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ARE AGROFUELS A CONSERVATION THREAT OR OPPORTUNITY FOR GRASSLAND BIRDS IN THE UNITED STATES?

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Abstract. In the United States, government-mandated growth in the production of crops dedicated to biofuel (agrofuels) is predicted to increase the demands on existing agricultural lands, potentially threatening the persistence of populations of grassland birds they support. We review recently published literature and datasets to (1) examine the ability of alternative agrofuel crops and their management regimes to provide habitat for grassland birds, (2) determine how crop placement in agricultural landscapes and agrofuel-related land-use change will affect grassland birds, and (3) identify critical research and policy-development needs associated with agrofuel production. We find that native perennial plants proposed as feedstock for agrofuel (switchgrass, *Panicum virgatum*, and mixed grass–forb prairie) have considerable potential to provide new habitat to a wide range of grassland birds, including rare and threatened species. However, industrialization of agrofuel production that maximizes biomass, homogenizes vegetation structure, and results in the cultivation of small fields within largely forested landscapes is likely to reduce species richness and/or abundance of grassland-dependent birds. Realizing the potential benefits of agrofuel production for grassland birds' conservation will require the development of new policies that encourage agricultural practices specifically targeting the needs of grassland specialists. The broad array of grower-incentive programs in existence may deliver new agrofuel policies effectively but will require coordination at a spatial scale broader than currently practiced, preferably within an adaptive-management framework.

Key words: *biofuels, biodiversity, cellulosic ethanol, Conservation Reserve Program, prairie, switchgrass.*

¿Son los Agrocombustibles una Amenaza o una Oportunidad para la Conservación de las Aves de Pastizal en Estados Unidos?

Resumen. En los Estados Unidos, se predice que el crecimiento impuesto por el gobierno en la producción de cultivos dedicados a biocombustibles (agrocombustibles) aumentará las demandas en las tierras de cultivo existentes, amenazando potencialmente la persistencia de las poblaciones de aves de pastizal que albergan. Revisamos la literatura publicada recientemente y las bases de datos para (1) examinar la habilidad de los cultivos alternativos de agrocombustibles y sus regímenes de manejo para brindar hábitat a las aves de pastizal, (2) determinar cómo la ubicación de los cultivos en los paisajes agrícolas y los cambios en el uso del suelo relacionados a los agrocombustibles afectarán

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las aves de pastizal, e (3) identificar necesidades de investigación críticas y de desarrollo de políticas asociados con la producción de agrocombustibles. Encontramos que las plantas nativas perennes propuestas como materia prima para los biocombustibles (*Panicum virgatum* y praderas mixtas de pastos y yuyos) tienen un potencial considerable para brindar hábitat nuevo a una amplia variedad de aves de pastizal, incluyendo especies raras y amenazadas. Sin embargo, la industrialización de la producción de agrocombustibles que maximiza la biomasa, homogeniza la estructura de la vegetación y resulta en el cultivo de pequeños campos adentro de paisajes mayormente forestados probablemente reduce la riqueza de especies y/o la abundancia de aves que dependen de pastizales. Entender los beneficios potenciales de la producción de agrocombustibles para la conservación de las aves de pastizal requerirá el desarrollo de nuevas políticas que promuevan prácticas agrícolas que apunten a las necesidades de los especialistas de pastizal. La amplia gama de programas de incentivo que existe para los productores puede proveer de modo eficiente nuevas políticas de agrocombustibles, pero requerirá coordinación a una escala espacial más amplia que la que se practica actualmente, preferiblemente dentro de un marco de manejo adaptativo.

INTRODUCTION

Biofuels, or more accurately, *agrofuels*, have become a core component of sustainable-energy policies worldwide because they represent a potential means of increasing energy independence while stimulating rural economies and cutting greenhouse-gas emissions. In the United States, federal mandates for production of agrofuel crops (Energy Independence and Security Act; H.R. 6—110th Congress 2007) and associated subsidies (e.g., Biomass Crop Assistant Program, H.R. 2419—110th Congress 2008) are encouraging the cultivation of new biomass crops and systems to manage them. Given that at least 206 000 km^2 of new cultivated land will be needed to meet U.S. energy demand by 2030 (West et al. 2009), biomass production has the potential to reshape landscapes over large scales. The expansion and intensification of agriculture may already pose severe threats to biodiversity (Tilman et al. 2001, Green et al. 2005, Firbank et al. 2008). Nevertheless, remarkably little information exists linking agrofuel crops to biodiversity or economically important ecosystem services (e.g., pest control) (Fargione et al. 2009, Dauber et al. 2010, Fletcher et al. 2011).

The few studies that have examined the ecological effects of increasing agrofuel production have focused on the implications for biodiversity in general (Groom et al. 2008, Fargione et al. 2009, Dauber et al. 2010) or for certain taxonomic groups (arthropods: Gardiner et al. 2010; vertebrates: Fletcher et al. 2011). Not surprisingly, these studies indicate that expansion of intensively managed monocultures of annual plants as feedstocks (e.g., corn, soybeans) could reduce biodiversity, but the development of native and/or perennial plants as feedstocks may actually increase species richness at the scales of the field and landscape (Groom et al. 2008, Fargione et al. 2009, Dauber et al. 2010, Fletcher et al. 2011). Such findings suggest that well-managed and properly planned agrofuel systems may meet future energy needs while simultaneously maintaining biodiversity. While these findings are encouraging, it remains unclear if these benefits will extend to the most rare and sensitive components of biodiversity (i.e., those of highest conservation priority) because using species richness and abundance as measures of a program's success can fall short in assessing the status of specialist species (Filippi-Codaccioni et al. 2010).

North American grassland birds have experienced population declines more dramatic and rapid than those of any other avian group in North America (Brennan and Kuvleski 2005) and represent a particularly sensitive biodiversity component likely to be affected by land-use change associated with projected growth in biomass production (Fargione et al. 2009, Fletcher et al. 2011). Thus evaluating the potential effects of agrofuel expansion on grassland birds ranks high as a conservation-research need and merits serious attention from policy makers. Compared to that on other taxa, the empirical literature on grassland birds also represents the richest available dataset linking biodiversity responses to components of agrofuel production.

Determining whether the expansion of agrofuels may represent a new opportunity for conservation or a potential threat to grassland bird populations requires information on the ability of particular feedstocks to support diverse and abundant bird assemblages and how production of agrofuel crops affects the availability of agricultural, semi-natural, and natural habitats and their landscape-scale patterning.

To understand how an increasing demand for agrofuel production will alter the abundance and context of habitats available to grassland birds we follow the conceptual framework of Firbank et al. (2008), describing agricultural systems according to three scales of intensification: (1) changes in the type of crops and their management at the field scale, (2) changes in the structure and diversity of agricultural landscapes, and (3) changes in large-scale land-use. Next, we identify current and future threats and opportunities for grassland bird conservation associated with agrofuels and identify critical research and policy development needed to create sound conservation guidelines for grassland birds.

We develop a conceptual model useful for understanding how these perspectives can be integrated into the production of agrofuel crops in the United States (Fig. 1).

UNDERSTANDING AGROFUEL CROPS AS HABITAT FOR GRASSLAND BIRDS

CROP SELECTION

Although grassland birds forage in row crops, fields of corn grown for ethanol provide limited breeding habitat (Best et al.

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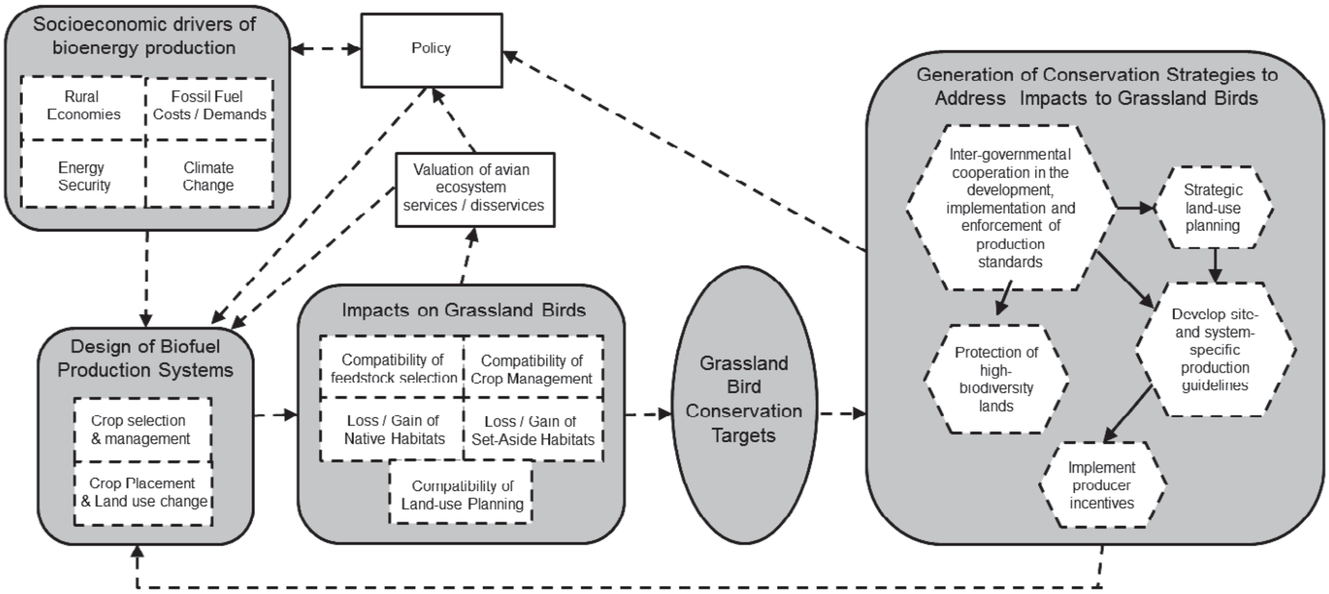

FIGURE 1. A conceptual model for understanding how grassland bird conservation can be integrated into the production of agrofuel crops in the United States. A complex set of socioeconomic and political drivers (top left) will ultimately determine which crops are selected for production in various agricultural regions and how they will be managed (bottom left). The direct and indirect effects of these production systems on grassland birds at local and landscape scales will need to be studied and monitored, then evaluated for their effectiveness in meeting regional conservation targets for grassland birds (bottom center). Conservation strategies must then be designed to mitigate the effects of agrofuel production on grassland birds (bottom right). Such strategies may include new intergovernmental cooperation to develop production standards that meet conservation targets for grassland birds within a broader strategy for biodiversity conservation, strategic land-use planning within the context of producer-incentive programs, and provisions for the conservation of critical habitat for grassland birds. Together with valuation of the economic costs and benefits (e.g., pest control) of grassland birds to agrofuel production, strategic conservation planning can help inform new sustainable agrofuel policy (top) that feeds back within this adaptive-management framework.

1995, Brennan and Kuvlesky 2005) as only a few species such as the Horned Lark (*Eremophila alpestris*) and Vesper Sparrow (*Pooecetes gramineus*) regularly nest in corn fields, often with limited success (Dechant et al. 2002, Dinkins et al. 2002). The incorporation of conservation tillage, cover crops, and organic farming regimes can increase the diversity and reproductive success of grassland birds (Beecher et al. 2002, Hole et al. 2005), but increasing demand for corn stover as a agrofuel feedstock should intensify agricultural practices (Wilhelm et al. 2007). This will leave less vegetative residue in the fields to protect soil and water resources and act as cover for birds.

Next-generation cellulosic technology, which produces ethanol from lignocellulose rather than from glucose or starch-rich components of row crops, is capable of producing liquid fuel from nonfood crops and is therefore targeted to be the leading source of renewable transportation fuel in the future (U.S. Renewable Fuels Standard, H.R. 6—110th Congress 2007). However, markets for cellulosic biomass are not well established, and research to improve crops, industrialize cellulosic technology, and identify optimal management practices is continuing. As a result, research investigating the ecological consequences of cultivation of perennial plants for cellulose will likely lag behind its implementation.

Perennial grasses such as *Miscanthus* × *giganteus* and reed canary-grass (*Phalaris arundinacea*) are leading candidates for dedicated agrofuel crops in the United States. Both produce high biomass when grown in monoculture. Additionally, floristically diverse grasslands such as restored or reconstructed prairies containing as little as 60% grass can also act as sustainable sources of cellulosic biomass (Tilman et al. 2006, Garlock et al. 2012).

Miscanthus is an exotic and potentially invasive species in the United States. But poorly established and weedy stands of *Miscanthus* can support species of high conservation concern and a relatively high diversity of breeding birds in the United Kingdom (Semere and Slater 2006), though these conditions will be atypical of stands managed for biomass. The early spring harvest schedule and low requirement for chemicals (reviewed in Lewandowski et al. 2000) mean limited disturbance for breeding birds, as well as dense habitat for wintering birds (King and Savidge 1995, but see Bellamy et al. 2009). To date, no information exists on how North American birds might use monocultures of *Miscanthus*. Kirsch et al. (2007) reported that reed canary-grass supports a low diversity but high abundance of birds, but as for *Miscanthus* little is known about the costs and benefits of large monocultures of reed canary-grass for grassland birds in the United States.

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The perennial feedstock best understood from the agrofuel–grassland-bird-habitat perspective is switchgrass (*Panicum virgatum*), a native perennial warm-season grass. Switchgrass is a model energy crop (McLaughlin and Walsh 1998) capable of providing habitat for breeding and migrating birds. Annual crops, like corn, do not provide useful habitat, in part, because fields of such crops are largely bare of vegetation during much of the year. Several species characteristic of grasslands nest in switchgrass fields, including the Northern Harrier (*Circus cyaneus*), Sedge Wren (*Cistothorus platensis*), Bobolink (*Dolichonyx oryzivorus*), Dickcissel (*Spiza americana*), Henslow's Sparrow (*Ammodramus henslowii*), and Grasshopper Sparrow (*A. savannarum*) (Murray and Best 2003, Roth et al. 2005, Bakker and Higgins 2009, Robertson et al. 2011a). Species using switchgrass as stopover habitat include the Northern Harrier, Sedge Wren, Bobolink, Eastern Meadowlark (*Sturnella magna*), Henslow's Sparrow, Le Conte's Sparrow (*A. leconteii*), and Nelson's Sparrow (*A. nelsoni*); Robertson et al. 2011b). Nesting success in switchgrass of at least one of these species, the Grasshopper Sparrow, is sufficient to sustain stable populations (Murray and Best 2003), but demographic information on other species is lacking.

The overall species richness of grassland birds in switchgrass monocultures during the breeding season (Bakker and Higgins 2009) and migration is lower than in native prairie but similar to that of restored mixed grass–forb prairie (Robertson et al. 2011a,b) and significantly higher than that of corn fields (Fig. 2). While some common species such as the Horned Lark and Brown-headed Cowbird (*Molothrus ater*) can occupy corn fields, obligate grassland species such as the Sedge Wren, Bobolink, Henslow's Sparrow, Grasshopper Sparrow, and other nongrassland species of conservation interest, such as the Common Yellowthroat (*Geothlypis trichas*) and Clay-colored Sparrow (*Spizella pallida*), appear to benefit from production of perennials for biomass. Plotting the relative abundance of breeding bird species in switchgrass or prairie vs. corn against the species' conservation status indicates that species of highest conservation concern will benefit most from the expansion of these perennial crops at the expense of corn for agrofuel (Fig. 2). Indeed, Fletcher et al. (2011) argued that corn-based ethanol production could affect birds of highest conservation concern disproportionately more than other agricultural, natural, and semi-natural types of land use.

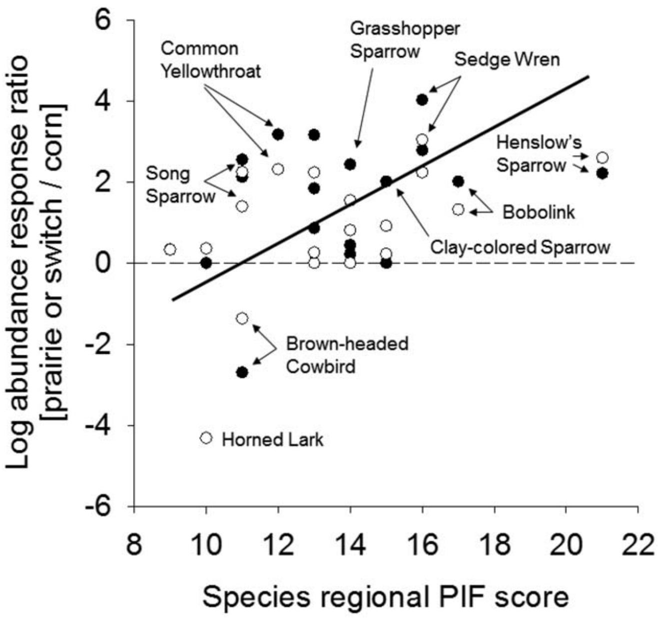

FIGURE 2. Average effect sizes (log response ratios) for abundances of 20 bird species in patches of prairie (open circles) and switchgrass (filled circles) (n = 20 each) and corn fields in southern Michigan. Using the approach employed by Fletcher et al. (2011), we found that species (only those with more extreme values are labeled) with higher regional Partners in Flight scores (indicating greater regional conservation concern; Carter et al. 2000) were more abundant in prairie or switchgrass fields than in corn fields (ANCOVA: $F_{1,38} = 9.4$, $P = 0.004$). This result suggests that species in greatest need of conservation will benefit most from production of perennial agrofuel crops at the expense of corn. The regression line is based on response ratios from both types of planting. We found no difference in slope between prairie and switchgrass ($F_{1,38} = 0.1$, $P = 0.76$). We used the ratio of estimates in prairie and switchgrass fields to corn fields ($\ln[X_{\text{prairie or switch}}/X_{\text{corn}}]$) as our measure of effect size (Hedges et al. 1999). Response ratios are based on estimates of the relative abundance of species detected on at least 5% of breeding-season surveys by Robertson et al. (2011a). Most fields were managed as restored prairie or wildlife habitat and not for biomass production.

CROP MANAGEMENT

Although little is known about how grassland bird communities will respond to the management associated with the industrialization of switchgrass and other monocultures and polycultures based on perennial plants, we can make predictions based on research with row crops (e.g., Rodenhouse et al. 1995). Improvements in feedstock genetics and crop-management techniques aim to maximize biomass production by producing dense monocultures of highly productive biomass crops (reviewed in Benton et al. 2003). While high-density plantings maximize fuel production, they tend to favor habitat generalists such as the Song Sparrow (*Melospiza melodia*) and grassland obligates that tolerate dense vegetation such as the Sedge Wren (Robertson et al. 2011a,b). Richness of breeding birds, as well of grassland specialists, is highest at intermediate values of vegetation density (Robertson et al. 2011a). Furthermore, the benefits of any monoculture as habitat are debatable as floral diversity generally begets faunal diversity. Applications of the results of previous bird research in switchgrass fields are likely an optimistic representation of industrialized monocultural plantations because most switchgrass fields are not currently managed for biomass production and are therefore not true monocultures (Roth et al. 2005, Bakker and Higgins 2009, Robertson et al. 2011a,b). Therefore, the relative value and benefits of switchgrass monocultures to grassland birds may be lower than those of other grass habitats because of a

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lack of heterogeneity, as has been found for some kinds of plantings under the Conservation Reserve Program (CRP; Millenbah et al. 1996, McCoy et al. 2001).

In addition to differing in structure and plant species diversity, grasslands managed for feedstock based on perennials will also differ in the timing and rate of vegetative succession, leading to corresponding differences in grassland bird assemblages. In largely unmanaged switchgrass systems such as those of the CRP, vegetation structure is dominated by remnant stalks from the previous year's growth and favors birds that prefer thick vegetation structure. However, stands actively managed for biomass production will experience the removal of vegetation that resets succession and promotes settlement of species that prefer open habitats (Murray and Best 2003, Roth et al. 2005, Robertson et al. 2011a). Periodic disturbance (e.g., patch-burn grazing, Coppedge et al. 2001) is good for grassland systems and grassland birds, but, at both the local and landscape scales, the intensity and uniformity of cropping results in structural and successional homogeneity among the fields that may limit habitat suitability for some grassland birds.

Because structural diversity of grassland vegetation, both within and between fields, promotes richness and abundance of breeding and migratory species (Millenbah et al. 1996, McCoy et al. 2001, Robertson et al. 2011b), alternative harvest strategies may have a role in avian conservation. For example, a staggered fall harvest of entire fields or portions of fields (e.g., strip harvesting) will expand the availability during fall migration of habitat for species preferring sites with structural diversity (Robertson et al. 2011b). Such novel strategies may also have the secondary effect of broadening the habitat's structural diversity within or between fields the following spring and summer by increasing standing dead vegetation. Coordinated harvesting could thus produce a mosaic of grassland habitats that enhances habitat value for all subsets of the avian community, not just those that prefer the predominant vegetation structure (fall: high biomass/dense structure; spring: low biomass/sparse structure). Because perennial crops require fewer chemicals and are harvested in fall, disturbance and the mortality of young associated with annual crops would be reduced (Beecher et al. 2002).

Still, a multitude of open questions remain. The effect of harvest and its timing on the availability of arthropods as food for breeding, post-breeding, and migrant birds is unknown. Although a fall harvest timing will avoid the direct mortality of nesting grassland birds and their young typical of earlier, mid-summer harvest (e.g., Bollinger et al. 1990), exactly how patterns of cropping influence cues for breeding birds' settlement remains unknown. Nonetheless, the timing of fall harvest may alter the rate and timing of revegetation that shape the attractiveness of patches to spring migrants (Robertson et al., in press) and summer breeding birds (Robertson et al. 2011a). In warmer regions where multiple annual harvests may be possible and the harvest could overlap birds' breeding season, the intensification of management could lead to even more severe consequences by turning commercial switchgrass fields into ecological traps (i.e., attractive population sinks; Best 1986, Bollinger et al. 1990). It is important to recognize the existing research is generally confined to the mixed-grass prairie region of the United States. Grassland birds adapted to shorter grasses farther west may find that biomass plantations rapidly become unsuitable as they increase in height and density during the breeding season.

LANDSCAPE STRUCTURE AND DIVERSITY

The spatial extent and configuration of agrofuel croplands should also shape their suitability as habitat for grassland birds (reviewed in Ribic et al. 2009). Switchgrass fields and restored prairie have more breeding species per area, of both grassland obligates and birds in general, with increasing patch size, but this pattern is not observed in corn fields (Robertson et al. 2011a). Large patches of habitat with a low edge-to-area ratio increase suitability for both edge-avoiding species and those that suffer reduced reproductive success near edges (Johnson and Temple 1990, Winter and Faaborg 1999). Because some grassland bird species are more likely to settle in patches embedded in landscapes with more grassland habitat (e.g., Bakker et al. 2002, Renfrew and Ribic 2008), concentrating acreage of perennial biomass crops may enhance grassland birds' use of smaller patches. Insofar as the economics of ethanol production are predicted to cause aggregation of crops near processing plants, there is the potential for altering the agricultural landscape's structure with positive consequences for grassland birds by creating large unfragmented habitat patches.

Woody biomass crops such as poplar (*Populus* spp.) may also come into production as monocultures. In addition to competing for space with crops suitable for grassland birds, woody crops could reduce the attractiveness or suitability of existing grasslands or grass-based crops if they are grown in predominantly agricultural/grassland landscapes (Fletcher and Koford 2002, Coppedge et al. 2001, Renfrew and Ribic 2008, Ribic et al. 2009). Indeed, in contrast to some other taxa (e.g., arthropods), increasing landscape diversity does not enhance the species richness or abundance of grassland birds on a local scale (Robertson et al. 2011a,b).

AGROFUELS AND LARGE-SCALE LAND-USE CHANGE

The possibility that expanded agrofuel production will lead to large-scale reductions in habitat for grassland birds is a fundamental concern regarding the ecological sustainability of agrofuels (Roth et al. 2005, Fargione et al. 2009, Fletcher et al. 2011). Indeed, meeting U.S. energy demands is projected to require that additional lands equal to the size of the state of Kansas come into production (West et al. 2009). Temperate grasslands will be affected more than the other biomes of the U.S. (McDonald et al. 2009). Federal bioenergy policies in the United States are based largely on the assumption that most energy crops will be produced on land already in use for agriculture, and so far most expansion in corn production has come from land previously used

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for other crops, especially soybeans (Secchi and Babcock 2007, USDA 2009). Yet mandates for ever-increasing production are placing heavier demands on agricultural lands and favoring conversion of native prairie and semi-natural grasslands associated with set-aside programs to corn-ethanol production (Secchi and Babcock 2007, Stephens et al. 2008, Fargione et al. 2009). Loss of native grasslands is projected to continue if commodity prices continue to increase, leading to estimated losses of 121 million ha in the prairie pothole region alone (Rashford et al. 2011). Indirect land-use consequences of bioenergy production are not unique to the United States. Bowyer (2010) reported that the European Union's goal to produce 10% of its transport fuel from renewable sources by 2020 will drive farmers to convert 69 000 km^2 of wild lands into fields and plantations.

The suitability of particular agrofuel feedstocks will vary according to geographic region (Evans et al. 2010). Even so, the ability of perennial feedstocks such as switchgrass to produce substantial biomass even on degraded lands or those with marginal soils (Fuentes and Taliaferro 2002) places abandoned farmland and "marginal lands" deemed unsuitable for corn and other traditional crops at the top of the list to provide the acreage required for next-generation fuels (e.g., Hoogwijk et al. 2005, Field et al. 2008). Native grasses like switchgrass can grow on such lands, further highlighting the capability of cellulosic feedstocks to fill energy shortfalls.

The distribution of lands that are unprofitable, except when crop prices are very high (i.e., "producer-defined marginal lands," Fig. 3), suggests that a number of grassland specialists could be affected by future agrofuel production. Perennial biomass crops are entering the American landscape most prominently in portions of the Dakotas where some of the largest areas of native prairie and rangeland in the United States remain and where current and projected losses of grasslands that benefit birds are most serious (Fargione et al. 2009). This region coincides with the breeding ranges of several prairie endemics such as Baird's Sparrow (*Ammodramus bairdii*), Chestnut-collared Longspur (*Calcarius ornatus*), and Sprague's Pipit (*Anthus spragueii*), all of which are of high conservation concern because of severe long-term population declines associated with loss and fragmentation of native grasslands. Additional grassland specialists could also be affected in other parts of the United States. Portions of northern Texas, western Oklahoma and Kansas, and eastern New Mexico where marginal lands have returned to corn production (Fig. 3) correspond closely to the remaining range of the Lesser Prairie-Chicken (*Tympanuchus pallidicinctus*), threatened by conversion of native prairie and semi-natural habitats (Rich et al. 2004, Hagen et al. 2005).

Predicting the effect(s) of agriculturally mediated habitat change on grassland birds is difficult because changes in land-use practices associated with agrofuel production are driven by interactions among cultural, technological, biophysical, political, economic, and demographic forces (Fig. 1; reviewed by Dale et al. 2011). Continuing losses of natural and semi-natural habitat related to the expansion of corn acreage are unlikely to

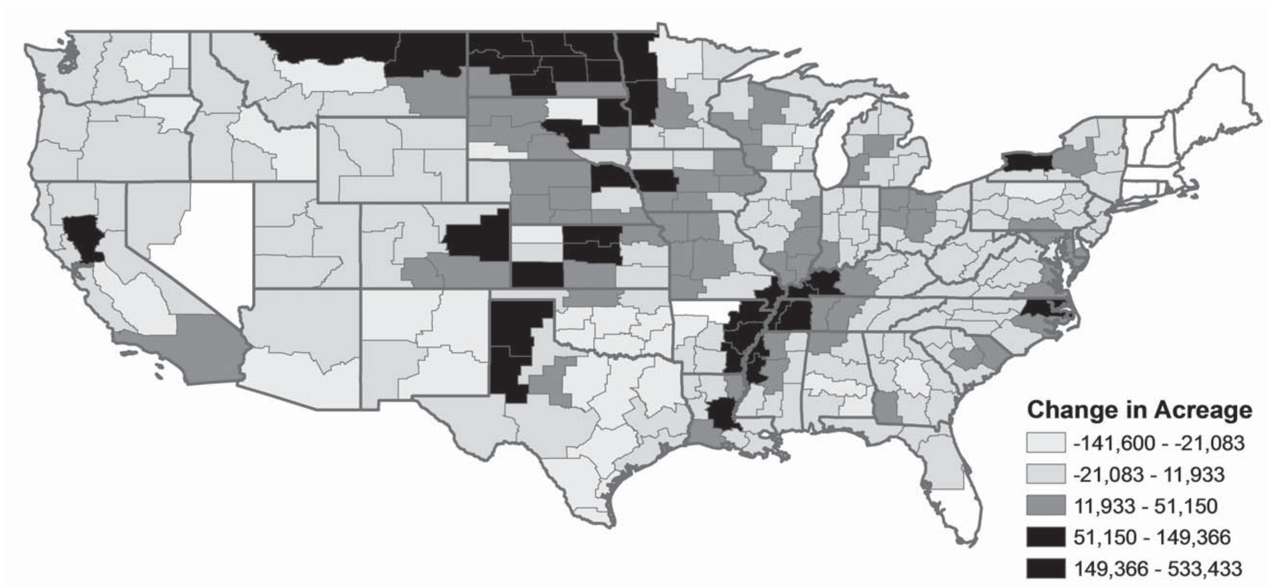

FIGURE 3. Change in average acreage of crops planted following the 2006 legislation to expand agrofuel production and the resulting rise in commodity prices. The map shows the difference between 2005–2006 and 2007–2009 in extent of crops by crop-reporting district (National Agricultural Statistics Service of the U.S. Department of Agriculture). The difference between these two periods represents, in part, the "producer-defined marginal lands." Crops included account for >90% of acreage planted in the U.S. (based on Agricultural Statistics Districts 2005–2009) and include corn, soybeans, wheat, barley, dry beans, canola, cotton, hay, oats, peanuts, rice, rye, safflower, grain sorghum, potatoes, safflower, sugar beets, sunflower, and tobacco. Crop prices began to climb in response to agrofuel expansion (along with other reasons) in the fall of 2006, so 2007 was the first year of planting in response to higher prices. Thus, for a measure of how higher crop prices have changed aggregate planted acreage, average planted acreage in 2005 and 2006 is used as the low-price-regime base. The average planted acreage in 2007, 2008, and 2009 is taken as a measure of planted acreage in a high-price regime.

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be reversed if they are simply replaced by perennial crops. Increasing agrofuel production can thus be expected to exacerbate long-term population declines in grassland birds (Fargione et al. 2009), though the effects may vary regionally (Fig. 3). Yet, if perennial bioenergy crops can be economically produced on marginal lands and replace sufficient acreage of alternative crops or land-cover types less capable of supporting grassland birds, the potential for net gains in the availability of grassland bird habitat increases (Murray et al. 2003, Meehan et al. 2010), at least for species that can tolerate the structural characteristics and successional patterns associated with biomass plantations.

LESSONS AND OPPORTUNITIES FOR POLICY DEVELOPMENT

American policies have largely triggered the development of agrofuel production through targets (Energy Independence and Security Act) and production subsidies (e.g., Biomass Crop Assistance Program), but environmental standards have lagged behind the rapid development of agrofuels. The United States has not adopted bioenergy-related standards to protect biodiversity, including grassland birds. Such standards will become increasingly critical to the success of biodiversity conservation as demand for food, feed, and fuel increases (Tilman et al. 2001, Groom et al. 2008). The development of biodiversity standards should draw on lessons from Europe, where agrofuel expansion and reductions in targets for set-aside programs have already reduced populations of grassland birds (Eggers et al. 2009).

The European Union (EU) addresses bioenergy-production issues through the revised Fuel Quality Directive (European Commission Environment 2009) and the Renewable Energy Sources Directive (EU-RES-D 2009/28/EC). These standards prohibit the production of biomass from land with high biodiversity value (including native grasslands), promote the use of contaminated or marginal lands through an incentive system, mandate that biomass be produced in accordance with EU standards (e.g., best agricultural practices and environmental conditions), and require that practices outside of the EU be monitored and specified through agreements with producing countries. However, these directives do not prevent indirect effects (Hennenberg et al. 2009) and allow biomass production on "set-aside" land (which otherwise cannot be used for production under EU agricultural rules), a policy that the U.S. Department of Agriculture has considered implementing. This is concerning because the continuing resilience of grassland birds in the United States is critically dependent on "surrogate grasslands" (Sample et al. 2003) including agricultural habitats such as pastures, hayfields, strip crops, small-grain fields, and lands set aside for conservation (as through the CRP; Herkert et al. 1996, Herkert 2009, Seigel and Lockwood 2010). Approximately 0.9 million ha of the area set aside in the EU has been used in recent years for agrofuel production (Eggers et al. 2009).

In addition, by focusing on species richness and abundance as measures of the programs' success, European set-aside programs have largely overlooked the habitat requirements and management needs of specialist species (Filippi-Codaccioni et al. 2010). This suggests that the U.S. will need to develop production guidelines specific for grassland birds within a larger policy targeting the conservation of biodiversity and ecosystem services (Dauber et al. 2010). Finally, the EU has not yet set minimum sustainability standards for all bioenergy crops nor established a robust and verifiable system of certification for agrofuels produced in the EU or imported.

The EU's experience suggests that even well-designed and enforced standards will not halt declines of grassland birds in the United States unless they are broadly implemented via incentives to growers and effective land-use planning (Hennenberg et al. 2009) (Fig. 1). The U.S. Biomass Crop Assistance Program was developed to provide financial assistance to owners and operators of agricultural lands and nonindustrial private forests who wish to establish, produce, and deliver biomass feedstocks. To date, this policy has provided subsidies largely to those already producing woody biomass as industrial waste and has done little to encourage new production of perennial grasses (Stubbs 2011). Biodiversity standards could, for example, be incorporated into a redesigned Biomass Crop Assistance Program as a condition of production subsidies. Uniquely, the U.S. has in place a large array of government set-aside programs that typically target wildlife conservation among other goals (e.g., CRP, Environmental Quality Incentives Program, Grassland Reserve Program, Conservation Security Program, Wildlife Habitat Incentives Program). The importance of these programs to bird conservation has been documented, even though the plant species composition of fields associated with incentive schemes like the CRP varies substantially from native species in mixed stands or monoculture to, in some regions, complete monocultures of exotic cool- or warm-season grasses (Herkert 2009). Therefore, the existing array of U.S. programs targeting different natural and agricultural habitats and ecological elements has great potential to act as an effective mechanism for delivery of bioenergy policy on private lands. Indeed, the failure of British "agri-environmental" schemes to protect some grassland specialists suggests that a wide variety of landowner incentives will be necessary to maintain populations of all species (Vickery et al. 2004).

Implementation of wildlife-friendly farming programs rarely considers the wider landscape context despite the importance of this perspective to conservation of avian diversity (Peach et al. 2001, Bradbury et al. 2004). Coordination between agencies managing set-aside programs (e.g., U.S. Department of Agriculture's Farm Service Agency, Natural Resources Conservation Service) and those managing birds (e.g., U.S. Fish and Wildlife Service, state wildlife action plans) has great potential to integrate information on the land (e.g., soil productivity), the people living on it, and biodiversity priorities. Such coordination could develop economic incentives that encourage the

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sowing of crops capable of optimizing habitat availability for grassland birds at temporal (e.g., long-term contracts) and spatial scales relevant to their population persistence (e.g., Rahmig et al. 2008; Fig. 1). For example, changes in the CRP to include the landscape-scale priorities of state natural-resource managers in the scoring of lands to be set aside have been successful in some regions and emphasize the potential for cooperative landscape conservation in agricultural systems. Even simple schemes encouraging growers to harvest biomass fuels before or after the regionally optimum date may provide biodiversity benefits by increasing heterogeneity in crop structure.

Ideally, policies will be implemented with a strategic approach to land-use planning that incorporates the value of private (unprotected) lands (e.g., Wilson et al. 2010) and can provide guidance about efficiently conserving biodiversity. Effective policies will contain provisions for law enforcement (e.g., U.S. Migratory Bird Treaty Act, International Convention on Biodiversity), delineation of areas dedicated to both production and protection (Groom et al. 2008), and evaluation of the effectiveness of programs in accomplishing conservation goals (Hennenberg et al. 2009). Given the large number of economic, political, and ecological unknowns, an adaptive-management approach is likely to be the best way to continually integrate new knowledge into the objectives of state and federal wildlife and agricultural programs (Williams et al. 2009) (Fig. 1). Closer integration of modeling with field-based monitoring is needed to strengthen the evidence available to decision makers, and this information must be distilled into clear recommendations digestible by producers, land managers, and policy makers.

New policy frameworks will require a major overhaul and integration of existing agricultural legislation in the United States and the formal recognition of the inherent tradeoffs between crop production and biodiversity and the ecosystem services (e.g., pest control) it provides (Fig. 1). Certainly, continuing agrofuel-driven changes in land use in the United States will bring the consideration of ecological sustainability in bioenergy production to the policy forefront.

CONCLUSIONS

An ever-increasing worldwide demand for fuel makes expanded farming for agrofuels inevitable. Our current state of knowledge suggests that perennial crops offer substantial opportunities for increasing the area and quality of habitat for grassland birds in agricultural landscapes. Yet realizing this potential will hinge critically on developments in the technological and economic feasibility of cellulosic bioenergy and on the ability and motivations of decision-makers to consider the needs of grassland birds in how they shape future energy and agricultural policy. Several conspicuous information gaps complicate the development of new policy and programs. For example, it remains unclear how agrofuel development is linked to other drivers of land-use change, how native and restored prairies will be directly or indirectly affected, and if conservation strategies focused on grassland birds may entail significant tradeoffs with other important taxa or ecosystem services. Agrofuel crops could become a central component of a new agricultural landscape of greater economic viability and ecological sustainability than that dominated by row crops (Scherr and McNeely 2008, Fargione et al. 2009, Fletcher et al. 2011). Ultimately, preventing growth in agrofuels from exacerbating already serious declines in grassland bird populations will require continuing investment in research and proactive new national policies targeting the needs of grassland birds.

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