leal et al. 2013; Phalan et al. 2013).

Effects of land changes due to biofuels should be considered in light of the particular context (Principle 2). For example, biofuel-driven expansion of corn planting in the US results in lower landscape diversity, thereby decreasing biocontrol services by reducing the supply of natural enemies to nearby fields (Landis et al. 2008). But those land changes should be interpreted in the context of trends of reduction in farmland area since the 1970s (USDA 2009) - largely due to urbanization, which had a stronger impact on biodiversity than recent land and crop changes due to biofuels. Examples of the effects of biofuel feedstock crops on biodiversity with their relative guiding principle are presented in Table 16. 1 and discussed below. Greater feedstock productivity per area is achieved by intensification of agricultural or forestry practices by second cropping, increased planting density, fertilizer use, or irrigation (Fernando et al. 2010; Prins et al. 2011). It is important to mention in this context that some areas in the world (arid and semi-arid lands) are bound to face water shortage with the expansion of irrigation for food production and bioenergy crops as well. As with any system, misuse or overuse of chemicals can result in contamination of the biota and the physical environment (e.g., Meche et al. 2009; Schiesari and Grillitsch 2011). On the other hand, some perennial crops being used for biofuels feedstocks require less chemical application and enhance soil and water conditions as compared to prior agricultural use (Sarkar et al. 2011).

In some circumstances, particular biofuel crops have a positive impact on biodiversity in relation to prior agricultural land uses (Milder et al. 2008; Parish et al. 2012). For example, perennial grasses used for biomass production can enhance avian species richness and abundance relative to avian diversity of corn fields in the US (Fletcher et al. 2011; Robertson et al. 2012, 2013). The benefits of perennial crops on biodiversity are enhanced when specific management practices are adopted such as avoiding harvest during nesting periods and promoting stream-side buffers (Principle 3) (McLaughlin and Walsh 1998; Tolbert and Wright 1998; Tolbert 1998). Natural biocontrol is higher in perennial grasslands than in annual croplands, increases with the amount of perennial grassland in the surrounding landscape, and is negatively related to insecticide use across the Midwestern United States (Meehan et al. 2012). Hence strategically positioned, perennial bioenergy crops could reduce insect damage and insecticide use on adjacent crops (Meehan et al. 2012).

Effects on biodiversity of the use of forest residues for bioenergy depend on forest harvest operations (Principle 3). Woody residue feedstocks are typically tops of trees that have no other commercial value. It is advisable to avoid coarse woody debris (CWD) (snags and downed logs), which provide sites for breeding, foraging and basking for a variety of organisms (more details in Chapter 13, this volume). Best Management Practices (BMPs) have been developed for woody bioenergy feedstocks in order to protect wildlife (Rupp et al. 2012). These practices suggest maintaining a diversity of age classes and stream-side buffers as well as harvesting at times that avoid nesting.

Table 16.1. Example effects of biofuel feedstock crops on biodiversity with the guiding principle involved in each example. The three guiding principles are (1) Conservation of priority biodiversity areas, (2) Context specificity of effects of feedstocks on biodiversity and ecosystem services, and (3) Need for location-specific management to maintain biodiversity and ecosystem services.

Region	Biofuel feedstock as landscape matrix	Taxonomic group	Process	Principle(s) involved	Ref.
Brazil	Sugarcane	Rodents	Increased abundance in relation to native vegetation	3	Gheler-Costa et al. (2012)
			Decrease of mesopredators and rodents following suspension of pre-harvest fire	3	
		Rodents	Spread of emergent infectious diseases (e.g., Hantavirus and Leptospirosis)	2,3	Verdade et al. (2012), Labruna (2012), Patz et al. (2008)
		Wild canids and felids	Increased abundance in relation to exotic pastures	1,2,3	Dotta and Verdade (2007, 2009)
		Passerine birds	Decreased diversity in relation to degraded exotic pastures	1,2,3	Penteado (2006)
		Birds	Decreased diversity in relation to secondary Atlantic forest	1,2	
USA	Eucalyptus	Birds	Decreased diversity in relation to secondary Atlantic forest	1,2,3	Millan et al. (2015), Penteado (2006)
		Marsupials	Increase in bird α -diversity in some plantations Affected dispersion	2	Prevedello and Vieira (2011)
	Annual crops (i.e., maize and soybean)	Insects (agricultural enemies of food crops)	Decreased abundance in relation to perennial grasslands	1,2	Werling et al. (2011)

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Region	Biofuel feedstock as landscape matrix	Taxonomic group	Process	Principle(s) involved	Ref.
USA	Annual crops (i.e., maize and soybean)	Grassland birds	Decreased habitat availability in relation to perennial grasslands	1,2	Fletcher et al. 2011, Meehan et al. (2010), Robertson et al. (2010, 2012)
	Annual crops (i.e., maize and soybean)	Migratory birds	Decreased habitat availability in relation to perennial grasslands	1,2	Robertson et al. (2013)
	Switchgrass	Migratory birds	Increased habitat and bird abundance (if harvest scheduled to avoid nesting period)	2,3	Tolbert and Wright 1998, Tolbert 1998, Tolbert et al. 1997
	Perennial crops	Fauna	Increased habitat when used as buffers between annual crops and waterways	2,3	McLaughlin and Walsh 1998
UK	Miscanthus	Flora and birds	Decreased diversity in relation to short rotation coppice (SRC) willow or poplar	1,3	Rowe et al. (2009)
SE Asia	Palm oil	Vertebrate species	Decreased diversity	1,2	Danielsen et al. (2009)
		Forest birds	Decreased diversity	1,2	Sodhi et al. (2005)
		Insectivorous birds	Predation on herbivorous insects that attack palm oil plants	2	Koh (2008)
Argentina	Soybean	Raptors	Decreased diversity	2	Carrete et al. (2009)

Sugarcane plantations for ethanol and sugar production cover approximately 8 M ha in Brazil and might expand to 14 M ha by 2016 (UNICA 2008). Expansion is predominantly occurring on degraded exotic pastures in Southeastern Brazil and does have local impacts on water eutrophication and soil pollution (Principle 2) (Verdade et al. 2012). While some claim that subsequent indirect pressures may drive deforestation in the Amazon basin (Lapola et al. 2010) such indirect effects are unlikely in the near future in Brazil. Sugarcane is planted in only 0.4% of the Amazon, for it does not grow well there, and a new Brazilian law prevents sugarcane planting in sensitive areas (Martinelli and Filoso 2008) (supporting Principle 1). However, such land-use systems reinforce inequality in land ownership contributing to rural–urban migration that ultimately fuels haphazard expansion of urban areas (Lapola et al. 2013).

Oil palm crops currently occupy over 13.5 million ha of former extremely diverse moist tropical forest in Southeast Asia (Fitzherbert et al. 2008), mainly (80%) in Indonesia and Malaysia. Palm oil is mostly used for cooking oils and soaps, and some of the oil and production wastes are used for biofuel (Corley 2009). Hence only a portion of its impacts is attributable to biofuels. More than 50% of the recent (1990–2005) palm oil expansion is directly related to deforestation (Koh and Wilcove 2008, Sodhi et al. 2010a). The rate of annual deforestation in Malaysia has been over 22,000 ha per year during the last three decades (Koh and Hoi 2003). Converting forests into palm oil crop is more profitable than preserving it for carbon credits traded in compliance markets (Butler et al. 2009). This trend is supported by the international market (Lenzen et al. 2012) and might result in massive biodiversity loss (Sodhi et al. 2004) especially of forest birds (Sodhi et al. 2005). Palm oil plantations support only 38% of the vertebrate species found in primary forest (and only 23% found in primary forests and plantations) (Danielsen et al. 2009). The Roundtable on Sustainable Palm Oil requires that “high conservation value forest” not be cleared to plant oil palm (www.rspo.org) (Principle 1). If this rule were rigorously implemented, the current rates of biodiversity loss in Southeast Asia would be greatly reduced.

The continuous increase in the supply and demand of cassava in developing countries has accentuated the negative impact cassava production and processing has had on the environment and biodiversity. The replacement of kerosene cooking fuel with ethanol produced from cassava in Nigeria requires the conversion of 400,000 ha of forest into farmland. Also, large volumes of waste streams are generated including toxic cassava effluent and solid wastes containing cyanide (Ohimain 2013). Cassava expansion also contributes to soil erosion, depletion of soil nutrient supply, and loss of biodiversity. Losses can include wild *Manihot* species, which may be of future importance for the incorporation of favorable characteristics, such as disease tolerance, in cultivated cassava.



16.2.2.2 Invasion of Exotic Species introduced through Biofuel Production Activities

Invasive species are associated with a variety of human activities and have driven many native species to extinction, altered the composition of ecological communities, changed patterns of periodical events, and altered ecosystem processes (Vitousek et al. 1987). Where nonnative plants are used as feedstocks, biofuel production may increase the risks and costs associated with invasive species as a direct consequence of the species and genotypes used to produce biofuels or of invasion of other taxa (Sala et al. 2009). This risk is relevant to both Africa (Blanchard et al. 2011, Witt 2010) and Europe (Genovesi 2010), where biofuel production is based on use of nonnative species. In some cases, however, introduced species used as feedstock provide habitat for native species (e.g., Eucalyptus and sugarcane, according to Dotta and Verdade 2011 and Gheler-Costa et al. 2012). The use of non-native species that have invasive characteristics requires adoption of specific management practices to reduce their potential for spread (Principle 3).

16.2.3 Ecosystem Services and Biofuel Feedstock Production

Ecosystem services as defined and described in the Millennium Ecosystem Assessment (MA 2005) provide a useful conceptual framework for structuring this review of the environmental impacts of biofuels following the trans-disciplinary approach proposed by Gasparatos (2013). Table 16.2 provides example services and effects related to feedstock production for biofuels, which has direct influences on provisioning, regulating and supporting services. In addition to supplying food, crops like corn, wheat, and sugarcane can contribute to biofuel production and enhance soil, water, and air conditions. The potential role of sustainable biofuels in mitigating climate change is still debated (see Chapters 9 and 12, this volume). The unresolved question is how much change is attributable to biofuels versus to other products and as compared to other land or energy uses.

Table 16.2 provides examples of the effects that feedstock production for biofuels can have on different ecosystem services. Effects are context specific and depend on prior uses of the land as well as the degree to which fossil fuel use is offset. Feedstock production practices can enhance or degrade air and water quality, and thereby affect biodiversity, food security, and soil quality.

16.2.4 Mitigating Impacts of Biofuel Production on Biodiversity and Ecosystem Services

There are several measures for avoiding or reducing environmental impacts of biofuel expansion. First, land-use planning with clearly defined agricultural production zoning can limit the expansion of biofuel crops into pristine ecosystems. Spatial planning based on

Table 16.2. Potential interactions with ecosystem services of production of terrestrial feedstock for biofuel (after Gasparatos et al. 2011).

Categories of Ecosystem Services	Service types	Positive and negative effects
Provisioning	Fuel	Biofuels provide around 3% of the world's fuel for transport and have potential for meeting a high proportion of liquid fuel needs in certain countries and regions. (Brazil: 23%, United States: 4%, European Union: 3%). (http://www.iea.org/aboutus/faqs/renewableenergy/)
	Food/ fodder	<p>Most feedstocks used for first generation biofuels are food crops (Gasparatos et al. 2011)]</p> <p>An important bi-product of biofuel production is food for animals (Dale et al. 2010a)</p> <p>Integrated systems can improve food production at the local level creating a positive influence on food security (Diaz-Chavez 2011)</p> <p>Biofuel feedstock production replaced 1.6% of the cultivated land globally as of 2007 (Fischer et al. 2009) but provides a reason for retaining land in agriculture in the face of world-wide urban expansion, which has claimed a much larger area of farmland</p>
	Water quantity and quality	<p>Some feedstocks are used to purify wastewater (Börjesson and Berndes 2006) and to restore contaminated aquifers and marginal lands (Gopalakrishnan et al. 2009)</p> <p>When perennial feedstock crops replace annual crops, less fertilizer is used and deep roots reduce runoff (Achten et al. 2008; Gmunder et al. 2010; Dale et al. 2010b, Parish et al. 2012)</p> <p>Palm Oil Mill Effluent (POME) and sugarcane mill effluent are used for oil palm and sugarcane irrigation, respectively</p> <p>Biofuel systems can degrade and exploit water quality and quantity (de Fraiture and Berndes 2009)</p> <p>Where water is limited, the use of irrigation in feedstock production can deplete vulnerable aquifers (Chiu et al. 2009)</p> <p>It can be more water-efficient to use biomass to produce bioelectricity than biofuels (Gerbens-Leenes et al. 2009)</p> <p>Biofuel production can produce effluents with high toxicity and Biological Oxygen Demand (BOD) (Gasparatos et al. 2011)</p> <p>The palm oil industry is a major source of water pollution in Malaysia (Muyibi et al. 2008)</p> <p>POME has high levels of BOD [approximately 2.5–3 tonnes of POME per tonne of palm oil (Wu et al. 2010)]</p> <p>Effluent from sugarcane mills is rich in BOD (12–13 liters of vinasse generated per liter of ethanol) (Martinelli and Filoso 2008)</p>

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»	Categories of Ecosystem Services	Service types	Positive and negative effects
	Provisioning (<i>cont.</i>)	Water quantity and quality (<i>cont.</i>)	<p>Expansion of feedstock production in previously uncultivated land in Brazil increases use of chemical compounds that can elicit neurotoxic, reprotoxic, carcinogenic, or endocrine-disrupting effects in humans and wildlife (Schiesari and Grillitsch 2011)</p> <p>Both nitrogen and phosphorus reduction can occur where lignocellulosic bioenergy feedstocks are grown that require little fertilizer and can absorb runoffs with their deep perennial rooting systems (Simpson et al. 2008, Almaraz et al. 2009, Parish et al. 2012)</p> <p>Using perennials feedstocks, alternative rotation systems, and sustainable crop production (e.g., no-till farming, reduced use of fertilizer, and riparian buffers) can reduce both nutrient input and the transport of nutrients and sediments to waterways (Dale et al. 2010a, Costello et al. 2009)</p> <p>Woody biomass-to-liquid production (BTL) may locally increase eutrophication and have subtle effects on acidification (Sunde et al. 2011)</p>
	Regulating	Soil quality/ Erosion regulation	<p>Jatropha can improve soil quality and control erosion on marginal lands (Achten et al. 2008; Gmunder et al. 2010)</p> <p>Martinelli and Filoso (2008) in (Gasparatos et al. 2011) mention that sugarcane cultivation is a significant driver of soil erosion in Brazil</p> <p>Soybean cultivation for biodiesel in Argentina exhibits greater soil erosion potential and greater negative effect on soil nutrients than switchgrass (van Dam et al. 2009)</p> <p>Smeets et al. (2008) suggest that leaving sugarcane residues on the field reduces erosion</p> <p>Creating bio-energy plantations on degraded land can positively affect soil and biodiversity (Danielsen et al. 2009)</p> <p>Growing switchgrass in the southern United States on land previously in pasture or annual crops reduces soil erosion (Parish et al. 2012)</p> <p>Deep-rooted perennial bioenergy feedstocks in the tropics could enhance soil carbon storage by 0.5 to 1 metric tonne ha⁻¹year⁻¹ on already cleared land (Fisher et al. 1994)</p> <p>Annual exposure of bare soil rich in Al can result in contamination of freshwater fish (Meche et al. 2009)</p> <p>Biofuels from crop residue can reduce soil carbon and increase CO₂ emissions (Liska et al. 2014; see also Chapters 13 and 18, this volume)</p>

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Categories of Ecosystem Services	Service types	Positive and negative effects
Regulating (<i>cont.</i>)	Climate regulation	<p>Sustainably produced biofuels substitute for fossil fuels and thereby contribute to mitigating climate change</p> <p>Biofuel systems can emit significant amounts of GHGs during their whole life cycle depending on prior land use (Hess et al. 2009)</p> <p>Oil palm plantations are net carbon sinks and protect the soil if they are established on marginal crop/grassland (Danielsen et al. 2009, Verwer et al. 2008)</p> <p>Danielsen et al. (2009) calculated that depending on the forest clearing method used, it takes 75–93 years for an oil palm plantation to compensate the carbon lost during the conversion of the initial forest and 600 years if that happens on peatland</p> <p>Georgescu et al. (2009) state that biofuel expansion in the US Corn Belt might affect regional climate as a result of conversion of land cover from one crop type to another and the associated changes in energy and moisture balance of the surface</p>
	Air quality	<p>Biofuel feedstock production can release Volatile Organic Compounds (VOCs) and NOx</p> <p>Use of cane for biofuels can reduce burning, which is a major source of particulate matter with aerodynamic diameter and Polycyclic Aromatic Hydrocarbons (PAHs) (Gasparatos et al. 2011)</p> <p>Introduction of biofuels in Brazil has contributed to improvements of air quality in the city of São Paulo (Goldemberg 2008)</p> <p>Air pollution can result from biofuels production (Williams et al. 2009) including anthropogenic emissions of NH₃ (Erisman et al. 2007)</p>
Supporting	Habitat	<p>Open habitats like sugarcane plantations attract species and migratory birds (Acevedo and Restrepo 2008)</p> <p>Changing from annual crops to perennial energy crops on metal polluted soils increased soil invertebrate density (Hedde et al. 2013)</p>

systematic conservation planning principles (Margules and Pressey 2000) can establish networks of sustainable protected areas (Principles 1 and 3). Secondly, wildlife friendly agricultural and forestry practices can be employed (Principle 3) as promoted by the work of FAO (2012) and the Forestry Guild (Forest Guild Biomass Working Group 2010, Forest Guild Pacific Northwest Biomass Working Group 2013, Forest Guild Southeast Biomass Working Group 2012). These approaches complement public policy (Charles et al. 2007, Lovett et al. 2011, Soderberg and Eckberg 2013) and market demands (Di Lucia 2010, Palmujoki 2009). However, both strategies depend on the implementation of a global network of long-term monitoring activities as discussed below.

16.2.4.1 Zoning

Zoning for particular uses could be established in countries that allow such land management systems. Agricultural or forestry zoning for biofeedstock production should be based on edaphic and hydrological limitations (Lal 2008) as well as unsuitable areas (Groom et al. 2007; Joly et al. 2010). Almost all countries identify and have some protection of environmentally sensitive areas; however their level of protection varies greatly. For those countries that allow zoning, the steps are set forth below. For other places, voluntary market-based incentives for appropriate resource management may be effective. Giving value to clean water, clean air, and other ecosystem services encourages their protection (Buyx and Tait 2011). Financial incentives to reduce carbon emissions from deforestation and forest degradation (REDD) provide economic compensation for landowners (Butler et al. 2009; Visseren-Hamakers et al. 2012; Kileen et al. 2011; Chapter 13, this volume). Furthermore, zoning is supported by promoting sustainable development in countries where agricultural and feedstock production are expanding (Martinelli and Filoso 2008).

The first step in zoning is selecting areas needed to protect threatened species and sensitive ecosystems. Then locations for biofuel feedstocks can be identified within the context of other ecosystem services and the needs of society. Expansion of biofuel crops over degraded lands instead of pristine ecosystems and food croplands has advantages for sustainability and food security (Fitzherbert et al. 2008; Henneberg et al. 2009; Koh and Ghazoul 2010; Obidzinski et al. 2012; Plieninger and Gaertner 2011; Ravindranath et al. 2011; Stoms et al. 2012; van Vuuren et al. 2009). The characteristics of degraded lands and their management need to be defined in specific contexts (Li et al. 2010). The zoning system should be complemented by wildlife-friendly management practices, as discussed below.

16.2.4.2 Wildlife Friendly Management Practices

Environmental impacts of agriculture and forestry can be mitigated by either improving or reducing productivity (Green et al. 2005) or selectively using areas most suitable for agriculture or forest production (Dale et al. 2011) (more details in Chapter 13, this volume). The successful implementation of this approach results in concentrated highly productive crop fields or forests and more natural areas maintained for conservation (Koh et al. 2009; Koh and Ghazoul 2010; Buckeridge et al. 2012). Such agroecosystems or forest systems are part of a landscape matrix that includes conservation areas and corridors as well as secondary remnants of native vegetation with conservation value (Wiens et al. 2011; Ranganathan et al. 2008; Smith et al. 2008; Smith and Gross 2007; Metzger et al. 2010; Koh 2008). Attributing economic values for agroecosystems and forest systems counters pressure for land development [such as is occurring in the southeastern United States (USDA Forest Service 2012)] and thereby maintains or even expands the area in forest and croplands, which provides more ecosystem services than developed areas. Environmental certification can strengthen such strategies. (see Chapter 19, this volume).

Retention of native vegetation within agricultural or forested landscapes (Principle 1) increases both the matrix permeability for specialist species and habitat quality per se thus enhancing landscape β -diversity (Verdade et al. 2014a). Hence, there are local improvements of ecosystem services (Gasparatos et al. 2011, George et al. 2012, Berry and Paterson 2009). Such a strategy builds multifunctionality of agricultural landscapes (Martinelli et al. 2010) including production of domestic species and conservation of wild species (Verdade et al. 2014a).

16.2.4.3 Biodiversity and Environmental Monitoring

Assessment of long-term effects of biofuels production on biodiversity requires a global monitoring network (Tilman et al. 2006; Sodhi et al. 2010a; FAO 2012; Dale and Kline 2013a; Verdade et al. 2014b). Such a program should feed into life-cycle impact assessments (LCA) of biofuel feedstocks and other crops and energy uses (Bare 2011; Markevicius et al. 2010; Reinherdt and von Falkenstein 2011; Weiss et al. 2012). An effective monitoring approach (e.g., Wilbur 1997) builds from use of targeted indicators (e.g., Scharlemann 2008). Environmental indicators of sustainability that should be monitored should reflect soil quality, water quality and quantity, greenhouse gases, biodiversity, air quality, and productivity (McBride et al. 2011). Key socioeconomic indicators include measures of social well-being, energy security, trade, profitability, resource conservation, and social acceptability (Dale and Kline 2013b). Sampling procedures should be systematized to reduce methodological uncertainties (e.g., Gao et al. 2011; Magnusson et al. 2014). Databases generated by sampling sites within the global network should be interoperable in order to connect patterns of diversity with processes (Verdade et al. 2014b). Monitoring and analysis should feed into adaptive management (Lattimore et al. 2009).

16.3 Conclusions

As with all land transformation activities, effects on biodiversity and ecosystem services of producing feedstocks for biofuel are highly variable and context specific. Advances toward more sustainable biofuel production benefit from a system's perspective, recognizing spatial heterogeneity and scale, landscape-design principles, and addressing the influences of context, such as the particular products and their distribution, policy background, stakeholder values, location, temporal influences, and baseline conditions. Good governance, strong institutions, market based voluntary certification, and access to information about appropriate management strategies and tactics all support sustainable resource use and management that can benefit biodiversity. Developing those management strategies takes time and effort. In summary, the negative effects of production of feedstocks for biofuel can be avoided or reduced by conservation of priority biodiversity areas, recognizing the context specific effects of feedstock production, and adopting location-specific management of production systems.



16.4. Recommendations

Agroecological zoning principles and enforcement is of paramount importance to impede the conversion of ecologically significant and sensitive areas for biodiversity and ecosystem services protection into producing feedstocks for biofuel. Good governance and strong institutions are the most critical determinants of sustainable land use, especially in terms of biodiversity. Without good governance, biofuels expansion will lead to environmental and social loss. As a highly sophisticated, innovative and efficient industry, biofuels can be part of the solution, not part of the problem.

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