Conservation Biology

Essay

The Power of Bioenergy-Related Standards to Protect Biodiversity

K. J. HENNENBERG,*†† C. DRAGISIC,† S. HAYE,‡ J. HEWSON,† B. SEMROC,† C. SAVY,† K. WIEGMANN,* H. FEHRENBACH,§ AND U. R. FRITSCHE*

*Oeko-Institut, Energy and Climate Division, Rheinstr. 95, 64295 Darmstadt, Germany
†Conservation International, 2011 Crystal Drive, Suite 500, Arlington, VA 22202, U.S.A.
‡Ecole Polytechnique Fédérale de Lausanne, Energy Center, BAC 004 Station 5, CH-1015 Lausanne, Switzerland
§Institute for Energy and Environmental Research Heidelberg GmbH (IFEU), Wilckensstr. 3, Heidelberg, 6912, Germany

Abstract: *The sustainable production of bioenergy is vital to avoiding negative impacts on environmental goods such as climate, soil, water, and especially biodiversity. We propose three key issues that should be addressed in any biodiversity risk-mitigation strategy: conservation of areas of significant biodiversity value; mitigation of negative effects related to indirect land-use change; and promotion of agricultural practices with few negative impacts on biodiversity. Focusing on biodiversity concerns, we compared principles and criteria set to address biodiversity and other environmental and social issues in seven standards (defined here as commodity-based standards or roundtables, or relevant European legislation): five voluntary initiatives related to bioenergy feedstocks, the Renewable Transport Fuel Obligation (United Kingdom), and the European Renewable Energy Source Directive. Conservation of areas of significant biodiversity value was fairly well covered by these standards. Nevertheless, mitigation of negative impacts related to indirect land-use change was underrepresented. Although the EU directive, with its bonus system for the use of degraded land and a subquota system for noncrop biofuels, offered the most robust standards to mitigate potential negative effects, all of the standards fell short in promoting agricultural practices with low negative impacts on biodiversity. We strongly recommend that each standard be benchmarked against related standards, as we have done here, and that efforts should be made to strengthen the elements that are weak or missing. This would be a significant step toward achieving a bioenergy industry that safeguards Earth's living heritage.*

Keywords: biofuel, certification, cultivation practice, degraded land, European Renewable Energy Source Directive, residues, risk mitigation, wastes

El Poder de las Normas para la Protección de la Naturaleza Relacionadas con la Bioenergía

Resumen: *La producción sustentable de bioenergía es vital para evitar impactos negativos sobre bienes ambientales como clima, suelo, agua y, especialmente, biodiversidad.Proponemos tres temas clave que deben atenderse en cualquier estrategia de mitigación de riesgos a la biodiversidad: conservación de áreas de valor significativo para la biodiversidad; mitigación de efectos negativos relacionados con el cambio indirecto de uso de suelo; y promoción de prácticas agrícolas con pocos impactos negativos sobre la biodiversidad. Enfocando preocupaciones sobre biodiversidad, comparamos principios y criterios definidos para atender asuntos de biodiversidad y otros temas ambientales y sociales en siete normas (definidas aquí como normas basadas en comodidades o mesas redondas, o legislación europea relevante): cinco iniciativas voluntarias relacionadas con existencias de bioenergía, el Compromiso de Combustible Renovable para Transporte (Reino Unido), y la Directiva Europea de Fuentes de Energía Renovable. La conservación de áreas de valor significativo para la biodiversidad fue relativamente bien cubierta por estas normas. Sin embargo, la mitigación de impactos negativos relacionados con el cambio indirecto de uso de suelo estuvo insuficientemente representada. Aunque*

††*email k.hennenberg@oeko.de*
Paper submitted January 6, 2009; revised manuscript accepted July 9, 2009.

Conservation Biology, Volume **, No. **, ***–***

DOI: 10.1111/j.1523-1739.2009.01380.x

la directiva de EU, con su sistema de bonos para el uso de suelos degradados y un sistema de sub-cuotas para biocombustibles no agrícolas, ofreció las normas más robustas para mitigar los potenciales efectos negativos sobre la biodiversidad. Recomendamos enfáticamente que cada norma sea comparada con normas relacionadas, como hemos hecho aquí, y que se hagan esfuerzos para reforzar los elementos que están débiles o faltantes. Estos sería un paso significativo hacia el logro de un industria bioenergética que salvaguarde el patrimonio vivo de la Tierra.

Palabras Clave: biocombustible, certificación, desechos, Directiva Europea de Fuentes de Energía Renovable, prácticas de cultivo, residuos, tierra degradada

Introduction

Although biomass has provided the primary source of energy for most of humanity for centuries, interest and demand for bioenergy—mainly for transport—is now booming globally in parallel with increasing oil prices and concerns about energy security and climate change (Junginger et al. 2008; OECD/FAO 2008). This trend is driven by, among others things, the European Union (EU) target to increase use of biofuels and other renewable energy in the transport sector from a current rate of 2% to a rate of 10% by 2020; the U.S. target of 7.5 billion gallons of biofuels by 2012 (2005 U.S. Energy Policy Act) and 36 billion gallons by 2022 (2007 Energy Independence and Security Act); and the introduction of biofuel quota systems or blending mandates in many other countries (GBEP 2007). The development of domestic and international bioenergy markets presents opportunities and risks for sustainable development, from local to global scales (OEKO 2006; CBD 2008; Groom et al. 2008; Milder et al. 2008). Opportunities may include a reduction in greenhouse gas (GHG) emissions, reduced dependency on imported oil, and opportunities for rural development, including access to modern energy. Bioenergy demand could also serve as a highly visible driver to promote sustainable, economically viable agriculture.

Risks may also arise, however, that could subvert the environmental sustainability of bioenergy. These risks may include increases in GHG emissions, especially from land-use changes, and decreases in biodiversity, natural habitats, and ecosystem services as a result of deforestation and changes in agricultural practices (Danielsen et al. 2008). Furthermore, impoverishment of local people and increased food insecurity could abound if unsustainable biofeedstock expansion occurs. Even if direct impacts are minimized, other impacts, which are more difficult to control (RFA 2008*a*), may emerge as a result of indirect land-use changes (iLUC). Given the current limitations of available land and yield enhancements, increased demand for bioenergy will most likely lead to expansion of cultivated areas, either directly or indirectly. This will result in further habitat loss and negative impacts on biodiversity, especially if this expansion occurs in forests, grass-, peat-, and wetlands or large monoculture plantations are created (CBD 2008).

This phenomenon may severely affect international targets for the protection of biodiversity, such as the Convention on Biological Diversity (CBD) 2010 Biodiversity Target. The 2010 Biodiversity Target—to achieve a significant reduction in the current rate of biodiversity loss—is already unlikely to be met (Mace et al. 2005) and may be further hampered by unsustainable bioenergy feedstock expansion. Enhanced international trade in bioenergy and biofuels (Junginger et al. 2008) may lead to pronounced biodiversity impacts globally, especially in tropical and subtropical developing countries where favorable growing conditions exist and a disproportionately high percentage of the Earth's biodiversity occurs (Olson & Dinerstein 2002; Mittermeier et al. 2004).

Unsustainable bioenergy feedstock expansion poses direct threats to habitats and species and could degrade natural areas that support ecosystem functions and services (e.g., provision of fresh water) (MEA 2005). Any disturbance in ecosystem function or service due to the degradation of these areas may ultimately have consequences for ecosystem sustainability and the subsistence of human populations.

To begin to tackle some of these risks, several governments, industries, and conservation organizations are working—through initiatives such as the multistakeholder Roundtable on Sustainable Biofuels (RSB)—to develop policies and standards to address biodiversity and broader environmental and social issues related to biofeedstock expansion. International agreements are also proceeding within the CBD and the Global Bioenergy Partnership (GBEP 2007, a G8 + 5 initiative), and projects of international organizations (e.g., U.N. Food and Agriculture Organization, U.N. Environment Programme, and U.N. Industrial Development Organization) and nongovernmental organizations (e.g., Conservation International, International Union for Conservation of Nature [IUCN], World Wide Fund for Nature) also address these issues.

The European Union currently addresses issues related to bioenergy through the Fuel Quality Directive and the Renewable Energy Sources Directive (EU-RES-D) and is leading the establishment of legal frameworks governing biofuel sustainability requirements with national initiatives in Belgium, Germany, The Netherlands, Switzerland, and the United Kingdom (van Dam et al. 2008). The

EU-RES-D, which entered into force on 5 June 2009 (http://eur-ex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:EN:PDF), covers a detailed set of sustainability criteria for biofuels and other bioliquids, thus establishing the first legally binding biofuel sustainability standards in Europe. These standards may prove to have global implications due to their reference to imported biofuels and respective feedstocks. In the United States, however, proposed sustainability requirements for biofuels mainly focus on greenhouse gas (GHG) reductions.

Several studies (e.g., European Environmental Agency 2006) have also designed risk-mitigation strategies to avoid or minimize negative impacts from bioenergy development on the environment (e.g., soil, water, agrochemicals, biodiversity). Within this context, and given that, for example, the Renewable Fuels Agency (RFA) Quarterly Report (April–July 2008) notes that only 20% of bioenergy used in the United Kingdom met environmental standards (RFA 2008*b*), there is an urgent need to fully develop and implement mandatory standards and certification systems.

Furthermore, although the criteria of the EU-RES-D aim to incorporate mainly GHG reduction targets and the protection of biodiversity, there is, as yet, no practical evidence that these will be effective in ensuring that the impacts on biodiversity are minimized. A thorough evaluation of the effectiveness of such criteria would greatly inform the process of developing legislative texts or conventions (e.g., CBD).

Therefore, we present a set of key issues for inclusion in the development of a biodiversity risk mitigation strategy that may be implemented by decision makers. We compared the proposed EU standards for sustainable bioenergy with other standards related to bioenergy, with particular focus on standards adopting different biodiversity approaches.

Key Issues for a Biodiversity Risk-Mitigation Strategy

During the ninth meeting of the Conference of the Parties (COP 9) to the CBD (2008), parties emphasized in the decision COP9 CBD IX/2 the challenge of promoting the positive impacts of biofuel production on biodiversity while minimizing negative effects. A risk-mitigation strategy should ideally remain flexible with regard to the various geographical origins, raw materials, and conversion technologies for biomass. Nevertheless, given the much greater biodiversity risks associated with cultivation practices used to produce the biomass (CBD 2008) necessary for bioenergy, risks related to fuel conversion are not addressed here. From the international literature on the protection of biodiversity, sustainable landscape planning, and sustainable development of agriculture and bioenergy, we derived three issues on which risk-mitigation strategies should focus: conservation of areas of significant biodiversity value; mitigation of negative effects on these areas related to iLUC; and promotion of agricultural practices with low negative impacts on biodiversity.

Conservation of Areas of Significant Biodiversity Value

Habitat loss as a result of direct and indirect land-use changes (LUC and iLUC, respectively) is the major threat to biodiversity, with over 80% of globally threatened birds, mammals, and amphibians affected wholly or in part by habitat loss (Baillie et al. 2004; Green et al. 2005). Areas of significant biodiversity value, due to the presence of threatened and endemic species and the provision of ecosystem services worth millions of dollars per year, are important broad-scale targets for conservation efforts throughout the world and are particularly concentrated in the tropics (Mittermeier et al. 2004; Turner et al. 2007). Past and ongoing deforestation trends, particularly in the tropics, are thus a central issue in conservation efforts (FAO 2006; Wassenaar et al. 2007). Other prominent factors causing the decline of biodiversity are habitat fragmentation and isolation, land-use intensification and overexploitation, species invasions, and adverse climate-change impacts (Groom et al. 2006; Pimm 2008). A central challenge for biodiversity conservation is to identify and conserve those areas harboring relevant portions of biodiversity (i.e., areas of significant biodiversity value).

Protected areas (PAs)—areas with public or private conservation status—provide the cornerstones of national and regional conservation strategies (Margules & Pressey 2000) and often represent the minimum threshold for areas of significant biodiversity value because of their legal recognition. These areas may be created for a number of biological, cultural, or economic reasons, as reflected by the six management categories currently recognized by the IUCN World Commission of Protected Areas (IUCN 1994; Chape et al. 2008; WDPA 2008). One objective of a PA network is to represent the biodiversity of each region and to protect this biodiversity from threats (IUCN 1994). Yet, existing PAs throughout the world are still far from fulfilling either global biodiversity commitments or the needs of species and ecosystems (Rodrigues et al. 2003; Dudley & Phillips 2006).

To exhaustively mitigate risks to biodiversity from bioenergy production, an assessment of areas of significant biodiversity value, whether protected or unprotected, will need to be conducted (Rodrigues et al. 2003). Several processes have been developed and tested to guide identification and mapping of such areas at a level of resolution practical for planning and management purposes. Some of these stem from conservation planning processes, such as IUCN's best-practice guidelines for gap analyses (e.g., Langhammer et al. 2007), and others have been developed as part of efforts to assist land managers in meeting certification requirements (e.g., HCV Network). The IUCN gap analysis approach (Langhammer et al. 2007) integrates a number of established existing approaches, such as Alliance for Zero Extinction sites (AZE, Ricketts et al. 2005) and Birdlife International's important bird areas (IBA, Stattersfield et al. 1998), to identify national sites of significant biodiversity value that are informed by minimum international standards, collectively known as key biodiveristy areas (KBAs).

The broader concept of high conservation value (HCV) areas (Table 1) was developed by the Forest Stewardship Council (FSC 1996) standard on sustainably managed forests. This concept encompasses six different conservation values (HCV1-HCV6) of global and national importance that are based on species, sites, ecosystems, and ecosystem-service values, including areas of cultural importance and subsistence use. The first high conservation value (HCV1) is defined as "globally, regionally, or nationally significant concentrations of biodiversity values (e.g., endemism, endangered species, refugia)." To transpose this general description into a workable framework, HCV areas are nationally or regionally identified by ad hoc committees that incorporate ongoing identification and mapping of important biodiversity areas, such as KBAs, that meet HCV criteria (i.e., areas that contain one or several HCV areas). Hence, the HCV concept can benefit from a systematic conservation-planning framework that includes identification of areas of significant biodiversity value.

Once areas of significant biodiversity value are excluded from potential production plans, the remaining land suitable for cultivation often includes natural or seminatural habitats. Partial or complete conversion of these areas also results in significant habitat loss, fragmentation, and GHG emissions—all of which ultimately affect biodiversity. Thus, the decision to cultivate these areas should be based on systematic conservation-planning processes, including identification of management requirements, to guarantee that the biodiversity value of these areas will not be threatened from expansion of feedstocks.

Even with careful planning, areas of significant biodiversity value, protected or not, are very likely to suffer losses if biomass extraction occurs that are incompatible with the conservation goals of those areas. For example, species-rich grasslands in Europe (EEA 2004) face this threat unless plans are established that permit only limited conversion without endangering important conservation value areas.

Mitigating Negative Effects Related to Indirect Land-Use Change

Whenever bioenergy cultivation displaces a prior land use, such as cultivation for food, feed, or fiber (direct LUC), these commodities are then likely to be substituted—at least partly—by increased production elsewhere in the world, resulting in iLUC. Negative impacts on protected and unprotected areas of significant biodiversity value caused by iLUC are difficult to predict, monitor, and mitigate (RFA 2008*a*) because they result from a myriad of complex drivers such as population and market forces.

Effective land-use planning policies, executed in a reliable manner at national, regional, and global scales, may present the most efficient mechanism for addressing iLUC. Nevertheless, unless every country where a displaced commodity or its substitute could be produced adopts and enforces such land-use planning policies, negative indirect land-use effects cannot be avoided. Thus, iLUC as a result of displacement of other crops should be minimized and alternative sources and areas for favorable bioenergy feedstock production sought. Residues and organic wastes represent favorable alternative bioenergy sources, because they have a low risk of causing iLUC, and alternative areas for favorable bioenergy-feedstock production include unused degraded land and abandoned farmland (RFA 2008*a*; Searchinger et al. 2008).

Another promising option to limit iLUC is the amendment of currently cultivated, underutilized lands to increase yields and decrease the area required for cultivation, and the cultivation of bioenergy feedstock on any land made available through these increased yields (e.g., Sparovek et al. 2007). Negative impacts on biodiversity, however, have previously been associated with increased yields; therefore, a careful consideration process would be required (overview in Green et al. 2005).

The use of biomass residues (e.g., manure, forest thinnings, straw) and wastes (e.g., organic fractions in residential and industrial wastes) to produce bioenergy could represent up to half of the bioenergy potential for selected countries (e.g., EEA 2006; Smeets et al. 2007). In addition to reducing the risk of iLUC, the use of residues and wastes may enhance other positive impacts, including avoided nitrogen leaching and generation of new revenue through production of bioenergy from such residues. Nevertheless, the change of natural nutrient and carbon cycles caused by removal of residues (e.g., crop residues or forest thinning) could negatively affect local biodiversity, reduce soil quality, enhance erosion, and deplete nutrient levels. Furthermore, because much of the rural population in developing and emerging countries already uses a significant amount of agricultural residues as cattle feed, compost, and energy for cooking (Karekezi et al. 2004), use of these residues for bioenergy could have negative social impacts. Thus, although national strategies for bioenergy should have a strong focus on opening up bioenergy resources from residues and wastes, these strategies must incorporate adequate management rules to safeguard against negative social and environmental impacts.

Table 1. Description of selected initiatives and their standards and criteria addressing biodiversity preservation within sustainable bioenergy or biomass production and the description of the six high-conservation-value (HCV) areas.*

Standard	*Description*
EU-RES-D	Within the sustainability scheme for biofuels of the EU-RES-D, risks to biodiversity are directly addressed by prohibiting the production of biomass from land with high biodiversity value, as defined through the four categories (1) primary forest and other wooded land, (2) highly biodiverse grassland (natural and nonnatural), (3) areas designated by law or by the relevant competent authority for nature protection purposes, and (4) areas for the protection of rare, threatened, or endangered ecosystems or species recognized. In addition, the EU standards seek to indirectly reduce pressure on biodiversity by promoting the use of severely degraded or heavily contaminated lands that are out of agricultural use through a bonus system and the use of waste and residuals to produce biofuels. Finally, it requires a reduced use of carbon-rich areas (wetlands, peatland, and continuously forested areas). Raw materials cultivated in the EU must be produced in accordance with general agricultural requirements and standards of the EU (cross compliance, good agricultural and environmental conditions). Furthermore, the sustainability scheme aims to require that cultivation practices outside the EU only need to be monitored, but they can be specified by voluntary bi- and multilateral agreements with third countries. Impacts as a result of displacement, inter alia, indirect land-use change shall be monitored.
RTFO	The RTFO initiative, implemented in the United Kingdom in April 2008, is the only national scheme in activity so far. This metastandard includes reporting obligations, but currently no binding component. Principle 2, entitled "Biodiversity Conservation," and subsequent criteria require compliance with existing legislation and prohibit conversion of high biodiversity areas after 30 November 2005. The indicators for this criterion include gazetted areas, areas containing the 6 HCV areas, UNESCO heritage sites, IUCN list of protected areas, and RAMSAR sites (in principle the latter three types are covered by the HCV definition). An additional recommendation is made to protect or enhance biodiversity on the production site through the preservation of ecological corridors, set-aside areas (10%), and use of good practices in production. The criteria developed by the so-called Cramer Commission (Cramer et al. 2007) in the Netherlands include a similar set of requirements but the cut-off date for conversion is fixed on 1 January 2007.
RSB	The RSB is an international initiative that brings together conservation and social organizations, the private sector, governments, and academia to develop a set of sustainability standards for biofuels. The preliminary version (Version Zero) of the RSB standards, which is currently available for public comment, includes a principle and set of criteria on conservation and biodiversity. Version Zero strictly prohibits the conversion of HCV areas, native ecosystems, ecological corridors, and any other public or private conservation areas. Version Zero also requires ecosystem services and functions to be preserved, after having been properly assessed locally. Existing ecological corridors and buffer zones on the production site and around must be protected or, ideally, created or restored. The RSB promotes the use of degraded or idle lands and the use of native species and encourages a regional approach to landscape planning and ecosystem management involving multiple stakeholders such as the government and other local institutions. The RSB standard is still under development through a multistakeholder dialog, with the expected release of Version One by November 2009.
RTRS	The RTRS, draft principles, criteria, and implementation and verification models, which are currently being revised following a period of public commentary, address the protection of biodiversity and HCV areas under principles 9 and 11, respectively. The subset criteria encourage the maintenance of natural vegetation and the identification, maintenance, and monitoring of HCV areas and areas where rare, endangered, or threatened species are found. Furthermore, environmental and social impact assessments must be undertaken prior to any expansion of soy cultivation, and degraded lands and cleared lands must be targeted in priority. Principles 6, Environmental Responsibility; 7, Responsible Water Management; and 8, Responsible Soil Management, could also indirectly affect biodiversity and HCV areas. Similar to the RSB, the RTRS has not yet developed indicators but includes some pieces of guidance under the corresponding criteria.
RSPO	The RSPO is a global, multistakeholder initiative on sustainable palm oil. The principles and criteria of the RSPO were finalized in 2007, and the certification of producers, in compliance with these criteria, began in 2008. In its principle on "development of new plantings," the RSPO requires potential impacts on HCV areas to be assessed and prohibits the conversion of primary forest and areas containing one or more of the 6 HCV areas after 30 November 2005. In addition, other principles, including Principle 4, Use of Best Practices by Growers and Millers, and Principle 7, Responsible Development of New Plantings, may also affect biodiversity.
FSC	The FSC is an independent, nongovernmental, nonprofit international organization established to promote the responsible management of the world's forests. In its principles and criteria, the FSC requires an environmental impact assessment be conducted prior to any site-disturbing operations from a landscape perspective. Other environmental criteria include the necessity to set conservation areas wherever needed; maintain or restore ecosystem function ("a. Forest regeneration and succession; b. Genetic, species, and ecosystem diversity; c. Natural cycles that affect the productivity of the forest ecosystem."); and discourage the use of exotic species unless well monitored and the conversion of forest areas into plantations. In addition, four specific criteria are included to the management, maintenance, and enhancement of HCV areas in forest.
SAN	The Sustainable Agriculture Network supported by the Rainforest Alliance links responsible farmers with conscientious consumers by means of the Rainforest Alliance Certified seal of approval. This proposed standard includes a number of principles that indirectly relate to biodiversity and HCV areas. Principle 2 requires

continued

Table 1. (continued).

Standard	*Description*
SAN	protection of ecosystems through the perspective of ecosystem services. Critical criterion 2.1 requires that "All existing natural ecosystems, both aquatic and terrestrial, must be identified, protected, conserved, and restored through a conservation program" and in no case destructed or converted. "Negative effects on national parks, wildlife refuges, biological corridors, forestry reserves, buffer zones, or other public or private biological conservation areas" must be avoided. The protection of natural water sources, enhancement of native vegetation, and the creation of buffer zones are also addressed in the SAN standard.
HCV	The HCV approach was originally developed to encompass all important ecological and social attributes to be maintained in sustainably managed forests, but have now been broadened to all types of ecosystems. According to the HCV Resource Network, "the key to using the HCV approach is the identification of the six High Conservation Values (HCVs), which cover the range of conservation priorities shared by a wide range of stakeholder groups, and include social values as well as ecological values. It is these values that are important and need to be protected. A High Conservation Value area is simply the area (e.g., a forest, a grassland, a watershed, or a landscape-level ecosystem) where these values are found, or, more precisely, the area that needs to be appropriately managed in order to maintain or enhance the identified values. Identifying the areas where these values occur is therefore the essential first step in developing appropriate management for them." According to the same, the six types of HCV areas are **HCV1.** Areas containing globally, regionally, or nationally significant concentrations of biodiversity values (e.g., endemism, endangered species, refugia). For example, the presence of several globally threatened bird species within a Kenyan montane forest. **HCV2.** Globally, regionally, or nationally significant large landscape-level areas where viable populations of most if not all naturally occurring species exist in natural patterns of distribution and abundance (e.g., a large tract of Mesoamerican flooded grasslands and gallery forests with healthy populations of Hyacinth Macaw, jaguar, maned wolf, and giant otter, and most smaller species). **HCV3.** Areas that are in or contain rare, threatened, or endangered ecosystems (e.g., patches of a regionally rare type of freshwater swamp in an Australian coastal district). **HCV4.** Areas that provide basic ecosystem services in critical situations (e.g., watershed protection, erosion control) (e.g., forest on steep slopes with avalanche risk above a town in the European Alps). **HCV5.** Areas fundamental to meeting basic needs of local communities (e.g., subsistence, health) (e.g., key hunting or foraging areas for communities living at subsistence level in a Cambodian lowland forest mosaic). **HCV6.** Areas critical to local communities' traditional cultural identity (areas of cultural, ecological, economic, or religious significance identified in cooperation with such local communities) (e.g., sacred burial grounds within a forest-management area in Canada).

Abbreviations and references: EU-RES-D, European Renewable Energy Sources Directive, Directive 2009/28/EC (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:EN:PDF); RTFO, Renewable Transport Fuel Obligation (Sustainability Reporting within the RFTO, Second Draft) (http://www.dft.gov.uk/pgr/roads/environment/rtfo/); RSB, Roundtable on Sustainable Biofuels (Version Zero) (http://energycenter.epfl.ch/biofuels); RTRS, Round Table on Responsible Soy (DG2-OUT-2.1-ENG) (http://www.responsiblesoy.org); RSPO, Roundtable on Sustainable Palm Oil (http://www.rspo.org); FSC, Forest Stewardship Council (FSC-STD-01-001 v.4-0) (http://www.fsc.org); SAN, Sustainable Agriculture Network (Rainforest Action) (v. 2/2008) (http://www.rainforest-alliance.org); HCV, high conservation value (HCV Resource Network 2005-7) (http://www.hcvnetwork.org/site-info/The%20high-conservation-values-folder).

The cultivation of biomass on unused degraded land or abandoned farmland (i.e., cleared land that has been abandoned for economic, political, or social reasons) could safeguard against many negative iLUC effects from bioenergy development (OEKO 2006; Field et al. 2008; Groom et al. 2008; Searchinger et al. 2008). The main advantage of these unused areas is that the risk of displacement of previous cultivation and the associated leakage into other areas is relatively low. The use of perennial crops, depending on the existing vegetation cover, would enhance above- and belowground carbon sequestration and thus provides an additional benefit. Caution is required, however, because some unused degraded lands may actually constitute areas of significant biodiversity value. In some regions, cultivation of degraded lands may place additional stress on scarce water resources if the crop requires increased irrigation or is characterized by high water use (Oeko-Institut et al., unpublished data). Furthermore, regeneration of degraded land to natural habitat may be more beneficial in terms of carbon sequestration and biodiversity conservation than any benefits accrued from bioenergy feedstock production. Prior to cultivation, a thorough evaluation of the effects of shifting degraded lands to cultivation should be included as an integral part of regional or national land-use planning. These evaluations should include the potential costs and yields of bioenergy feedstock production on these lands and assess and mitigate any negative trade-offs for biodiversity, the environment, and local communities. Where such evaluations are performed and opportunities are identified, unused degraded land or abandoned farmland may provide a convenient option for bioenergy production because of the potential positive impacts generated and negative impacts avoided with the use of such areas.

Promotion of Agricultural Practices with Low Negative Impacts on Biodiversity

Implementation of conservation goals for protection of biodiversity requires systematic planning strategies for managing landscapes, including areas allocated to both production and protection (Margules & Pressey 2000; Groom et al. 2006; Dragisic et al. 2008). The CBD, for example, recognizes the limitations of PAs as the sole tool for conservation and promotes an ecosystem approach, which seeks to mainstream biodiversity conservation into broader land- and seascape management (Dudley & Phillips 2006). The International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD 2008) has also stressed that to successfully meet development and sustainability goals, a fundamental shift in agriculture is needed toward protection of a natural resource base and ecological provisioning of agricultural systems.

Although cultivation best practices, with respect to biodiversity, vary widely depending on geography and feedstock, certain features are common to nearly all cases (e.g., Groom et al. 2008; Scales & Marsden 2008; UNEP-UNCTAD 2008). These include use of native species and local varieties, avoidance of monocultures, prioritization of perennial crops, adequate rotation schemes, low-erosion land-use methods (e.g., no-till systems), low input of agrochemical application and machinery, and minimal irrigation. Landscape-scale elements include design and implementation of biodiversity corridors, creation of stepping stones of natural habitats within farms or plantations, and maintenance of buffer zones around sensitive areas. Additional considerations include protection of riparian areas, slopes, and other fragile areas, and incorporation of land-use planning beyond property boundaries, especially at a landscape scale (Langhammer et al. 2007; Milder et al. 2008; Dragisic et al. 2008). Although sustainable cultivation practices tend to result in reduced yields and decreased productivity per hectare, potentially leading to an increased risk of iLUC (Green et al. 2005), results of some studies show that this does not need to be the case (Badgley et al. 2007; Smith et al. 2008). Consequently, there is an urgent need to identify appropriate cultivation systems that address the need for increased productivity and decreased negative impacts on biodiversity (compare IAASTD 2008).

Comparison of Biodiversity-Related Criteria

Several standards related to sustainable production of bioenergy or feedstock commodities (e.g., wood, sugar, soy, oil palm) have developed principles and criteria that aim to preserve, among other aspects, biological diversity and ecosystem services and functions, and to maintain ecologically sensitive areas. We have included here an overview of the relevant principles and criteria developed by several such initiatives—focusing on biofuels, agriculture, and forestry because many requirements are common to all—as well as those now endorsed by the EU (Table 1; see overview of further initiatives in Scarlat & Dallemand [2008] and van Dam et al. [2008]).

Although the initiatives are at different stages of development, making a direct comparison of their intent, content, and implementation difficult, almost all of the initiatives are structured according to a set of principles providing the general orientation of action, a set of criteria (Table 2) developed for each principle (further detailing how to concretely comply with these principles), and technical guidance, recommendations, or indicators for assessing compliance with the criteria.

Because the protection of ecosystem services and functions and conservation of natural habitats directly affect biodiversity, we included these elements in our analysis of the criteria. We also compared suggested best practices, where included in the standards (Table 2). Although most initiatives also address topics of soil, water, and waste management, which relate indirectly to the impacts of bioenergy production on biodiversity or environmentally sensitive areas, these topics are beyond the scope of this analysis.

Conservation of Areas of Significant Biodiversity Value

Broadly speaking, most of the standards we assessed take a similar approach to protecting biodiversity by focusing on species and habitats. All of the initiatives we reviewed include criteria related to unprotected areas of significant biodiversity value and criteria directly related to endangered or vulnerable species. Six of the seven also include criteria on the need to protect or restore native ecosystems or include some language against the conversion of forest or natural habitats with respect to production of the relevant commodity, and one refers to the more general term *wildlife*. All standards, except the EU-RES-D and SAN, prohibit conversion of HCV areas for feedstock production. Whereas the United Kingdom Renewable Transport Fuel Objective (RTFO) and Roundtable on Sustainable Palm Oil (RSPO) consider HCV areas as "no go" (i.e., where no exploitation can happen), the FSC, Round Table on Responsible Soy (RTRS), and Roundtable on Sustainable Biofuels (RSB) authorize a limited exploitation of HCV areas whenever the HCVs they include are maintained.

Mitigation of Negative Effects Related to Indirect Land-Use Change

Comparison of the selected standards revealed a lack of consensus on criteria to mitigate the impacts of iLUC, which reflects the fact that this subject has gained widespread attention only recently. Four initiatives specifically include criteria promoting the use of

Table 2. Summary of the relevant principles and criteria in seven separate standards addressing biodiversity preservation within sustainable bioenergy and biomass production.

	Organization/Standard[a]						
Key issue/criteria	*EU-RES-D*	*RTFO*[b]	*RSB*[b]	*RTRS*[b]	*RSPO*	*FSC*	*SAN*
Conservation of areas of significant biodiversity value							
protected areas/biological conservation areas	++ (§17-3)	-	++ (7.a)		+ (5.2)	+ (7.1)	++ (2.3)
unprotected areas of significant biodiversity value (including HCV areas)	++ (§17-3); no HCV	++ (2.2); + (2.3)	++ (7.a)	++ (9.2); + (11.5)	+ (5.2); ++ (7.3)	++ (6.2); +(9)	++ (2.1)
native ecosystems/natural habitats	++ (§17-3); ++ (§17-4)	-	++ (7.a)	+ (9.3)	+ (7.3)	++ (6.2); ++ (6.4); + (10.2); + (10.5)	++ (2.1); ++ (2.8)
forest/natural habitat conversion	++ (§17-3); ++ (§17-4)	+ (1.1); + (2.2)	-	+ (11.3)	+ (5.1); + (7.1); ++ (7.3)	++(6.10); ++(10.9)	++ (2.4) ++ (9.5)
wildlife (general)	-	-	-	-	-	-	+ (3.1); ++ (3.2); + (3.4); + (3.5); + (3.6)
endangered/vulnerable species	++ (§17-3)	+ (2.3)	+ (7.a)	++ (9.2); + (11.5)	++ (5.2)	++ (6.2); + (7.1)	+ (2.4) + (3.2)
Mitigation of negative effects related to indirect land-use change							
use of degraded lands	+ (Annex VII)	-	++ (3.e); ++ (6.a)	++(11.2)	+ (7.3)	-	-
use of waste and residues	+ (§17-1)	+ (3.3)	++ (3.e); ++ (6.a)	-	-	-	-
mitigation of indirect land-use change or indirect impacts (general)	-	-	++ (3.e); + (7.a)	+ (6.1)	-	-	+ (2.2)
Promotion of agricultural practices with low negative impacts on biodiversity							
best practices (see details in the text)	+ (§17-5)	+ (2.4); ++ (3.2); + (4.2)	-	-	+ (4.2)	-	-
native species	-	-	+ (7.a)	+ (9.1)	+ (4.5); +(5.1)	++(10.4)	+ (2.8)
exotic species	-	-	-	-	-	+ (6.9); ++(10.4)	+ (3.6)
ecosystem functions	-	-	+ (7.b)	-	-	++ (6.3)	-
ecosystem services	-	-	+ (7.b)	-	-	-	-
buffer zones around fragile areas	-	-	++ (7.c)	+ (7.2); ++ (9.1)	+ (4.4)	-	+ (2.5); ++ (2.6); ++ (2.7)
ecological corridors, stepping stones	-	+ (2.4)	++ (7.c)	+ (7.2); ++ (9.1)	+ (4.4)	-	+ (2.5); ++ (2.6); ++ (2.7)
illegal hunting and fishing	-	-	++ (7.a)		++ (5.2)	++ (6.2)	++ (3.3)
mitigation of negative environmental impacts (general)	+ (§17-5)	-	++ (7.c)	+ (7.2); ++ (9.1)	+ (4.4)	-	+ (2.5); ++ (2.6); ++ (2.7)

[a] *See Table 1 for abbreviation and explanation of organizations and standards. Numbers or number and letter combinations in parentheses refer to the relative section of the standard that references the relevant criteria. Key: -, no mention; +, mentioned, but judged insufficient to promote and guide effective implementation on the ground; ++, mentioned and judged sufficient to promote and guide effective implementation on the ground.*

[b] *Draft document: principles, criteria, or standards are not yet complete and may be modified.*

degraded lands for cultivation, and the EU-RES-D gives a premium to biofuels feedstock produced on these lands. Three initiatives recommend the use of waste products or residues, and three have criteria that include some language on mitigating impacts of iLUC. Nevertheless, no initiative specifically promotes land-use planning or cultivation on abandoned farmland to mitigate iLUC.

Promotion of Agricultural Practices with Low Negative Impacts on Biodiversity

Most striking is the divergence among the policies on criteria related to protection of biodiversity in productive landscapes. Each initiative promotes at least one specific method to mitigate impacts of commodity production on biodiversity. Five include criteria that mention ecological corridors or stepping stones, and four specifically mention buffer zones. Use of native species is recommended in five of these documents, and exclusion of nonnative species is mentioned in only two of them. Four initiatives include criteria prohibiting illegal hunting or collecting, or in some cases harvesting of endangered species. Only two initiatives include criteria specifically addressing the protection of ecosystem functions, and just one addresses ecosystem services. Although each of these elements is important individually, it is the full set of these measures, when combined with the other issues mentioned in this section, that is needed for effective conservation. Some initiatives recognize this more broadly: five include a criterion with general language related to mitigation of negative environmental impacts, and three include language on the use of best agricultural practices.

Protection of Biodiversity under Existing Standards

Policy makers developing standards designed to guarantee conservation of global biodiversity must recognize that no standards by themselves will be sufficient. This is mainly because a standard usually targets individual stakeholders (e.g., feedstock producers) or regulation at national or regional levels, but none is able to encompass all levels of responsibility. Furthermore, conservation of global biodiversity depends on a myriad of factors far outside the control of those developing or implementing the standards. Even within the scope of the standards themselves, conservation depends on efficient and effective interpretation and application of standards in production landscapes through the use of appropriate information and tools. As such, standards should be judged by their strength, clarity, scope, and applicability. Following the key issues we identified for a risk-mitigation strategy, we evaluated to what extent the considered standards will mandate and shape needed action on the ground.

Conservation of Areas of Significant Biodiversity Value

All standards considered placed a strong emphasis on conserving areas of significant biodiversity value and on conserving native ecosystems and natural habitats wherever possible. The application of this concept in productive landscapes is especially promising because several related databases already exist or are under development, and most initiatives include reference to the HCV concept. When explicitly informed by the IUCN guidelines on gap analysis and existing protected-area data, some HCV criteria may be useful conceptual frameworks for identifying areas of significant biodiversity value that are currently not protected.

Although the EU standards do not reference the HCV concept, they consider areas harboring rare, threatened, or endangered ecosystems or species recognized by international agreements, intergovernmental organizations, or the IUCN. The EU standards restrict biofuels produced from biomass grown in PAs, primary forests, wood- and wetlands, and highly biodiverse grasslands and thereby strongly mitigate potential negative effects on areas of significant biodiversity value.

Mitigation of Negative Effects Related to Indirect Land-Use Change

Our comparison of the selected standards showed that mitigation of negative effects from iLUC on biodiversity is underrepresented. In addition, mitigation systems are weak or absent that assure bioenergy originates from raw material with low risks of iLUC, such as biomass cultivated on unused, degraded land or organic wastes and residues (a topic also stressed within the key issues for a risk mitigation strategy) are weak or absent.

The two most-effective instruments to mitigate iLUC and possible negative effects on biodiversity are exclusion of raw materials with high risks of iLUC (e.g., cultivation on productive farmland) and integration of sustainable production standards into broader land-use planning initiatives that combine food, feed, fiber, and fuel production with effective conservation of areas needed for the protection of biodiversity and ecosystem services. Establishing a fixed quota and introducing incentives for bioenergy from raw materials with low risks for iLUC (e.g., waste materials and residues or feedstock produced on unused degraded and abandoned land) can result in less significant impacts on biodiversity. The EU standards address the latter by awarding a bonus for bioenergy feedstock cultivated on degraded land and through biofuels from residues and wastes being subject to a "doubling" factor for the EU biofuel quota.

The EU standards also require reporting on iLUC relative to bioenergy production pathways. Such reporting will only be able to indicate the amount of direct displacement caused by bioenergy production. Due to the nature of iLUC, however, monitoring the effect of this displacement on biodiversity elsewhere will not be possible. Global monitoring of the loss of biodiversity as carried out by UNEP or monitoring within areas identified as likely to be affected by bioenergy-related iLUC may be suitable. In case of ongoing loss of biodiversity during the next few years, especially in areas of high potential iLUC, we strongly recommend that standards and policy instruments standardize and strengthen the provisions related to iLUC caused by bioenergy.

Promotion of Agricultural Practices with Low Negative Impacts on Biodiversity

Agricultural practices with low negative impacts on biodiversity are inconsistent among the considered initiatives. Several standards include a full set of criteria regarding landscape elements that mitigate negative effects from cultivation (e.g., buffer zones) and enhance connectivity between areas of significant biodiversity value and the survival of biodiversity within cultivated areas (e.g., corridors, stepping stones, and illegal hunting). We expect these programs to be the most effective in production landscapes.

Effective standards for cultivation practices that address biodiversity are almost absent within the standards we reviewed. None of the standards requires the development of new, highly productive cultivation systems with low impacts on biodiversity, an issue with a high chance of success for bioenergy production systems because a wide variety of feedstock could be incorporated in such systems. Promising examples are reviewed in Badgley et al. (2007), Smith et al. (2008), Gomiero et al. (2008), and UNEP-UNCTAD (2008).

Due to the binding character of the EU standards and the fear of conflicts with World Trade Organization (WTO) law (Van den Bossche et al. 2007), the EU standards only refer to cross-compliance and good agricultural practice. It is questionable whether such standards will be able to stop the loss of biodiversity in Europe (Kleijn & Sutherland 2003; Henle et al. 2008). The binding standards for cultivation are not applicable to countries outside the EU, but they can be specified through bilateral agreements. This argument may be valid for local environmental goods, but global commons such as biodiversity—as already addressed by standards for conserving areas of significant biodiversity value—should also be covered by the EU-RES-D within cultivation practices or at least required as landscape elements within cultivated areas.

Conclusions

It would be ingenuous to assume that all standards could, or should, adopt a uniform set of criteria to mitigate potential risks to global biodiversity. Each standard has a precise role to play at a given level of the bioenergy-value chain or the decision-making process, and their coordinated and converging implementation would prove far more efficient for biodiversity than if these were implemented in isolation.

We do, however, recommend that each standard be benchmarked against related standards (as we have done here) and efforts be made to strengthen areas noted as missing or weak. More specifically, every standard should ensure minimally acceptable criteria for each of the three identified elements of a sound mitigation strategy as follows.

1. The protection of areas of significant biodiversity value should not only include protected areas and other habitat for endemic, threatened, or endangered species, but also address habitat fragmentation and migration corridor protection. Areas that maintain ecosystem services on which all species (including humans) depend, commonly including wetlands, peatlands, and natural and seminatural forests, should also be protected.
2. To mitigate indirect land-use change, a factor nearly absent from every standard reviewed, explicit preference or support should be given to biofuels produced on abandoned or unused degraded lands or from waste material, whereas use of raw materials with a high risk of iLUC should be discouraged unless a source-specific review shows that iLUC has been avoided.
3. Finally, standards should require application of recognized best management practices for all sourcing regions. These practices should include not only current cultivation techniques, but also adoption of new high-productivity, low-impact production systems and protection of large-scale elements (buffer zones, corridors) within the agricultural landscape.

Well-designed standards alone will not be sufficient to protect biodiversity from the impacts of bioenergy cultivation and use. Success will depend largely on broad implementation of these standards, effective land-use planning in cultivation regions, enforcement of existing laws, and compatible production and use incentives. Nevertheless, inclusion of the minimum elements noted above in all relevant standards would be a significant step toward achieving a bioenergy industry that safeguards Earth's living heritage.

Acknowledgments

We thank J. Scharlemann for his valuable comments on the final version of the manuscript. We also warmly thank A. Hermann for support on WTO law. Results presented in this paper are embedded in the project Sustainability Standards for Internationally Traded Biomass, funded by the Federal Environment Agency (UBA, project ID: FKZ 3707 93 100) on behalf of German Ministry for Environment (BMU), and this material is based on work supported by the U.S. Department of Energy under award number DE-FG36-08GO18044.

Literature Cited

Badgley C., et al. 2007. Organic agriculture and the global food supply. Renewable Agriculture and Food Systems **22:**86–108.

Baillie, J. M., C. Hilton-Taylor, and S. N. Stuart. 2004. 2004 IUCN red list of threatened species: a global species assessment. International Union for Conservation of Nature, Species Survival Commission, Gland, Switzerland.

CBD (Convention on Biological Diversity). 2008. The potential impacts of biofuels on biodiversity—matters arising from SB-STTA recommendation XII/7. Note by the Executive Secretary, UNEP/CBD/COP/9/26. CBD, Montreal, Canada.

Chape S., M. Spalding, and M. Jenkins. 2008. The world's protected areas: status, values and prospects in the 21st century. University of California Press, Berkeley, California.

Cramer, J., et al. 2007. Testing framework for sustainable biomass. Final report from the project group 'Sustainable Production of Biomass.' Energy Transition's Interdepartmental Programme Management (IPM), The Netherlands. Available from http://www.lowcvp.org.uk/assets/reports/070427-Cramer-FinalReport_EN.pdf (accessed December 2008).

Danielsen, F., et al. 2008. Biofuel plantations on forested lands: double j(?)eopardy for biodiversity and climate. Conservation Biology **23:**348–358.

Dragisic, C., et al. 2008. Biofuels. Pages 93–114 in R. Mittermeier et al., editors. A climate for life: meeting the global challenge. CEMEX Conservation Book Series, ILCP, Arlington, Virginia.

Dudley, N., and A. Phillips. 2006. Forests and protected areas: guidance on the use of the IUCN protected area management categories. International Union for Conservation of Nature, Gland, Switzerland.

EEA (European Environmental Agency). 2004. High nature value farmland characteristics, trends and policy challenges. EEA report 1/2004. EEA, Copenhagen.

EEA (European Environmental Agency). 2006. How much bioenergy can Europe produce without harming the environment? EEA report 7/2006. EEA, Copenhagen.

FAO (Food and Agriculture Organization of the United Nations). 2006. Global forest resources assessment 2005—progress towards sustainable forest management. Forestry paper 147. FAO, Rome.

Field, C. B., J. E. Campbell, and D. B. Lobell. 2008. Biomass energy: the scale of the potential resource. Trends in Ecology & Evolution **23:**65–72.

FSC (Forest Stewardship Council) 1996. FSC international standards, FSC principles and criteria for forest stewardship. FSC-STD-01-001 (version 4-0) EN. Forest Stewardship Council A.C., Bonn.

GBEP (Global Bio-Energy Partnership). 2007. A review of the current state of bioenergy development in G8 + 5 countries. GBEP Secretariat, Rome. Available from ftp://ftp.fao.org/docrep/fao/010/a1348e/a1348e00.pdf (accessed December 2008).

Gomiero, T., M. G. Paoletti, and D. Pimentel. 2008. Energy and environmental issues in organic and conventional agriculture. Critical Review in Plant Sciences **27:**239–254.

Green, R. E., S. J. Cornell, J. P. W. Scharlemann, and A. Balmford. 2005. Farming and the fate of wild nature. Science **307:**550–555.

Groom, M. J., E. M. Gray, and P. A. Townsend. 2008. Biofuels and biodiversity: principles for creating better policies for biofuel production. Conservation Biology **22:**602–609.

Groom, M. J., G. K. Meffe, C. R. Carroll, and contributors. 2006. Principles of conservation biology. 3rd edition. Sinauer Associates, Sunderland, Massachusetts.

Henle, K., et al. 2008. Identifying and managing the conflicts between agriculture and biodiversity conservation in Europe—a review. Agriculture, Ecosystems and Environment **124:**60–71.

IAASTD (International Assessment of Agricultural Knowledge, Science and Technology for Development). 2008. Executive summary of the synthesis report of the IAASTD. IAASTD, Johannesburg, South Africa.

IUCN (International Union for Conservation of Nature). 1994. Guidelines for protected area management categories. IUCN, Gland, Switzerland, and Cambridge, United Kingdom.

Junginger, M., et al. 2008. Developments in international bioenergy trade. Biomass and Bioenergy **32:**717–729.

Karekezi, S., K. Lata, and S. Teixeira Coelho. 2004. Traditional biomass energy: improving its use and moving to modern energy use. International Conference for Renewable Energies, Bonn, Germany. Available from http://www.renewables2004.de/pdf/tbp/TBP11-biomass.pdf (accessed December 2008).

Kleijn, D., and W. J. Sutherland. 2003. How effective are European agri-environment schemes in conserving and promoting biodiversity? Journal of Applied Ecology **40:**947–969.

Langhammer, P. F., et al. 2007. Identification and gap analysis of key biodiversity areas: targets for comprehensive protected area systems. IUCN, Gland, Switzerland.

Mace, G., et al. 2005. Biodiversity. Pages 77–122 in R. Hassan, R. Scholes, and N. Ash, editors. Ecosystems and human well-being: current state and trends. Volume 1. The Millennium Ecosystem Assessment series. Island Press, Washington, D.C.

Margules, C. R, and R. L. Pressey. 2000. Systematic conservation planning. Nature **405:**243–253.

Milder, J. C., J. A. McNeely, S. A. Shames, and S. J. Scherr. 2008. Biofuels and ecoagriculture: can bioenergy production enhance landscape-scale ecosystem conservation and rural livelihoods? International Journal of Agricultural Sustainability **6:**105–121.

MEA (Millennium Ecosystem Assessment). 2005. Ecosystems and human well-being: synthesis. P1. Island Press, Washington, D.C.

Mittermeier, R. A., et al. 2004. Hotspots revisited: earth's biologically richest and most threatened terrestrial Ecoregions. CEMEX, Mexico, D.F.

OECD/FAO (Organisation for Economic Co-operation and Development/Food and Agricultural Organization of the United Nations). 2008. OECD-FAO agricultural outlook 2007. OECD/FAO, Rome.

OEKO (Oeko-Institut). 2006. Sustainability standards for bioenergy. World Wildlife Fund, Frankfurt.

Olson, D. M., and E. Dinerstein. 2002. The global 200: priority ecoregions for global conservation. Annals of the Missouri Botanical Garden **89:**199–224.

Pimm, S. L. 2008. Biodiversity: climate change or habitat loss – which will kill more species? Current Biology **18:**117–119.

Ricketts, T. H., et al. 2005. Pinpointing and preventing imminent extinctions. Proceedings of the National Academy of Sciences of the United States of America **102:**18497–18501.

RFA (Renewable Fuels Agency). 2008*a*: The Gallagher Review of the indirect effects of biofuels production. RFA, St. Leonards-on-Sea, United Kingdom.

RFA (Renewable Fuels Agency). 2008*b*. Quarterly report: 15 April – 14 July 2008. RFA, St Leonards-on-Sea. Available from http://www.renewablefuelsagency.org/_db/_documents/RFA_quarterly_report_Apr_Jul_2008_v1.1.pdf (accessed December 2008).

Rodrigues, A. S. L. et al. 2003. Global gap analysis: towards a representative network of protected areas. Advances in applied biodiversity science 5. Conservation International, Washington, D.C.

Scales, B. R., and S. J. Marsden. 2008. Biodiversity in small-scale tropical agroforests: a review of species richness and abundance shifts and the factors influencing them. Environmental Conservation **35:**160–172.

Scarlat, N., and J. F. Dallemand. 2008. Biofuels certification schemes as a tool to address sustainability concerns: status of ongoing initiatives. Proceedings of the Second international symposium on energy from biomass and waste. Environmental Sanitary Engineering Centre (CISA), Venice, Italy.

Searchinger T., et al. 2008. Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land use change. Science **319:**1238–1240.

Smeets, E. M. W., A. P. C. Faaij, I. M. Lewandowski, and W. C. Turkenburg. 2007. A bottom-up assessment and review of global bio-energy potentials to 2050. Progress in Energy and Combustion Science **33:**56–106.

Smith, R. G., K. L. Gross, and G. P. Robertson. 2008. Effects of crop diversity on agroecosystem function: crop yield response. Ecosystems **11:**355–366.

Sparovek, G., et al. 2007. Sugarcane ethanol production in Brazil: an expansion model sensitive to socioeconomic and environmental concerns. Biofuels, Bioproducts and Biorefining **1:**270–282.

Stattersfield, A. J., M. J. Crosby, A. J. Long, and D. C. Wege. 1998. Endemic bird areas of the world: Priorities for biodiversity conservation. Conservation series 7. Bird Life International, Cambridge, United Kingdom.

Turner, W. R., et al. 2007. Global conservation of biodiversity and ecosystem services. BioScience **57:**868–873.

UNEP-UNCTAD (United Nations Environment Programme—United Nations Conference on Trade and Development). 2008. Organic agriculture and food security in Africa. United Nations, New York.

Van Dam, M. J., et al. 2008. Overview of recent developments in sustainable biomass certification. Biomass and Bioenergy **32:**749–780.

Van Den Bossche, P., N. Schrijver, and G. Faber. 2007. Unilateral measures addressing non-trade concerns. A study on WTO consistency, relevance of other international agreements, economic effectiveness and impact on developing countries of measures concerning non-product-related processes and production methods. The Ministry of Foreign Affairs of The Netherlands, The Hague.

Wassenaar, T., et al. 2007. Projecting land use changes in the Neotropics: the geography of pasture expansion into forest. Global Environmental Change **17:**86–104.

WDPA (World Database on Protected Areas). 2008. World database on protected areas. United Nations Environment Programme, World Conservation Monitoring Centre, Cambridge, United Kingdom. Available from http://www.wdpa.org (accessed December 2008).