Effects of Bioenergy Production on Wildlife and Wildlife Habitat

Technical Review 12-03

December 2012

THE WILDLIFE SOCIETY

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Edited by

Theodore A. Bookhout

Cover Images

Front cover, clockwise from upper left: Prairie cordgrass at EcoSun Prairie Farms, South Dakota/Credit: Dr. Carter Johnson, South Dakota State University; Thirteen-lined ground squirrel/Credit: Benjamin Carroll; East Texas little bluestem cultivar trials/Credit: Chuck Kowaleski; Dragonfly/Credit: Craig Novotny, EcoSun Prairie Farms; Ethanol production and wildlife study sites in South Dakota/Credit: John Bender, South Dakota State University; Deer in switchgrass/Credit: Dr. Arvid Boe, South Dakota State University. **Back cover**: Northern bobwhite quail/Credit: Ben Robinson, Kentucky Department of Fish & Wildlife Resources.

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Eastern gama grass cultivar trials at NRCS East Texas Plant Materials Center/Credit: Chuck Kowaleski.

Table of Contents

List of Tables and Figures

Foreword

Presidents of The Wildlife Society occasionally appoint an ad hoc committee to study and develop a technical paper on a wildlife management or conservation issue of current concern. These papers ordinarily appear as either Technical Reviews or Position Statements. Technical Reviews are designed to provide the most current scientific information based on the views of committee members and do not represent the official position of The Wildlife Society. Position Statements are usually based on Technical Reviews and define The Wildlife Society's policy on the issue; preliminary versions are made available for comment by Society members.

Although originally charged as the "Biofuels Technical Review Committee," in the course of completing the review it became apparent that the wildlife-related implications of using plant-based materials to produce biofuels were, in most instances, the same as for bio-based sources of heat, power, and even bioproducts. The scope of the review was, therefore, broadened to address all types of bioenergy. However, there is a heavy emphasis on cellulosic forms of bioenergy for heat and ethanol production within the continental United States.

The first challenge faced by the Technical Review Committee was to decide on a functional structure for the report that provided flexibility for a wide range of potential readers – from research scientists to field-level managers – while also presenting the greatest biological meaning for wildlife resources. Initial consideration was given to organizing the report based on various "feedstocks" (i.e., products used as the basis for manufacture other products) used for bioenergy production. However, it soon became apparent that there would be considerable overlap of feedstocks among different ecosystems and that wildlife guilds would not necessarily align themselves in a logical manner. A species-centered approach did not appear feasible due to similar concerns. Discussion eventually centered on an ecosystem approach that tried to identify key biomass management practices within those systems. This allows the report to be oriented toward management practices, which will be more useful for non-scientists, while still identifying key wildlife groups within functional ecosystems. The committee recognizes there may be shortcomings with this approach. Lack of information in some systems or overlap of feedstocks in different ecosystems may result in gaps in information at one extreme and replication of information of material at others. We have attempted to minimize such problems while not sacrificing content. Given the rapid rate at which the bioenergy industry is currently expanding and policies are changing, the technical review subcommittee acknowledges that much of this information is likely to change or even be obsolete in the near future. Therefore, the primary recommendation of the technical review committee is that this information be revisited, and possibly revised, frequently in the coming years.

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Acknowledgments

Eastern gama grass seed heads and flowers at cultivar trials at NRCS East Texas Plant Materials Center/Credit: Chuck Kowaleski.

We thank past-President Richard Lancia and The Wildlife Society Council for appointing the Technical Review Committee on the Impacts of Biofuels Development on Wildlife and Wildlife Habitat and addressing this important and growing issue. Additionally we recognize President Paul Krausman and past-Presidents Tom Ryder, Bruce Leopold, Thomas Franklin, Daniel Svedarski, John Organ, and Robert Brown for continuing to recognize the importance of this review and encouraging its completion. We also thank TWS Council Technical Review Subcommittee Chairs Darren Miller and Gary Potts and Subcommittee members Jack Connelly, Karl Martin, Tom Decker, Marti Kie, and Tom Ryder for their guidance and review of previous drafts. Our appreciation goes out to Ted Bookhout for his detailed edits and keen eye in reviewing the final draft. TWS provided financial assistance and logistical support for the review and for committee meetings. Finally, we give special thanks to the National Wildlife Federation for providing the necessary financial support for production and publication.

Executive Summary

The production of biobased feedstocks (i.e., plant-or algal-based material used for transportation fuels, heat, power and bioproducts) for bioenergy production has been expanding rapidly in recent years. Unfortunately, there are considerable knowledge gaps relative to implications of this industry expansion for wildlife. This information deficit is likely to grow as the industry expands and rapidly evolves in new directions in the coming years. Although current liquid fuels are produced nearly entirely from sugars – mainly from corn, sorghum and sugar cane; and from oils – mainly soy and camelina, the next generation of biofuels is expected to be based on cellulosic materials from perennial grasses and trees, and from oils produced from micro-crops such as algae and aquatic plants. Nearly all of the feedstocks currently in use or proposed for use can be used for liquid transportation fuel, solid fuel to produce heat and/or power, or for biobased products such as plant-based plastics, textiles, and pharmaceuticals.

This technical review focuses on the current state of knowledge about effects of growing, managing, and harvesting feedstocks for bioenergy on wildlife and wildlife habitat – the portion of the bioenergy supply chain that will likely have the greatest direct and indirect effects on wildlife and wildlife habitat (Fig. 1). It is most likely that effects will fluctuate greatly from site to site depending on a common list of variables. To determine possible wildlife impacts, a site manager needs to consider a number of questions and scenarios. Some of those include: What bioenergy crop is being produced? Is it replacing natural vegetation as a dedicated energy crop? Does it result in a land use change? How productive was the site to start with in terms of fertility, growing season, and moisture? How intensively and with what inputs is it being managed for production? How much of the landscape will be occupied by the feedstock? Does it complement, improve, change, or eliminate current or projected future wildlife habitat? How much, how often, and when will it be harvested? What type of habitat structure may be provided (or eliminated) by this feedstock? Are managers willing to trade some production potential for wildlife habitat conservation? What is the potential to maintain elements of habitat structure (e.g., snags, buffers, etc.) on the landscape? What wildlife species and communities are currently occupying the site and what do they need to survive? What wildlife species

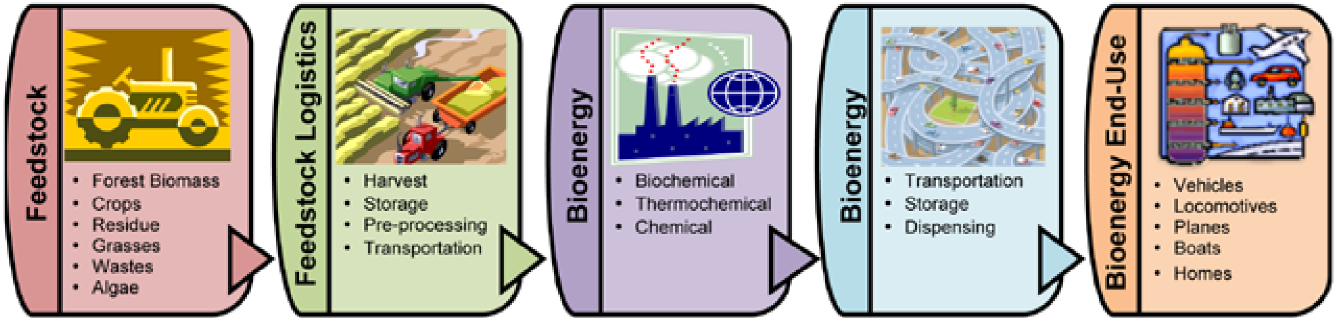


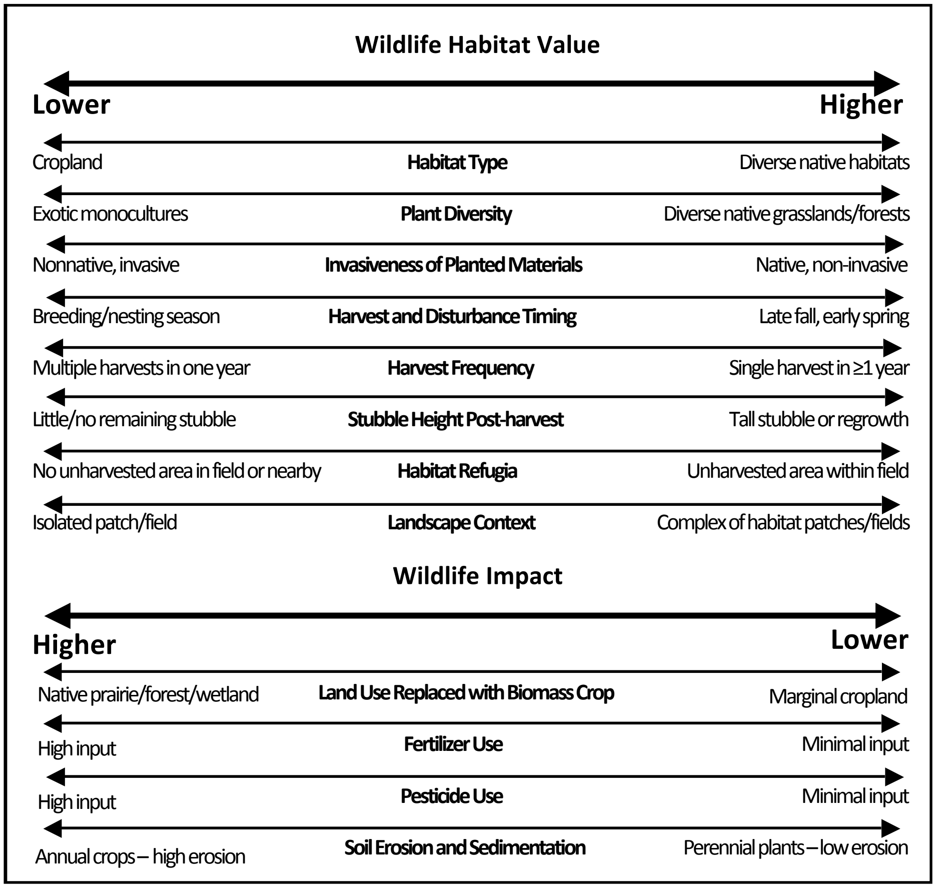
Figure 1. This Technical Review focuses on the effects of feedstock production and harvesting on wildlife and wildlife habitat. Figure 1 depicts the biomass to bioenergy supply chain.

or suites of species are considered desirable or undesirable on the site? Are any of the species or communities of conservation concern, especially protected species and imperiled ecosystems? How do the quantity, composition, and configuration of available onsite and surrounding habitat types affect wildlife use and survival?

Throughout this publication, the authors have tried to provide information that answers these questions so that site managers might better predict consequences of managing bioenergy feedstocks. Unfortunately, very little research has been done that specifically addresses the impact of bioenergy production on wildlife habitat. That, combined with bioenergy companies continuous search and development of new feedstocks, makes developing specific recommendations difficult at this time.

However, general guidelines exist for qualitatively assessing value of different crop types and management practices on wildlife and associated habitat (Fig. 2; Tables 2 and 3, pps. 26 & 27; Appendix A). Efforts have been made to provide links to best management practices and renewable fuel standards throughout the document so the user can research the information more completely as needed.

Demand for bioenergy will continue to increase as human populations expand and wildlife continues to feel the pressures of competing interests. Research on wildlife effects from bioenergy production is limited. We hope that this technical review will expose areas in need of additional attention and encourage stakeholders to continue pursuing knowledge for the sake of our wildlife resources.



Wildlife Habitat Value

Lower		Higher
Cropland	**Habitat Type**	Diverse native habitats
Exotic monocultures	**Plant Diversity**	Diverse native grasslands/forests
Nonnative, invasive	**Invasiveness of Planted Materials**	Native, non-invasive
Breeding/nesting season	**Harvest and Disturbance Timing**	Late fall, early spring
Multiple harvests in one year	**Harvest Frequency**	Single harvest in ≥1 year
Little/no remaining stubble	**Stubble Height Post-harvest**	Tall stubble or regrowth
No unharvested area in field or nearby	**Habitat Refugia**	Unharvested area within field
Isolated patch/field	**Landscape Context**	Complex of habitat patches/fields

Wildlife Impact

Higher		Lower
Native prairie/forest/wetland	**Land Use Replaced with Biomass Crop**	Marginal cropland
High input	**Fertilizer Use**	Minimal input
High input	**Pesticide Use**	Minimal input
Annual crops – high erosion	**Soil Erosion and Sedimentation**	Perennial plants – low erosion

Figure 2. Factors influencing wildlife habitat value of bioenergy crops. For each factor, the qualities associated with greater wildlife benefit (or less impact) are listed on the right side of the figure, and the qualities that are associated with less wildlife benefit (or greater impact) are listed on the left side of the figure (Adapted from Fargione et al. 2009).

Introduction

Although energy prices in the United States (U.S.) are among the cheapest in the world, dependence on imported oil, concerns over finite reserves, and environmental costs associated with mining, processing, and combusting fossil fuels have increased development of domestically produced clean burning renewable fuels (McLaughlin et al. 1999). As a result of increased private and governmental funding and research, domestic bioenergy production has grown rapidly in recent years. Transportation fuel production has expanded from 6 billion liters in 2000 to 52.6 billion liters in 2011 (Renewable Fuels Association 2012; **www.ethanolrfa.org/pages/statistics#A**). Biomass now accounts for >4% of total U.S. primary energy consumption (U.S. Department of Energy 2011:7).

Producing dedicated bioenergy crops or using existing natural vegetation communities to meet this growing demand requires combining near-term objectives of maximizing potential production with longer term objectives of improving and protecting production capacity through breeding and biotechnology (McLaughlin et al. 1999), while maintaining environmental sustainability. Despite this expanding production and consumption of biomass for biofuel and bioenergy production, the ultimate interactive effects on the economy and environment remain unclear (National Resource Council 2010, Environmental Protection Agency 2011). Research is just beginning to peel back the layers of these issues.

There are few robust scientific studies examining bioenergy production and wildlife communities. The greatest consequences for wildlife will likely stem from habitat alteration created by either conversion of existing landscapes to large-scale bioenergy production or more intensive resource extraction from landscapes. A combination of resources (e.g., food, cover, water, space) and environmental conditions (e.g., temperature, precipitation, presence of predators and competitors) arranged in such a way so as to promote occupancy by individuals or populations is needed for wildlife to survive and reproduce. Therefore, when effects of feedstock production on wildlife populations are considered, direct impacts on species' resources, spatial arrangement of those resources, and shifts in inter- and intraspecific interactions that may lead to changes in survival and viability must be evaluated.

Establishment, maintenance, and harvest procedures for bioenergy/biomass production may differ from fields and forests managed for multiple uses, including those to benefit wildlife (Bies 2006). The value of an area for wildlife habitat will be influenced by vegetation type, including plant diversity and species; if the feedstock is native, exotic, or exotic invasive; timing, frequency and amount of harvest; stubble height following herbaceous harvest; presence of refugia; and landscape context (Fargione et al. 2009). Frequency, intensity, and timing of harvesting may be the most important factors to consider from both a wildlife and bioenergy standpoint (McLaughlin and Walsh 1998, Bies 2006). For example, seasonal timing of harvest can affect biomass yield and quality for energy production in fermentation, gasification, or direct combustion systems (McLaughlin et al. 1999, Adler et al. 2006, Lee et al. 2007). Though harvesting herbaceous biomass in fall or winter may not directly affect neotropical migrant grassland birds, species composition, abundance, diversity, and nest success the subsequent spring may be affected by changes in vegetation structure due to harvesting (Murray and Best 2003). In contrast, spring harvest of some crops (e.g., perennial grasses) may provide cover for resident species during winter while simultaneously increasing biomass quality for certain bioenergy applications, such as biofuel production (Murray and Best 2003, Adler et al. 2006). However, such harvests may affect amount and quality of spring nesting/brood rearing cover available.

Relevant Federal and State Policies

The expanded interest in biofuels and other bioenergy sources has been driven largely by the surge in state and federal mandates and incentives to promote these industries. In 2006, more than 150 political mandates explicitly supported biofuels at the state level and another 30+ at the federal level (National Research Council 2010). The Biomass Research and Development Act of 2000, which launched significant government investment into developing biobased sources of fuels and products, indicated support for the industry was needed to: (1) increase energy security of the U.S.; (2) create jobs and enhance economic development of the rural economy; (3) enhance environment and public health; and (4) diversify markets for raw agricultural and forestry products (7 U.S.C. 7624 note Sec. 307).

Liquid Biofuels.— Subsidies for liquid biofuels production began with the Energy Tax Act of 1978, which reduced the excise tax on fuel blended with 10% ethanol by the equivalent of $0.10 for each liter of ethanol blended into gasoline. The excise tax, now known as the "Volumetric Ethanol Excise Tax Credit (VEETC)," was raised and lowered numerous times over the years. Although the VEETC, last reported at $0.12 per liter, was given a last minute one-year extension in 2010, fiscal pressures eroded support in Congress and it expired at the end of 2011. Several legislative proposals surfaced to divert some of the funding used for the tax credit into special ethanol infrastructure (blender pumps and pipelines), but those efforts were unsuccessful.

Many other subsidies and incentives were enacted in the 1980s, including a tariff on imported liquid biofuels that was part of the 1980 Omnibus Reconciliation Act. This $0.14 per liter tariff on imported liquid biofuels, which also expired at the end of 2011, provided U.S. ethanol producers with a cost advantage over Brazilian sugar-based ethanol (Babcock 2010). More recently, several kinds of loan guarantees, tax credits, research and grant programs have been added and are administered by the Departments of Agriculture (USDA) and Energy (DOE).

Although tax credits, tariffs, and a host of other programs led to a steady increase in ethanol production from 662 million liters in 1980 to 12.8 billion liters in 2004, passage of the first federal Renewable Fuels Standard (RFS) mandate for renewable fuels use in 2005 led to an explosion of growth in the industry. The RFS was originally enacted as part of the Energy Policy Act of 2005 (Public Law 109-58) but was greatly expanded in the Energy Independence and Security Act (EISA) of 2007 (Public Law 110–140). As part of the EISA, the federal government mandated a production capacity of 136 billion liters of liquid biofuel by 2022, of which 79.5 billion liters are supposed to come from cellulosic and other advanced biofuels (Fig. 3). As a result, ethanol production quickly increased to 40 billion

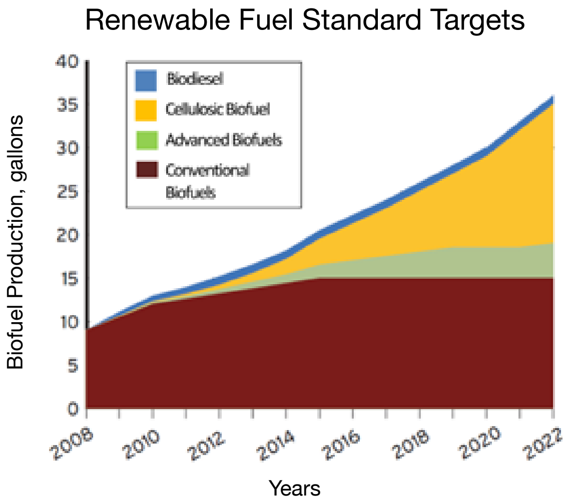


Figure 3. Renewable Fuel Standard (RFS) targets as outlined by the Renewable Fuels Association in 2010. As part of the Energy Independence and Security Act of 2007, a production capacity of 136 billion liters (36 billion gallons) of biofuel is mandated by 2022, 76.5 billion liters (21 billion gallons) of which are supposed to come from cellulosic and other advance biofuels. These targets have been adjusted downward over the years as market capacity has failed to meet these standards.

liters by 2009 (Renewable Fuels Association 2012), of which more than 95% came from corn starch, and grain and sweet sorghum made up most of the balance (Schnepf 2010). Between 2005 and 2009, the number of hectares of corn used for ethanol production increased by almost 200% (Brooke et al. 2009). These targets have been adjusted downward over the years as market capacity has failed to meet these standards. Still, the ultimate influence of policy on demand for and harvests of forest biomass remains uncertain.

Feedstocks used to produce renewable fuels under the federal RFS must meet conditions established under the law's definition of "renewable biomass" (Box 1). This provision severely restricts use of biomass from public lands, allowing only "biomass obtained from the immediate vicinity of buildings and other areas regularly occupied by people, or of public infrastructure, at risk from wildfire" (P.L. 110-140 Energy Independence and Security Act of 2007, Title II Sec.201(i)(I)(v)).

Forest harvest residues and pre-commercial thinning may be used from private forest lands except for "ecological communities with a global or state ranking of critically imperiled, imperiled, or rare pursuant to a state Natural Heritage Program, old growth forest, or late successional forest" (P.L. 110-140 Energy Independence and Security Act of 2007, Title II Sec. 201(i)(1)(iv)). Use of whole trees for biomass is limited to actively managed tree plantations that were established prior to passage of the law. In at least one state, North Carolina,

Box 1. Title II—Energy Security Through Increased Production of Biofuels

Subtitle A—Renewable Fuel Standard

SEC. 201. Definitions

Section 211(o) (1) of the Clean Air Act (42 U.S.C. 7545(o)) is amended to read as follows:
''(1) DEFINITIONS.—In this section:....

''(I) RENEWABLE BIOMASS.—The term 'renewable biomass' means each of the following:

''(i) Planted crops and crop residue harvested from agricultural land cleared or cultivated at any time prior to the enactment of this sentence that is either actively managed or fallow, and nonforested.

''(ii) Planted trees and tree residue from actively managed tree plantations on non-federal land cleared at any time prior to enactment of this sentence, including land belonging to an Indian tribe or an Indian individual, that is held in trust by the United States or subject to a restriction against alienation imposed by the United States.

''(iii) Animal waste material and animal byproducts.

''(iv) Slash and pre-commercial thinnings that are from non-federal forestlands, including forestlands belonging to an Indian tribe or an Indian individual, that are held in trust by the United States or subject to a restriction against alienation imposed by the United States, but not forests or forestlands that are ecological communities with a global or State ranking of critically imperiled, imperiled, or rare pursuant to a State Natural Heritage Program, old growth forest, or late successional forest.

''(v) Biomass obtained from the immediate vicinity of buildings and other areas regularly occupied by people, or of public infrastructure, at risk from wildfire.

''(vi) Algae.

''(vii) Separated yard waste or food waste, including recycled cooking and trap grease.

Etc...

The definitions of renewable biomass according to the renewable fuel standards can be found in P.L. 110-140 Energy Independence and Security Act of 2007, Title II Sec. 201 (i)(I).

where demand for biomass to meet state renewable energy standards is high, some whole tree harvests have been undertaken and such biomass sourcing has been approved by the state utility commission (Environment and Energy Study Institute 2011). The law also prohibits planting biomass crops or gathering residues from agricultural land that has been cleared and cultivated after its passage in December 2007 (National Research Council 2010). However, the Environmental Protection Agency's (EPA) final rule does not enforce this provision, choosing instead to monitor land use changes to determine if significant amounts of grassland areas are converted to cropping (40 CFR 80.1454(g)). Several environmental groups petitioned the EPA to reconsider this decision, but the petition was denied.

The definition of renewable biomass in the RFS has come under frequent attack in Congress by those who feel that it is too restrictive. Numerous bills were introduced to Congress between 2008 and 2011 to change the definition. A frequently offered alternative is to use the definition in the 2008 Farm Bill, which would impose fewer restrictions on use of public lands and allow biomass to be harvested from any private land, without restrictions.

The RFS does not include additional conditions on biomass sourcing beyond restrictions in the definition. However, it does require EPA to report to Congress every 3 years on environmental impacts, including those affecting soil conservation, water availability, ecosystem health and biodiversity, forests, grasslands, and wetlands. Furthermore, it requires updates on growth and use of cultivated invasive or noxious plants and their impacts on the environment and agriculture (National Research Council 2010). The first draft report was issued for comment in January 2011 but has yet to be finalized.

Production of bioethanol from agricultural wastes, wood, algae, and grasses is just now beginning to transition from research and demonstration into commercial implementation. As of early 2012, no commercial-size cellulosic ethanol facilities were in operation in the U.S. However, several demonstration plants are currently in operation and some commercial-size facilities are expected to begin production by fall 2012, many focusing on corn stover (i.e., dried stalks and leaves remaining after the grain has been harvested) and switchgrass *(Panicum virgatum)*. Nevertheless, a thousand-fold increase in scale over the next few years will be needed to meet the goal of the RFS for cellulosic fuels by 2022. As previously mentioned, the EPA has had to issue waivers to the cellulosic mandate due to lack of available volumes of cellulosic ethanol to meet the RFS.

Bio-based Heat and Power.— Liquid biofuels are only one part of the bioenergy equation. Bio-based sources of heat and power have also been steadily increasing in recent years. Although accounting for only 4.1% of U.S. energy production, biomass currently provides more energy than any other renewable energy source (U.S. Department of Energy 2011:8). It is estimated that biomass has the potential to provide 10% of the nation's electricity needs (Environmental Protection Agency 2009). The American Recovery and Reinvestment Act of 2009 extended the federal production tax credit (PTC) to biomass generators through 2013, which helps make investments in biopower more cost-competitive with traditional fossil fuel (Pew Center on Global Climate Change 2009). Efforts to put a price on carbon and/or to enact a federal Renewable Electricity Standard, which would have required utilities to produce a percentage of their electricity from renewable sources (including biomass), faltered in the 111th Congress. Despite this, 27 states plus the District of Columbia have proceeded with enacting renewable portfolio standards (Fig. 4, p. 5; Table 1, p. 6).

An additional factor driving up demand for biomass in the United States is the European Union's target of supplying 20% of their total energy consumption through renewable sources by 2020. Demand for wood and grass pellets used as a fuel source in boilers for electrical generation and heat production has outpaced domestic production in several countries in recent years, driving increases in imports from other countries, including the United

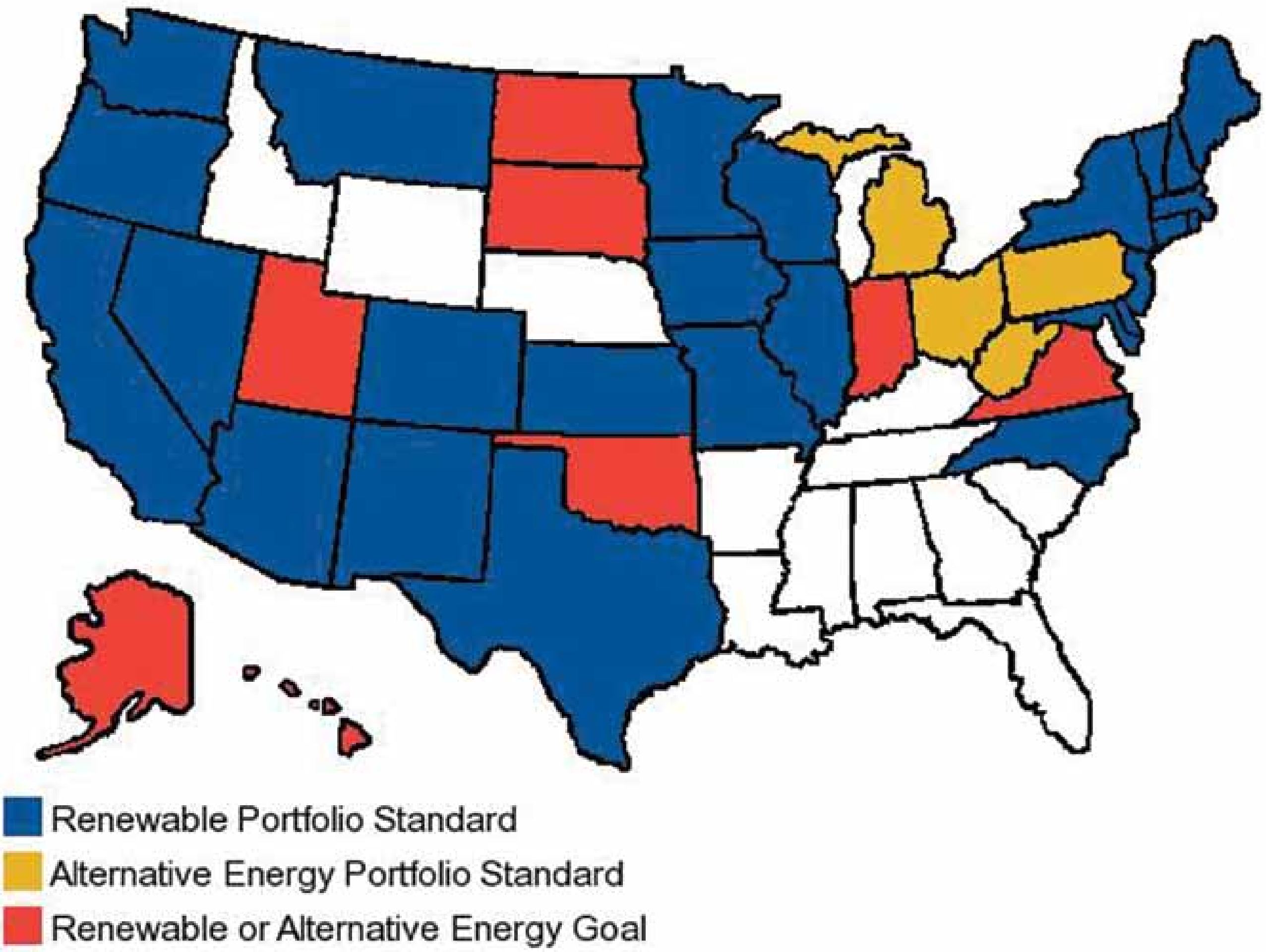


Figure 4. Twenty-seven states plus the District of Columbia have renewable portfolio standards. Several others have created alternative energy portfolio standards or set renewable/alternative energy goals (Source: Center for Climate Change and Energy Solutions 2012; www.c2es.org/what_s_being_done/in_the_states/rps.cfm*).*

States. The U.S. exported 85,000 tons of pellets to the Netherlands in 2008, which increased to 600,000 tons in 2010. Total shipments from the U.S. and Canada have doubled in just 2 years (Eckstrom 2011). Pellet exports are anticipated to increase greatly in the coming years (Liesch 2011).

Promoting Biomass.— A major policy driver very likely to have a significant effect on how biomass feedstocks are grown or gathered – whether for liquid fuels, heat or power – is the Biomass Crop Assistance Program (BCAP) (7 USC 8111). This program was created as part of the 2008 Farm Bill but only fully launched in December 2010. Although the future of the program is uncertain, BCAP is structured to provide financial assistance to landowners growing dedicated biomass feedstocks (including agricultural residues and forestry materials) and matching payments for delivery of biomass feedstocks to energy facilities. Participants must develop and/or implement a conservation or forest stewardship plan. Previously untilled grasslands and invasive and noxious species are ineligible. Because most of those growing or gathering biomass will likely seek assistance from the BCAP program, quality and enforcement of required conservation and forest stewardship plans could have a significant impact on how wildlife are affected by expansion of bioenergy.

Table 1. Summary of state renewable portfolio standards and the organizations that are administering these standards. Percentages refer to a portion of electricity sales and megawatts (MW) to absolute capacity requirements. Most of these standards phase in over years, can be annually adjusted, and the date refers to when the full requirement takes effect. (Source: Renewable Fuels Association 2012)

State [a/]	Amount	Year	Organization Administering RPS
Arizona	15%	2025	Arizona Corporation Commission
California	33%	2030	California Energy Commission
Colorado	20%	2020	Colorado Public Utilities Commission
Connecticut	23%	2020	Department of Public Utility Control
District of Columbia	20%	2020	DC Public Service Commission
Delaware	20%	2019	Delaware Energy Office
Hawaii	20%	2020	Hawaii Strategic Industries Division
Iowa	105 MW		Iowa Utilities Board
Illinois	25%	2025	Illinois Department of Commerce
Massachusetts	15%	2020	Massachusetts Division of Energy Resources
Maryland	20%	2022	Maryland Public Service Commission
Maine	40%	2017	Maine Public Utilities Commission
Michigan	10%	2015	Michigan Public Service Commission
Minnesota	25%	2025	Minnesota Department of Commerce
Missouri	15%	2021	Missouri Public Service Commission
Montana	15%	2015	Montana Public Service Commission
New Hampshire	23.8%	2025	New Hampshire Office of Energy and Planning
New Jersey	22.5%	2021	New Jersey Board of Public Utilities
New Mexico	20%	2020	New Mexico Public Regulation Commission
Nevada	20%	2015	Public Utilities Commission of Nevada
New York	24%	2013	New York Public Service Commission
North Carolina	12.5%	2021	North Carolina Utilities Commission
North Dakota	10%	2015	North Dakota Public Service Commission
Oregon	25%	2025	Oregon Energy Office
Pennsylvania	8%	2020	Pennsylvania Public Utility Commission
Rhode Island	16%	2019	Rhode Island Public Utilities Commission
South Dakota	10%	2015	South Dakota Public Utility Commission
Texas	5,880 MW	2015	Public Utility Commission of Texas
Utah	20%	2025	Utah Department of Environmental Quality
Vermont	10%	2013	Vermont Department of Public Service
Virginia	12%	2022	Virginia Department of Mines, Minerals, & Energy
Washington	15%	2020	Washington Secretary of State
Wisconsin	10%	2015	Public Service Commission of Wisconsin

a/ Five states (i.e., North Dakota, South Dakota, Utah, Virginia, and Vermont) have set voluntary goals for adopting renewable energy instead of portfolio standards with binding targets.

Part 1: Agricultural Lands and Croplands

In the U.S., changes in agricultural practices over the last century have led to dramatic increases in productivity. Biomass energy from agricultural lands is available from a variety of sources including grains, crop stovers, perennial grasses, woody perennials, and emerging specialty crops. Initial development of liquid biofuels based on corn and soybeans was partially driven by searching for a new market when these grains represented low-cost feedstocks. From a national perspective, the continued shift to row-crops from small grains has been ongoing since 1950, and increased acreage needs for corn may cause that trend to continue. Currently, grain-based ethanol and biodiesel dominate the renewable energy portfolio for transportation fuels, but production of cellulosic ethanol and other biofuels has greater potential to meet national energy needs without directly competing with feed and food demands (Perlack et al. 2005, Schmer et al. 2008). The U.S. Department of Energy (2011:143) has projected that, at prices of $60 per dry ton of biomass, about 24 million hectares of cropland and pastureland could potentially be converted to energy crops. Agricultural sources in the U.S. currently provide between 59 and 244 million dry tons of biomass, depending upon management intensity and price per dry ton (U.S. Department of Energy 2011: 86). Estimates of future production indicate perennial grasses, woody crops, and annual energy crops could annually produce 101 to180 million dry tons by 2017 and 400 to 799 million dry tons by 2030 (U.S. Department of Energy 2011:144).

Increased demand for ethanol has brought a variety of concerns: (1) competing use for crop or crop products, (2) competition for land base, and (3) sustainable management strategies (Fargione et al. 2009, McDonald et al. 2009, Dale et al. 2010, Mitchell et al. 2010). Truly sustainable management strategies for producing food, fiber, and energy from agricultural lands must also protect and balance environmental effects (Robertson et al. 2008, Dale et al. 2010). From a wildlife perspective, changing land uses and increased harvest pressures on a variety of agricultural lands will present challenges and tradeoffs (Bies 2006, Groom et al. 2008, Fargione et al. 2009).

Agricultural lands, for the purposes of this review, are lands on which the native vegetation has been replaced with planted crops or forages with the exception of Conservation Reserve Program (CRP) lands, which will be discussed separately. Additionally, these agricultural fields are embedded in landscapes that include native prairies, rangelands, forestlands, developed lands, wetlands, and smaller-scale remnant habitat patches such as fencerows, hedgerows, field borders, woodlots, planted tree belts or windbreaks, and grassed and wooded riparian areas (Best et al. 1995, Koford and Best 1996). Although many species of wildlife are unable to breed, raise young, and find cover in agricultural lands, many nongame species and common game species, including ring-necked pheasants *(Phasianus colchicus* - hereafter 'pheasants'), northern bobwhites *(Colinus virginianus)*, white-tailed deer *(Odocoileus virginianus)*, and wild turkeys *(Meleagris gallopavo)*, among others, use agricultural land to some extent. In many cases this use is closely linked with availability of and proximity to non-cropland habitat types (Harmon and Nelson 1973, Best et al. 1995, Koford and Best 1996).

Current agricultural lands, including row-crops, small grains, hayland and pastures, and idle land (including CRP, which will be discussed in conjunction with grasslands later in this report) are being considered for biomass production. Typically, agricultural lands are intensively managed with high levels of inputs (e.g., fertilizers, herbicides, water) and frequent disturbances to achieve high production levels for food, forage, and fiber. However, the high nutrient applications on croplands needed to achieve such production are frequently associated with hypoxic conditions in streams, lakes, and estuaries (Dale et al. 2010, Mitchell et al. 2010). Many proponents look at biomass for bioenergy production as simply another crop, or another use for existing crops, on agricultural lands with the added potential of reducing agricultural runoff if the right feedstocks and harvesting strategies are employed.

Effects of bioenergy derived from agricultural lands on wildlife will primarily be determined by four factors: (1) crop type, (2) level of plant diversity (use of monocultures versus polycultures), (3) crop management practices (e.g., tillage, removal of stover, use of buffers/field borders, and harvest timing, intensity and frequency), and (4) landscape context (prevalence and configuration of feedstock cropping with other available habitat on the landscape). Each of these will affect individual wildlife species and landscape structure differently. In this review, we focus on the first 3 with the fourth effect implicit throughout.

Crop Type

Different feedstock species will likely influence biodiversity in different ways. Current biofuels are primarily produced from monocultures of summer annual crops including corn and soybeans, and to a lesser extent sorghum, sugar beets, wheat, barley, and crop stovers. In addition to traditional row crops, other monoculture, perennial crops have been considered for bioenergy development (e.g., eucalyptus [*Eucalyptus spp.*], hybrid poplar [*Populus spp.*], jatropha [*Jatropha spp.*], miscanthus [*Miscanthus spp.*]), sugar cane [*Saccharum spp.*], and switchgrass) (Fig. 5). Many of these crops are compatible with conventional farming practices and equipment, which also provides an opportunity for them to be quickly incorporated into existing cropping systems and produced on a large scale.

Figure 5. Technical review committee member Julie Sibbing stands beside napier grass (Pennisetum purpureum) at British Petroleum's (BP) Biofuels Versipia Project in Florida, USA/Credit: National Wildlife Federation.

Level of Plant Diversity

Effect of bioenergy crops on wildlife will depend largely on what they replace in the landscape and if they are grown in monocultures or polycultures. Currently, most commercial biomass plantings are confined to single species (i.e., monocultures) with known qualities selected for purposes such as co-firing or use with a specific cellulase enzyme for fuel or chemical production. Mixed plantings (i.e., polycultures) introduce factors that complicate these processes and are generally avoided. However, there is little argument that mixed plantings are more beneficial to wildlife communities than monoculture crops because of the structural diversity they create. If polyculture, perennial bioenergy crops replace row crop monocultures (e.g., corn) that have little value for wildlife, effects likely will be neutral to positive. However, if bioenergy crops are grown on land converted from existing habitat, effects are likely to be negative.

Annual Monocultures

Similar to row-cropping of traditional agricultural crops, the greatest effect on wildlife resulting from monoculture production of bioenergy crops is habitat change. Whether the bioenergy crop represents a net gain or loss of habitat depends on the type of land that it is replacing (Fargione et al. 2009), the crop being produced (e.g., corn versus switchgrass) and the wildlife species in question. Much of the increase in corn acreage has come from land that had been used to grow soybeans and wheat, but there also is evidence that some increased corn acreage has come from land that previously provided higher quality wildlife habitat, including native prairie, pastureland, and CRP land (Hill et al. 2009, Webster et al. 2010).

Management of summer annual monoculture crops normally involves intensive use of fertilizers to promote crop growth and productivity, tillage or herbicide use to limit weed competition with crops for water and nutrients, and supplemental irrigation when needed and available. Of the various types of agricultural lands, row crops are the most productive and most intensively managed and in general provide relatively little value for wildlife independent of other available cover types (Warner 1994, Best et al. 1995, Koford and Best 1996, Santelmann et al. 2005, Brady 2007). However, there is evidence that implementing winter cover crops on such lands can provide some habitat value to wildlife. In western Kansas, USA, cover crops increased pheasant populations by 80% compared to areas with bare ground (Rodgers 2002). Small grain crops planted in the fall also can provide food and protection for wildlife during winter (Taylor et al. 1978, Hartley 1994, Rodgers 1999, Devries et al. 2008). In some instances, winter cover crops could also be used for bioenergy production.

If bioenergy monocultures must be used to meet feedstock requirements, establishment using minimum applications of herbicide will extend the period of initial high vegetative diversity and benefit early successional birds and other wildlife. In practice, however, establishment techniques including amount of herbicide used will vary regionally along a continuum addressing wildlife versus biomass production. Interseeding with prostrate forms of legumes, which remain shorter than biomass harvest height, both reduces need for fertilization and increases short-term wildlife value immediately after harvest. Companion plantings of wildlife-friendly grasses, legumes and other forbs and shrubs (if site appropriate) as field borders and alternating strips at least 15 m wide between 100-m-wide monoculture plantings will greatly enhance vegetative diversity and use by wildlife (Harper and Keyser 2008). These diverse native plantings provide needed year-round food and brood areas, travel/escape corridors, and refugia sites during and after biomass harvest. Harper and Keyser (2008) recommended either leaving at least 5% of the field for wildlife cover with the remaining cover located near field edges or other cover or harvesting only 50% of the field each year. They also recommended that cover strips at least

15-m wide and blocks of no less than 0.2 ha in size be retained to reduce overhead predation on birds and small mammals.

Perennial Monocultures

Monocultures of perennial grasses (e.g., switchgrass) alone could annually produce between 90 to 154 million dry tons by 2017 and 255 to 462 million tons by 2030 (U.S. Department of Energy 2011:144). Perennial crops that have been considered for bioenergy development include eucalyptus, hybrid poplar, jatropha, miscanthus, sugar cane, and switchgrass. Scientific studies evaluating wildlife response to different perennial feedstocks are largely absent.

After evaluating 34 candidate species, DOE's Bioenergy Feedstock Development Program (BFDP) chose switchgrass as its primary herbaceous bioenergy crop because of its abundance, high biomass production, tolerance to climatic conditions, compatibility with conventional farming practices, and minimal maintenance requirements (Graham et al. 1995, Tolbert and Schiller 1995, McLaughlin and Walsh 1998, McLaughlin et al. 1999, Rinehart 2006). Switchgrass is often used for reseeding cultivated lands to native grass because it is relatively easy to establish, stabilizes soils, and provides excellent winter cover for numerous wildlife species when mixed with cool season grasses (Ohlenbusch 1983, George 1988). Because it is related to the corn and sorghum family, switchgrass seeds are often highly desired by songbirds and upland game birds. Furthermore, the fibrous root systems of switchgrass have other environmental benefits including reducing runoff, increasing soil organic matter, and changing soil surface hydrology (McLaughlin and Walsh 1998). Because of realistic prospects for large-scale production of perennial grasses as a source for bioenergy production, commercial-scale, pre-operational testing of facilities that may use switchgrass as a primary fuel are already underway in numerous states (e.g., Alabama, Iowa, South Dakota, and Tennessee).

Miscanthus and reed canary grass *(Phalaris arundinacea)* also are being investigated for use as bioenergy crops. European studies indicate that plantings of both species are less diverse than more natural field margins (Semere and Slater 2007) and sometimes less diverse than even conventional fields (Vepsalainen 2010). As with other crops, some species may benefit but not others (Bellamy et al. 2009, Sage et al. 2010).

Wildlife Responses to Agricultural Monocultures

Birds.— Monoculture corn and soybean field crops that predominate current biofuels feedstocks are often reported to have low avian richness, very low abundances of breeding birds, and a paucity of nesting birds (Kirsch and Higgins 1976, Taylor et al. 1978, King and Savidge 1995, Best et al. 1997, Cederbaum et al. 2004, Brooke et al. 2009, Fletcher et al. 2010, Meehan et al. 2010, Robertson et al. 2010). Studies of bird use of small grain fields, especially winter annuals (planted in fall and harvested in the summer) that include varieties of winter wheat, rye, oats, and barley, indicate that wildlife effects of those crops may be more beneficial to waterfowl and pheasants than primary row crops of corn and soybeans (Taylor et al. 1978, Hartley 1994, Rodgers 1999, Devries et al. 2008). Soybeans did not occur in esophageal contents of several waterfowl species despite widespread availability of this resource (Krapu et al. 2004). Additionally, increased efficacy of weed control on cropland planted to genetically modified soybeans further diminishes value to wildlife (Krapu et al. 2004). Given evidence that high-energy food and numerous populations of seed-eating species found on farmlands are declining, and the potential risk to game and nongame wildlife populations if high-energy foods become scarce, a comprehensive research effort to study the problem appears warranted (Krapu et al. 2004).

Mammals.— Few studies have evaluated importance of monoculture croplands for mammals. Waste corn, soybeans, and sorghum are considered high value food sources for a variety of resident wild mammals, most prominently white-tailed deer (Dusek et al. 1988, Walter et al. 2009) and raccoons *(Procyon lotor*; Pedlar et al. 1997, Beasley et al. 2007). A 1983 study of irrigated cornfields in western Kansas (Fleharty and Navo 1983) showed that cornfields provide suitable habitat for populations of some small mammal species (e.g., grasshopper mice *[Onychomys leucogaster]*) from October through April and that survival of populations was likely due in part to small patches of prairie interspersed with cropland that served as refugia. Olson and Brewer (2002) reported that winter wheat furnished valuable habitat for small mammals and that value of winter wheat as small mammal habitat may be underestimated.

Herpetofauna.— Fragmentation of native habitat by croplands may create challenges for amphibians that require moist upland sites for foraging or hibernation, increasing risk of desiccation or destruction by agricultural activities (Kolozsvary and Swihart 1999). Body size within age classes of amphibians was lower in playa wetlands surrounded by cropland compared to wetlands surrounded by grasslands in the Southern High Plains (Gray and Smith 2005). Semlitsch and Bodie (2003) reviewed buffer zones around wetlands and riparian areas for reptiles and amphibians, reporting that terrestrial habitat needs for herptiles extended from 127 to 289 m from the edge of aquatic sites and that current buffer widths of 15 to 30 m typically used to protect water quality on agricultural wetlands are inadequate for amphibians and reptiles. Agricultural chemicals also may pose a risk to some amphibians and reptiles, although the body of evidence related to this issue is equivocal (Mann and Bidwell 1999, Lajmanovich et al. 2003, Edginton et al. 2004, Wojtaszek et al. 2004, Relyea 2005, Fawcett 2006, Solomon et al. 2008, Rohr and McCoy 2010, Spolyarich et al. 2011).

Invertebrates.— Gardiner et al. (2010) found that prairie and switchgrass supported a greater abundance and diversity of beneficial insects (pollinators and natural insect enemies) than did corn, but cautioned that management and harvest of switchgrass as a bioenergy crop may decrease diversity and abundance of beneficial insects. Annual wheat crops in Kansas provided lower richness of insects, a lower volume of insects, and a near absence of pollinators (Glover et al. 2010) than perennial grasslands. Landis et al. (2008) used a modeling approach and concluded that a 19% increase in corn production from 2006 to 2007 in the U.S. may have contributed to a decrease in landscape diversity, thereby reducing soybean aphid *(Aphis glycenes)* biocontrol by 24% at a cost of $58 million per year to soybean producers. An earlier evaluation by Fox et al. (2004) showed that natural insect predators could be important for suppressing soybean aphids from reaching high numbers. In an examination of insects important to game bird chicks, Taylor et al. (2006) reported that "weedy plots" containing spring wheat *(Triticum aestivum)*, wild oat *(Avena fatua),* common pigweed *(Amaranthus retroflexus),* and fat hen *(Chenopodium album)* had 12 times the biomass of insects, and intermediately diverse vegetative plots (i.e., weedy mix plus herbicide) 8 times the biomass of insects, than did monocultures (i.e., spring wheat only). Burger et al. (1993) reported that abundance and biomass of invertebrates in CRP fields were 4 times that of soybean fields. With increased interest in certain feedstocks for use as cellulosic crops, there has been a renewed interest in understanding potential pests to these crops as well. For example, *Blastobasis repartella* is a borer in the proaxis and basal nodes and internodes of above ground stems of switchgrass (Adamski et al. 2010). Ongoing studies are evaluating potential preferences of *B. repartella* for certain cultivars of switchgrass and quantifying infestation rates (P. Johnson, South Dakota State University, *personal communication*).

Crop Management Practices

Regardless of crop type, approaches to management practices will affect wildlife species found there. Developing appropriate harvesting strategies that maximize both yield and wildlife use has been identified as a research priority if various feedstocks are expected to significantly expand as energy crops (Tolbert and Schiller 1995, McLaughlin and Walsh 1998). In this section, we discuss the following agricultural practices as they relate to wildlife: tillage, removal of stover, use of buffers/field borders, and harvest intensity, frequency, and timing.

Tillage

Tillage refers to the series of operations required to prepare and cultivate a field for crop production. Conventional tillage disrupts and exposes soil, which can potentially lead to soil erosion, increased sedimentation of waterways, reduced soil quality, and disturbance to wildlife habitat. Conservation tillage, also known as reduced tillage, is a system that leaves at least 30% of residue cover on the ground after planting. No-till (i.e., crop production in which the soil is left undisturbed from harvest to planting) and conservation tillage practices increase wildlife biodiversity on agricultural land, especially for birds (Cowan 1982, Warburton and Klimstra 1984, Basore et al. 1986, Flickinger and Pendleton 1994), invertebrates, and mammals (Warburton and Klimstra 1984) when compared to conventional tillage. However, Best (1986) noted that no-till fields may be an ecological trap for nesting birds that are attracted to fields with high residue depending on the timing of field operations, including planting. Conservation tillage methods – especially no-till – heavily rely on pesticides for weed and insect control that may have wildlife effects.

Stover/Residue

Wildlife benefits on many harvested croplands may be further reduced with intensive harvest of crop residues (plant material remaining after harvesting, including leaves, stalks, roots) for bioenergy production. Corn fields provide post-harvest sources of waste grain on crop fields that are considered a high-value food source for migratory waterfowl (Krapu et al. 2004, Kross et al. 2008), pheasants (Larsen et al. 1994, Bogenschutz et al. 1995), and wild turkeys (Kane et al. 2007). However, improvements in harvest efficiency and the related decline in post-harvest corn residues over the past 20 years have resulted in less available forage for sandhill cranes (Grus canadensis) and waterfowl (Krapu et al. 2004) – a situation that may be exacerbated by harvesting of stover for bioenergy production. An additional concern related to removal of crop residues is reduction in wildlife cover, which could impact small mammals and birds, in particular. Specific work by Rodgers (2002) in Kansas indicated substantial benefits of tall wheat stubble for ring-necked pheasants, implying a likely reduction in pheasant use if wheat stubble was harvested for bioenergy. In addition, removal of crop residues may reduce organic matter and recycling of nutrients into soils and decrease infiltration of moisture (Mann et al. 2002, Wilhelm et al. 2004, Dale et al. 2010). Reduced infiltration means a potential increase in runoff with less residue on the soil surface, potentially resulting in higher loads of nutrients and sediment leaving fields and entering aquatic systems (Mann et al. 2002, Wilhelm et al. 2004, Dale et al. 2010).

Buffers

Buffers have traditionally been retained on agricultural lands to reduce soil erosion and enhance water quality of surface water flowing off fields, but use of these for bioenergy production, or as a means of introducing diversity, cover and/or travel corridors for wildlife within monoculture biomass plantings, has been a topic of discussion (Harper and Keyser 2008). Buffers include filter strips and riparian buffers adjacent to aquatic areas, field borders such as those found in corners of circular irrigation systems, and other areas of wildlife habitat established along edges or within agricultural fields. Research has indicated positive responses by birds when buffers are placed in agricultural fields (Heard et al. 2000, Clark and Reeder 2005, Henningsen and Best 2005, Clark and Reeder 2007). However, benefits to birds are often constrained by buffer width, with narrow buffers often resulting in low nest success (Heard et al. 2000, Peak et al. 2004, Henningsen and Best 2005, Conover et al. 2009). Wider buffers also have been linked to increased use by winter birds (Conover et al. 2007), but Smith et al. (2005) found no difference between buffered and unbuffered field edges and noted a strong impact of the adjacent plant community on winter birds. Some evidence indicates benefits to both grassland and forest birds may be less likely to accrue when buffers are placed in croplands adjacent to forest patches (Peak et al. 2004, Riddle et al. 2007).

Some buffers established in agricultural fields around wetlands and riparian areas can fail to meet the life-cycle needs of herptiles (Semlitsch and Bodie 2003, Harper et al. 2008). Grass buffers established near streams as part of an intensive pasture management system appeared to support a rich and abundant small mammal community (Chapman and Ribic 2002). Butterfly abundance and diversity was found to be positively related to filter strip width (Reeder et al. 2005, Davros et al. 2006). Buffers can also provide benefits when established between native habitat patches and agricultural fields both in terms of potentially providing beneficial insect and wildlife habitat and in lessening potential for detrimental impacts from crop production activities on adjacent habitat types (pesticide application, escape of novel or invasive species from agricultural fields to native plant communities).

Intensity, Frequency, and Timing

Biomass crops on agricultural lands are likely to be intensively managed and extensively harvested. Because croplands are typically completely harvested, timing of harvest may be critical relative to wildlife (McLaughlin and Walsh 1998, Bies 2006). Avoidance of harvest during key reproductive periods for wildlife that may be using biomass plantings may reduce direct negative impacts on wildlife populations. For resident wildlife that are able to use biomass crops for part of their life cycle, populations may be limited by availability of habitat refugia where they can survive after biomass crops are harvested. Refugia may be provided by leaving unharvested portions of biomass fields, unharvested buffers, and/or adequate habitat adjacent to or near biomass fields. Research on wildlife use of small grain crops, especially wheat (Rodgers 2002) indicates that taller stubble remaining after harvest may provide additional wildlife benefits over winter and in the following breeding season. Similarly, regrowth on biomass crops harvested late in the growing season (after primary nesting seasons are over) may also provide additional wildlife benefits. Harvesting of herbaceous biomass in fall or winter, though ideal for bioenergy production, may affect wildlife species composition, abundance, diversity, and nest success the subsequent spring due to changes in vegetation structure (Murray and Best 2003).

Management Implications

Grain crops grown on agricultural lands currently comprise most feedstocks being used to produce biofuels. Because most agricultural lands are already intensively managed for production of food and/or animal feed, the wildlife benefits of these lands are limited to certain crops, crop residues, and waste grain during certain seasons. As crop production methods have advanced with clean farming methods (i.e., removal of weeds and noncrop habitats), wildlife benefits on these lands have continued to decline. However, advances in tillage methods, especially no-till, have reduced negative off-field impacts of soil erosion and water quality for a host of fish and wildlife species. On-field harvest and management activities (e.g., leaving unharvested portions, habitat buffers) can be applied to maintain some level of wildlife benefits on bioenergy crop fields. Comparative studies of actively managed and harvested bioenergy crops to agricultural crops they replace are needed; such studies must be “apple to apple” comparisons of actively managed croplands producing grain crops with actively managed bioenergy crops and appropriate controls.

CRP field planted to monoculture of old world bluestem in Texas/Credit: Chuck Kowaleski.

Part 2: Grasslands Ecosystems and CRP Grasslands

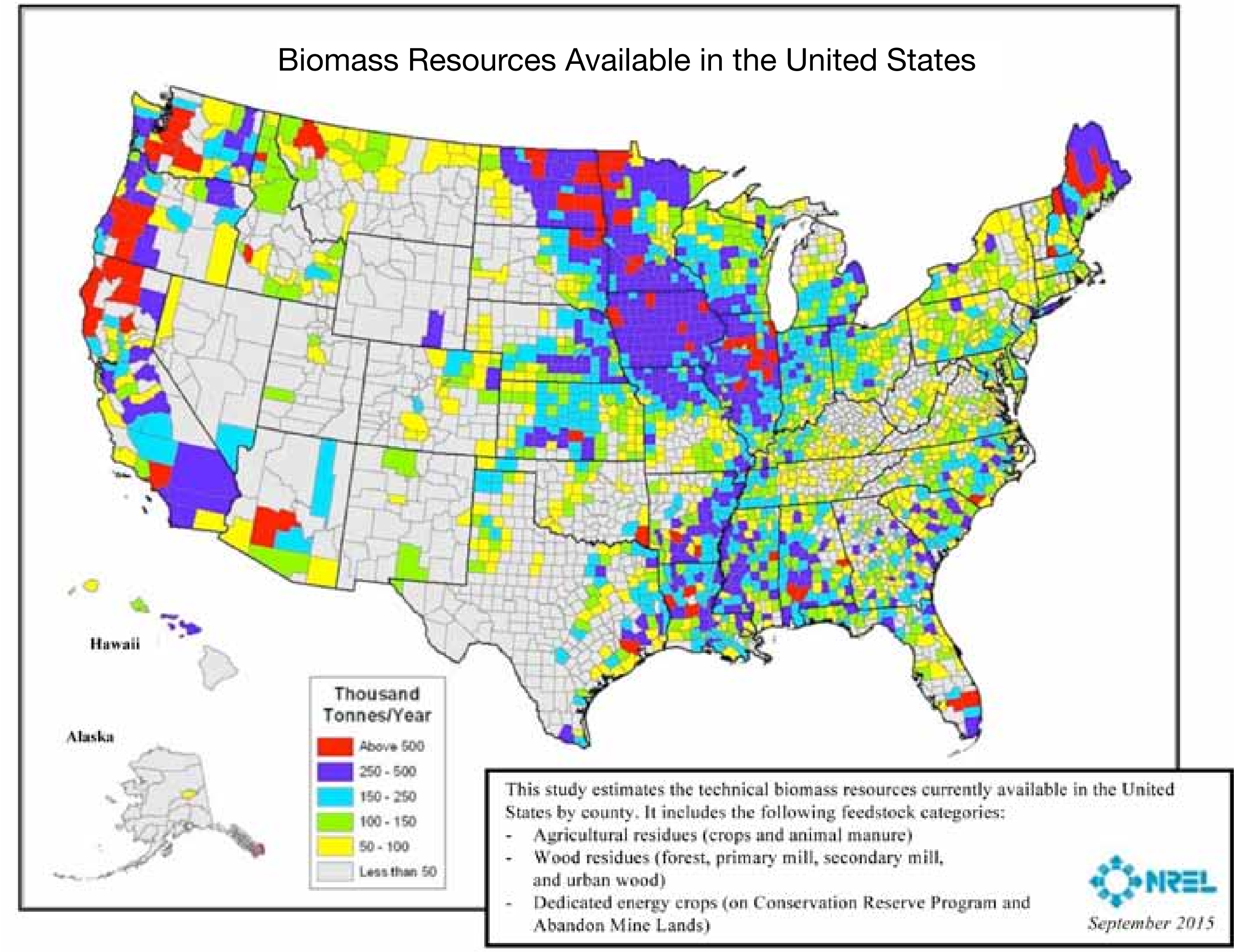
Historically, grasslands occupied approximately 405 million hectares in the U.S. — about one- half of the landmass of the lower 48 states (Conner et al. 2002). The ecological and economic importance of grasslands lies not only in the immense area they cover, but also in the diversity of benefits they produce (Conner et al. 2002) including nutrient cycling, water retention, aquifer recharge, and storage of substantial amounts of atmospheric carbon. Healthy and well-managed grasslands maintain an efficient hydrologic cycle by improving water infiltration and quality of runoff water (Conner et al. 2002). Poorly managed grasslands or those converted to other uses, such as row crops, can result in increased soil erosion and decreased water quality through increases in sedimentation, dissolved solids, nutrients, and pesticides (Conner et al. 2002).

Figure 6. The prairie pothole region is critical for waterfowl recruitment, producing 50–80% of the continent's duck populations (Cowardin et al. 1983, Batt et al. 1989, Reynolds 2005), and providing breeding habitat for more than one-half of the grassland bird species breeding in North America (Knopf 1994) (Source: U.S. Fish and Wildlife Service 2012; www.fws.gov/kulmwetlands/pothole.html).

Grasslands dominated by native perennial grasses and forbs provide critical habitat for many wildlife species (George 1988, McLaughlin and Walsh 1998). For example, the prairie pothole region (Fig. 6), which contains wetland-grassland complexes, is critical for waterfowl recruitment, producing 50–80% of the continent's duck populations (Cowardin et al. 1983, Batt et al. 1989, Reynolds 2005), and providing breeding habitat for more than one-half of the grassland bird species breeding in North America (Knopf 1994). However, as a result of human impact, the biotic diversity of North American grasslands is the most highly impacted of any of the continent's terrestrial ecosystems (Conner et al. 2002). Tallgrass prairies and savannas of the midwestern states have declined by as much as 99% (Samson and Knopf 1994, Conner et al. 2002, Fletcher et al. 2006). Similarly, mixed-grass prairies have declined by an estimated 30-81% and shortgrass prairies by an estimated 20-80%, with estimates varying by state (Samson and Knopf 1994, Conner et al. 2002). Research strongly suggests that maintenance of remaining tracts of native sod prairies is critically important to avoid detrimental impacts on specialist grassland species (Madden et al. 2000, Bakker and

Higgins 2009, Fisher and Davis 2011). Because native grasslands are so critical to ecosystem function, wildlife species, and the economy, every effort should be made to retain the few remaining tracts that exist.

At present, Wisconsin is the only state to have approved sustainable planting and harvest guidelines for non-forest biomass (Hull et al. 2011) even though the prairie region of the upper Midwest has emerged as the largest ethanol production area in the country (Fig. 7; National Research Council 2010). Additional to large amounts of corn produced throughout the region, perennial grasses, whether they are found in prairies, rangeland, pastureland, or CRP, are considered prime candidates for cellulosic ethanol production. This is due to their high biomass production, ability to sequester carbon, tolerance to extreme climatic conditions, compatibility with conventional farming practices, and minimal maintenance requirements (Graham et al. 1995, Tolbert and Schiller 1995, McLaughlin and Walsh 1998, McLaughlin et al. 1999, Rinehart 2006). Low-input high-diversity (LIHD) mixtures of native grassland perennials used to generate biofuel can provide more usable energy, greater



This study estimates the technical biomass resources currently available in the United States by county. It includes the following feedstock categories:

- Agricultural residues (crops and animal manure)
- Wood residues (forest, primary mill, secondary mill, and urban wood)
- Dedicated energy crops (on Conservation Reserve Program and Abandon Mine Lands)

Figure 7. The prairie region of the upper Midwest has emerged as the largest ethanol production area in the country (Source: National Renewable Energy Laboratory 2005; www.nrel.gov/gis/biomass.html).

greenhouse gas reductions, and less agrichemical pollution per hectare than corn grain ethanol or soybean biodiesel (McLaughlin et al. 1999, Bies 2006, Tilman et al. 2006). Tilman et al. (2006) reported that experimental plots of high-diversity (i.e., mixed) grasslands had bioenergy yields 238% greater than monoculture yields after a decade. Furthermore, LIHD biofuels thrived on degraded lands, which circumvented the need to displace other economically important agricultural crops. In addition, gains in net energy returns from perennial grass production are derived from reduced energy investments at all steps of the crop production and conversion pathway leading to ethanol formation (McLaughlin and Walsh 1998).

Conservation Reserve Program Grasslands

Though initially established to reduce crop production, diminish soil erosion, and improve water quality on highly erodible agricultural lands, many native perennial grasses used for CRP have also been considered for use as cellulosic bioenergy crops (Tolbert and Schiller 1995, Milbrandt 2005, Bies 2006, Lee et al. 2007, Schmer et al. 2008). In June 2011, more than 12.5 million ha were enrolled in all forms of CRP (Fig. 8; USDA Farm Service Agency 2011). Of approved program lands in July 2011, 79% were planted in grass mixes, 7% were

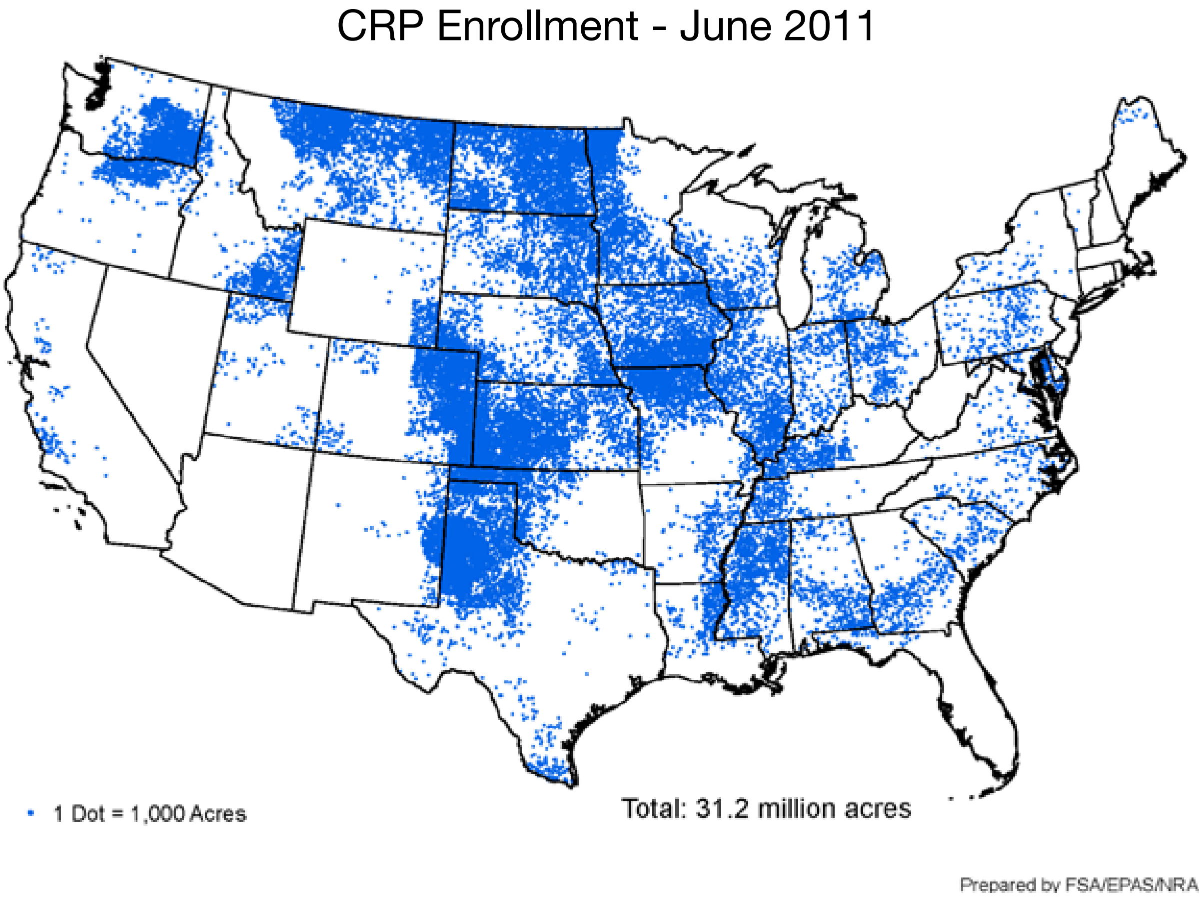


Figure 8. As of June 2011, 12.6 million ha (31.2 million acres) of land were enrolled in the Conservation Reserve Program (Source: Farm Service Agency 2011; www.fsa.usda.gov/Internet/FSA_File/enrolldotmap0611.pdf*).*

planted in trees, and 8% were enrolled in wetland or riparian buffer practices. Six percent of the cover could not be determined by type (e.g., rare and declining habitat, salinity reducing vegetation) though much of it probably is in some form of herbaceous plant mix.

Amount of CRP established in native versus exotic/introduced grass cover types is not currently documented. According to Osborn et al. (1992), introduced grasses and legumes were planted on 71% of the hectares during the first 11 signups. Typically, these plantings reached greatest diversity during establishment when early successional forbs and grasses took advantage of available open space (McCoy et al. 2001a). Landowners saw an equally quick response by wildlife species that preferred early successional habitat types such as eastern cotton-tailed rabbits *(Sylvilagus floridanus),* northern bobwhite, and pheasants. As these pasture grasses became more established, number and diversity of plant and wildlife species generally declined over time (Millenbah et al. 1996, McCoy et al. 2001a, Johnson 2005). If introduced grasses are very aggressive, CRP fields often became monoculture stands with limited wildlife use except as escape, thermal, and nesting cover (Cade et al. 2005). This also seemed to be the fate of many fields in which introduced grasses were unsuccessfully replanted to native grasses or introduced grasses invaded the site from surrounding areas.

A survey of CRP landowners by Vandever et al. (2002) indicated a regional preference in different vegetation covers. Most CRP tree plantings occurred in the Southeast and Mississippi Alluvial Valley, whereas much of the rest of the country was planted to grass. Native grasses were planted more often than introduced grasses in the northern and Midwestern tier of states, and more introduced grasses were planted in the southern Mountain and Pacific states. Over the last 25 years, wildlife species requiring large diverse grasslands, such as lesser prairie chickens *(Tympanuchus pallidicinctus),* have expanded their ranges in states where most CRP plantings were native and have undergone range contractions in states where CRP was largely planted to introduced grasses (Rogers and Hoffman 2005).

Using CRP for Bioenergy

Conservation Reserve Program and marginal croplands are often perceived as underutilized land that could be put into production of nonfood, perennial bioenergy crops for fuel and other uses (Fargione et al. 2009). For some, this would seem to be the ideal solution for solving the on-going food versus fuel debate surrounding use of corn and soybeans for biofuels. But, such a conversion of existing cover on as much as 8 million ha of grassland CRP and other marginal lands likely would have a tremendous effect on its current use by wildlife, especially in the Great Plains. The U.S. Fish and Wildlife Service (USFWS) estimates that CRP has increased duck populations by more than 2 million birds per year in the Prairie Pothole Region since its establishment more than 25 years ago (Reynolds 2005). Nielson et al. (2006) estimated that pheasant populations increase 22% for every 4% increase in CRP within large units of pheasant habitat in cropland settings. In many prairie states, tallgrass prairie conversion to other uses has reached more than 99% and mixed-grass conversion is approaching 80%. This has pushed grassland obligate species into major declines (Johnson 2005). Because almost a quarter of the nation's CRP is in the northern Great Plains, even small, incremental reductions in wildlife benefits may have significant, continental impacts on wildlife populations (Ducks Unlimited 2006).

At present, government incentive programs prohibit use of native, unplowed grasslands (i.e., native sod) for bioenergy feedstock production. In addition to prohibition on use of biomass "harvested from agricultural land cleared or cultivated at any time prior to [December 19, 2007]" in the Renewable Fuels Standard, BCAP also excludes use of federal lands; state-owned, municipal, or other locally-owned lands; and land that is already enrolled in

CRP, Wetlands Reserve Program, or Grassland Reserve Program for bioenergy crop production. Rules allowing use of newly planted CRP biomass for bioenergy production vary depending on whether the land is enrolled in general or Continuous CRP (CCRP) and in forest or grassland cover. More restrictions are placed on use of biomass on environmentally sensitive CCRP lands. On all sites, any removal of biomass must be part of a pre-established site conservation plan or allowed under temporary emergency conditions. Use of CRP grass for economic gain, such as managed harvesting of biomass, imposes a 25% reduction in the annual rental payment to the landowner for the year that such removal takes place, is restricted to set intervals, and must take place outside the primary avian nesting and brood rearing season for that state.

Grassland Bioenergy Planting Considerations

Key Issues for Planting

Distinct vegetational diversity and structural changes occur over time on a field planted in perennial grasses. Overall, warm season grass fields tend to be taller and have more bare ground than cool season fields (McCoy et al. 2001b). On a planting site with adequate soil, growing season length, and moisture, normal succession consists of a 1- to 3-year establishment phase with forb production peaking during the first 2 years. Wildlife that avoid predators by sight and consume forbs and their seeds are dominant during this time. The forb stage is followed by a thickening of the grass stand canopy cover in years 2 through 5. As grasses increase in dominance, early open-area cover and low-growing annual forbs and legumes are replaced by denser cover and taller perennial forbs that alter wildlife use and usher in a different suite of wildlife.

Dense grass establishment after years 3 to 5 causes a reduction in plant species diversity and avian nesting cover and an increase in litter layer (Millenbah et al. 1996, McCoy et al. 2001 *a,b,*, Cade et al. 2005). Because most grasses developed under disturbance factors that included grazing pressure and fire regimes, lack of such factors causes an accumulation of standing biomass and litter and a reduction in vigor as site nutrients are tied up. There are wildlife species that use this stage but overall numbers and diversity are often low. Such decadent, low diversity stands are common situations on older and reenrolled CRP fields or planted monocultures in which little standing biomass has been removed by fire, haying, grazing, or other management. In such instances, biomass harvest can be used to increase grass stand health, productivity, and species diversity (Knapp and Seastedt 1986). Any successional rollback will be short lived, however, because established grasses regrow rapidly if sufficient nutrients and moisture are available.

Perennial grass stands in areas with very short growing seasons, limited moisture, or poor soils will experience delays reaching maximum stand density. Under harsh growing conditions, the forb stage may be extended and the grass canopy may slowly continue to increase for 10 years or more. These sites may not be suitable for bioenergy crop production.

Wildlife Responses to Grassland Bioenergy Crop Planting

Birds.— Expanding perennial grass bioenergy crop production may have positive and negative effects on grassland bird species. During the last 25 years, resident and migratory grassland bird populations have shown steeper, more consistent, and more geographically widespread declines than any other behavioral or ecological guild of North American bird species (Knopf 1994, Herkert 1995, Igl and Johnson 1997, Peterjohn and Sauer 1999, Fletcher and Koford 2002, North American Bird Conservation Initiative, U.S. Committee 2011). Because of severe habitat loss, habitat restoration is the key to conservation of grassland ecosystems (Herkert et al. 1996, Fletcher et al. 2006) and planting mixed-native perennial grass/forb fields might provide some of this needed habitat. However, if bioenergy crop plantings replace existing native habitat types and are improperly managed or harvested, or planted to pure grass stands lacking forbs or to monocultures of introduced species, the current pattern of habitat loss would likely continue or even intensify. A suite of factors associated with agricultural intensification also can reduce habitat quality for grassland birds. These include greater potential for inappropriate or excessive use of pesticides, herbicides and fertilizer; removal of natural field edges; spring plowing; land drainage; replacement of mixed farms with farms dominated by one crop; harvesting or mowing earlier in the season when birds are still nesting or rearing broods; and harvesting needed winter thermal cover or early spring nesting cover (Askins et al. 2009).

Mammals.— Although few studies have investigated effects of bioenergy production on grassland-dwelling mammals, Hall and Willig (1994) studied responses of small mammal populations in Texas to species composition, diversity, and succession of exotic grass CRP plantings. They found that the greatest mammalian species diversity occurred during the first 3 years after stand establishment at which point small mammal diversity was similar to that in surrounding native short grass prairie, although species density composition was significantly different, possibly due to lack of disturbance on CRP.

Invertebrates.— Landis and Werling (2010) reviewed potential impacts of perennial grass bioenergy crop planting on arthropods and potential effect of arthropods on bioenergy production. They concluded that:

- Arthropods are possible pests on bioenergy crops due to increases in existing pests, emergence of new ones, pest spillover into surrounding crops, increases in insecticide resistance, and potential loss of biological control agents as vegetation diversity declines with some bioenergy crop production scenarios.

- Bioenergy crop production can negatively affect arthropod habitat, communities, distribution, and availability as prey for other trophic levels by decreasing species richness.

- Bioenergy crops can act as hosts for crop diseases and arthropod pests. Huggett et al. (1999) found that corn leaf aphids readily colonized miscanthus in a greenhouse and transmitted Barley Yellow Dwarf Virus (BYDV) to it. Miscanthus could then act as a bridging host for the virus by passing it from summer to fall and winter cereal crops. Switchgrass also hosts BYDV (Huggett et al. 1999) and corn flea beetles. Wilson and Shade (1966) observed that cereal leaf beetle larvae feed on reed canary-grass *(Phalaris arundinacea),* which can act as a host reservoir for the spread of this pest to grain crops.

- Replacing native, diverse vegetation with monoculture stands of bioenergy crops may reduce current natural biological control. According to Bianchi et al. (2006), forests and grasslands provide critical habitat for natural enemies of arthropod crop pests.

- Polyculture stands of native bioenergy crop species can harbor and increase beneficial insects, including pollinators. Switchgrass and native grass/forb mixes supported abundant populations of beneficial insects that could reduce biomass losses to pests.

- Replanted native grass mixes used for bioenergy supported more arthropod diversity than did monocultures of crops or bioenergy plantings but not as much as unbroken native prairies. The most diverse landscapes supported the most diverse arthropod populations.

Similarly, Robertson et al. (2012) found the diversity and biomass of arthropod communities associated with 2 types of candidate perennial biomass plantings (i.e., switchgrass and mixed prairie) were substantially enhanced relative to those associated with corn ethanol production. Results indicated switchgrass and mixed-grass–forb prairie plantings were associated with a 230% and 324% increase in arthropod family diversity and a 750% and 2,700% increase in arthropod biomass, respectively, when compared to annually planted corn. Furthermore, results emphasized an important role for crop placement within the landscape in determining diversity and biomass of terrestrial arthropod communities and the provisioning of arthropod functional groups responsible for important ecosystem services.

Management Implications

Wildlife use of grassland bioenergy crops depends on herbaceous species present, habitat quality, site productivity, rainfall, growing season length, surrounding vegetation on a local and regional spatial scale, timing, amounts and patterns of harvests, and ongoing management (McCoy et al. 2001a, Farrand and Ryan 2005, Johnson 2005, Fargione et al. 2009). Vegetation located on good soils in mesic sites with longer growing season areas establish and mature faster and provide greater amounts of cover for wildlife and biomass harvesting than poor sites with drier and/or shorter growing seasons (Burger 2005). Sites with the highest vegetative and structural diversity also contain the greatest wildlife diversity (Cade et al. 2005). Over time, unmanaged grasslands decline in diversity and wildlife use (Millenbah et al. 1996, McCoy et al. 2001a, Johnson 2005).

Depending on the bioenergy species planted, its tolerance to various herbicides, and its response to fertilizer applications, chemicals may be used to reduce competition and increase productivity during the early establishment phase. Use of herbicides may reduce site diversity and affect wildlife use, but it is also possible that selective herbicides could improve habitat for some species by favoring wildlife-friendly plants in addition to biomass crops. Fertilizing may be beneficial during site establishment and can maximize amount of biomass produced. Fertilizers should be limited to the minimum amount needed to establish the stand and replace nutrients lost through harvesting. Excessive fertilization wastes money, limits stands to the few species able to tolerate dense monocultures, and may result in nutrient runoff to nearby waterways, negatively impacting water quality and aquatic species. Properly applied best management practices can significantly reduce potential water quality impacts of fertilization.

From a wildlife diversity standpoint, planting multispecies herbaceous bioenergy mixes consisting of native ecotypes are preferred because they are best suited to local environmental conditions and provide the highest quality wildlife habitat. Use of native ecotypes rather than nonecotypical natives, introduced species, or genetically modified organisms also reduces risk of bioenergy plantings becoming invasive (Fargione et al. 2009) or causing unexpected disease or pest problems (Landis and Werling 2010).

From a production standpoint, Tillman et al. (2006) reported that diverse (16 species) native mixes planted on degraded infertile land produced more than twice the biomass a decade after establishment compared to monoculture plantings and contained 51% more overall energy than current corn and soybean biofuels grown on fertile lands. Fornara and Tilman (2008) stated that addition of legumes to a native grass mix also naturally increased nitrogen and carbon sequestration levels on the site.

Managers should note that CRP and grassland bioenergy production fields make up just part of the overall local landscape mosaic. Such fields are often intermixed with cropland, pastureland, rangeland, forest, and developed parcels. Sizes of these differing parcels, their juxtaposition to each other, and seasonal food and cover that each provides (or fails to provide) are major determinants of use of an area by different wildlife species (Cade et al. 2005). This can be especially critical for species requiring specialized habitat types (most at-risk species) or large contiguous blocks of habitat (Rogers and

Hoffman 2005). Because crop and grasslands and surrounding landscape uses are dictated by landowner goals, in most landscapes it is not possible to create the ideal spatial blend of habitat types needed to benefit targeted wildlife species. Wildlife needs should be considered wherever possible by those planning any projects intended to be environmentally beneficial. Under CRP rules, wildlife is considered a co-equal resource concern with soil and water and must be taken into account during vegetation establishment and management.

Grassland Bioenergy Crop Maintenance Considerations

Wildlife's Responses to Bioenergy Crop Maintenance

Birds.— Increasing site disturbance through occasional fire, disking, or other method can help increase bird use, because bird species that prefer open ground are quick to use newly planted or disturbed fields for feeding and brood rearing. Vegetational diversity peaks during the pre-grass establishment period with an influx of early successional grasses and forbs on recently planted sites (McCoy et al. 2001a). Site diversity declines as grasses become dominant and out-compete annual and perennial forbs (McCoy et al. 2001a). Bird use shifts from nesting to brood rearing as grass establishment progresses. Depending on the site and speed of grass establishment, nesting success generally remains low during the first year or 2 after planting due to limited screening cover for birds and their nests (Millenbah et al. 1996) but increases as overhead cover improves during mid-establishment years. If the site remains undisturbed after grasses are fully established, overall nesting activity declines due to the decreasing site diversity while brood rearing activity increases (Millenbah et al. 1996, McCoy et al. 2001a). Applying fertilizer increases stand thickness, which shades out competing vegetation and limits movement of ground-nesting and dwelling species such as northern bobwhite. A checkerboard of fields in various stages of establishment, disturbance, and harvest maximizes wildlife use of an area.

Mammals.— Hall and Willig (1994) recommended periodic disturbance of perennial grasslands through fire or grazing to maintain vegetative diversity and restore composition of early successional mammalian species.

Herpetofauna.— Little research has examined herpetofauna use of perennial grass or response to biomass removal. Sites with well-managed, diverse native bioenergy or companion plantings should provide the food, travel corridors, and cover needed for most grassland herpetofauna species. Such travel corridors should connect to aquatic habitat types wherever possible to maximize benefits for amphibians and other wetland dependent species.

Invertebrates.— Landis and Werling (2010) observed that long-term management of native and reconstructed prairies impacted arthropod numbers and diversity. Mixed-species plantings increased beneficial insect numbers including pollinators. Invertebrate diversity decreased over time with increased biomass removal. Reductions in burning or amount of flowering plants also reduced some arthropod taxa. Similarly, Robertson et al. (2012) indicated switchgrass and mixed-grass–forb prairie plantings were associated with an increase in arthropod family diversity and arthropod biomass when compared to annually planted corn.

Management Implications

Wildlife-beneficial bioenergy management should maintain site diversity and travel corridors through multispecies or companion plantings and ongoing management such as disking, burning, and interseeding. Well-considered monoculture bioenergy plantings, with interspersed strips of diverse native companion plantings, also can minimize biological pests and spread of disease. Sites with companion or interseeded plantings of forbs and legumes will require regularly performed management such as fire, disking, or interseeding to maintain diversity, vigor, and wildlife-friendly stand structure. Older stands may benefit from occasional prescribed burns to release nutrients, restore grass vigor, and reduce litter accumulation. Burning, disking, and other disturbances also can open the stand and promote increased site diversity.

Harvesting Grassland Bioenergy Crops

Key Issues for Harvesting

Harvesting bioenergy crops temporarily removes overhead and thermal cover and reduces structure until the following growing season. Depending on site conditions, species planted, and other management factors, harvesting may take place annually or biennially. Unlike the initial establishment phase, full regrowth of harvested cover usually occurs within 1 growing season in mesic areas. This limits increases in vegetative diversity on disturbed sites to a short window.

Most herbaceous bioenergy crops are harvested after the first hard frost when the plant has moved the bulk of above-ground nutrients back to roots. Dormant season harvesting maximizes cellulosic content of standing biomass, minimizes process contaminants such as metals, reduces moisture, and reduces fertilizer inputs needed to maintain a healthy stand (Adler et al. 2006, Harper and Keyser 2008). Removal of standing biomass prior to March can negatively impact wildlife if it is needed for winter thermal or escape cover, but late fall or early winter removal causes less direct mortality than harvesting during nesting, fawning or brood rearing seasons (Harper and Keyser 2008).

Conversely, current CRP rules (U.S. Department of Agriculture Farm Service Agency 2010) require biomass harvest only once every 3 years. Harvest and removal must be completed within 120 days of the end of primary nesting/brood rearing season for birds. This time period generally falls during the active growing season and, if done early enough, may provide the site with a chance to reestablish critical nesting, fawning, thermal, and escape cover in the subsequent year. However, growing season harvest removes nutrients from the site which may have to be replaced by fertilization. Growing season harvest also lowers quality of the biomass for some uses (Adler et al. 2006, Harper and Keyser 2008).

Wildlife Responses to Harvesting

Birds.— Murray and Best's (2003) study of avian response to switchgrass harvesting noted that abundances of bird species in fields changed due to differences in vegetation structures present in totally harvested, partially harvested, and unharvested fields, although total bird abundance and species richness did not. Niche partitioning was noted: grasshopper sparrows *(Ammodramus savannarum)* preferred harvested areas, and sedge wrens *(Cistothorus platensis)*, nesting pheasants, and northern harriers *(Circus cyaneus)* preferred unharvested fields.

A recent study of response of pheasants and waterfowl to harvest intensity of warm-season perennial grasses for biofuel production in southeastern South Dakota indicated no effect of residual stubble height on bird diversity, abundance, or nest success during summer surveys following a fall harvest (Bender 2012). However, a significant difference was detected in nest initiation dates for hen mallards *(Anas platyrhynchos);* nests were initiated a full month later on harvested sites versus non-harvested sites (S. P. Rupp, South Dakota State University, personal communication). Total biomass yield averaged 0.8 short tons/ha on sites with a residual stubble height of 10 cm, whereas sites harvested at 30 cm averaged 0.4 short tons/ha (Bender 2012) – well below the target goal of 3.2 to 4 dry tons/ha/year established by DOE (English et al. 2006).

As part of the same study in southeastern South Dakota, Maves (2011) determined that the most important factor regarding biomass stands and their use by grassland songbirds is structural diversity resulting from harvest intensity. Densities of savannah sparrow *(Passerculus sandwichensis)* and dickcissel *(Spiza americana)* males were significantly higher on harvested sites in 2010 than on non-harvested sites in 2009. In contrast, differences in average maximum density of territorial males among treatments were not significant for grasshopper sparrows or bobolinks. Therefore, a single harvest strategy cannot be recommended. Ultimately, the key to more diverse vegetative structure and bird species composition is to vary harvest intensities (Maves 2011).

Mammals.— Current perennial grass cover is used by a variety of large and small mammals. It is often the only dependable cover available to them in primarily farmed or arid areas. Biomass harvesting exposes small mammals and other prey species to avian and land-based predators attracted by the activity. Companion strip and block plantings as well as unharvested areas can provide escape cover and safe travel lanes during harvest (Harper and Keyser 2008).

Herpetofauna.— As mentioned previously, little research has examined herpetofaunal use of perennial grass or response to biomass removal. Biomass removal during late fall and winter would be expected to have little impact on hibernating reptiles and amphibians. Lack of cover during mating and dispersal periods may negatively impact some species by increasing predation or desiccation.

Management Implications

Harvesting biomass affects amount and diversity of food and cover available to wildlife. Ideally, whether a site should be partially or completely harvested depends on current wildlife use and ability of the site and surrounding landscape to continue providing food, water, cover, and space to resident wildlife. Landowners and managers should identify potential limiting factors for local species of concern both on and off site when creating bioenergy crop harvest management plans. Harper and Keyser (2008) recommend leaving 5% of cover in the field after harvesting in widths and patterns that provide wildlife refugia.

Height and timing of plant material removal also influence both plant and animal species diversity on site. Removal during the growing season favors established warm-season grass regrowth, whereas removal during the early dormant season allows growth of cool-season forbs and legumes on harvested sites. However, biomass production for bioenergy requires, in most cases, dormant-season harvesting to maximize cellulosic content of standing biomass (Adler et al. 2006, Harper and Keyser 2008).

Delaying harvesting of bioenergy crops until late winter/early spring retains winter thermal cover for wildlife when it may be critically needed. Delayed harvest has added benefits of providing flexibility in harvest timing, allowing product storage on the field and reducing bioenergy crop moisture content without yield reductions in areas receiving less than 23.6 cm of snow per year (Harper and Keyser 2008). Over-winter cover retention also can be achieved by staggering harvest of standing bioenergy crops so that one-half of the material is left in the field to be harvested the following year in areas with a biennial cycle. According to Harper and Keyser (2008), even though only one-half the standing bioenergy crop is harvested each year, most of both years' normal bioenergy crop production is retained over the 2-year cycle and still available at harvest.

Part 3: Forest Ecosystems

Biomass from forests currently accounts for more global energy consumption than all other forms of "renewable" energy combined (Fig. 9; Food and Agriculture Association 2010). In 2008, woody biomass provided about 3% of total energy used in the U.S. and about 33% of renewable energy consumed (Taylor 2010). Most wood-derived energy is currently generated by the forest products industry and used in its manufacturing facilities (Taylor 2010). Although demand has been lower in North America compared to other continents, interest is growing in deriving energy from wood, particularly from pellets and residues, and various types of dedicated feedstock supplies (Food and Agriculture Association 2010). More recently, demand for pellets in Europe has led to increased exports of wood pellets from the United States. Depending upon market conditions, the U.S. DOE (2011:50) has projected that forest thinnings, harvest residues, and wood wastes could annually provide 79 to 97 million dry short tons of bioenergy feedstocks in 2012 and 83 to 102 million dry short tons by 2030.

Woody biomass is derived from forest ecosystems that vary widely in attributes such as species composition, structure, and age class in response to factors such as climate, geology, soils, natural disturbance regimes, and management practices (Bailey and Smith 2009). In the U.S., forest area has been relatively stable for the last 100 years, and approximately 304.0 million ha, or 33.2% of the land area, is forest (Smith et al. 2009). However, land often transitions between different uses (e.g., agriculture, forest, development) and forests routinely change in structure and composition due to succession, natural disturbance, and management. Most (92%) forests in the U.S. are of natural origin and planted forests (8% nationally) are most common in the southern U.S., about 20% of all southern forests (Smith et al. 2009). Private ownership is more prevalent in the eastern U.S. than in the western U.S. (81% vs. 30%), and averages about 56% nationally. About two-thirds (208.1 million hectares) of U.S. forests are classed by the USDA Forest Service as timberland (capable of producing

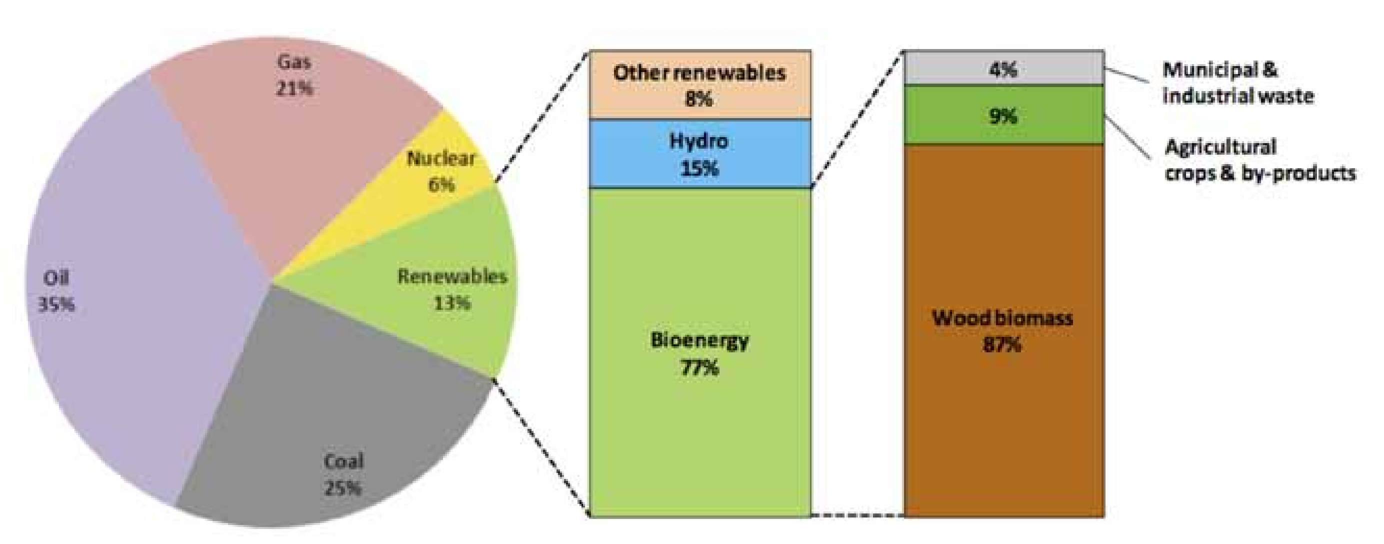


Figure 9. Share of bioenergy in the world primary energy mix (Source: IEA Bioenergy ExCo: 2009:05; www.globalbioenergy.org/uploads/media/0908_IEA_Bioenergy-Bioenergy_%E2%80%93_A_sustainable_and_reliable_energy_source_ExSum.pdf*).*

Table 2. Comparison of existing forest biomass harvesting guidelines in the United States. Italics indicate recommendations that reference existing guidelines for general harvests. Acronyms used in the table include those for fine woody debris (FWD) and coarse woody debris (CWD).

Provisions	KY	MD	ME	MA	MI	MN	MO	PA	WI
Litter, stumps and roots	Discouraged	--	Retain	--	Retain	Retain	--	Retain	Retain
FWD – Existing	Retain 15-30 %	--	Retain as much as possible	--	Retain as much as possible	Retain as much as possible	Retain as much as possible--	Retain as much as possible	Retain as much as possible
FWD – harvest residue	Retain 15-30 %	--	Retain as much as possible	20%	Retain 1/6 – 1/3 tops and limbs < 10.2 cm	Retain 33% + 10-15% incidental breakage	Retain ≥ 33 %	Retain ≥ 10 %	Retain ≥ 10 %
CWD – existing	General recommendations	--	Retain as much as possible	--	Retain as much as possible	Retain as much as possible	--	--	Retain as much as possible
CWD – harvest residue	--	General recommendations	Retain as much as possible	General recommendations	General recommendations	Retain 4.9 – 12.4 bark-on down logs/ha > 30 cm diameter	Retain ≥ 33 %	Retain 15% - 30% Fell 4.9 – 12.4 leave logs ha	--
Snags	General recommendations	General recommendations	Retain all possible	General recommendations	General recommendations	Retain all possible	Habitat specific	2.5 - 12.4 snags/ha	*≥ 7.4/ha*
Green trees / cavity trees	General recommendations	--	Retain live cavity trees	10-20%	General recommendations	5% clumps OR 14.8 – 29.7/ha	Size class specific	12.4 cavity trees/ha	*5% - 15%*

1.4 m^3 per hectare of industrial wood annually) and are not legally reserved from timber harvest (Smith et al. 2009). It is from these forests that most forest bioenergy feedstocks are likely to be derived. During 2006, net growth of wood on timberland exceeded growing-stock removals (e.g., wood harvested) by about 72% (Morgan et al. 2009). Roundwood harvested for fuel during 2006 represented only about 5.3% of net growth (Smith et al. 2009).

Forests, including those that are intensively managed, provide habitat for many species of conservation concern, support major components of regional biodiversity, and comprise a large proportion of land cover in many regions (Carnus et al. 2006, Stephens and Wagner 2007, Brockerhoff et al. 2008). However, because biomass harvesting practices change forest structure and may be applied more widely than intensive forest management, questions have been raised about potential responses by wildlife. By altering structural features (e.g., snags, tree density, plant species composition) at the stand scale, forestry practices can enhance or reduce habitat for particular wildlife species (Duguay et al. 2000, Weakland et al. 2002). Exactly how more expansive biomass harvesting

Table 3. Special provisions and web access information for forest biomass harvesting guidelines by state. Italics indicate recommendations that reference existing guidelines for general harvests.

Provisions	KY	MD	ME	MA	MI	MN	MO	PA	WI
Specific mast tree guidelines	--	--	YES	--	YES	YES	YES	--	*YES*
Discouraging re-entry	YES	YES	YES	YES	--	YES	YES	YES	--
Primary nesting season restrictions	--	--	--	--	--	--	--	--	--
T&E species and/or rare habitats	YES	YES	YES	--	YES	YES	YES	YES	YES
Thinning	--	--	--	YES	YES	--	YES	--	--
Harvest of understory vegetation	--	--	--	--	--	--	--	--	--
Short-rotation woody crops	YES	YES	--	YES	--	--	--	YES	--
Intercropping	--	--	--	--	--	--	--	--	--

Kentucky:	www.forestry.ky.gov/Documents/Biomass Harvesting Recommendations Oct 2011.pdf
Maine:	www.maine.gov/doc/mfs/pubs/biomass_retention_guidelines.html
Maryland:	www.dnr.state.md.us/forests/pdfs/MDBiomassGuidelines.pdf
Massachusetts:	www.mass.gov/eea/docs/doer/renewables/biomass/bio-silviculture.pdf
Michigan:	www.michigan.gov/documents/dnr/WGBH_321271_7.pdf
Missouri:	mdc4.mdc.mo.gov/applications/MDCLibrary/Library.aspx?ArtID=19813
Minnesota:	www.frc.state.mn.us/documents/council/site-level/MFRC_FMG&Biomass_2007-12-17.pdf
Pennsylvania:	www.dcnr.state.pa.us/PA_Biomass_guidance_final.pdf
Wisconsin:	www.council.wisconsinforestry.org/biomass/

practices might impact wildlife is unclear but likely will vary depending on the taxa affected, the nature, extent and context of the specific silvicultural practice, spatial and temporal scales of assessment, and other factors. Ultimately, silvicultural practices used to procure woody biomass for bioenergy production will depend primarily on energy markets.

To address concerns about environmental issues associated with biomass harvests, 9 states have developed forest biomass harvest guidelines that focus on harvest methods that could increase in the near term and that need further research and evaluation (Tables 2 and 3). Guidelines in all 9 states emphasize some combination of retention of downed coarse woody debris (DCWD), fine woody debris (FWD), snags, and green trees. Recommended retention levels for these features understandably vary among states and range from the general suggestion to retain as much as possible to more specific numeric thresholds. Guidelines in 7 of 9 states explicitly encourage harvesting biomass concurrently with normal thinning or timber harvest operations to reduce impacts of multiple re-entries. Most also provide guidance for conservation-priority forests containing threatened and endangered species, sensitive plant communities, or rare habitat types. Guidelines have also been developed by other organizations (e.g., Forest Guild Biomass Working Group 2010, 2012) and some sustainable forestry certification programs are considering adjustments to their standards to more specifically address issues related to biomass harvest.

Bioenergy feedstocks will be derived largely from forests through 4 practices: (1) removal of harvest residues, (2) forest thinnings, (3) short-rotation woody cropping systems, and (4) intercropping (Riffell et al. 2011a). Each of these will affect forest structure differently at the stand scale, and each likely will be applied differently across landscapes. Thus, we discuss below potential wildlife responses to each of these practices.

Removal of Harvest Residues

Large amounts of woody residue often remain after traditional forest harvest operations. These forest harvest residues include growing stock volume cut or knocked down during harvest (e.g., tree-tops, limbs, slash, foliage, and felled non-crop trees), small-diameter trees with lower values that do not justify costs of removing them, and dead wood and non-commercial tree species typically left at harvest sites (Gan and Smith 2006). Because these residues could potentially help meet increasing demand for bioenergy, the practice of removing harvest residues could become economically and practically feasible.

Key Issues for Harvest Residue Removal

Removing harvest residues most likely would lead to reductions in density of snags and amount of other types of woody debris in such managed stands because residues would typically be left in (or redistributed over) the stand after harvest operations are finished. Thus, 3 major issues for wildlife include:

1. *Changes in snag density.* Snags are standing dead trees ≥ 1.8 m in height and ≥ 10.2 cm diameter at breast height (dbh) (Thomas 1979).

2. *Changes in volume of coarse woody debris.* DCWD is dead wood such as logs, stumps, piles of limbs, and other woody material found on the forest floor. No universally recognized minimum size criteria exist (Jones et al. 2009). However, most studies have defined DCWD as > 10 cm in dbh and > 60 cm in length.

3. *Changes in fine woody debris volume.* FWD is down, dead woody material < 10 cm in dbh or < 60 cm in length.

Wildlife Response to Harvest Residue Removal

Various taxa use different forms of dead wood to meet breeding habitat requirements and other life-history needs (Harmon et al. 1986, DeMaynadier and Hunter 1995, Freedman et al. 1996, McIver and Starr 2001, Russell et al. 2004, Jones et al. 2009), but it is unclear the extent to which different taxa require woody debris because manipulative studies are few (except for birds), limited in geographic scope, and offer mixed results.

Birds.— A recent meta-analysis of experimental manipulations of snags and DCWD indicated that bird communities were less diverse and bird guilds and species were less abundant on treatments with lower amounts of snags and/or DCWD (Riffell et al. 2011b). This response was consistent across all types of manipulations (e.g., DCWD removal and snag addition), and effects were much greater for birds than for other taxa (Riffell et al. 2011b).

Positive relationships between birds and snags in forested landscapes have been well-documented (e.g., McIver and Starr 2001), and many more species decrease than increase when snags are removed (Sallabanks and Arnett 2005, Riffell et al. 2011b). Salvage-logging also consistently reduces abundance of many bird species, especially fire-dependent species (Hutto and Gallo 2006, Schwab et al. 2006, Koivula and Schmiegelow 2007, Saab et al. 2007). Changes in abundance of snags and DCWD may influence birds by reducing availability of breeding sites, invertebrates that serve as food resources for cavity nesters and other birds, and sites for foraging, perching, and communication (Lohr et al. 2002 and references therein).

Response to CWD removal may not be as pronounced for wintering birds (Lohr et al. 2002, Riffell et al. 2011b). Wintering birds are typically non-territorial, less strongly tied to particular habitat types, and may forage over larger spatial areas. Snag and DCWD reduction may facilitate winter flock formation and improve predator vigilance by decreasing canopy density. Furthermore, wintering bird communities often contain a different suite of species compared to breeding birds (Lohr et al. 2002).

Mammals.— Response of mammals to changes in snag densities is not well studied (Mosely et al. 2008, Riffell et al. 2011b). A recent meta-analysis observed a small negative response by mammals to snag additions (Riffell et al. 2011b) suggesting that snag removal may not lower mammal diversity, but this was based on only a few species responses. However, mammals often use DCWD as cover and for travel corridors (Zollner and Crane 2003, Waldien et al. 2006) and to forage for or store food (Seastedt et al. 1989). Nonetheless, a meta-analysis of 4 papers involving manipulations of DCWD indicated little or no consistent response of mammal diversity to DCWD manipulations (Riffell et al. 2011b). Although positive correlations between DCWD volume and small mammal abundance have been observed for several species of shrews, rats, and mice (Carey and Johnson 1995, Lee 1995, Maidens et al. 1998, Butts and McComb 2000, McCay 2000, McCay and Komoroski 2004, Cromer et al. 2007), positive correlations are lacking in many other situations (Menzel et al. 1999, Bowman et al. 2000, Billig and Servello 2002, Payer and Harrison 2003, McCay and Komoroski 2004).

Existing correlative studies hint at 2 potentially important caveats of mammal response to DCWD manipulations. First, mammals may respond more strongly to DCWD in intensively managed forests where DCWD volumes are typically lower (Carey and Johnson 1995, Bowman et al. 2000) and where biomass harvests are most likely to occur. Second, mammals may be most strongly affiliated with older, larger, more decayed DCWD (Maidens et al. 1998, Bowman et al. 2000, Butts and McComb 2000, McCay 2000, Cromer et al. 2007) and influence of biomass harvests on older, decayed DCWD for several years (or more) post-harvest likely will depend upon the extent to which this material is suitable as a feedstock. The physical and chemical properties of wood influence efficiency of most energy conversion processes (Kenney et al. 1990) and, therefore, will affect decisions about types of material are harvested from a site.

Herpetofauna.— Current knowledge about how amphibians respond to changes in snags is limited, and reptile responses are even less understood (Russell et al. 2004). In a manipulative experiment in South Carolina, reptile and amphibian diversity and abundance were lower when snags were added, possibly because adding snags increased predation pressure from birds (Owens et al. 2008, Riffell et al. 2011b). If similar patterns are observed in other regions and forest types, then removing snags for bioenergy production may not negatively influence herpetofauna.

Forest herpetofauna use DCWD as refugia, as foraging substrates, and for basking and mating displays (Harmon et al. 1986). Additionally, poikilotherms may gain thermoregulatory and moisture-retaining benefits from DCWD and litter (deMaynadier and Hunter 1995, Russell et al. 2004, Semlitsch et al. 2009). For amphibians, moist, decaying wood lowers risk of desiccation (Harpole and Haas 1999, Semlitsch et al. 2009), increases survival (Rothermal and Luhring 2005), and lowers evacuation rates from clearcut harvests (Semlitsch et al. 2008). Data specific to reptiles are lacking.

Although herpetofaunal diversity and abundance often have been associated with higher levels of DCWD (Enge and Marion 1986, Crosswhite et al. 2004), meta-analysis of manipulative experiments indicates that responses to changes in DCWD and snags may not be large nor consistent (Riffell et al. 2011b). For reptiles, diversity and abundance increased – but only slightly – when DCWD was increased, and decreased when DCWD was removed (Owens et al. 2008, Todd and Andrews 2008). Both additions and removals of DWCD decreased amphibian diversity (Riffell et al. 2011b), possibly indicating that amphibian response is related to disturbance associated with manipulating woody debris, although responses were only from a single forest type (i.e., loblolly pine [Pinus taeda] forest in South Carolina). Use of DCWD may be greater when their primary refuge – litter – is reduced or not available (Moseley et al. 2004). Removal of harvest residues may not elicit strong responses from amphibians in the short-term because amphibians may prefer old, decayed DCWD (Herbeck and Larsen 1999, Grialou et al. 2000, Hicks and Pearson 2003, McKenny et al. 2006). However, long-term responses (several years post-harvest) could be large and negative if removing harvest residue changes the long-term availability of older, decayed DCWD in managed forests.

Invertebrates.— Invertebrate biomass often decreases when snags and DCWD are removed (Riffell et al. 2011b). Richness and abundance of taxonomic groups responded less often, less strongly, and in contrasting ways – diversity and abundance responded negatively both when DCWD and snags were removed and when DCWD or snags were added (Riffell et al. 2011b). However, 93% of measured responses in the Riffell et al. (2011b) meta-analysis were from loblolly pine forests in South Carolina, so it is impossible to extrapolate these results to other regions and forest types.

Removing dead wood may influence many groups of insects by small amounts, but cumulative reduction in total invertebrate biomass may be substantial (Horn and Hanula 2008:165) and could be the mechanism responsible for negative responses of birds to removing dead wood (Lohr et al. 2002). More research about links among dead wood, invertebrate prey, and birds is needed to establish this as a causal relationship. Removal or reduction of DCWD and snags also may influence invasive species with negative ecological or economic effects. For example, Todd et al. (2008) observed that the invasive, red imported fire ant *(Solenopsis invicta)* was more abundant in DCWD removal plots, and fire ants are a predator on birds, mammals, reptiles, and amphibians (Allen et al. 2004, Suarez et al. 2005).

Fine woody debris (< 10 cm dbh or < 60 cm length) is typically considered an important structural part of forest ecosystems. However, research about how wildlife use FWD is scarce, making it difficult to accurately predict how biodiversity will respond to changes in FWD related to removing harvest residues. In one study, small mammals used FWD disproportionately to availability, but experimental changes in post-harvest FWD treatments did not affect populations (Manning and Edge 2008). Similar to how invertebrates appear to respond to DCWD removal, spider density – but not diversity – declined when FWD was removed in Appalachian forests (Castro and Wise 2009). Community composition also changed because different spider guilds responded both positively and negatively (Castro and Wise 2009). FWD may be more important for invertebrates when levels of DCWD are low (Kruys and Jonsson 1999).

Management Implications

Birds most likely would respond negatively, at least in the short term, if removal of harvest residues results in sustainably less down or standing CWD. Invertebrate biomass may also be decreased. How removal of forest harvest residues will affect other taxonomic groups is unclear. Negative impacts of removing harvest residues may be limited by several operational realities. First, biomass harvesting will not likely happen across entire landscapes nor happen at the same time, so that even where frequent biomass harvests occur, dead wood resources should be available in much of the landscape at any given point in time. Second, the increasingly diverse and fragmented forest ownership in many parts of the U.S. will help ensure high landscape-scale diversity, which will help maintain dead wood resources. Third, biomass harvest within context of traditional forestry often will take place on large private forest ownerships under auspices of forestry certification programs that have biodiversity considerations that require participants to establish and maintain components of forest structure, such as CWD and snags on the landscape.

Forest Thinning

Forest thinning is a silvicultural treatment that reduces tree density primarily to improve tree growth, enhance forest health, or promote economic returns (Helms 1998). Stands can be thinned before competitive self-thinning to meet economic and biodiversity conservation objectives (Hayes et al. 1997, Carey and Wilson 2001, Hayes et al. 2003) and forest restoration (Hayes et al. 2003, Harrod et al. 2009). Wood products resulting from thinning operations are used in a variety of ways, although currently up to 60% of harvested material remains on-site (Parikka 2004). An increase in availability of biofuels processing facilities may increase removal and use of thinned material (USDA Forest Service 2005) which may partially offset harvest cost while meeting some of the increasing demand for bioenergy (Page-Dumroese et al. 2010).

Thinning can increase structural complexity of young forests, subsequently increasing wildlife species diversity (Spies and Franklin 1991, Hayes et al. 1997). Thinning produces a variety of short- and long-term changes to forest structure, the most obvious of which is a decrease in tree density, an increase in forest canopy gaps, and abundance and diversity of mid-story trees (Artman 2003, Hayes et al. 2003, Agee and Skinner 2005, Harrod et al. 2009). More profound effects for wildlife species may be related to development of more complex understory vegetation due to increased light availability below the canopy (Doerr and Sandburg 1986, Bailey and Tappeiner 1998, Wilson and Carey 2000, Garman 2001, Homyack et al. 2005). Thinning can be represented in 3 broad categories: precommercial, commercial, and fuels treatment. The frequency with which each of these strategies is used across a landscape depends on landowner objectives, forest type, physiographic region, and other considerations.

Key Issues for Forest Thinning

Wildlife response to forest thinning likely will depend on the taxa, thinning technique, region or biophysical setting in which the harvest takes place, and intensity of harvest.

1. *Thinning technique* – Precommercial thinning (PCT) is removal of trees, not for immediate financial return but to reduce stocking density prior to natural self-thinning, allowing increased growth of more desirable crop trees (Helms 1998). Commercial thinning is a partial-cutting process that produces merchantable material at least equal to the value of direct harvesting costs (Helms 1998). A fuels treatment is any manipulation or removal of wildland fuels to reduce likelihood of ignition or to lessen potential damage and resistance to control wildfire (Helms 1998).

2. *Region/biophysical setting* – Land-use objectives, thinning techniques used, and wildlife response are likely to vary strongly by region and land ownership. Precommercial thinning is commonly used in the Pacific Northwest of the U.S., especially in Douglas-fir (Pseudotsuga menziesii) forest types (Briggs 2007), increasingly used in Acadian forests of the Northeast (Homyack et al. 2007), decreasingly used on industrial forest lands in the upper Midwest (D'Amato et al. 2008), and not common in commercial forests of the Southeast (Folegatti et al. 2007). As a result of decades of fire suppression efforts, fuels treatment forest thinning is increasingly used across the western U.S. and Canada (especially on public lands) as a mechanism to reduce forest understory density and restore forest health (Agee and Skinner 2005, USDA Forest Service 2005).

3. *Thinning intensity* – Volume of wood removed in forest thinning varies significantly by forest type and objective (Hayes et al. 1997). Total basal area removed during fuels treatment thinning is often less than for commercial and precommercial thinning. However, depending on length of time

that fire has been suppressed from the stand, fuels treatment thinning can include merchantable trees to decrease crown density and add more wood volume to timber sales (Skog and Barbour 2006). Closed canopy or dense forest obligate species can decline with higher intensity forest thinning treatments (Griffin and Mills 2007, Homyack et al. 2007, Wilk et al. 2010). However, species often associated with forested conditions, such as some cavity nesting birds, increased after thinning despite a decrease in number of available snags (Hagar et al. 1996, Siegel and DeSante 2003). Variable thinning intensities and harvest patterns (e.g. variable density thinning, clumped retention, or patch cuts) have been reported to produce favorable forest stand conditions for a variety of fauna (Carey and Wilson 2001, Garman 2001, Carey 2003).

Wildlife Response to Forest Thinning

Birds.— Positive responses by many bird species to forest thinning have been well documented (Hayes et al. 1997, Hunter 2001, Hayes et al. 2003, Hagar et al. 2004, Kalies et al. 2010). Proposed mechanisms for increased abundance and diversity of bird species in thinned stands include increased regeneration and development of shrub and understory layers resulting from greater light access to the canopy floor (Hayes et al. 1997) or increased horizontal or vertical variation in forest structure (McComb and Noble 1980, Sullivan et al. 2002, Carey 2003). In a recent meta-analysis, Verschuyl et al. (2011) compared 274 bird responses from 13 studies involving comparisons of thinned and unthinned forest stands and reported a significantly positive response of birds (both breeding and wintering) to thinning treatments across North America.

Of the three types of thinning, fuels treatment thinning had the most favorable effect on bird species abundance and diversity, and cumulative response to precommercial and commercial (non-fuels treatment) thinning was not significant (Verschuyl et al. 2011). In stands thinned as a fuels treatment, Siegel and DeSante (2003) observed canopy, cavity, and especially shrub-nesting avian species in greater abundance than in comparable unthinned stands. In the southeastern U.S., response to fuels treatment thinning was influenced by treatment intensity, whether the thinning was followed with a burn, and which guild of birds species was being investigated (Zebehazy et al. 2004, Greenberg et al. 2007b).

Thinning intensity is often a significant determinant of bird response to forest thinning. In studies reviewed by Verschuyl et al. (2011), birds responded favorably to light and moderate thinning. Some negative responses to forest thinning were reported when > 66% of basal area was removed from treatment stands. Tree- and shrub-inhabiting birds may respond negatively to heavier thinning intensities (Norton and Hannon 1997) or certain treatments or forest types (Christian et al. 1996). Negative responses to thinning treatments may be due in part to the short-term nature of many studies (typically 1-4 years post-treatment). Most thinning operations will have an initial short-term negative effect on biodiversity due to understory disturbance caused by the operation itself (Hagar et al. 2004). Although diversity measures often may increase with thinning, consideration needs to be given to species of high conservation priority that may be positively or negatively affected, either directly or indirectly, by thinning.

Mammals.— Numerous studies have documented a positive response of small mammals to forest thinning (Zwolak 2009). Thinning may be beneficial to open-habitat and generalist small mammal species through increased light to and productivity of understory vegetation (Homyack et al. 2005). Increased understory shrub and herbaceous vegetation increases forage and cover for deer mice *(Peromyscus maniculatus),* jumping mice *(Napaeozapus or Zapus spp.),* and most vole species (i.e., members of the subfamily Arvicolinae)(Wilson and Carey 2000, Suzuki and Hayes 2003, Homyack et al. 2005), although response to the increase may be short-lived (Suzuki and Hayes 2003). Bats are typically favored by thinning operations across geographies through increased access to flying insects (Humes et al. 1999, Tibbels and Kurta 2003, Loeb and Waldrop 2008), but species-specific responses must be considered (Patriquin and Barclay 2003).

The thinning operation itself can significantly change understory characteristics (e.g., prey availability, vegetative cover, and microclimate) that are linked to demographic parameters of many small mammals. As a result, thinning initially can have significant short-term effects on abundance and diversity of small mammals (both positive and negative) that do not persist (Greenberg et al. 2006, Greenberg et al. 2007a, Greenberg et al. 2007b).

Wildlife response to thinning varies by thinning type, thinning intensity, and region. Verschuyl et al. (2011) reported a positive cumulative response of mammalian species abundance and diversity to all types of thinning. Magnitude of response, however, was greatest for fuels treatment thinning and least for precommercial thinning. Although commercial thinning resulting in open canopies and increased understory growth may favor measures of mammalian species abundance or diversity, it may not improve habitat conditions for species associated with closed-canopy conditions (Lehmkuhl et al. 2002). Despite being associated with low intensity harvest, precommercial thinning may reduce small mammal species diversity in some instances (Etcheverry et al. 2005).

Although generally positive in all locations, magnitude of mammalian response to thinning treatments also varies significantly among regions. For example studies from the Pacific Northwest of the U.S. showed no significant diversity or abundance response to thinning treatments (Verschuyl et al. 2011).

There was little difference in mammalian response by type of thinning intensity in studies reviewed by Verschuyl et al. (2011). However, there was a gradual decrease in response magnitude for studies ranging from light through heavy thinning intensities, the latter response being not significant. Intermediate or variable density thinning treatments may produce habitat conditions for generalists and closed canopy or arboreal specialists (Carey and Wilson 2001, Lehmkuhl et al. 2002, Carey 2003, Ransome et al. 2004). Despite generally positive responses by mammals to forest thinning, some direct and indirect effects of forest thinning on species of conservation concern may warrant further review (Carey 2000, Gomez et al. 2005, Griffin and Mills 2007, Homyack et al. 2007).

Herpetofauna.— In a comprehensive review of amphibian response to forest management in North America, deMaynadier and Hunter (1995) report the short-term, stand-level response of salamanders to timber harvest is typically negative, especially for clearcutting, usually through the mechanisms of reduced leaf litter, canopy cover, and soil moisture (Pough et al. 1987, deMaynadier and Hunter 1995, Ash 1997, Semlitsch et al. 2009). This response may be short in duration, because thinning is thought to encourage earlier development of late-seral conditions, and potential negative responses by terrestrial amphibians can be at least partially mitigated with an abundance of down wood (Rundio and Olsen 2007).

Many studies compare amphibian response in clearcut and forested stands (e.g., Enge and Marion 1983, Karraker and Welsh Jr. 2006, Todd and Rothermel 2006). However, fewer studies are available on amphibian response to partial harvest or thinning. Some research suggests that detrimental effects of stand disturbance (e.g., soil compaction, stream sedimentation) on amphibian populations persist even when the disturbance is a less severe partial cut (Harpole and Haas 1999, Semlitsch et al. 2009). Pough et al. (1987) showed a strong positive linear relationship of understory vegetation and leaf litter depth with above-ground salamander activity and Ash (1997) reported timing of amphibian return to previously harvested stands closely follows re-development of the litter layer. However, Brooks and Kyker-Snowman (2008) observed forest floor temperature and humidity to be similar between partial, selection-based timber harvests and unharvested control stands. In addition, several studies report mixed or even positive effects of thinning on amphibian populations (Pough et al. 1987, Ford et al. 2000, Grialou et al. 2000, Renken et al. 2004, McKenny et al. 2006), suggesting that thinning harvests can maintain forest amphibian populations.

Research documenting reptile response to timber harvest is limited (Russell et al. 2004, Todd and Andrews 2008), despite the fact that many reptile populations are potentially experiencing declines (Gibbons et al. 2000). Solar radiation and thermal cover are important habitat characteristics for reptiles (Kiester 1971). At least in the short term, standard clearcutting provides ample solar radiation for morning sunning, but may not provide adequate night time thermal cover in some regions. Thinning, on the other hand, may provide a more moderate environment for many reptile species than closed-canopy forest stands or recently clearcut stands (Todd and Andrews 2008).

Forest harvest can variously affect reptile species depending on their life histories (Renken et al. 2004). However, summary reptile response from 3 reviewed studies was significantly positive (Verschuyl et al. 2011). Fuels-treatment thinning provided favorable results for 2 lizard species (Kilpatrick et al. 2004), whereas Matthews et al. (2010) reported no effect of mechanical fuels-treatment thinning on reptiles. In more intense treatments such as even-age harvesting, many lizard species have greater abundance in recently harvested stands (Greenberg et al. 1994, Kilpatrick et al. 2004). However, more research would be required to draw conclusions about response to different thinning intensities across various geographic regions (Verschuyl et al. 2011).

Invertebrates.— Insects are affected in a variety of ways by changes to the forest canopy, understory, and litter layers, and can themselves be significant drivers of forest productivity and nutrient cycling (Hunter 2002). Diversity of arthropod functional groups can be a good measure of overall habitat complexity (Hunter 2002, Yi 2007). However, effects of forest thinning on invertebrates are not well understood (Duguay et al. 2000, Schowalter et al. 2003, Yi 2007). Mechanisms for increase or decline of certain invertebrates in response to forest thinning are often specific to functional groups being examined. Some examples include increases in abundance of herbivorous arthropods in recently thinned stands caused by increased availability of canopy level forage, and declines in populations of detritovores and some predators resulting from reduced habitat and food resources (Progar et al. 1999). Thinning that changes community composition and structure of understory vegetation can increase diversity and abundance of some insect groups in the short term (Taki et al. 2010).

Depending on their life history characteristics, invertebrate communities may respond positively (Yi 2007), negatively (Niemela et al. 1993), or minimally (Schowalter et al. 2003, Apigian et al. 2006) to forest thinning and other canopy-opening disturbances. Verschuyl et al. (2011) demonstrated a significant positive cumulative response of arthropod biomass and diversity of arthropod orders to forest thinning treatments. However, they included only 2 studies (46 responses) of commercial thinning, 1 in the northwestern U.S. (Yi 2007) and another in the upper midwestern U.S. (Tibbels and Kurta 2003).

Management Implications

Though harvesting live trees for bioenergy production as part of a sustainable forest management program disturbs forest structure, such disturbances do not negatively affect biological diversity in most cases (Janowiak and Webster 2010). The available literature describes a positive stand-level response by diversity and abundance of a variety of taxa to forest thinning treatments across most thinning intensities and forest types. The magnitude of response to forest thinning, either positive or negative, is often small. Furthermore, thinning (as with any silvicultural practice) is not implemented simultaneously across the landscape, and consideration for unique biological features (e.g., occurrences of imperiled species, old-growth) has become an integral aspect of sustainable forestry. As a result, biomass thinning harvests across a range of intensities likely will increase diversity of forest types and hence landscape-level species diversity and abundance.

Forest thinning (along with other disturbances), can increase species diversity at stand and landscape scales by creating a variety of habitat types through a mosaic of forest development stages (Hunter 1999, Franklin et al. 2002, Loehle et al. 2002, Lindenmayer et al. 2006). However, species response to disturbance can depend on biophysical setting of the landscape (McWethy et al. 2010). In highly productive systems with lengthy inter-disturbance periods, a few species can begin to dominate the plant community, leading to reduced levels of plant and animal diversity (Huston 1999, 2004, Odion and Sarr 2007). Forest thinning for bioenergy production in highly productive forests may provide the disturbance necessary to counteract competitive dominance of canopy tree species. Alternately, in less productive forests, more care may be required to blend objectives for biomass harvest with those for maintenance of biological diversity (Janowiak and Webster 2010, Page-Dumroese et al. 2010). Disturbance intensity and biophysical setting are likely to be strong determinants of response by wildlife and vegetation to biomass thinning harvests (Greenberg et al. 2007b). Thinning designed to promote species abundance and diversity likely will need locally tailored prescriptions of intensity and pattern (Hagar et al. 2004).

Short-Rotation Woody Crops (SRWC)

Short-rotation woody cropping systems produce woody biomass using short harvest cycles (1 to 15 years), intensive silvicultural techniques (e.g., fertilization, irrigation, and competition control), high-yielding varieties, and coppice regeneration (Dickmann 2006). In North America, SRWCs may potentially be profitable in the Southeastern, Midwestern, Pacific Northwest, and boreal regions (Weih 2004, Dickmann 2006, Dale et al. 2010). Current species that show promise as SRWC re-sprout vigorously post-harvest and include *Populus* spp. (poplars and cottonwood), willow (*Salix* sp.), loblolly pine, alder (*Alnus* sp.), black locust (Robinia pseudoacacia), silver maple *(Acer saccharinum)*, sycamore *(Platanus occidentalis)*, *Eucalyptus* sp., and sweetgum *(Liquidambar styraciflua)*. Of these, most research on both production and biodiversity response has focused on poplars, cottonwoods, and willows (Philips et al. 1995, Dickmann, 2006).

Most SRWCs likely will be established on agricultural land (Christian et al. 1994, Sage et al. 2006, Rowe et al. 2009, Fletcher et al. 2010), but SRWCs may increasingly become a more prominent component of forested landscapes. SRWCs sometimes may be planted on previously forested lands (e.g., Auclair and Bouvarel 1992, Weih 2004). More likely, much of the agricultural land potentially used for SRWC (especially marginal croplands that are often targeted for alternate uses) may have been forested in the past. Similarly, afforestation efforts often involve SRWC species (Twedt 2006). Thus, fully understanding how SRWCs will affect wildlife at the landscape and regional scales is impossible without SRWC versus forest comparisons.

Key Issues for SRWC

1. *Monocultures versus multi-species forests.* SRWCs are typically even-aged stands dominated by rapidly growing species. Relative to other types of forest, SRWCs are generally associated with lower diversity, but they may have greater diversity than agricultural systems.

2. *Crop species.* Different SRWC species likely influence effects on biodiversity, particularly if planted species are native or exotic.

3. *Harvesting cycle.* Planting density and harvest frequency will influence height and structure of SRWC stands. Biomass production in temperate regions will likely feature high density plantings and short rotations (1 to 6 years, Dickmann 2006), although these may be longer at more northern latitudes (Weih 2004).

4. *Herbicide and pesticide use.* Controlling weed competition and insect pests in SRWC monocultures often requires chemical inputs (Dickmann 2006, Landis and Werling 2010), with potentially direct impacts of some chemicals on wildlife although most effects, especially for herbicides, will be indirect effects via changes in abundance or diversity of plant and insect species on which wildlife depend (Miller and Miller 2004).

5. *Landscape connectivity and regional effects*. Effects of SRWCs on landscape- and regional-scale biodiversity will depend in part on amount and configuration of SRWCs relative to other land uses across the landscape and whether SRWCs are planted in primarily forested or prairie ecosystems.

Wildlife Response to SRWC

Birds.— Knowledge about bird response to SRWCs, although incomplete, is more extensive than for other taxa. Recent meta-analyses indicate that bird diversity is often lower on SRWCs than reference forests (Riffell et al. 2011c). Abundance of individual species varies, as expected, with some species less abundant on SRWC plantations (compared to forested lands) while others are more abundant on SRWC plantations (Riffell et al. 2011c). Species that benefit from SRWC plantations are those associated with dense, shrubby habitat structure. In contrast, species associated with relatively mature forests and cavity-nesters are scarce or absent. SRWC plantations are typically harvested at early ages, and so never develop large stems that provide cavities for hole-nesting birds. Nest site availability could potentially be increased by adding nest boxes to SRWC plantations (Twedt and Henne-Kerr 2001) or retaining some large stems in SRWC harvest units.

Avian diversity response may vary depending on the type of forest being compared to SRWC plantations (Riffell et al. 2011c). For example, Populus plantations were less diverse and had lower overall bird abundance than nearby bottomland hardwoods and other forest types, but may be similarly or more diverse than some upland hardwood forests (Riffell et al. 2011c and references therein). Furthermore, bird diversity and community structure should be influenced by the crop species chosen for short-rotation systems. Generally, crop species with growth forms that promote structural heterogeneity should support more diverse bird communities (Kavanagh 1990, Sage and Robertson 1996, Christian et al. 1998). In SRWC systems using *Salix* or *Populus*, birds may even nest preferentially in some clones over others (Dhondt et al. 2004). Unfortunately, knowledge about other crop species is lacking (Riffell et al. 2011c).

SRWC plantations likely will become more diverse as they age (Sage and Robertson 1996, Berg 2002, Moser and Hilpp 2004, Riffell et al. 2011c). Longer inter-harvest cycles allow SRWC plantations to transition from open habitat conditions (initially after planting) to dense shrubby vegetation and taller forms with canopy and understory if the harvest cycle is long enough. As a result of these increases in both vertical structure and heterogeneity, number of different nesting and foraging substrates also increases (MacArthur 1964).

Pesticides used to control insect pests (Dickmann 2006) might directly impact birds through toxic effects (e.g., Freemark and Boutin 1995, Fleischli et al. 2000) or indirectly by reducing prey availability. Herbicides commonly used in forest management, when applied according to label instructions, pose little risk to wildlife (Tatum 2004). Herbicides, however, do have the potential to indirectly affect birds, positively or negatively, via associated changes in vegetation and insect communities, but this has not been studied in SRWC systems. Effects likely would vary by chemical and bird species.

Mammals.— Few studies have directly compared mammals in SRWCs versus other forests, and they have provided little clarity about mammal response (Riffell et al. 2011c). Diversity and abundance of mice (Staten 1977, Christian et al. 1997) and shrews (Christian et al. 1997) were consistently lower on *Populus* plantations than on surrounding woodlands. In the midwestern U.S., *Populus* plantations had fewer rabbits (*Silvilagus* spp.) in winter compared to surrounding forest, and other forest mammals were rarely detected in plantations (Christian 1997). The reverse was true in cottonwood plantations compared to surrounding forests in the Mississippi Alluvial Valley (Staten 1977, Wesley et al. 1981). Elsewhere in the Mississippi Alluvial Valley, *Populus* plantations contained a similar number of species to reference forests, but total abundance was intermediate between bottomland hardwoods (lower than *Populus*) and upland hardwoods (higher than *Populus*) (McComb and Noble 1980). Additionally, these differences can change seasonally. SRWCs in Italy had fewer small mammals compared to surrounding forests in summer, but relatively more in autumn (Giordana and Meriggi 2009). Unlike birds, diversity and abundance of small mammals in SRWC plantations do not necessarily increase with stand age (Christian et al. 1998), and may even decline with stand age (Moser et al. 2002).

Even less is known about how large mammals are affected by SRWC plantations. Browse damage to SRWC plantations by ungulates (Christian 1997) indicates that SRWC crop trees and other vegetation may be suitable forage. White-tailed deer also have been observed using *Populus* in the midwestern U.S. (Christian 1997) and may favor *Populus* plantations during parturition in the southern U.S. (Wigley et al. 1980, Wesley et al. 1981).

Although differences in mammal abundance and community composition among different SRWC species and effects of SRWC stand age have not been adequately quantified, species should respond to differences in structure in ways consistent with their habitat needs. As with birds, herbicides could potentially have indirect effects via associated changes in vegetation and insect communities, but this has not been studied in SRWC systems. Effects would likely vary by chemical and mammal species.

Herpetofauna.— Basic information about effects of SRWC systems on herpetofauna is lacking. Reptiles and amphibians likely would respond to habitat structure and harvest regimes of SRWC systems in ways consistent with known habitat associations and as they respond to harvest of more traditional forests managed for timber (Semlitsch et al. 2009). This, however, is speculative until empirical research is completed.

Invertebrates.— Short-rotation Populus plantations can have abundant and diverse insect communities that can be food sources for birds and other wildlife (Rowe et al. 2007, Landis and Werling 2010). However, no comparisons of insect communities between SRWC plantations and other forest types have been made. One caution is that fire ants were more common in cottonwood plantations and implicated in > 11% of bird nest failures (Twedt et al. 2001). Research about how SRWC could facilitate (or hinder) invasive and pest species is sorely needed.

Landscape Connectivity and Regional Effects of SRWC

Although diversity and abundance of birds and mammals are generally lower on SRWC plantations compared to reference forests (Riffell et al. 2011c), SRWC plantations could contribute to overall landscape diversity in forest-dominated landscapes by providing shrubby habitat structure for non-forest species and increasing structural heterogeneity. For example, maximizing wildlife diversity in the Mississippi Alluvial Valley may require ≤ 5% of the landscape to be comprised of shrub/scrub habitat types, which SRWC plantations could provide (Wilson et al. 2007). Patches of SRWC also could increase overall forest connectivity or serve as stepping stones for shrub-associated species.

Management Implications

In relatively small amounts, SRWC plantations have the potential to augment biodiversity in primarily forested landscapes, provided they do not replace forested patches of high conservation value or other diverse forest systems. However, extensive conversion of grasslands or native or intensively-managed forests to SRWC likely would decrease overall diversity, especially if grasslands replace high conservation value habitat types (Archaux and Martin 2009). Longer rotations and harvest schedules that provide a variety of canopy heights would maximize biodiversity value but may reduce economic viability of SRWC plantations. Value of SRWC plantations to wildlife will depend on crop species (or clones) that are planted, harvest interval, latitude, and amount of chemical inputs needed. Unfortunately, much of this information is currently lacking.

Intercropping Biomass Crops on Existing Forest Lands

Intensive forestry presents opportunities for intercropping herbaceous or woody biomass species between tree rows. This type of intercropping would involve woody species planted or perennial herbaceous crops seeded between rows of planted trees, and then harvested periodically until crop trees shade out inter-crops. Biomass would be used for co-firing in local energy plants or potentially as cellulosic feedstocks. Of the potential feedstock species that could be intercropped, switchgrass has received the most evaluation (e.g., Schmer et al. 2008, Mitchell et al. 2008, Keshwani and Cheng 2009). Other species that could be intercropped include a suite of native prairie grasses (Tilman et al. 2006, Nash 2007, Lee et al. 2009), reed canary grass *(Phalaris arundinacea;* Casler et al. 2009) and miscanthus *(Miscanthus x giganteus)* (Bellamy et al. 2009).

Intercropping dedicated energy crops, such as switchgrass, within planted pine stands may become a viable option four biofuel feedstock production although sustainability of such practices are just now being examined/Credit: Sam Riffell, Mississippi State University, courtesy of Weyerhaeuser and Catchlight Energy, LLC.

A recent review revealed no publications directly evaluating wildlife response to intercropping systems in intensive forest systems in North America (Riffell et al. 2011a). Some forest companies are exploring intercropping systems (D. A. Miller, Weyerhaeuser Company, *personal communication*), but operational scale research of wildlife response to intercropping is only now being examined. Marshall et al. (2012) recently reported initial effects of removing woody biomass after clearcutting and intercropping switchgrass on rodents for 2 years post-treatment in regenerating pine plantations in North Carolina. Species richness and diversity of rodents did not change due to switchgrass intercropping or biomass removal. However, *Peromyscus leucopus* was more abundant and had the greatest survival in treatments without switchgrass. The invasive *Mus musculus* was most abundant in treatments with switchgrass. Until more research is conducted in intercropped forests, literature about managing switchgrass and other native warm-season grasses (NWSG) in row-crop settings provides enough information to make some initial predictions and identify research needs. However, most of this research involves birds and little is known about other wildlife taxa and other bioenergy crops.

Key Issues for Intercropping

1. *Bioenergy crop species.* Different feedstock species would affect wildlife species in different ways.

2. *Timing of harvest.* Timing of harvest relative to wildlife species life-histories will influence wildlife response.

3. *Harvest-related vegetation changes*. Harvest regimes may change the vegetation in ways that persist months or years following harvest.

4. *Surrounding forest structure and row spacing.* How the structure created by intercropping herbaceous crops among trees changes over time and interacts with the dominant landscape cover will influence wildlife response.

Wildlife Response to Intercropping

Bioenergy crop species.— Intercropping switchgrass or other perennial grasses would alter the ground layer in young, regenerating stands and has potential to alter stand structure and biological diversity. In the southeastern U.S., where intercropping is most likely to occur, young tree stands would be planted primarily to pines, with perennial grasses planted between rows. Later in the rotation, pine-grassland intercropping systems may, to some extent, mimic pine-grassland systems (at least structurally) that were historically dominant across the southern U.S. Intercropped switchgrass or other NWSG would represent a net addition of grasslands, albeit potentially different structurally from native grasslands, in primarily forested landscapes. As a result, wildlife species that favor recently clearcut-harvested and regenerating forests may respond negatively.

Timing of harvest.— Haying or mowing grasslands during the breeding season usually results in nesting bird and other wildlife mortality (Bollinger et al. 1990). However, a single, post-senescence harvest (e.g., September-November) likely maximizes biofuel potential of switchgrass (Harper et al. 2008, Mitchell et al. 2008), so harvest operations would not directly affect breeding birds or other breeding wildlife species. Potentially, some other NWSGs may have biomass yields in spring harvests that are similar to that of fall harvests (Mitchell et al. 2008, Lee et al. 2009), which would allow vegetation to remain over winter as cover.

Harvest-related vegetation changes.— In some instances, biomass harvests may mimic aspects of natural disturbances (e.g., fire), reduce accumulation of dead vegetation, and ameliorate development of dense vegetation characteristic of switchgrass that reduces habitat suitability for grassland birds. Although biomass harvest of switchgrass may not affect overall bird diversity (e.g., number of nesting bird species) (Henningson and Best 2005), it will likely shift community structure towards species that prefer shorter grass heights, whereas species that prefer taller, denser grasslands might become less common (George et al. 1979, Murray and Best 2003, Roth et al. 2005). Most likely, bird communities in other NWSG fields (mixed or monocultures) would respond in similar ways. In intercropping systems, harvest regimes designed to provide a mosaic of different grass heights likely would maximize bird diversity across the landscape (Flaspohler et al. 2009, Riffell et al. 2011a). Little is known about how changes in vegetative structure related to harvest might influence other taxa (but see Kaufman and Kaufman 2008).

Surrounding forest structure and row spacing.— In many landscapes, grassland birds have lower success near wooded edges or avoid them altogether (Bollinger and Gavin 2004, Patten et al. 2006). In intercropping systems, rows of growing crop trees may create functional edges by separating the intercropped stand into narrow strips of herbaceous vegetation. In a study of switchgrass filter strips 8- to 36-m wide [the closest approximation to the 6.1 m planted row width currently under evaluation in the southeastern U.S. (D. A. Miller, Weyerhaeuser Company, *personal* *communication*)], some species avoided nesting in filter strips bordered by woody vegetation and others had lower nesting success because of increased predation (Henningson and Best 2005). Moving to a 6.1-m spacing probably would benefit both birds and mammals in the first 2 years after planting (Mihalco 2004, Bechard 2008, Taylor 2008, Lane 2010), but long-term influences of tree-spacing on wildlife are unknown.

Understanding how arrangement would impact wildlife is complicated, because early in the rotation planted trees may be short enough that intercropped stands function as large grassland tracts with much interior area. However, growing trees eventually will create strips of grassland bordered by trees. Over time, the bird community would shift from mostly grassland species to shrubland/ edge species, and eventually to forest species as the crop trees grow (Dickson et al. 1993, Wilson and Watts 2000, Coppedge et al. 2001). Additionally, characteristics of the surrounding landscape structure can mediate the nature and extent of edge effects (Chalfoun et al. 2002).

Management Implications

Intercropping herbaceous biomass crops has potential to add grassland habitat structure into forest dominated landscapes, which may increase wildlife diversity. In the southeastern U.S., these systems also may result in forested plantations that more closely mimic the structure of pine-grassland systems that originally dominated the region. However, intercropping most likely will not mimic the functional processes of native systems because biomass crops used for bioenergy production are unlikely to persist into older-aged plantations or allow for the development of a pine overstory/grass understory structure. Because so little is known about wildlife response to intercropping systems, predicting effects of widespread adoption is difficult.

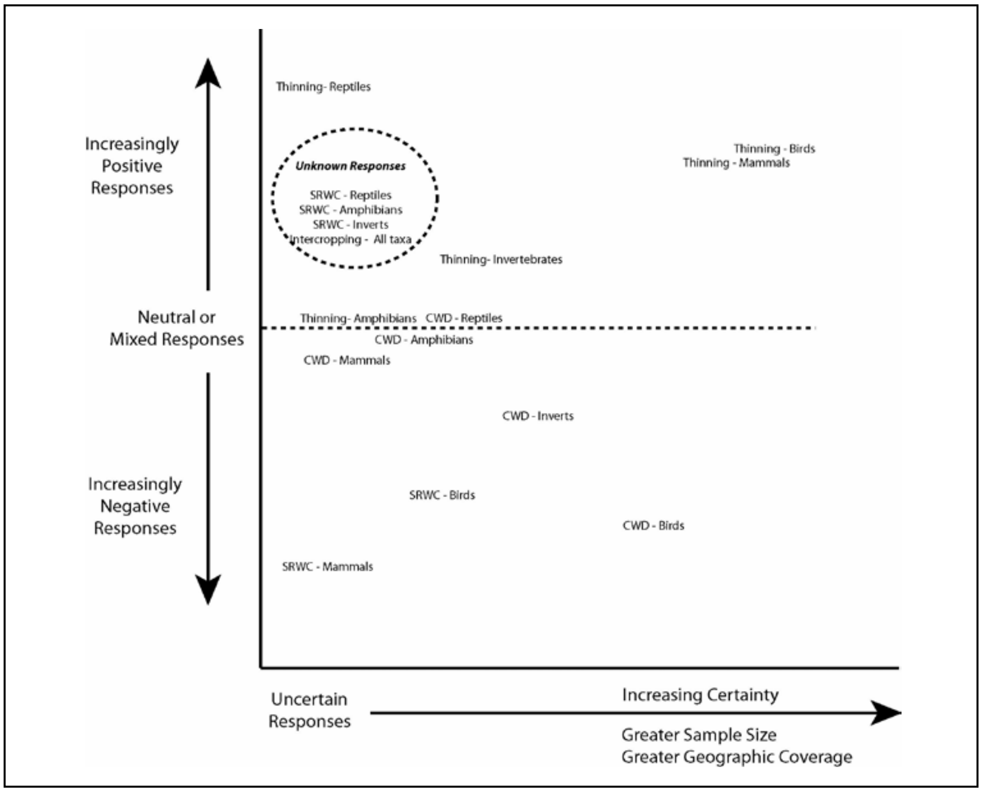


Figure 11. Summary of biodiversity responses to biomass harvest systems. Production system codes are as follows: thinning = thinning; CWD = removal of forest harvest residues; SRWC = short-rotation woody crops; and intercropping = intercropped grasses.

Part 4: Algae and Aquatic Feedstocks

Figure 10. Parabell's demonstration facility in Fellsmere, Florida, USA, uses duckweed (Lemnaceae sp.) as a feedstock to create biofuels and a high value, concentrated protein for animal feed/Credit: Julie Sibbing, National Wildlife Federation.

One of the fastest growing fields in biofuel research is that of algae and other aquatic micro-crops (Fig. 10). Additionally, other aquatic crops such as duckweed (subfamily *Lemnoideae*), cattail (*Typha* sp.), and prairie cordgrass (*Spartina pectinata*) are becoming increasingly popular prospects for pilot and research facilities studying bioenergy sources. This growth has been driven in part by the federal government, which has invested tens of millions of dollars in algal biofuels research and created a National Algal Biofuels Technology Roadmap (U.S. Department of Energy 2010) towards commercialization of algal biofuels. Although research has been underway for years on the best technologies and feedstocks for algal and other aquatic biofuels feedstocks, little is known about implications for wildlife. Because algae do not require soil for growth and can be grown in freshwater or saltwater, some of the land-use issues associated with other forms of biomass can be avoided. However, many other potential impacts on wildlife and wildlife habitat must be considered. These implications are highly dependent on type of feedstock (e.g., micro-algae versus macro-algae, native versus non-native or genetically modified species) and type of system (natural ecosystem, open pond, closed system, etc). What follows are only some of the many critical issues for wildlife and wildlife habitat that must be addressed by future research.

Potential for Invasion

Given that micro-algae can easily aerosolize and spread, potential for algae to escape from a biomass production facility is high, and instances of algae escaping into the environment from research laboratories have occurred (Maron 2010). According to a researcher at University of Kentucky, "complete containment of algae is completely impossible" (Crocker 2010 cited in Glaser and Glick 2012; p. 22). This raises particular concerns regarding use of invasive, exotic, and genetically modified strains of algae. Although open ponds likely will pose considerably higher risk, even in a closed system algae might be able to escape through ventilation systems or even on the clothes of workers. These risks must be evaluated with the potential for non-native or modified strains to outcompete native strains.

Effects of Managed Harvest of Existing Species on Ecosystems

Some companies have recently become interested in harvesting wetland species for bioenergy. Cattails, for instance, are lauded as a potential bioenergy crop, because they are highly prolific, easy to cultivate, and rapidly produce large amounts of biomass. Although harvesting invasive aquatic species, such as narrow leaf cattail, from invaded wetland systems could improve wetland conditions for wildlife, planting such species in natural wetlands may have significant effects on biodiversity and wildlife. Research is needed on sustainable rates of harvest and effects of harvest on wetland ecosystems and wildlife.

Establishment of Aquatic Crops in Existing Aquatic Ecosystems

In October 2011, DOE proposed to exempt projects that harvest algae for biomass in salt water and freshwater environments from the environmental review process (National Archives and Records Administration 2011). Although they did not list specific projects, the proposal raises concerns about potential for use of non-native species. The exemption specifies that projects must not "...involve genetically engineered organisms, synthetic biology, governmentally designated noxious weeds, or invasive species, unless the proposed activity would be contained or confined in a manner designed and operated to prevent unauthorized release into the environment and conducted in accordance with applicable requirements, such as those of the Department of Agriculture, the Environmental Protection Agency, and the National Institutes of Health" (10 CFR 1021, Subpart D, Appendix B to Subpart D of Part 1021; **<ceq.hss.doe.gov/nepa/regs/nepa1021_rev.pdf>** *Accessed 16 July 2012).* Yet lists of noxious weeds are not always comprehensive, and algae can never be fully contained. Studies are needed to evaluate bioenergy projects in existing aquatic ecosystems that use non-native species or genetically modified species that may have invasive qualities.

Land Use Impacts

In addition to potential consequences on habitat from managed harvest of existing species and establishment of aquatic crops, several other potential habitat effects need to be investigated further. For example, some types of facilities that grow algae for biofuels use digestible organic carbon inputs instead of sunlight and carbon dioxide. One such input that is being tested is acetate that is derived from switchgrass. This could lead to a range of additional wildlife impacts discussed under the "agriculture crops" section.

Water Quality and Quantity

All algal biomass facilities require water as an input, and amount of water required could potentially be immense (Ryan 2009). Research into effect of various types of algal biomass facilities on water resources and nearby aquatic ecosystems is particularly needed.

Part 5: Conclusions and Recommendations

Expanded interest in the bioenergy industry in the U.S. has been driven, in large part, by the surge in state and federal mandates and incentives to promote these industries. Despite expanding production and consumption of biomass for biofuel and bioenergy production, however, the ultimate interactive effects on the economy and environment remain unclear. Increased demand for ethanol has brought a variety of concerns: (1) competing use for crop or crop products, (2) competition for land base, and (3) sustainable management strategies. Implications of bioenergy production on wildlife will depend largely on where the feedstocks are grown, what is planted, how the biomass is managed and harvested, and landscape extent and context.

Available literature can be used to infer effects of bioenergy production on wildlife. However, robust scientific studies of effects of bioenergy production on wildlife resources are deficient at this time. Areas in need of additional research regardless of feedstock used include effects of:

- Conversion of natural systems to bioenergy production over both the short- and long-term. Controlled studies must be "apples to apples" comparisons of actively managed bioenergy crops to the natural habitat they replace.

- Crop or plant community composition, annual harvests, refugia, stubble height, and fertilization on sustainable yield and wildlife and plant diversity.

- Using biomass sources that do not require a bigger agricultural footprint, such as from residues or other wastes.

- Harvest timing, frequency, and additional site management to maximize production of wildlife and bioenergy while maintaining water quality and limiting soil erosion.

- Intercropping or strip cropping of grasses, legumes, forbs, and site appropriate shrubs to provide the necessary diversity of food and cover for wildlife during bioenergy production.

- Bioenergy production on wildlife population and community structure and indirect effects on food webs and ecosystem stability.

- Diversification of feedstocks and resulting implications for wildlife.

Most studies at this time focus on response of avian populations to habitat alteration due to bioenergy feedstock production. Research on response of mammals, invertebrates, and herpetofauna to bioenergy production are lacking in all ecosystems. In addition, much of the available information in the literature is based on species abundance data. Because abundance is not always related to habitat quality (Van Horne 1983), future research should investigate measures of fitness and extend data collection over longer periods of time. Lastly, manipulative studies to this point mostly have involved small experimental units embedded in an unharvested matrix, so it is unknown how results from these studies might scale up to operational extents. These and other research needs will need to be prioritized based on current and pending legislation to have the greatest potential influence on policy that considers wildlife sustainability in the context of bioenergy development.

Currently, grain-based ethanol and biodiesel dominate the renewable energy portfolio for transportation fuels. As crop production methods have advanced with clean farming methods, wildlife benefits on these lands have continued to decline. However, advances in tillage methods, especially no-till, have reduced negative, off-field impacts of soil erosion and water quality for many fish and wildlife species. Impact of bioenergy crops on wildlife will depend largely on what they replace in the landscape and if they are grown in monocultures or polycultures. If diverse bioenergy crops replace crop monocultures that have little value for wildlife, impacts likely will be neutral to positive. However, if bioenergy crops are grown on new cropland converted from existing habitat, effects will likely be negative. On-field harvest and management activities (e.g., leaving unharvested portions, habitat buffers) can be applied to maintain some level of wildlife benefits on bioenergy crop fields. Comparative studies of actively managed and harvested bioenergy crops to agricultural crops they replace are largely absent.

The prairie pothole region of the upper Midwest has emerged as the largest ethanol production area in the country (National Research Council 2010). However, this region produces 50–80% of the continent's duck populations (Cowardin et al. 1983, Batt et al. 1989, Reynolds 2005), and provides breeding habitat for more than one-half of the grassland bird species breeding in North America (Knopf 1994). In addition to large amounts of corn produced throughout the region, perennial grasses, whether they are present in prairies, rangeland, pastureland, or CRP, are considered prime candidates for cellulosic ethanol production. In such grassland systems, incorporating wildlife benefits while also managing for bioenergy production requires careful planning. Management to lessen potential effects on wildlife may include managing the site for less than maximum biomass production through use of diverse native biomass mixes or interplantings; managing stubble and/or areas of unharvested material to provide additional cover; rotating harvesting of grassland biomass fields so that only a portion of each field is harvested each year; implementing best management practices; and incentivizing adherence to certain sustainability standards. As with croplands, further research is needed to determine effects of such bioenergy management practices on wildlife and associated habitat.

Whereas Wisconsin is the only state to have approved sustainable planting and harvest guidelines for non-forest biomass (Hull et al. 2011), forest biomass harvest guidelines exist for several states (Tables 1 and 2). In forested systems, biomass feedstocks can be produced through a variety of practices such as thinning and fuels treatments, use of harvest residues including fine (foliage, small limbs and trees) and coarse (snags and downed logs) woody debris, establishment and harvesting of short-rotation woody crops, and harvesting of natural biomass or intercropped herbaceous plant species between crop tree rows in intensively managed stands. When applied across a broad spatial extent, intensive biomass production in forests that support a large proportion of biodiversity has potential to alter species composition, nutrient cycling, and overall biodiversity. Wildlife response to biomass harvesting techniques varies among taxa and production systems (Fig. 11, p. 40, Riffell et al. 2011a) but most taxa respond positively to thinning treatments. Reducing coarse woody debris likely will decrease bird diversity, but other taxa may not respond strongly. If reductions in coarse woody debris from actual harvests are less than 70% to 95% reductions used in experimental studies, overall wildlife responses may be minimal. Short-rotation woody crops may have lower diversity of birds and mammals than managed forests, but there is considerable uncertainty. No studies have specifically assessed wildlife response to intercropping of native, warm season grasses in commercial forests. The strong geographic bias in available studies for some practices increases uncertainty about consistency of observed responses across different landscapes of North America. Additional research at larger spatial scales and of added or increased frequency of harvesting operations would strengthen understanding wildlife response and the technical basis for harvesting guidelines.

Tens of millions of dollars have been directed towards algal biofuels research, making it one of the fastest growing bioenergy markets. Although research has been underway for years on the best technologies and feedstocks for algal and other aquatic biofuels feedstocks, little is known about implications for wildlife. Given that micro-algae can easily aerosolize and spread, use of invasive, exotic, and genetically modified strains of algae and their potential for escape are of particular concern. Other aquatic species (e.g., cattails) have been considered as potential feedstocks, but no research on effects to wildlife exists. Research on impacts of algal biomass facilities on water resources and nearby aquatic ecosystems also is needed.

Demand for bioenergy will continue to increase as human populations expand and wildlife will continue to feel pressures of competing interests. The technical review committee attempted to provide links to best management practices and renewable fuel standards throughout the document so users can research information more completely as needed. In addition, following an extensive literature review and subsequent discussion, we concur with the general guidelines that have been put forth by the Association of Fish and Wildlife Agencies (Appendix A). In conjunction with the management implications specifically outlined in this report, we hope that this technical review will expose areas in need of additional attention and encourage stakeholders to continue pursuing knowledge for the sake of our wildlife resources.

Grasshopper sparrow in restored native Texas prairie/Credit: Chuck Kowaleski.

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Appendices

AFWA Biofuels Working Group Best Management Practices

(Adapted from the Association of Fish and Wildlife Agencies draft document)

Habitat Type

Diverse perennial biomass energy crops have much greater potential to provide wildlife benefits than annual monoculture crops.

- Production costs will be much lower for perennial biomass than for annual crops, resulting in more economically, environmentally, and energetically sustainable renewable biomass.

- Compared with annual crops, perennial alternatives means less herbicide, pesticide, fertilizer and petro-fuel consumption, which equates to cleaner air and water for public uses and benefits for aquatic species.

- Improved technology to produce biofuels should focus on the use and harvest of diverse mixtures of grasses and forbs, or trees and shrubs that are wildlife friendly and fit the landscape to better mimic natural habitats and provide for wildlife indigenous to the landscape.

- Grasses/forbs should be planted on the prairies and trees/shrubs in the forests

- Current technology suggests that the next generation of biomass biofuels will likely be monoculture plantings for efficiency considerations. Wildlife benefits from monocultures could be improved by incorporating BMPs that add diversity to these monocultures.

    - Crop- and forest-management practices/rotations would be one of many ways to add wildlife-beneficial diversity to monoculture-biomass plantings.

    - Interseeding with forbs and legumes in grass biofuel situations could also supply necessary wildlife food and brood cover while providing a natural source of nitrogen to increase grass production. Such interseedings could be in the form of prostrate forb/legume species or multispecies strips separating grass stand blocks.

- Energy crops should be developed to be sustainably harvested with minimal inputs (fertilizer, irrigation water, pesticides, petrofuels)

Land Use

- The conversion of lands to dedicated energy crops will be most beneficial for wildlife on lands that have been previously altered, such as current cropland, pasture land, and plantation forest lands.

- Conversion of native grasslands, woodlands, or wetlands to energy crops will result in net losses of biodiversity, and should be avoided.

    - These native habitats, already greatly diminished in quality or quantity in some areas, provide multiple benefits to society and they are important to conserve rather than convert.

    - Native habitats may provide incidental biofuels from management activities (e.g., removal of invasive species, haying, forest thinnings, and waste wood) that can supplement biomass production. Improvements in technology that can use diverse sources of biomass will provide opportunities for limited sustainable use of native habitats for bioenergy production

  - Residue produced incidental to sustainable management of native forestland, including forestlands impacted by disease and wildfire, could result in significant contributions to biofuels while conserving native forestland and associated wildlife values.

- In areas with existing fragmented grassland and woodland habitats, the addition of biomass areas on cropland and marginal pastureland, with proper planning can be used to buffer fragments, provide additional habitat area to increase suitability for certain wildlife species, and develop potential corridors to assist in wildlife movement among habitat patches.

- Any incentives for planting and producing biomass must consider the economics of location and distance to processing facilities for the wise use of the Nation's limited land resources.

Invasive Plants

- Wildlife benefits will be maximized by using native plant species or wildlife-friendly species adapted for U.S. regions. Use of invasive plant species, or species with potential to become invasive and further harm native ecosystems, should not be allowed.

- If invasive plant species like reed canary grass *(Phalaris arundinacea)* are used for biomass production the industry should make every effort to ensure only sterile varieties are approved for biomass production.

  - Research currently is being conducted to develop genetically altered biofuel crops that produce higher yields, optimize root to shoot ratios, resist temperature extremes, drought, flooding, high salt concentrations, and heavy metal exposure. Through genetic engineering, researchers can increase the resistance of these crops to herbicides, insects, fungi, and other microbial organisms. Many genetically engineered food crops already possess some of these traits. Results of these engineered changes could extend the range of biofuel crops into new environments, potentially allowing these crops to become invasive and changing the landscape by altering soil chemical and physical properties and water availability, and impacting native animals and plant species. Transgene flow among plants, even of different species, is well-documented and could result in the loss of native genes. Potential environmental impacts from plant and animal species exposed to transgenic plants include interbreeding or hybridization, horizontal gene transfer to species related to the genetically engineered organism (GEO), and the creation of novel organisms that could be potential pests and competitors, or could depress the fitness of wild relatives. GEOs potentially could replace native grasses, habitat, and transgene flow.

  - Prior to intentional releases or extensive field trials, a risk assessment should be conducted to assess the consequences of an intentional introduction of genetically engineered crops.

Harvest Timing, Frequency, and Stubble Management

- Harvest times should be scheduled to avoid local nesting and brood-rearing seasons of bird species and fawning/calving of big game species that might use these blocks of habitat by either harvesting before nesting/fawning activity begins or waiting until after young birds have fledged and young animals are capable of leaving the area during harvest activities.

Harvest of grassland based biomass:

- Single harvest of biomass should be completed outside nesting and brood-rearing seasons. Research indicates benefits to perennial biomass (in terms of translocating nutrients back into the roots) for harvest after a killing frost, in addition to being most economically efficient and wildlife friendly. Examples of wildlife friendly harvest practices include, but are not limited to:

- Taller stubble heights at harvest will result in better wildlife habitat. We recommend stubble heights of at least 30.5 cm to provide useful winter cover for resident game birds like pheasants, grouse, and quail; and spring nesting habitat for a variety of waterfowl, game birds, and grassland songbirds on lands managed for biomass production.
    - Recommended harvest heights from USDA typically focus on how short plants can be harvested without impacting plant survival; those heights should be viewed as an absolute minimum, and regional wildlife needs should be factored-in to determine adequate stubble height that meets the needs of local wildlife, particularly ground-nesting birds.

    - Taller stubble heights can improve soil moisture by catching snow and shading to reduce evaporative loss. The added soil moisture the following year can boost production in some parts of the country.

- Habitat refugia:

- Sites should be harvested in blocks rather than strips. This is more efficient for harvesting and transporting biomass. Harvesting in strips has the potential to increase predation on certain wildlife species.

- Complete harvest of fields, at any time of the year, should be avoided.

    - From a wildlife standpoint, leaving a portion of the field unharvested each year will provide winter and nesting cover for species requiring taller cover than stubble would provide on fully-harvested fields.

    - Alternating harvested areas on fields (harvest a different 1/3 or ½ of the field every year) will help maintain wildlife benefits.

    - Leaving vegetation resistant to lodging during winter months can provide valuable winter cover for wildlife and can result in an economical way to stockpile biomass for harvest and use the following spring.

    - Having at least some portion of fields unharvested each year can serve as a biomass reserve in time of drought or other emergency.

Harvest of woody biomass

- Native forest land should be managed in accordance with a plan that maintains the diversity of native species within the stand, consistent with sustaining the forest ecosystem in which the stand is located.

- Timber-stand improvement and harvest of commercial trees, which produce biomass incidental to such management, should be performed to conserve and maintain a diverse understory beneficial to wildlife.

- Savanna, prairie, grassland, and glade restorations (that use native species) on sites formerly occupied by those habitats could result in on-going sources of woody and herbaceous biomass to help diversify and ensure biomass availability in some geographies.

- Fragmentation of native forest-land through conversion of native forest to woody biomass monocultures should be avoided.

- Forest harvest should be planned so that patches of forest habitat for native wildlife species are present in the landscape in current and future years.

- Commercial production of trees specifically from woody biomass should use native, site appropriate tree species managed according to state sustainability standards or plans

Water Quality

- A well-managed but unharvested buffer should be maintained around all water resources on site and in areas of off-site surface flow, where chemical and nutrients are not applied. Seeding of buffers to mixes that provide additional wildlife benefits and that may not be available in harvested areas should be encouraged.

Northern Rocky Mountains forest and river in Banff National Park, British Columbia, Canada/Credit: Chuck Kowaleski.

Glossary of Terms

(Adapted from: Biomass Energy Data Book, U.S. Department of Energy)

Agricultural Residue - Agricultural crop residues are the plant parts, primarily stalks and leaves, not removed from the fields with the primary food or fiber product. Examples include corn stover (stalks, leaves, husks, and cobs); wheat straw; and rice straw. Approximately 32 million ha of corn are planted annually, so corn stover is expected to become a major biomass resource for bioenergy applications.

Alcohol - The family name of a group of organic chemical compounds composed of carbon, hydrogen, and oxygen. The molecules in the series vary in chain length and are composed of a hydrocarbon plus a hydroxyl group. Alcohol includes methanol and ethanol.

Anaerobic digestion - Decomposition of biological wastes by micro-organisms, usually under wet conditions, in the absence of air (oxygen), to produce a gas comprising mostly methane and carbon dioxide.

Annual removals - The net volume of growing stock trees removed from the inventory during a specified year by harvesting, cultural operations such as timber stand improvement, or land clearing.

Biobased product - The term 'biobased product,' as defined by Farm Security and Rural Investment Act (FSRIA), means a product determined by the U.S. Secretary of Agriculture to be a commercial or industrial product (other than food or feed) that is composed, in whole or in significant part, of biological products or renewable domestic agricultural materials (including plant, animal, and marine materials) or forestry materials.

Biochemical conversion - The use of fermentation or anaerobic digestion to produce fuels and chemicals from organic sources.

Biodiesel - Fuel derived from vegetable oils or animal fats. It is produced when a vegetable oil or animal fat is chemically reacted with an alcohol.

Bioenergy - Useful, renewable energy produced from organic matter - the conversion of the complex carbohydrates in organic matter to energy. Organic matter may be used directly as a fuel, be processed into liquids and gasses, or be a residual of processing and conversion.

Bioethanol - Ethanol produced from biomass feedstocks. This includes ethanol produced from the fermentation of crops, such as corn, as well as cellulosic ethanol produced from woody plants or grasses.

Biorefinery - A facility that processes and converts biomass into value-added products. These products can range from biomaterials to fuels such as ethanol or important feedstocks for the production of chemicals and other materials. Biorefineries can be based on several processing platforms that use mechanical, thermal, chemical, and biochemical processes.

Biofuels - Fuels made from biomass resources, or their processing and conversion derivatives. Biofuels include ethanol, biodiesel, and methanol.

Biogas - A combustible gas derived from decomposing biological waste under anaerobic conditions. Biogas normally consists of 50 to 60% methane. See also landfill gas.

Biogasification or biomethanization - The process of decomposing biomass with anaerobic bacteria to produce biogas.

Biomass - Any organic matter that is available on a renewable or recurring basis, including agricultural crops and trees, wood and wood residues, plants (including aquatic plants), grasses, animal manure, municipal residues, and other residue materials. Biomass generally is produced in a sustainable manner from water and carbon dioxide by photosynthesis. The 3 main categories of biomass are primary, secondary, and tertiary.

Biomass energy - See Bioenergy.

Biomass processing residues - Byproducts from processing all forms of biomass that have significant energy potential. For example, making solid wood products and pulp from logs produces bark, shavings and sawdust, and spent pulping liquors. Because these residues already are collected at the point of processing, they can be convenient and relatively inexpensive sources of biomass for energy.

Biopower - The use of biomass feedstock to produce electric power or heat through direct combustion of the feedstock, through gasification and then combustion of the resultant gas, or through other thermal conversion processes. Power is generated with engines, turbines, fuel cells, or other equipment.

Biorefinery - A facility that processes and converts biomass into value-added products. These products can range from biomaterials to fuels such as ethanol or important feedstocks for the production of chemicals and other materials. Biorefineries can be based on a number of processing platforms that use mechanical, thermal, chemical, and biochemical processes.

British thermal unit - (Btu) A non-metric unit of heat, still widely used by engineers. One Btu is the heat energy needed to raise the temperature of one pound of water from 60°F to 61°F at one atmosphere pressure. 1 Btu = 1055 joules (1.055 kJ).

Bulk density - Weight per unit of volume, usually specified in pounds per cubic foot.

By-product - Material, other than the principal product, generated as a consequence of an industrial process or as a breakdown product in a living system.

Carbon Cycle - The uptake of carbon dioxide by plants through photosynthesis, its ingestion by animals, and its release to the atmosphere through respiration and decay of organic materials. Human activities like the burning of fossil fuels contribute to the release of carbon dioxide in the atmosphere.

Carbon dioxide (CO2) - A colorless, odorless, non-poisonous gas that is a normal part of the ambient air. Carbon dioxide is a product of fossil fuel combustion.

Catalyst - A substance that increases the rate of a chemical reaction, without being consumed or produced by the reaction. Enzymes are catalysts for many biochemical reactions.

Cellulose - The main carbohydrate in living plants. Cellulose forms the skeletal structure of the plant cell wall.

Commercial species - Tree species suitable for industrial wood products.

Conservation Reserve Program - CRP provides farm owners or operators with an annual per-hectare rental payment and one-half the cost of establishing a permanent land cover in exchange for retiring environmentally sensitive cropland from production for 10 to 15 years. In 1996, Congress reauthorized CRP for an additional round of contracts, limiting enrollment to 14.7 million hectares at any time. The 2002 Farm Act increased the enrollment limit to 15.7 million hectares. Producers can offer land for competitive bidding based on an Environmental Benefits Index (EBI) during periodic signups, or can automatically enroll more limited acreages in practices such as riparian buffers, field windbreaks, and grass strips on a continuous basis. CRP is funded through the Commodity Credit Corporation (CCC).

Coppicing - A traditional method of woodland management, by which young tree stems are cut down to a low level, or sometimes right down to the ground. In subsequent growth years, many new shoots will grow up, and after a number of years the cycle begins again and the coppiced tree or stool is ready to be harvested again. Typically coppice woodland is harvested in sections, on a rotation. In this way a crop is available each year.

Cord - A stack of wood comprising 128 cubic feet (3.62 m3); standard dimensions are 4 x 4 x 8 feet, including air space and bark. One cord contains approximately 1.2 U.S. tons (oven-dry) = 2400 pounds = 1089 kg.

Corn Distillers Dried Grains (DDG) - Obtained after the removal of ethanol by distillation from the yeast fermentation of a grain or a grain mixture by separating the resultant coarse grain fraction of the whole stillage and drying it by methods employed in the grain distilling industry.

Cropland - Total cropland includes 5 components: cropland harvested, crop failure, cultivated summer fallow, cropland used only for pasture, and idle cropland.

Cropland used for crops - Cropland used for crops includes cropland harvested, crop failure, and cultivated summer fallow. **Cropland harvested** includes row crops and closely sown crops; hay and silage crops; tree fruits, small fruits, berries, and tree nuts; vegetables and melons; and miscellaneous other minor crops. In recent years, farmers have double-cropped about 4% of this acreage. **Crop failure** consists mainly of the acreage on which crops failed because of weather, insects, and diseases, but includes some land not harvested due to lack of labor, low market prices, or other factors. The acreage planted to cover and soil improvement crops not intended for harvest is excluded from crop failure and is considered idle. **Cultivated summer fallow** refers to cropland in sub-humid regions of the West cultivated for 1 or more seasons to control weeds and accumulate moisture before small grains are planted. This practice is optional in some areas, but it is a requirement for crop production in the drier cropland areas of the West. Other types of fallow, such as cropland planted with soil improvement crops but not harvested and cropland left idle all year, are not included in cultivated summer fallow but are included as idle cropland.

Cropland pasture - Land used for long-term crop rotation. However, some cropland pasture is marginal for crop uses and may remain in pasture indefinitely. This category also includes land that was used for pasture before crops reached maturity and some land used for pasture that could have been cropped without additional improvement.

dbh - Tree diameter measured at approximately breast high from the ground.

Deck - (also known as "landing", "ramp", "set-out") An area designated on a logging job for the temporary storage, collection, handling, sorting, and loading of trees or logs.

Distillers Dried Grains (DDG) - The dried grain byproduct of the grain fermentation process, which may be used as a high-protein animal feed.

Distillers Wet Grains (DWG) - The product obtained after the removal of ethyl alcohol by distillation from the yeast fermentation of corn.

Effluent - The liquid or gas discharged from a process or chemical reactor, usually containing residues from that process.

Emissions - Waste substances released into the air or water. See also Effluent.

Energy crops - Crops grown specifically for their fuel value. These include food crops such as corn and sugarcane, and nonfood crops such as poplar trees and switchgrass. Currently, 2 types of energy crops are under development: short-rotation woody crops, which are fast-growing hardwood trees harvested in 5 to 8 years, and herbaceous energy crops, such as perennial grasses, which are harvested annually after taking 2 to 3 years to reach full productivity.

Enzyme - A protein or protein-based molecule that speeds up chemical reactions occurring in living things. Enzymes act as catalysts for a single reaction, converting a specific set of reactants into specific products.

Ethanol (CH5OH) - Otherwise known as ethyl alcohol, alcohol, or grain-spirit. A clear, colorless, flammable oxygenated hydrocarbon with a boiling point of 78.5 degrees Celsius in the anhydrous state. In transportation, ethanol is used as a vehicle fuel by itself (E100 – 100% ethanol by volume), blended with gasoline (E85 – 85% ethanol by volume), or as a gasoline octane enhancer and oxygenate (E10 – 10% ethanol by volume).

Exotic species - Introduced species not native or endemic to the area in question.
Feedstock - A product used as the basis for manufacture of another product.

Fermentation - Conversion of carbon-containing compounds by micro-organisms for production of fuels and chemicals such as alcohols, acids, and energy-rich gases.

Fiber products - Products derived from fibers of herbaceous and woody plant materials. Examples include pulp, composition board products, and wood chips for export.

Fine materials - Wood residues not suitable for chipping, such as planer shavings and sawdust.

Forest land - Land at least 10% stocked by forest trees of any size, including land that formerly had such tree cover and that will be naturally or artificially regenerated. Forest land includes transition zones, such as areas between heavily forested and nonforested lands that are at least 10% stocked with forest trees and forest areas adjacent to urban and built-up lands. Also included are pinyon-juniper and chaparral areas in the West and afforested areas. The minimum area for classification of forest land is 0.4 ha. Roadside, streamside, and shelterbelt strips of trees must have a crown width of at least 36.5 m to qualify as forest land. Unimproved roads and trails, streams, and clearings in forest areas are classified as forest if less than 36.5 m wide.

Forestry residues - Includes tops, limbs, and other woody material not removed in forest harvesting operations in commercial hardwood and softwood stands, as well as woody material resulting from forest management operations such as precommercial thinnings and removal of dead and dying trees.

Forest health - A condition of ecosystem sustainability and attainment of management objectives for a given forest area. Usually it is considered to include green trees, snags, resilient stands growing at a moderate rate, and endemic levels of insects and disease. Natural processes still function or are duplicated through management intervention.

Fossil fuel - Solid, liquid, or gaseous fuels formed in the ground after millions of years by chemical and physical changes in plant and animal residues under high temperature and pressure. Oil, natural gas, and coal are fossil fuels.

Fuel cycle - The series of steps required to produce electricity. The fuel cycle includes mining or otherwise acquiring the raw fuel source, processing and cleaning the fuel, transport, electricity generation, waste management, and plant decommissioning.

Gasification - A chemical or heat process to convert a solid fuel to a gaseous form.

Gasifier - A device for converting solid fuel into gaseous fuel. In biomass systems, the process is referred to as pyrolitic distillation. See Pyrolysis.
Genetic selection - Application of science to systematic improvement of a population, e.g. through selective breeding.

Grassland pasture and range - All open land used primarily for pasture and grazing, including shrub and brush land types of pasture; grazing land with sagebrush and scattered mesquite; and all tame and native grasses, legumes, and other forage used for pasture or grazing. Because of the diversity in vegetative composition, grassland pasture and range are not always clearly distinguishable from other types of pasture and range. At one extreme, permanent grassland may merge with cropland pasture, or grassland often may be found in transitional areas with forested grazing land.

Greenhouse effect - The effect of certain gases in the Earth's atmosphere in trapping heat from the sun.

Greenhouse gases - Gases that trap the heat of the sun in the Earth's atmosphere, producing the greenhouse effect. The two major greenhouse gases are water vapor and carbon dioxide. Other greenhouse gases include methane, ozone, chlorofluorocarbons, and nitrous oxide.

Habitat - The area where a plant or animal lives and grows under natural conditions. Habitat includes living and non-living attributes and provides all requirements for food and shelter.

Hectare - Common metric unit of area, equal to 2.47 acres. 100 ha = 1 km2 kilometer.

Hemicellulose - Hemicellulose consists of short, highly branched chains of sugars. In contrast to cellulose, which is a polymer of only glucose, a hemicellulose is a polymer of 5 different sugars. It contains 5-carbon sugars (usually D-xylose and L-arabinose) and 6-carbon sugars (D-galactose, D-glucose, and D-mannose) and uronic acid. The sugars are highly substituted with acetic acid. The branched nature of hemicellulose renders it amorphous and relatively easy to hydrolyze to its constituent sugars compared to cellulose. When hydrolyzed, the hemicellulose from hardwoods or grasses releases products high in xylose (a 5-carbon sugar). The hemicellulose contained in softwoods, by contrast, yields more 6-carbon sugars.

Herbaceous - Non-woody type of vegetation, usually lacking permanent strong stems, such as grasses, cereals and canola (rape).

Hydrolysis - A process of breaking chemical bonds of a compound by adding water to the bonds.

Idle cropland - Land in cover and soil improvement crops, and cropland on which no crops were planted. Some cropland is idle each year for various physical and economic reasons. Acreage diverted from crops to soil-conserving uses (if not eligible for and used as cropland pasture) under federal farm programs is included in this component. Cropland enrolled in the Federal Conservation Reserve Program (CRP) is included in idle cropland.

Industrial wood - All commercial roundwood products except fuelwood.

Invasive species - A species that has moved into an area and reproduced so aggressively that it threatens or has replaced some of the original species.

Legume - Any plant belonging to the family Leguminosae. It is characterized by pods as fruits and root nodules enabling the storage of nitrogen.

Lignin - Structural constituent of wood and (to a lesser extent) other plant tissues, which encrusts the cell walls and cements the cells together.

Logging residues - The unused portions of growing-stock and non-growing-stock trees cut or killed by logging and left in the woods.

Moisture content - (MC) The weight of the water con tained in wood, usually expressed as a percentage of weight, either oven-dry or as received.

Moisture content, dry basis - Moisture content expressed as a percentage of the weight of oven-dry wood, i.e.: [(weight of wet sample - weight of dry sample) / weight of dry sample] x 100

Moisture content, wet basis - Moisture content expressed as a percentage of the weight of wood as-received, i.e.: [(weight of wet sample - weight of dry sample) / weight of wet sample] x 100

Monoculture - The cultivation of a single species crop.

Municipal solid waste (MSW) - Garbage. Refuse offering the potential for energy recovery; includes residential, commercial, and institutional wastes.

National Environmental Policy Act (NEPA) - A federal law enacted in 1969 that requires all federal agencies to consider and analyze the environmental impacts of any proposed action. NEPA requires an environmental impact statement for major federal actions significantly affecting the quality of the environment. NEPA requires federal agencies to inform and involve the public in the agency´s decision making process and to consider the environmental impacts of the agency´s decision.

Nonforest land - Land that has never supported forests and lands formerly forested where use of timber management is precluded by development for other uses. (Note: Includes area used for crops, improved pasture, residential areas, city parks, improved roads of any width and adjoining clearings, powerline clearings of any width, and 0.4 to 1.8-ha areas of water classified by the Bureau of the Census as land. If intermingled in forest areas, unimproved roads and nonforest strips must be more than 36.5 m wide, and clearings must be more than 0.4 ha in area to qualify as nonforest land.)

Oilseed crops - Primarily soybeans, sunflower seed, canola, rapeseed, safflower, flaxseed, mustard seed, peanuts, and cottonseed, used for the production of cooking oils, protein meals for livestock, and industrial uses.

Old growth - Timber stands with the following characteristics; large mature and over-mature trees in the overstory, snags, dead and decaying logs on the ground, and a multi-layered canopy with trees of several age classes.

Other forest land - Forest land other than timberland and reserved forest land. It includes available forest land that is incapable of annually producing 1.4 cubic meters per ha of industrial wood under natural conditions because of adverse site conditions such as sterile soils, dry climate, poor drainage, high elevation, steepness, or rockiness.

Other removals - Unused wood volume from cut or otherwise killed growing stock, from cultural operations such as precommercial thinnings, or from timberland clearing. Does not include volume removed from inventory through reclassification of timberland to productive reserved forest land.

Other sources - Sources of roundwood products that are not growing stock. These include salvable dead, rough, and rotten trees, trees of noncommercial species, trees less than 1.97 cm dbh, tops, and roundwood harvested from non-forest land (for example, fence rows).

Pilot scale - The size of a system between the small laboratory model size (bench scale) and a full-size system.

Poletimber trees - Live trees at least 1.97 cm in dbh but smaller than sawtimber trees.

Pyrolysis - The thermal decomposition of biomass at high temperatures (greater than 400° F, or 200° C) in the absence of air. The end product of pyrolysis is a mixture of solids (char), liquids (oxygenated oils), and gases (methane, carbon monoxide, and carbon dioxide) with proportions determined by operating temperature, pressure, oxygen content, and other conditions.

Renewable Fuel Standards - Under the Energy Policy Act of 2005, EPA is responsible for promulgating regulations to ensure that gasoline sold in the United States contains a minimum volume of renewable fuel. A national Renewable Fuel Program (also known as the Renewable Fuel Standard Program, or RFS Program) will increase the volume of renewable fuel required to be blended into gasoline, starting with 15 billion liters in calendar year 2006 and nearly doubling to 28.4 billion liters by 2012. The RFS program was developed in collaboration with refiners, renewable fuel producers, and many other stakeholders.

Renewables Portfolio Standards/Set Asides - Renewables Portfolio Standards (RPS) require that a certain percentage of a utility’s overall or new generating capacity or energy sales must be derived from renewable resources, i.e., 1% of electric sales must be from renewable energy in the year 200x. Portfolio Standards most commonly refer to electric sales measured in megawatt-hours (MWh), as opposed to electric capacity measured in megawatts (MW). The term "set asides" frequently is used to refer to programs in which a utility is required to include a certain amount of renewables capacity in new installations.

Residues - Bark and woody materials that are generated in primary wood-using mills when roundwood products are converted to other products. Examples are slabs, edgings, trimmings, sawdust, shavings, veneer cores and clippings, and pulp screenings. Includes bark residues and wood residues (both coarse and fine materials) but excludes logging residues.

Rotation - Period of years between establishment of a stand of timber and the time when it is considered ready for final harvest and regeneration.

Saccharification - The process of breaking down a complex carbohydrate, such as starch or cellulose, into its monosaccharide components.

Salvable dead tree - A downed or standing dead tree that is considered currently or potentially merchantable by regional standards.

Saplings - Live trees 2.54 cm through 1.93 cm dbh.

Silviculture - Theory and practice of controlling the establishment, composition, structure, and growth of forests and woodlands.

Stand - (of trees) A tree community that possesses sufficient uniformity in composition, constitution, age, spatial arrangement, or condition to be distinguishable from adjacent communities.

Stand density - The number or mass of trees occupying a site. It is usually measured in terms of stand density index or basal area per ha.

Starch - A naturally abundant nutrient carbohydrate, found chiefly in the seeds, fruits, tubers, roots, and stem pith of plants, notably in corn, potatoes, wheat, and rice, and varying widely in appearance according to source but commonly prepared as a white, amorphous, tasteless powder.

Stover - The dried stalks and leaves of a crop remaining after the grain has been harvested.

Sustainable - An ecosystem condition in which biodiversity, renewability, and resource productivity are maintained over time.

Switchgrass - *Panicum virgatum,* is a native grass species of the North American Prairies that has high potential as an herbaceous energy crop. The relatively low water and nutrient requirements of switchgrass make it well suited to marginal land, and it has long-term, high yield productivity over a wide range of environments.

Watershed - The drainage basin contributing water, organic matter, dissolved nutrients, and sediments to a stream or lake.

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