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Debate: Can Bioenergy Be Produced in a Sustainable Manner That Protects Biodiversity and Avoids the Risk of Invaders?

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Weighing contrasting evidence is an integral element of science (Osborne 2010). The dominant forum for doing this and for scientific exchange in general is the peer-review and publication process. It tends to be slow because of the time required to conduct critical reviews. Rapid exchange and discourse, in the form of a live debate, can also move science forward. Whether fast or slow, debate and discourse are particularly important in sustainability research when novel human activities with unknown consequences are introduced. For example, whether bioenergy can become a sustainable future source of energy is a contentious issue. Topics of disagreement include the relative importance of different aspects of sustainability, regional variation in benefits, the validity of methods used to perform environmental assessments, choices of sustainability targets, and the reliability of sustainability certification (Acosta-Michlik et al. 2011, Jorgensen and Andersen 2012).

We held a modified Oxford-style debate at the 2012 ESA Annual Meeting in Portland, Oregon. Here, we summarize the key arguments advanced by opposing debate positions on the thesis that *Producing bioenergy can be sustainable for habitat availability and biodiversity and can avoid the risk of new invaders.* We gauged audience reactions to arguments made by representatives of both sides. We highlight the salient uncertainties in the debate, describe effective rhetorical strategies, and discuss purposes and appropriate contexts for scientific debate in general.

The sustainability debate

We invited two experts to support and two to oppose the above thesis. Experts were asked to develop compelling arguments to support their assigned positions, which did not necessarily represent their actual views. We polled the audience on their a priori support for the thesis using real-time polling software, SMS Poll (www.smspoll.net). The software permitted up to 50 votes via text or web interface, representing roughly half of the ~100-member audience. The two sides alternated delivering main arguments within a seven-minute time limit, supported by published literature. After each speaker, we informally polled the audience regarding support for the speaker's position. Main arguments were followed by three minutes of rebuttal, allowing each expert to counter opposing arguments. We conducted an identical online poll after the debate to determine whether arguments swayed opinions. We concluded by soliciting both oral questions and written comments from the audience.

Main arguments to the thesis[1]

Argument 1. In support

First, biofuels will replace a portion of fossil fuels, thereby avoiding associated large-scale biodiversity impacts from seismic exploration lines, drilling, and transporting petroleum and gasoline (Parish et al. 2012). Second, bioenergy feedstocks will not necessarily be grown as monocultures; cultivation of mixtures of native grassland perennials or algal communities is possible. Even where the feedstock is a single species, it can be managed so that other species are nearby. Moreover, diverse communities used as biofuel feedstocks can have significant environmental benefits other than biodiversity, such as a high energy return on investment, reduced net greenhouse gas emissions, and low agrochemical pollution (Tilman et al. 2006). Stockenreiter et al. (2012) found that lipid production is higher in more diverse microalgal communities. Including fish can, in theory, stabilize algal cultivation ponds by keeping zooplankton consumers of algae low (Smith et al. 2010).

1 Arguments and supporting references are abbreviated here compared to those in the oral debate.

Biodiversity can be enhanced by following these recommendations:

1) Grow crops on low-diversity lands. Plant diversity increases if perennial grasses or trees displace monoculture crops or brownfields. Aquatic biodiversity may be enhanced if highly fertilized crops are displaced. Algal biofuels can be produced on brownfields or paved areas.

2) Maintain structural complexity. Complexity of vegetation structure is related to biodiversity, and bioenergy crops can be managed to promote this. Moser et al. (2002) recommend maintaining a diversity of forest ages. Dhondt et al. (2007) found that the number of bird species on plantations with mixed ages of coppice willow and poplar was comparable to that in shrublands and successional fields. Wintering raptors preferred hybrid poplar plantations to adjacent habitat types in Oregon (Moser and Hilpp 2003). Small mammals preferred 1–3 year old hybrid poplar plantations with abundant understory to older plantations (Moser et al. 2002). Murray et al. (2003) recommended interspersing nonharvested switchgrass fields with harvested fields to support more grassland birds.

3) Select species as feedstocks to avoid invasion risk. Invasiveness is a combination of invasive potential of species and invasibility of the native community. Some species used as feedstocks have broad geographic ranges. For example, switchgrass is native to most of North America east of the Rocky Mountains. Switchgrass and the nonnative giant *Miscanthus*, a sterile hybrid, have been tested and found not to be invasive in dryland regions of California (Barney et al. 2012). Most species of eukaryotic microalgae and cyanobacteria being proposed as algal feedstocks are cosmopolitan and native, already inhabiting many water bodies. The use of saltwater algae in inland environments and use of freshwater algae near coasts can lower invasion risk.

Clearly, there are ways to manage biofuel feedstocks that will support biodiversity conservation and reduce invasion risk.

Argument 2. In opposition

Commercial-scale bioenergy production threatens habitat availability for many organisms in ways that are unlikely to be easily mitigated. For example, meeting federally mandated renewable fuel targets could require harvest of biomass from hundreds of millions of hectares of agricultural lands, forest, and uncultivated lands set aside for conservation (e.g., Conservation Reserve Program lands). Increased harvest will reduce habitat availability for critical taxa for a variety of reasons. In a recent meta-analysis, Fletcher et al. (2011) conclude that “vertebrate diversity and abundance are generally lower in biofuel crop habitats than in non-crop habitats these crops may replace.” Bioenergy production in agricultural landscapes will require placing marginal lands that currently provide habitat into production. Meehan et al. (2010) conclude that producing annual bioenergy crops in marginal lands will lead to up to a 65% loss of avian richness across 20% of the Midwest. Moreover, conversion of marginal lands will exacerbate other threats to wildlife, including pesticide use. For example, loss of noncrop habitat reduces natural pest suppression, resulting in increased pesticide use in agricultural crops (Meehan et al. 2010). Harvest in forest systems changes forest structure (Littlefield and Keeton 2012) and reduces coarse and fine woody debris. Extraction of fine woody debris might reduce this key habitat component by up to 45%, affecting over 280 species (Dahlberg et al. 2011). Finally, industrialization of bioenergy production will cause each region to converge to the most efficient bioenergy crop, reducing habitat diversity to the detriment of many species.

Intensification of bioenergy production will inexorably lead to losses of biodiversity and ecosystem services. In agriculture, crop yields have been increased by using more fertilizers and pesticides, planting monocultures, and decreasing landscape complexity, which has resulted in local species extirpations (Kleijn et al. 2009). Functional diversity is also being lost (Flynn et al. 2009), raising the specter of system collapse. Similarly, intensification in managed forests is reducing biodiversity and associated ecosystem services. Moreover, as the value of wood increases, forested lands will be converted to fast-growing species that support fewer species (Flaspohler and Webster 2011). Despite good intentions to diversify working landscapes, powerful economic and social forces will undoubtedly favor intensified bioenergy production systems with concomitant losses in biodiversity and ecosystem services.

Argument 3. In support

Production of biomass feedstock and conservation of biodiversity are not mutually exclusive. Empirical evidence from forested systems shows that common best practices maintain biodiversity in working landscapes. Of course, potential effects are largely dictated by spatial scale, landscape composition, and individual species response (Efroymson et al. 2013).

A series of meta-analyses (Riffell et al. 2011*a*, *b*, Verschuyl et al. 2011) examined possible impacts of biofuel feedstock production on forest biodiversity. A review of 68 studies concluded that (1) response varied by taxa and production system; (2) most taxa responded positively to thinning; (3) reduction of coarse woody debris may negatively impact some birds, but effects on other taxa were equivocal; (4) short-rotation woody crops may negatively affect birds and small mammals, but responses are variable and addition of shrubby habitat types on some landscapes may be beneficial; and (5) if woody biomass removal is <70–95% of experimental removals, impacts on overall biodiversity may be minimal. Related to point 5, it is uneconomical to eliminate most woody debris through forest residual harvest (see retention levels cited in Riffell et al. [2011a]). Additionally, harvest in a forested landscape would occur on a very small proportion of land in any given year, minimizing negative effects.

Another opportunity for feedstock production in managed forests is intercropping an herbaceous crop between rows of planted pine (Fig. 1a). Although more work is needed (Riffell et al. 2012), recent results show similar plant diversity between traditional planted pine stands and those intercropped with switchgrass (155 plant species), a diverse breeding bird community (54 species) in intercropped stands, and negligible effects on rodent and herptile communities. Early results indicate that intercropping may not substantially affect the diverse plant and wildlife communities associated with planted pine in a saw-timber rotation.

Implementation of science-based, best management practices (BMPs) (e.g., buffer strips and streamside management zones) and protecting unique ecological communities and those with threatened and endangered species can effectively retain elements of native biodiversity in commodity-based landscapes. Additionally, in most landscapes, not every acre will be available for biomass production.

This mixture of land uses may increase habitat heterogeneity and promote higher biodiversity. Retaining key habitat elements (e.g., snags) is a practical solution to maintain biodiversity in managed landscapes. Using portions of some landscapes for intensive biomass feedstock production may alleviate pressures on other managed lands, thus conserving wildlife habitat and biodiversity at larger spatial scales. Finally, bioenergy production may provide landowners with economic incentive to maintain forest and/or agricultural landscapes. This will reduce one of the largest threats to privately owned rural and wild landscapes: urbanization.

Argument 4. In opposition

The large-scale land use and landscape changes necessary to meet U.S. government-mandated benchmarks for renewable bioenergy (McDonald et al. 2009) will likely promote invasiveness. Reduced landscape heterogeneity in "new" areas of large-scale monoculture plantings increases susceptibility to invasion (Hoffman et al. 1995), particularly by introduced and weedy plants that take advantage of changed environmental conditions (Simberloff 2008). More notably, biomass feedstocks themselves are candidates for invasive spread (Fig. 1b); their establishment from seed in altered low-competition environments (Barney et al. 2012) and invasive spread has already been documented (Buddenhagen et al. 2009).

At the forefront of the issue of invasibility is the fear that biomass feedstocks have many traits associated with invasiveness, including C4 photosynthesis, long canopy duration, few-to-no known pests or diseases, rapid growth and belowground partitioning of nutrients early in the growing season, and high water use efficiency (Raghu et al. 2006). Some of these same traits are targets of genetic improvement efforts, and others are not compromised at the expense of improvements in biomass (Rogers et al. 2012). Indeed, risk assessments to predict weediness and invasiveness of biomass feedstocks (e.g., Cousens 2008) are a necessary and precautionary step before widespread cultivation (e.g., Buddenhagen et al. 2009, Gordon et al. 2011).

Genes and propagules can spread into surrounding areas in many ways. For alien plants used as biomass feedstocks, "effective" seed dispersal will be necessary for invasive spread. For native feedstocks and alien feedstocks with reproductively compatible relatives, successful pollination provides another avenue along which agronomic genes spread. Introgression of agronomic and transgenes into wild and compatible populations has been documented (Watrud et al. 2004). To reduce likelihood of invasive spread, sterile varieties of feedstocks must be developed (Quinn et al. 2010), which has proven difficult.

Rebuttals to the main arguments

Rebuttal 1. In support

Our opponents argued that Fletcher et al. (2011) conclude that biodiversity and abundance are generally lower in biofuel crops than in the noncrop areas they replace. This evidence is based on row crops, pine, and poplar. But the same authors acknowledge lack of evidence to make that claim for second-generation crops like switchgrass.

Meehan et al. (2010) analyzed expansion of corn and soybean for bioenergy onto marginal land in the Midwest, but they also say, "In contrast, replacement of annual with diverse perennial bioenergy crops (e.g., mixed grasses and forbs) is expected to bring increases in avian richness between 12% and 207% across 20% of the region, and possibly aid the recovery of several species of conservation concern."

Similarly, arguments about agricultural intensification are not likely to apply to perennial crops because these require much lower nutrient and pesticide supplements. Species selection, modification, landscape design, and monitoring will help mitigate risk of species invasiveness. Measured changes in biodiversity and how those changes are interpreted will depend on context (Efroymson et al. 2013), including focal species, region and previous land use, land management, and scale of measurement.

Rebuttal 2. In opposition

The "increased risk of invasion" argument put forward has been challenged on two main fronts. First, polycultures have been championed over monocultures. How bioenergy crops are grown will likely be a function of biomass yield and economics. Limited research in this area shows that monocultures produce higher yields than polycultures and make the most sense from an economic perspective (Griffith et al. 2011). Thus, monocultures will be the norm. Second, feedstock species put forward as less likely to pose invasive risks included cosmopolitan algae and crops that are either native or that were not shown to be invasive in case studies. Algae production, especially in open systems, is ripe with risk. Biofuel "type" strains of algae, cosmopolitan or not, may pose invasive threats to aquatic systems and public waterways (Wilkie et al. 2011). As for species specifically mentioned as not being invasive, the same case study used to illustrate this also showed that switchgrass is capable of establishing by seed in disturbed, low-competition areas outside its native range (Barney et al. 2012). Finally, using bioenergy crop plants native to a particular region does not necessarily lower invasion risk. On the contrary, introgression into native populations of conspecifics or other compatible relatives may well be applicable for some bioenergy feedstocks (Kwit and Stewart 2012).

Rebuttal 3. In support

Our opponents used definitive language to imply that reduced habitat and biodiversity would be a "foregone conclusion" following widespread biofuel feedstock production. However, both presenters fail to acknowledge that, to date, science-based data are very limited, especially at larger spatial scales. Their arguments also ignore effective strategies for mitigating potential negative effects such as landscape planning and BMPs. The presenters do not acknowledge that most large forest landowners adhere to sustainable forestry standards, which have metrics for protection of unique ecological communities, sensitive species, provision of wildlife habitat, and management of invasive species. Additionally, positive or negative impacts of biomass system establishment will depend completely on landscape context, and responses by individual species and communities will be varied. Further, it has been argued that biofuel production equates with "habitat loss" when, in many cases, it is actually "habitat change." This distinction is important; any habitat change will positively impact some species and negatively impact others. Our opponents also generalize that changes in forest structure will be necessarily negative, when this is not the case (e.g. Riffell et al. 2011*a*, Verschuyl et al. 2011). Due to differing landowner objectives and other factors, it is probable that establishment of short-rotation woody crops will only comprise portions of landscapes, and that positive and/or negative effects on biodiversity will be dependent on landscape context. Additionally, short-rotation pine forests support local and regional biodiversity (e.g., Miller et al. 2009), and the general supposition that this must lead to reduced biodiversity is flawed.

Rebuttal 4. In opposition

The supporters of the thesis suggest that bioenergy production and maintenance of habitat availability and biodiversity are not mutually exclusive; they argue that there may even be opportunities for synergies. They suggest that additional research can be conducted and BMPs applied to achieve optimal bioenergy systems. I find this position to be very optimistic.

Although we certainly need to be optimistic, as scientists we might also ask what is the probability that such favorable outcomes will be achieved? Our opponents repeatedly used qualifications including, "can," "may," "might," and "could" when describing aspects of a sustainable bioenergy future. Given their uncertainty, we might look to the track records of the two major industry players in commercial bioenergy production in the United States: agriculture and forestry. Both already operate within an extensive framework of federal and state regulation. Both have also shared the ideal of "sustainable management" for at least three decades. And yet examples abound where ideals do not match realities. In agriculture, data show that farmers regularly apply excess fertilizer to corn. Although we have multiple BMPs to prevent this, agricultural pollution of surface and groundwater is common. Similarly, in forest management, decades of research has been conducted to develop and implement BMPs (e.g., thinning schedules and riparian buffer zones), and yet in some places we continue to struggle with fire-prone landscapes with degraded water quality. What makes us optimistic that research and policy can help us avoid similar outcomes for an expanding bioenergy industry?

As a society, we are about to embark on an experimental shift in land use at a grand scale. These changes, caused by commercialization of bioenergy production systems, will impact hundreds of millions of hectares of diverse landscapes across North America. We hope to manage this shift with thoughtful legislation, wise regulation, and cooperation of individual land owners and industry leaders whose long-term interests truly do lie in developing and implementing sustainable approaches. Unfortunately, we are not as optimistic as our opponents that this will easily be achieved, but the question remains: What might we as ecologists do to tip the balance in favor of sustainable otcomes?

Audience polls and responses

Comparison of pre- and post-debate electronic polling of 50 audience members showed no significant difference in opinion before and after the debate (Table 1; $\chi^2 = 1.989$, $P = 0.158$). Although this did not represent a probability sample, it included nearly half of the audience. This test assumes independence, but we note that accounting for autocorrelation never increases power. If we had been able to obtain repeated measures by tracking the votes by individual, we could have used a more powerful test suitable for nonindependent data. Voting after each speaker showed that *all* arguments presented were supported by most audience members (Table 2).

We received written comments from 15 audience members. Some of those who agreed with the thesis expressed a need to maintain optimism about energy alternatives to fossil fuels. Those who disagreed echoed debaters' arguments about the poor track record of industries (agriculture, forestry) and the high likelihood of energy crop invasions. Others in disagreement cited evidence not presented during the debate; one emphasized that sustainable bioenergy will not be achievable because of soil quality deterioration. General comments on the debate format included suggestions to better define the terms and scope of the debate at the outset, and to provide more time for audience questions and feedback.

Synthesis

Our live, formal debate focused on a thesis that was sufficiently broad to permit a variety of perspectives and arguments from scientists. Each side addressed elements of the thesis to support their stance, selectively presenting evidence and arguments deemed to be compelling. The content and rhetorical style used by each participant was selected to persuade the audience. For instance, the first argument presented by the supporting side highlighted algae production in some locations as a way to avoid species loss and invasion; this point was not forcefully countered by the opposing side. The other main argument presented by the supporting side drew from research on forest bioenergy systems. The side opposing the thesis cited historical evidence by analogy with agronomic systems, voicing doubt that biodiversity would be maintained in bioenergy systems. This debater used the first person pronoun "we" rhetorically to sway the audience as ecologists *and* members of society. Both sides highlighted uncertainties in opposing arguments. The audience responded positively to arguments as shown in the results of the middebate hand votes (Table 2).

Our debate clarified what aspects of bioenergy and biodiversity remain uncertain and what hypotheses could be tested to reduce scientific uncertainty. Key uncertainties included: (1) invasive potential of alternative feedstocks in different situations; (2) magnitude (area) of land conversion from bioenergy; (3) which land uses (i.e., urban vs. marginal vs. agricultural) will be replaced by each feedstock; (4) qualitative and quantitative effects of alternative bioenergy management practices on ecosystems; and (5) whether the cost of implementing ecologically sustainable management practices will be low enough. Research to clarify these questions will help to reduce uncertainty with respect to the broad thesis.

Formal debate is an efficient means of facilitating scientific discourse at meetings because it capitalizes on the presence of experts, promotes lively and interactive exchange of scientific information, and deliberately intersperses contrasting points of view on controversial topics (Table 3). Theory tenacity is dangerous to good science. Alternating between arguments for and against the thesis counteracts our tendency to seek out information that conforms to our previously held beliefs (Sarewitz 2004). Immediate feedback between ideas and counter-arguments leads to more efficient progress toward a shared assessment of the likelihood that elements of a thesis are true, and what aspects remain uncertain. Ideally, this clarification will guide research in directions that will reduce scientific uncertainty. With the advent of electronic publishing, we are seeing even more direct public discourse between researchers in written formats; some journals publish articles, comments, and author responses simultaneously.

Professional societies have an opportunity to enhance scientific exchange by directly engaging their membership through live dialogue and debate at their meetings. This has been done at the Society of Environmental Toxicology and Chemistry and the Entomological Society of America conferences. In the latter case, students participate in debate, which helps to develop professional scientists with important critical thinking skills (Osborne 2010).

The debate format also has drawbacks (Table 3). Formal debate tends to polarize positions, thereby causing more complex dimensions or nuances to be lost. One way to recover these facets is by engaging the audience in a post-debate question-and-answer session. Debate can lower scientific credibility if it is felt that debaters are advancing particular interests by selectively representing a body of knowledge or exaggerating scientific certainty. Further, the debate format is not suitable for all situations. For example, it is less interesting to debate topics with overwhelming scientific support for one side. Debate is also a poor choice for communicating uncertainty to nonscientists, who may consider scientific results to be absolute and exact truths (Rabinovich and Morton 2012). We nevertheless strongly support live debate as a communication tool for scientific meetings.

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Fig. 1. (a) Switchgrass intercropped in a pine plantation of Lenoir County, North Carolina. Photo credit: Jessica Homyack, (b) *Miscanthus sinensis* escaped from horticultural plantings in central Kentucky. Photo credit: Lauren Quinn.

Table 1. Results of real-time polling of the audience. Audience members were asked to text or submit their view online of the following thesis: “Producing bioenergy can be sustainable for habitat availability and biodiversity, and can avoid the risk of new invaders.” Pre and post-debate opinion was not statistically different ($\chi^2 = 1.989$, $P = 0.158$).

	Pre-debate (n = 50)	Post-debate (n = 50)
Agree (%)	64	48
Disagree (%)	36	52

Table 2. Mid-debate audience voting. Green represents “agreement with” and red represents “disagreement with” (a) Main argument 1, In support; (b) Main argument 2, In opposition,; (c) Main argument 3, In support; (d) Main argument 4, In opposition.

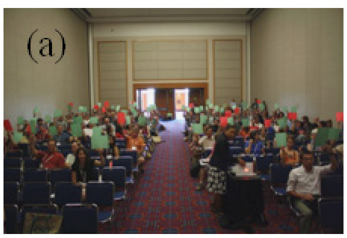
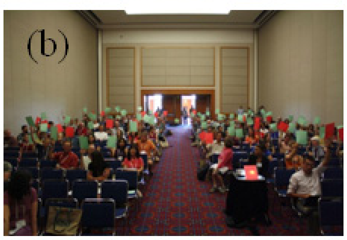
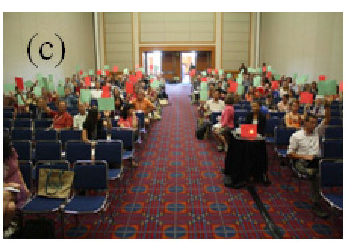
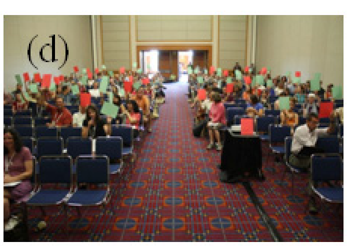
	Green/Agree	Red/Disagree
	50 (76%)	16
	44 (69%)	20
	41 (62%)	25
	34 (59%)	24

Table 3. Debate vs. journal articles as a forum for scientific communication.

Factor	Debate	Journal articles
Speed of exchange	rapid exchange	slow peer review and revision process
Rigor of science	depends on sources presented	high, peer reviewed
Degree of consensus	low, contrasting views	high among authors
Nuanced presentation	low, extreme viewpoints presented and strict time limits enforced	high, context and limitations described
Communication of uncertainty	only as inferred from differences of opinion	yes, qualitative or quantitative
Role of rhetorical style	high	low
Entertainment value	high	low