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Title

Modeling wildlife and other trade-offs with biofuel crop production

Permalink

<https://escholarship.org/uc/item/40f8x430>

Journal

GCB Bioenergy, 4(3)

ISSN

1757-1693

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Publication Date

2012

DOI

10.1111/j.1757-1707.2011.01130.x

Peer reviewed



Wildlife and water-use trade-offs with biofuel crop production

Journal:	<i>Global Change Biology Bioenergy</i>
Manuscript ID:	Draft
Manuscript Type:	Original Research
Date Submitted by the Author:	n/a
Complete List of Authors:	Stoms, David; University of California Santa Barbara, Bren School of Environmental Science and Management Davis, Frank; University of California Santa Barbara, Bren School of Science and Management Jenner, Mark; University of California Davis, California Biomass Collaborative Nogeire, Theresa; University of California Santa Barbara, Bren School of Science and Management
Keywords:	biofuels, biomass feedstock, California Wildlife Habitat Relationships system, habitat suitability, geographic information systems, Marxan, trade-off analysis, renewable energy, water demand, agroecosystems

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4 1 **Wildlife and water-use trade-offs with biofuel crop production**

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7 2 Running title: Trade-offs: biofuel, biodiversity, and water

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9 3 **David M. Stoms¹, Frank W. Davis¹, Mark W. Jenner², Theresa M. Nogeire¹, and Stephen R. Kaffka²**

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27
28 14 **Target journal:** Global Change Biology—Bioenergy

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31 15 **Keywords:** Biofuels, biomass feedstock, California Wildlife Habitat Relationships system,

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33 16 habitat suitability, geographic information systems, Marxan, trade-off analysis, renewable

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36 17 energy, water demand, agroecosystems

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4 19 **Abstract:** Biofuels from agricultural sources are an important part of California's strategy to
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6 20 reduce greenhouse gas emissions and dependence on foreign oil. Land conversion for
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8 21 agricultural and urban uses has already imperiled many animal species in the state. This study
9
10 22 investigated the potential impacts on wildlife of shifts in agricultural activity to increase biomass
11
12 23 production for transportation fuels. We applied knowledge of the suitability of California's
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14 24 agricultural landscapes for wildlife species to evaluate wildlife effects associated with plausible
15
16 25 scenarios of expanded production of three potential biofuel crops (sugar beets, bermudagrass,
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18 26 and canola). We also generated alternative, spatially-explicit scenarios that minimized loss of
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20 27 habitat for the same level of biofuel production. We used trade-off analysis to compare the
21
22 28 marginal changes per unit of energy for transportation costs, wildlife, and water-use, and found
23
24 29 that all three of these factors were influenced by crop choice. Sugar beet scenarios require the
25
26 30 least land area: 3.5 times less land per liter of gasoline equivalent than bermudagrass and five
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28 31 times less than canola. Canola scenarios had the largest impacts on wildlife but the greatest
29
30 32 reduction in water use. Bermudagrass scenarios resulted in a slight overall improvement for
31
32 33 wildlife over the current situation. Relatively minor redistribution of lands converted to biofuel
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34 34 crops could produce the same energy yield with much less impact on wildlife and very small
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36 35 increases in transportation costs. This framework provides a means to systematically evaluate
37
38 36 potential wildlife impacts of alternative production scenarios and could be a useful complement
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44 37 to other frameworks that assess impacts on ecosystem services and greenhouse gas emissions.
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40 **Introduction**

41 Biofuels have gained support as environmental, economic, and political concerns about the
42 production and use of fossil fuels have grown. A number of recent studies suggest that the
43 substitution of biofuels for fossil fuels could in many cases reduce anthropogenic greenhouse gas
44 (GHG) emissions (de Oliveira et al. 2005; Kim and Dale 2005; Hill et al. 2006; and Tilman et al.
45 2006). However, the biomass used to produce biofuels has a lower energy-density than coal and
46 petroleum and requires larger land areas per unit of energy (McDonald et al. 2009). Meeting
47 ambitious policy targets for biofuel production may cause widespread land use change with
48 unintended consequences for biodiversity, water quality and quantity, and ecosystem services
49 (Groom et al. 2008; Robertson et al. 2008; McDonald et al. 2009; Dominguez-Faus et al. 2009;
50 Williams et al. 2009; Dauber et al. 2010; and Dale et al. 2011). The sustainability of biofuels
51 with respect to these environmental indicators will depend on the type of biomass and where it is
52 grown (Robertson et al. 2008).

53 There has been little quantitative analysis of the potential impacts of biofuel crop production on
54 species habitats (Geyer et al. 2010b). Predicting these impacts is challenging because
55 distributions of both wild species and biofuel crops are environmentally and geographically
56 constrained, so that impact analysis requires spatially explicit models (Barney and DiTomaso
57 2010; Evans et al. 2010; and Jager et al. 2010). In addition, the starting land use conditions from
58 which effects are calculated vary across the landscape. The likelihood of conversion of land to
59 biofuel crops depends on economic factors such as net profit relative to existing crops or land use
60 and proximity to biofuel conversion facilities. Compounding this complexity is the finding that
61 biodiversity impacts can be non-linear with the level of biofuel production, such that each

1
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3 62 consecutive marginal increase in production leads to a more rapidly increasing impact (Geyer et
4
5 63 al. 2010b).

6
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8 64 Before policy makers and business leaders commit to large-scale production of biofuels, they
9
10 65 need to be informed about the potential impacts of that production on biodiversity (Hanegraaf et
11
12 66 al. 1998; and Chan et al. 2004) and water (Dominguez-Faus et al. 2009; and Wu et al. 2009).

13
14 67 Shifting from current land use to biofuel crops could have positive effects on some species. For
15
16 68 example, planting perennial crops like switchgrass or mixed grasses on degraded annual
17
18 69 cropland is predicted to improve habitat quality for some species (Meehan et al. 2010). On the
19
20 70 other hand, scientists have speculated that policies and market forces favorable for biofuel could
21
22 71 make some marginal and retired lands attractive for conversion to annual energy crops to the
23
24 72 detriment of some wildlife species (Fargione et al. 2009; and Meehan et al 2010). Effects of
25
26 73 increased biofuels production on water consumption will also vary geographically depending on
27
28 74 supply, cost to growers, and the irrigation requirements of particular crops.

29
30 75 Robertson et al. (2008) called for an integrated framework to assess trade-offs between biofuel
31
32 76 production and other environmental objectives beyond the conventional factors of greenhouse
33
34 77 gas emissions and fossil energy use. Several spatially-explicit frameworks have explored trade-
35
36 78 offs between energy production and a suite of environmental concerns such as GHG emissions,
37
38 79 net energy, and ecosystem goods and services with respect to profit (Graham et al. 1996; Bryan
39
40 80 et al. 2010; and Zhang et al. 2010). The frameworks of Bryan et al. (2010) and Zhang et al.
41
42 81 (2010) used process simulation models to predict yields and other impacts from environmental
43
44 82 variables. Bryan et al. (2010) used life cycle assessment to derive greenhouse gas emissions and
45
46 83 net energy. They then applied economic modeling to identify economically-viable lands at
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48 84 different levels of subsidy. Other authors have used similar bioeconomic models of competition
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3 85 between biofuel crops to allocate them spatially (Walsh et al. 2003; Scheffran and BenDor 2009;
4
5 86 and Hellmann and Verburg 2011). Zhang's framework applied multiobjective optimization
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8 87 modeling for optimal spatial allocation to biofuel crop production to meet different combinations
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11 88 of objectives. Bryan et al. (2010) assumed rationale economic behavior to drive their spatial
12
13 89 allocation. So far, biodiversity concerns have generally not been integrated in these frameworks,
14
15 90 although recent work has begun to address this shortcoming (Gevers et al. in press).

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18 91 Here we evaluate potential effects of expanded biofuel crop production on wildlife species and
19
20 92 water use in California. Our analysis combines agroeconomic modeling of currently grown crops
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22 93 and potential biofuel crops, spatial analysis of available and suitable land, and species-specific
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24 94 wildlife habitat suitability modeling. We generate spatially-explicit scenarios of crop production
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26 95 based on competing objectives of minimizing costs to transport biomass from farms to
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28 96 biorefineries vs. minimizing habitat loss. We evaluate alternative futures in terms of social,
29
30 97 economic, and environmental concerns such as biofuels costs, biodiversity, and water to address
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32 98 the following research questions:

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38 99 • How might habitat suitability for wildlife species of special concern change in response
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40 100 to plausible scenarios of production of three contrasting types of biofuel crops in
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42 101 California?
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45 102 • How much flexibility exists to reduce adverse effects on wildlife species while producing
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47 103 the same total yield of biofuel crops? How much would this change increase
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49 104 transportation costs of hauling biomass to biorefineries?
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105 **Materials and Methods**

106 *Study area*

107 California is a leader in the transition to renewable energy to mitigate the effects of climate
108 change. The Governor's Executive Order S-06-06 sets goals for increasing reliance on in-state
109 production of biofuels, stipulating that California produce 75 percent of the biofuels consumed in
110 the state by 2050. With projected demand for gasoline that contains 5.7 percent ethanol by
111 volume (E5.7) and five percent content of renewable biodiesel (B5), this target translates to
112 roughly 3,300 million liters of ethanol and 1,100 million liters of biodiesel by 2050. Initial
113 estimates suggest that half of the state's irrigated crop land would be needed to fully meet targets
114 with biofuel crops (California Biomass Collaborative 2006).

115 If such a massive conversion of land to dedicated energy crops occurs, substantial effects on
116 other values may follow. The state's agricultural land is highly productive of food and fiber,
117 producing more than half of all US grown fruits, nuts, and vegetables (California Department of
118 Food and Agriculture 2010). Most potentially arable land is already in production. Nearly half of
119 the terrestrial vertebrate species in California use the state's agricultural lands, and many of the
120 native plants and animals associated with these landscapes are threatened or endangered (Brosi et
121 al. 2006). Some remnants of native habitats persist in major agricultural regions such as the San
122 Joaquin Valley, Sacramento Valley, Imperial Valley and Salinas Valley (Figure 1), although
123 these habitats are fragmented and often highly degraded. California's Mediterranean climate of
124 dry summers and rainy winters requires most farmland to be irrigated. There is a perennial
125 conflict over water allocation to satisfy agricultural and urban water demand while meeting
126 desired environmental flows (Hanak et al. 2011).

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3 127 [insert Figure 1 about here]
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6 128 We limited our analysis to the most important agroecosystem regions in the state: the Central
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8 129 Valley (comprised of the San Joaquin and Sacramento Valleys), the Salinas Valley, and the
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10 130 Imperial Valley (Figure 1). Cultivated land within these regions equals approximately 3.9 million
11
12 131 ha. We use “agroecosystem” as a general term that includes crop and pasture habitats plus the
13
14 132 remnants of natural or semi-natural habitats within and adjoining those habitats. We delineated
15
16 133 agroecosystems by one square-mile “sections” (approximately 260 hectares) based on the Public
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18 134 Land Survey System (PLSS) where crops were grown in 2005 as reported to the California
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20 135 Department of Pesticide Regulation (DPR). For completeness of the agroecosystem landscape,
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22 136 adjacent and interspersed sections of natural or semi-natural habitats were also included in the
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24 137 study area, which encompasses 25,715 sections or approximately 6.7 million ha (~16% of total
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26 138 land area of California).
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32 33 139 *Candidate biofuel crops* 34 35

36 140 Three crops are analyzed that have potential to become more widespread as biofuel feedstock
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38 141 crops in California—sugar beets (*Beta vulgaris*) for sugar-based ethanol, perennial bermudagrass
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40 142 (*Cynodon dactylon*) for lignocellulosic ethanol, and canola (*Brassica campestris*) for biodiesel
41
42 143 (Williams et al. 2007, Kaffka 2009). This set of crops represents three different feedstock types
43
44 144 (sugar, cellulose, and oil) and corresponding refining technologies, although cellulosic
45
46 145 conversion technology is still not commercially viable. Each grows best in different regions, has
47
48 146 different water requirements, and has different wildlife habitat attributes. Determining the effects
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50 147 on native wildlife species of increasing production of any of these crops requires spatially-
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52 148 explicit scenarios of conversion from current crops to specific biofuel crops, and models of how
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54 149 each species might respond to that conversion.
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3 150 To address this challenge, we developed a four-step integrated framework. Step 1: a farm-scale
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5 151 agroeconomic model predicts the level of biofuel crop production and associated water demand
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8 152 at an assumed level of profit. Farms are stratified by 45 geographic subregions that are relatively
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10 153 homogeneous in terms of climate and agronomic factors. Step 2: habitat suitability modeling
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12 154 estimates current landscape suitability for a set of wildlife species and a revised suitability should
13
14 155 the landscape be converted to biofuel crop production. Step 3: a land allocation model generates
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16 156 spatially-explicit scenarios of biofuel crop production that seek to minimize the total cost to
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18 157 transport biomass to the nearest biorefinery. Alternative scenarios are also generated to minimize
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20 158 loss of wildlife habitat. Step 4: trade-off analysis uses a multicriteria decision analysis of
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22 159 scenario effects on cost, wildlife, and water. The following sections describe these steps in more
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24 160 detail.
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30 161 *Biofuel crop production and water modeling*

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33 162 A key but uncertain variable in modeling biofuel production is the future location of
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35 163 infrastructure to produce biofuels from agricultural feedstocks. We adopt the sites from Tittmann
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37 164 et al. (2008), who modeled optimal locations for ethanol and biodiesel refineries based on
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39 165 potential supply of biomass in California. Although that study only considered existing feedstock
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41 166 sources (e.g., forest and agricultural residues, municipal solid waste), the locations of potential
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43 167 biorefineries are a reasonable basis for crop biomass biorefineries in the absence of a focused
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45 168 analysis. Biorefineries in Tittmann et al. tend to be located where transportation and transmission
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47 169 infrastructure reduce costs associated with biofuel production. Tittmann et al. (2008) also
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49 170 calculated average transportation costs to move biomass from county centroids through the road
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51 171 and railway network to their least-cost biorefinery site. We extrapolated those transportation
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53 172 costs from county centroids to individual farms as a function of distance and biomass weight.
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3 173 The California Bioenergy Crop Adoption Model (Kaffka and Jenner 2011) is an agroeconomic
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5 174 optimization model that identifies the amount of land that might be converted to these potential
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8 175 biofuel crops under advantageous price conditions. The model simulates economic conditions for
9
10 176 farms producing annual or short-lived perennial crops on crop land in the state of California. The
11
12 177 model's primary purpose is to identify the price and yield at which new bioenergy crops enter
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14 178 cropping systems, area and locations for crop adoption, which crop activities are displaced, and
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16 179 the associated change in water consumption. It was assumed that the agricultural water levels
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18 180 between 1998 and 2007 were available for use, and water could be transferred between crops or
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20 181 reduced on farms, as is common practice by California growers. The model was parameterized
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22 182 for 45 subregions that account for significant regional differences in climate and soils among
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24 183 farms. Kaffka and Jenner (2011) simulated a range of output prices, input costs, and crop yields
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26 184 that resulted in \$50 and \$100 per hectare (\$20 and \$40 per acre) profits for biofuel crops. We
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28 185 used the land area in each subregion that was predicted for a \$100 per hectare profit to guide the
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30 186 detailed scenarios. Therefore our scenarios assume the maximum potential adoption of biofuel
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32 187 crop production within the range of profits that was investigated. This profit level is extremely
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34 188 optimistic and may only be possible with very high oil prices and/or generous government
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36 189 subsidies. The entry of biofuel crops were modeled individually, rather than allowing them to
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38 190 compete with each other as well as with the current crops. Therefore each spatially-explicit
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40 191 scenario analyzes the effects of a single biofuel crop.
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49 192 Production of biofuel feedstocks was excluded on public or privately-protected lands, water
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51 193 bodies and wetlands, and lands with high capital investment (e.g., existing urban development,
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53 194 orchards, and vineyards) (Haughton et al. 2009). Land that is not cropland or pasture was also
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55 195 assumed to be physically (and hence economically) unsuitable to produce biofuel crops.
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3 196 Subregions where the California Bioenergy Crop Adoption Model predicted biofuel crops would
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6 197 not be adopted even at the \$100 per hectare profit benchmark were screened from the set of
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8 198 available and suitable land, regardless of their ownership or current land cover. Roughly half of
9
10 199 the study area was considered available and suitable for sugar beets and canola, with only one-
11
12 200 third for bermudagrass. We describe below in the scenarios section how the land area predicted
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14 201 for each crop by the California Bioenergy Crop Adoption Model were allocated within these
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16 202 available and suitable lands.
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20 203 *Wildlife habitat suitability modeling*

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23 204 We used an existing database to assign species-specific habitat suitability scores to land use/land
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25 205 cover types. The California Wildlife Habitat Relationships (CWHR) database is a state-of-the-art
26
27 206 information system about California's wildlife (Airola 1988), developed and maintained by the
28
29 207 California Department of Fish and Game. The core feature of CWHR is a set of expert-based
30
31 208 habitat suitability ratings summarized in a matrix with 695 species and 59 habitat types,
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33 209 including eight agricultural types (Irrigated Row and Field Crops, Dry Grain Crops, Irrigated
34
35 210 Grain Crops, Deciduous Orchard, Evergreen Orchard, Vineyard, Irrigated Hayfield, and Pasture).
36
37 211 Each habitat type is scored as high (1), medium (0.66), low (0.33), or unsuitable (0) for
38
39 212 reproduction, cover, and feeding for each species. We used the average of the three scores as a
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41 213 measure of overall suitability. The CWHR database also contains a biogeographic range map for
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43 214 every species. We assumed species were confined to suitable habitats within their biogeographic
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45 215 range (Airola 1988).
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52 216 We compiled a map of habitat types from two sources. Existing natural and semi-natural habitat
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54 217 types were interpreted from a recent, 30m resolution land cover map produced for the U.S. Gap
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56 218 Analysis Program (Lennartz et al. 2009). We re-assigned the Cropland type in the map to
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3 219 specific crop types based on the Department of Pesticide Regulation's database and then re-
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6 220 coded those crop types to the corresponding CWHR habitat. The three biofuel feedstock crops
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8 221 being analyzed belong to four distinct habitat types (Table 1). Canola can be grown with or
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10 222 without irrigation depending on the region of the state. Note that bermudagrass is a model for
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12 223 other salt tolerant perennial grasses that might find use as a biofuel feedstock in California.

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16 224 [insert Table 1 about here]

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19 225 For this study, we limited the analysis to fifty-three terrestrial wildlife species of Special
20
21 226 Concern identified by the State of California that are associated with agroecosystems (Comrack
22
23 227 et al. 2008). These species (see Appendix) are either federally-listed as threatened or endangered,
24
25 228 meet the State definition for listing but have not yet been listed, have experienced rapid
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27 229 population declines or range restrictions, or have naturally small populations that are highly
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29 230 susceptible to risk factors. They may be especially vulnerable to a change in habitat area and
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31 231 suitability if biofuel crops were produced in California's agroecosystems.

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36 232 Information from the habitat map, geographic range maps, and the habitat suitability matrix were
37
38 233 used to calculate a suitability score for each PLSS section as an area-weighted suitability rating
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40 234 of the constituent habitat types for reproduction, cover, and feeding separately. An overall
41
42 235 suitability score per species was calculated as the average of the three scores. If the section was
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44 236 available and suitable for biofuel crop production, a similar score of area-weighted suitability
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46 237 was calculated for each biofuel crop type.

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49 238 *Generating spatially-explicit biofuel crop production scenarios*

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54 239 An appropriate integrated model is not readily available that can generate spatially-explicit
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56 240 scenarios and assess trade-offs between biofuel crop production and wildlife habitat effects

241 (Robertson et al. 2008). Crop production modeling integrates agronomic production factors with
 242 socioeconomic processes to identify the sites where a crop is highly likely to be grown at a given
 243 market price, but such modeling omits wildlife effects (Bryan et al. 2008 and 2010; Scheffran
 244 and BenDor 2009; and Hellmann and Verburg 2011). Models for biodiversity come from the
 245 area of systematic conservation planning to identify a nominal network of potential conservation
 246 areas that efficiently meet representation targets for biodiversity (Margules and Pressey 2000).
 247 However, these reserve selection tools do not model resource production such as biofuels.
 248 Variations of these models have incorporated resources but have not attempted to meet
 249 production targets (Polasky et al. 2008; and Wilson et al. 2010). In the case of biofuels, with
 250 many individual decision makers and flexibility in where crops could be grown and refined, we
 251 sought a framework that supported proactive, strategic analysis. To this end, we adapted a
 252 conservation planning tool (Marxan) to generate spatially-explicit scenarios of land use and crop
 253 cultivation based on data on biofuel yield and the cost of transporting crops to hypothetical
 254 biorefineries.
 255 Marxan is a freely available and commonly used software tool in conservation planning. It uses a
 256 simulated annealing with iterative improvement algorithm to select a set of planning units for a
 257 conservation area network at minimum cost (Ball et al. 2009). Selection is guided by the
 258 following objective function:

$$\text{Minimize } Z = \sum_{j=1}^J c_j * x_j + \sum_{i=1}^I SPF_i * p_i \quad (1)$$

$$\text{Subject to } \sum_{j=1}^J a_{ij} x_j \geq r_i \quad (2)$$

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3 261 where a_{ij} is a measure of the amount of feature i in planning unit j (i.e., sections), x_j is a $\{0,1\}$
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5 262 variable that has a value of 1 if section j is selected and 0 otherwise. Each section has a cost c_j ,
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7
8 263 and each feature is assigned a desired target r_i . The second term in Eq. 1 is a penalty for failing
9
10 264 to achieve the target constraints in Eq. 2 and is comprised of a penalty factor (SPF) for feature i
11
12 265 multiplied by difference between the desired and achieved amount of the feature in the final
13
14
15 266 solution (p_i , the “shortfall” for feature i). We included features for biofuel and the wildlife
16
17 267 Species of Special Concern. The targets for biofuel were the biofuel yields by subregion in liters
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19
20 268 of gasoline equivalent (LGe) associated with the land area predicted by the California Bioenergy
21
22 269 Crop Adoption Model at the subregional crop yield rates and conversion efficiencies (Table 2).
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24 270 Similarly farm-level LGe was derived from the land area available and suitable in each section.
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26
27 271 This value served as the amount, a_{ij} , of biofuel that a section could produce. The a_{ij} for Species
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29 272 of Special Concern was the net change of species habitat suitability from current conditions to a
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31
32 273 biofuel crop future.

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35 274 [insert Table 2 about here]

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38 275 We generated basic crop allocation scenarios for the three alternative biofuel conversion
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40 276 technologies. Basic scenarios were designed to achieve subregion-specific production targets for
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42 277 biofuel predicted by the California Bioenergy Crop Adoption Model results at minimum cost
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44
45 278 (i.e., “Minimize Cost” scenarios). The cost in this case was the transportation cost associated
46
47 279 with hauling the biomass yield over the least-cost distance to a potential biorefinery. Alternative
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49 280 scenarios minimized habitat loss while still meeting biofuel production levels (i.e., “Minimize
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51
52 281 Loss” scenarios) by adding a “cost” of suitability loss to the transportation cost. It was expected
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55 282 that minimizing habitat suitability loss would require greater overall transportation costs. In
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3 283 contrast to conventional conservation planning practice, no conservation targets were set for
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5 284 wildlife species.

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9 285 *Trade-off analysis*

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11 286 The scenarios generate information about total biofuel production, costs, and impacts. That
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13 287 information needs to be evaluated to compare the three biofuel crops and the trade-offs among
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15 288 criteria. Because the crops have different energy content and conversion efficiency, it is
16
17 289 necessary to standardize some of the criteria according to social preferences from 100 for most
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19 290 desirable social outcome to 0 for least desirable outcome. Five criteria were standardized for the
20
21 291 trade-off analysis: cost-effectiveness as mean transportation cost per LGe (lower cost is desired),
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23 292 total energy (LGe) produced (more energy is desired), mean habitat suitability for the Species of
24
25 293 Special Concern (more suitability is desired), water efficiency in savings per LGe relative to
26
27 294 current crop patterns (less water used is desired), and land efficiency in m² per LGe (less land is
28
29 295 desired). The habitat suitability criterion was scaled from 100 for the best outcome to 0 for a
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31 296 10% net loss, which we assumed is the maximum acceptable loss for sensitive species.
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38 297 **Results**

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40
41 298 *Biofuel crop scenarios*

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44 299 Based on the California Bioenergy Crop Adoption Model using a \$100 per hectare profit
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46 300 benchmark, canola scenarios would occupy the most land, approximately 8% of California's
47
48 301 agroecosystem lands (Table 3). Sugar beet scenarios used 44% as much land, and bermudagrass
49
50 302 scenarios only 19% of the land used in the canola scenario. The Minimize Cost and Minimize
51
52 303 Loss scenarios would occupy essentially the same land area and produce the same amount of
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54 304 energy (Table 3). Sugar beets could produce more LGe of biofuel than the other two potential
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3 305 crops studied. The bermudagrass scenarios produced 13% of the energy of the sugar beet
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5 306 scenarios, and canola produced 45% of the energy of the sugar beet scenario despite occupying
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7
8 307 the most land.
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11 308 [insert Table 3 about here]
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13
14 309 Comparing the land requirement on an energy basis (per LGe), sugar beets scenarios require less
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16 310 than 2 m² (0.0002 hectares) per LGe on average (4,896 LGe/hectare, Table 2). Bermudagrass
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18 311 requires 7 m² per LGe (1,401 LGe/hectare), and canola takes 10 m² (995 LGe/hectare)
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20
21 312 respectively. Canola and bermudagrass have much lower biomass yields per hectare than sugar
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23 313 beets, although this is partially offset by their higher energy content and conversion efficiencies.
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25
26 314 Land requirements for any given crop were virtually identical for the Minimize Cost and
27
28 315 Minimize Loss scenarios.
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31 316 The collective effects on the 53 Species of Special Concern, expressed as net species' habitat
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33 317 gain or loss, vary between crops and scenarios (Table 4, effects on individual species is provided
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35 318 in the Appendix). Canola scenarios negatively impacted the greatest number, whereas sugar
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37 319 beets and bermudagrass scenarios resulted in only small effects for most species. For example,
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39 320 the bermudagrass scenario produced no more than 2% habitat suitability loss for any of the
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41 321 species and resulted in habitat suitability increases for 22 species, but also converted much less
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43 322 land and produced less energy than the other biofuel crops in the modeling. Effects on most
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45
46 323 amphibians, reptiles, and mammals were slightly negative or neutral. Only the Western
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48 324 spadefoot (sugar beets or canola scenarios) and Kit fox (bermudagrass scenarios) had positive
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50 325 effects in these taxa. Most of the large effects (i.e., >5% loss or >2.5% gain) occurred for birds.
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53 326 Long-Billed Curlew had gains of 6-20% in bermudagrass and canola scenarios. Vermillion
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55 327 Flycatcher had large losses for sugar beets and canola but large gains for bermudagrass. Several
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3 328 other birds had large gains with canola (Northern Harrier, Loggerhead Shrike, Vesper Sparrow,
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5 329 and Savannah Sparrow), whereas as many as 13 had large losses. Round-tailed ground squirrel in
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8 330 the canola scenarios was the only mammal with large losses.
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11 331 [insert Table 4 about here]
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14 332 Canola, being a winter crop that can be largely rain-fed, resulted in the largest overall reduction
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16 333 in water use at nearly 6% of current statewide irrigation. Moreover the water reduction would
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18 334 occur in a majority of crop subregions throughout the state. For bermudagrass, reductions were
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20 335 only predicted in a few crop subregions, so the average reduction per LGe was quite small. Sugar
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22 336 beets required the same amount of irrigation water as the crops they would replace so there
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25 337 would be no net change.
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28 29 338 *Trade-offs* 30

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32 339 As expected, scenarios that attempt to reduce the impact of biofuel crop production on habitat
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34 340 suitability for the Species of Special Concern increase the cost of transporting the biomass to the
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36 341 least-cost biorefinery (Figure 2). For sugar beets, the cost would increase about 2% from \$0.149
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38 342 to \$0.153 per LGe whereas the loss of habitat suitability could be reduced 22%. The
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40 343 transportation cost in bermudagrass scenarios is one-half of that for sugar beets. This lower cost
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42 344 is primarily due to the higher energy content of bermudagrass so that less biomass needs to be
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45 345 transported to produce each LGe of fuel. The second major difference is that the effect of
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47 346 bermudagrass scenarios on habitat suitability overall is equally positive in the Minimize Cost and
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49 347 Minimize Loss scenarios. Cost also is virtually the same in both bermudagrass scenarios. Canola
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51 348 would cost approximately 4% more per LGe to reduce habitat suitability loss by 63%. Canola,
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53 349 despite very low biomass yields relative to sugar beets, has a higher energy density, making the
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3 350 transportation costs very low (only \$0.03 per LGe). Because the biomass yields are lower,
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5 351 producing one LGe occupies more land than sugar beets, so the net impact of canola is much
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8 352 greater.

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11 353 [insert Figure 2 about here]

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14 354 One way to visually compare trade-offs is with a spidergram that portrays the relative
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16 355 performance between the alternatives (three biofuel crops) on the criteria (Figure 3). The results
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18 356 shown here are for the Minimize Loss scenarios, but the Minimize Cost results are very similar.
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20 357 No crop is superior in all criteria. All three crops retain at least 97% of current habitat suitability.
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22 358 The canola scenario scores best for transportation costs and water reductions. It scored lowest of
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24 359 the crops for land area per LGe and habitat impacts. Less energy was produced with canola
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26 360 relative to sugar beets. Sugar beets were the most expensive crop for transporting on an LGe
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28 361 basis and had no benefits for water consumption. This crop showed the greatest potential to
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30 362 produce ethanol assuming the \$100 per hectare benchmark, and it used the least land area per
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32 363 LGe. At the assumed price, bermudagrass could only supply 16% of the energy as sugar beets. It
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34 364 scored moderately high in land area and cost. It scored low on water savings but highest on
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36 365 habitat suitability.

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43 366 [insert Figure 3 about here]

44 45 46 367 **Discussion and Conclusions**

47 48 49 368 *Response of wildlife species to biofuel crop scenarios*

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52 369 Agricultural lands in California have relatively low suitability for wildlife Species of Special
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54 370 Concern that utilize agroecosystems compared to the suitability of natural habitats for those same
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56 371 species. Nevertheless, our findings show that the choice of biofuel crop matters for these species.

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3 372 In general, suitability rankings are lower for reproduction than for foraging or cover, which
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5 373 indicates that most wildlife species tend to rely on adjacent patches of natural habitat for
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8 374 reproductive habitat. If these remnant patches were converted to biofuel crops, the ability of the
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10 375 entire landscape to support wildlife would diminish further. Based on the agroecomic
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12 376 modeling, the scenarios varied from converting as little as 100,000 hectares to bermudagrass to
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15 377 more than 500,000 hectares for canola. The aggregate change for all 53 Species of Special
16
17 378 Concern ranged from a 2.2% loss of total suitability in the agroecosystems statewide with
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19
20 379 canola's Minimize Cost scenario to a slight increase of 0.8% for bermudagrass if it was grown
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22 380 like alfalfa hay in the Minimize Loss scenario. Fletcher et al. (2011) reported similar wildlife
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24 381 benefits of cropland being converted to grass. Bermudagrass is rated as moderate risk for
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27 382 invasion in California, particularly in disturbed riparian areas (Cal-IPC 2006) and thus may have
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29 383 additional consequences not captured by the habitat suitability modeling. Given that
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31
32 384 bermudagrass is already common grown in pastures, hayfields, parks, golf courses, and lawns
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34 385 and in widely dispersed irrigation ditches throughout the state, the marginal risk associated with
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36 386 growing bermudagrass for biofuel may be modest. Comparing net habitat effects on a per LGe
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38 387 basis, canola would have the highest negative impact, sugar beets a medium impact, and
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41 388 bermudagrass a small positive net gain in suitability. These averages, however, mask wide
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44 389 variation in individual species' responses.

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47 390 *Trade-offs between wildlife and transportation costs*

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49 391 Despite the large area of land conversion from food crops to biofuel crops in the scenarios, there
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52 392 is sufficient available and suitable cropland to provide flexibility in where conversion might
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54 393 occur. A relatively slight relocation of farms producing biomass in the Minimize Cost scenarios
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56 394 could dramatically reduce wildlife impacts. We found this result for all three biofuel crops, but
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3 395 especially for canola. It is encouraging that in these scenarios the increase in transportation cost
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5 396 would be relatively small compared to large gains (reduced losses) in habitat suitability. The
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8 397 California Bioenergy Crop Adoption Model predicted low production levels for bermudagrass,
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10 398 relative to sugar beets and canola. Thus there is more flexibility to redistribute bermudagrass to
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12 399 satisfy other social objectives such as wildlife conservation and yet be almost as cost-effective as
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14 400 when minimizing cost alone.

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18 401 Agroecosystems also provide many ecosystem services that are affected by land use decisions
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20 402 such as changing to biofuel crops (Dale et al. 2011). These potential impacts were not assessed in
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22 403 our study. As an example, bermudagrass can also be used for reclamation of salt affected lands
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24 404 and for other aspects of salinity management (Kaffka 2009). Perennial crops such as
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26 405 bermudagrass sequester more carbon in soil and roots than annual crops (Tilman et al. 2006).
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28 406 Potential biofuel crops and the food crops they may replace also have specific requirements for
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30 407 nitrogen fertilization. Crops requiring greater fertilization may emit higher levels of nitrogen into
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32 408 surface waters causing eutrophication and nitrous oxide, a potent greenhouse gas, to the
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34 409 atmosphere (Kaffka 2009). These flows and their impact on ecosystem services should be
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36 410 considered in a more comprehensive trade-off analysis.

41 411 *Model uncertainties and limitations*

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45 412 The key inputs to our framework are:

- 46
47 413 • Location of hypothetical biorefineries, biomass yields and water use.
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49 414 • Conversion efficiencies of biomass to energy.
- 50
51 415 • Rules about which lands are suitable and available for biofuel crop production.
- 52
53 416 • A map of current wildlife habitats.
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- A matrix of species-habitat suitability ratings.

The wildlife analysis depended on the availability of the CWHR database. Similar habitat suitability models have been developed by the U.S. Gap Analysis Program, which is currently completing geographic range maps and distribution models for vertebrate species across the entire country (Aycrigg 2010). To the extent that these models include habitat information, especially information that distinguishes different crop types in a way that allows comparison of alternative biofuels, they will allow analyses similar to ours in other regions and with other potential biofuel crops.

Our results and any conclusions about impacts, trade-offs, or sustainability of biofuel crops are all contingent upon many assumptions (detailed in Stoms et al. 2011) made at each of the four steps in the framework. A sensitivity analysis with the California Bioenergy Crop Adoption Model found a wide range in area of biofuel crop adoption in response to changes in key assumptions about crop price and crop biomass yield (Kaffka and Jenner 2011). Those results have not yet been extended to the wildlife effects assessment. For reference, the \$50 per hectare profit benchmark predicted much less land relative to the \$100 per hectare benchmark (55% for sugar beets, 23% for bermudagrass, and 38% for canola; Kaffka and Jenner 2011). The reduction in crop adoption was not uniform across the state, however, as biofuel crops would not be adopted in some subregions at the lower profit level. It is also worth noting that at the height of the state's sugar beet industry in the early 1970s, a maximum of around 120,000 ha was planted, compared to the 218,000 ha modeled here. Because of these variations in amount and location in crop adoption at different potential profit levels, total wildlife impacts would not scale proportionally with area or profit level. The common assumption in California is that for all practical purposes, it is unlikely to expect an expansion of irrigated lands in California in the

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3 440 future and that the land that currently can be profitably cultivated and irrigated is likely an upper
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5 441 limit (Kaffka and Jenner 2011). Therefore the California Biofuel Crop Adoption Model was run
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8 442 exclusively on existing irrigated cropland. A small amount of land is farmed in California
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10 443 without irrigation in foothill regions in the central coast and surrounding California's Central
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12 444 Valley. There may be modest opportunities to increase cropped areas in these regions, which are
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14 445 highly suitable for a range of wildlife species. These lands were not included in the irrigated land
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16 446 model. When that assumption is relaxed, net habitat suitability would be 0.7-3.0% lower for
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18 447 Minimize Cost scenarios and 0.1-1.8% lower for Minimize Loss (Stoms et al. 2011).
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22 448 We modeled scenarios for each biofuel crop separately because the analysis with the California
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24 449 Bioenergy Crop Adoption Model did not consider introductions of multiple crops. More likely,
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26 450 they would be produced as a mixture of feedstocks along with other sources of biomass (e.g.,
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28 451 forest residues, agricultural residues, and municipal solid wastes). This modeling remains to be
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30 452 done. We did not take into account any global increases in crop prices in response to reduction of
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32 453 crop land in California. These price increases might induce landowners abroad to clear native
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34 454 habitats to fill the void, with consequent effects on biodiversity (e.g., Searchinger et al. 2008).
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36 455 Most of the crops displaced in the California Bioenergy Crop Adoption Model, however, are not
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38 456 traded internationally from California or only in small amounts unlikely to affect large price
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40 457 signals. The actual response is a complex set of crop shifts within the state in response to largely
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42 458 local price signals, resulting in within-state crop production. In the absence of a price signal,
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44 459 there might be no indirect effect on land change abroad. We allocated all impacts to the
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46 460 production of biofuel crops. As there are often co-products generated in association with
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48 461 biofuels, such as animal feed (e.g., oilseed meals, sugar beet pulp) or chemicals (e.g., glycerin),
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50 462 the full impacts should not be allocated solely to biofuel (Halleux et al. 2008). The positive
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3 463 effects of bermudagrass on most species in this assessment are based on the assumption that
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5 464 bermudagrass grown for biofuel would have the same habitat suitability as irrigated hayfields,
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8 465 which in California are mostly alfalfa. There is evidence that bermudagrass will have slightly
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10 466 lower suitability than alfalfa hayfields for some wildlife species (Nogeire et al. in preparation).
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12 467 Therefore the beneficial effects of bermudagrass reported here may be overestimated.
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16 468 *Future research directions*
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18
19 469 Assessing biodiversity impacts from renewable energy production poses a number of
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21 470 methodological challenges. Researchers in life cycle assessment (LCA) have endeavored to
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23 471 develop methods for incorporating biodiversity as an indicator in their impact assessment
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25 472 methods. Biofuel crops in particular have been a promising product system to test because of the
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27 473 large-scale changes in land use and habitats involved in commercial scale production. Geyer et
28
29 474 al. (2010a and 2010b) proposed a methodology based on the type of wildlife habitat suitability
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31 475 modeling used in this study, and results such as reported here can be readily incorporated to
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33 476 provide biodiversity indicators for LCA s of bioenergy development.
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38 477 Some studies have excluded prime farmland from consideration for growing biofuel crops to
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40 478 avoid conflicts with food production (Lovett et al. 2009; Fiorese and Guariso 2010). We did not
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42 479 evaluate this policy option in this study because of the assumption that only irrigated cropland
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44 480 would be converted to biofuel crops. The framework could readily accommodate this variation,
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46 481 however, either by masking prime farmland as “unsuitable” for biofuel crops or by excluding
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48 482 sections with prime farmland in the scenario runs. Prime farmland is quite widespread in the
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50 483 study area. Very little land in California is considered marginal or underutilized that could
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52 484 supply biofuel crop feedstock compared to other agricultural regions (Hill et al. 2006; and
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54 485 Meehan et al. 2010). We expect that policy options that retained all prime farmland for food
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3 486 production might either increase the transportation costs dramatically or fail to achieve the
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6 487 biofuel output levels. Consequently preserving food production would have to be balanced
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8 488 against energy production or cost.
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11 489 *Complementing an integrated framework for trade-off analysis*
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14 490 Robertson et al. (2008) called for an integrated framework to assess trade-offs between biofuel
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16 491 production and environmental objectives. Our framework and Zhang's both apply forms of
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18 492 multiobjective optimization modeling for spatial allocation to biofuel crop production to meet
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20 493 different combinations of objectives. We did not model many of the impacts in the other
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22 494 frameworks such as greenhouse gas emissions or nutrient loss. On the other hand, our analysis is
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24 495 unique in identifying impacts on and the potential for trade-offs with wildlife species. We
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26 496 anticipate that our habitat suitability modeling or something similar could be adapted to function
27
28 497 within the other frameworks. Our framework has a further advantage in that it can be used to
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30 498 assess full or partial scenarios generated externally. For instance, biodiversity conservation
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32 499 stakeholders might design a scenario of sites they wish to preserve, which could be excluded
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34 500 from any biofuel scenario (i.e., declare the land unavailable for biofuel crops) to determine the
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36 501 effect of conservation. The framework can also assess the relative marginal effects of individual
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38 502 biorefineries or energy production levels (Stoms et al. 2011). The most noteworthy contribution
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40 503 presented here is that the approach is more spatially-explicit than many others (McDonald et al.
41
42 504 2009), which are top-down and aggregated in ways that cannot represent the finer-scale
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44 505 characteristics of landscapes that are all-important in determining wildlife effects. Without this
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46 506 level of spatial detail, the trade-offs between renewable energy and biodiversity cannot be
47
48 507 adequately portrayed to stakeholders.
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508 **Acknowledgements**

509 This project was funded by the California Energy Commission's Public Interest Energy Research
510 (PIER) Program under Contract #500-02-004. This paper was prepared as the result of work
511 sponsored by the California Energy Commission. It does not necessarily represent the views of
512 the Energy Commission, its employees or the State of California. The Energy Commission, the
513 State of California, its employees, contractors and subcontractors make no warrant, express or
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515 represent that the uses of this information will not infringe upon privately owned rights. This
516 paper has not been approved or disapproved by the California Energy Commission nor has the
517 California Energy Commission passed upon the accuracy or adequacy of the information in this
518 paper.

519 Many individuals and groups helped us with parts of the trade-off analysis. Peter Tittmann from
520 the University of California Davis generously provided data on locations of potential
521 biorefineries and the associated transportation costs. Atte Moilanen gave us the critical insight
522 into a method for modeling biofuel production and habitat change in a conservation planning
523 tool, for which we are extremely grateful. The conservation planning tool (Marxan) was
524 developed by Hugh Possingham's research group at the University of Queensland, Australia, and
525 is freely distributed from their web site at <http://www.uq.edu.au/marxan/>.

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678 **Tables and Figures**679 **Table 1. Habitat types associated with biofuel feedstock crops.**

Crop	Habitat name
Sugar beets	Irrigated Row and Field Crops
Bermudagrass	Irrigated Hayfield ^a
Canola (rain-fed)	Dry Grain Crops ^b
Canola (irrigated)	Irrigated Grain Crops ^b

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681 ^a Bermudagrass is classified as Pasture in CWHR when it is grazed, but we assumed that for biofuel it would be grown tall and
 682 harvested, more like an alfalfa habitat type. We therefore classified it as Irrigated Hayfield.

683 ^b Canola is grown in the winter rainy season. We assumed it (and other small grains) would be cultivated as Dry Grain Crops in
 684 northern California and as Irrigated Grain Crops in the south where rainfall is less.

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687 **Table 2. Conversion coefficients from tons of crop biomass to liters gasoline equivalent (LGe) and**
 688 **LGe per hectare.**

Crop	Biofuel type	Biofuel yield (liters biofuel / ton feedstock)	Gasoline equivalent (liters-gasoline/ l-biofuel)	Energy yield (LGe / ton feedstock)	Biomass yield (tons feedstock / hectare) ^e	Biofuel yield (LGe / hectare) ^e
Sugar beets	Ethanol	103.7 ^a	0.67 ^d	69.5	70.7	4,896
Bermudagrass	Ethanol	216.1 ^b	0.67 ^d	144.8	10.1	1,459
Canola	Biodiesel	431.5 ^c	1.03 ^d	444.4	2.2	995

689 ^a Williams et al. 2007; Shapouri et al. 2006; ^b Anderson et al. 2008; ^c Tyson et al. 2004;

690 ^d Tittmann et al. 2008. Note that the yield for bermudagrass is still largely theoretical.

691 ^e Derived from results of California Bioenergy Crop Adoption Model and energy conversion coefficients,
 692 averaged over the State of California. Conversion rates of cellulosic biomass sources like bermudagrass
 693 or other perennial grasses to ethanol are theoretical values at this time. Converting vegetable oils to
 694 biodiesel and sugar to ethanol is currently done on a commercial scale, so empirical conversion factors
 695 can be used.
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700 **Table 3. Statewide totals of “Minimize Cost” (MC) and “Minimize Loss” (ML) biofuel crop**
 701 **scenarios.**

	Sugar beets (MC)	Sugar beets (ML)	Bermuda grass (MC)	Bermuda grass (ML)	Canola (MC)	Canola (ML)
Land area converted to biofuel crop in thousand hectares (% of agroecosystem lands)	218.2 (3.5%)	218.2 (3.5%)	120.2 (1.5%)	120.2 (1.5%)	512.2 (7.8%)	512.3 (7.8%)
Biofuel production in million LGe per year^a	1068.5	1068.4	168.5	168.4	509.6	509.7
Net change in habitat suitability	-1.0%	-0.8%	+0.8%	+0.8%	-2.2%	-0.8%
Net reduction in water demand in million cubic meters (% of all irrigation)—from CBCAM model results	0 (0%)	0 (0%)	14.8 (0.1%)	14.8 (0.1%)	1283.1 (6.7%)	1283.1 (6.7%)

702
 703 LGe = liters of gasoline equivalent; CBCAM = California Bioenergy Crop Adoption Model

704 **Table 4. Number of Species of Special Concern by level of change in habitat suitability for**
 705 **Minimize Cost (MC) and Minimize Loss (ML) biofuel crop scenarios.**

Percent change	Sugar beets (MC)	Sugar beets (ML)	Bermuda grass (MC)	Bermuda grass (ML)	Canola (MC)	Canola (ML)
> 10% loss	0	0	0	0	8	6
7.5 – 10% loss	0	0	0	0	2	1
5 – 7.5% loss	1	2	0	0	4	3
2.5 – 5% loss	5	3	0	0	7	1
0 – 2.5% loss	22	23	19	20	13	21
0% - no change	17	17	12	12	12	13
0 – 10.7% gain	8	8	22	21	7	8
Total number of species	53	53	53	53	53	53

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3 708 **Figure 1. California agroecosystems considered for biofuel crop conversion in this study.**
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6 709 **Figure 2. Trade-offs between cost and net impact on habitat suitability per liter of gasoline**
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8 710 **equivalent (LGe) for the three biofuel crops. The axes are drawn so that social benefit is highest at**
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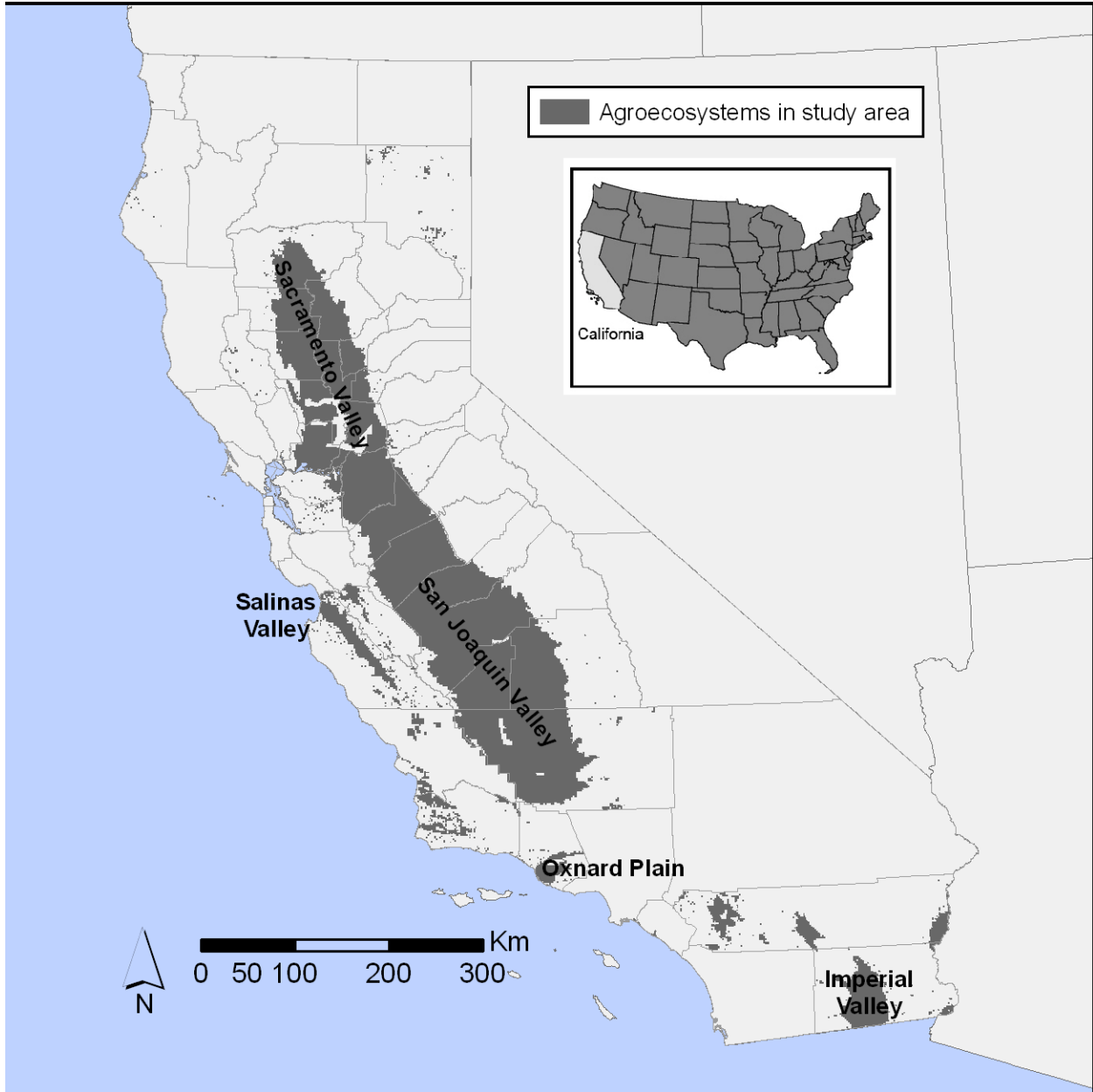
10 711 **the origin (i.e., lowest cost and positive impact on wildlife). MC = Minimize Cost scenarios, ML =**
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12 712 **Minimize Loss scenarios.**
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15 713 **Figure 3. Spidergram of trade-offs between criteria for the three biofuel crops in the Minimize Loss**
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17 714 **scenarios. Axes drawn with best societal outcome at 100, poorest at zero.**
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Figure 1. California agroecosystems considered for biofuel crop conversion in this study.

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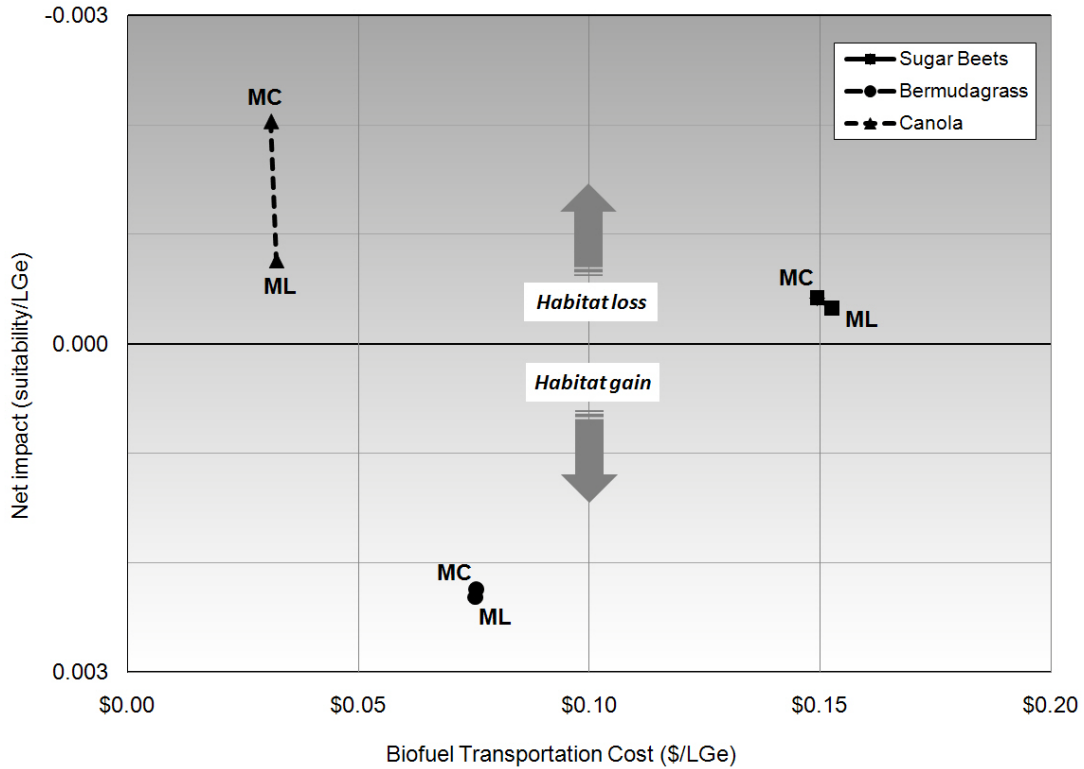
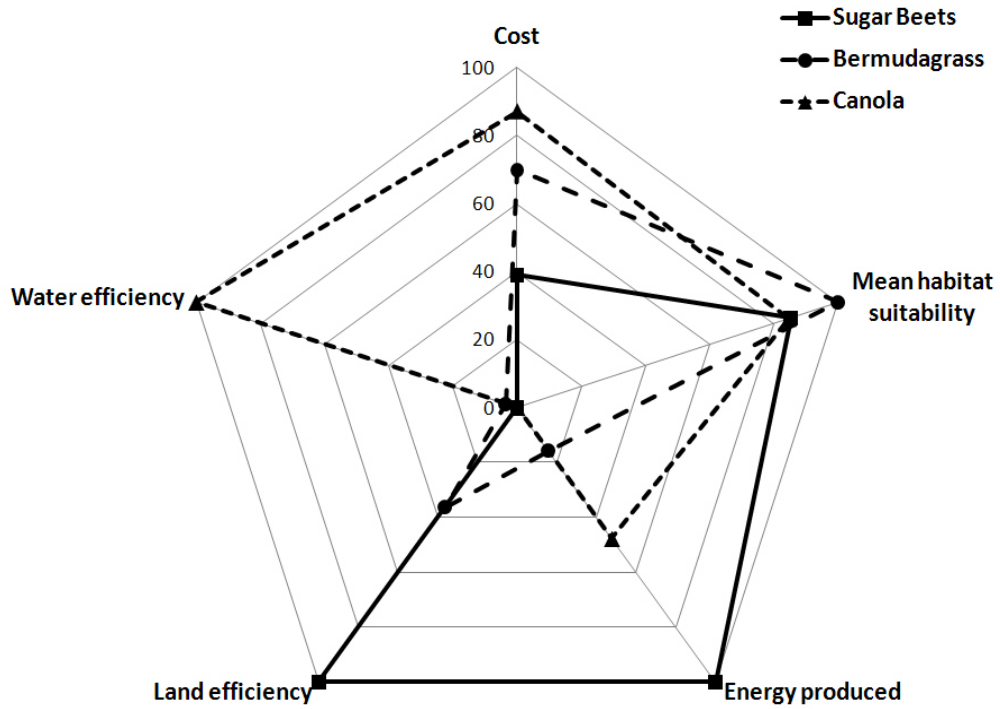


Figure 2. Trade-offs between cost and net impact on habitat suitability per liter of gasoline equivalent (LGe) for the three biofuel crops. The axes are drawn so that social benefit is highest at the origin (i.e., lowest cost and positive impact on wildlife). MC = Minimize Cost scenarios, ML = Minimize Loss scenarios.



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726 **Figure 3. Spidergram of trade-offs between criteria for the three biofuel crops in the Minimize Loss**
 727 **scenarios. Axes drawn with best societal outcome at 100, poorest at zero.**

728 **Appendix. Species of Special Concern and suitability-weighted area under biofuel crop scenarios as a**
 729 **percent of current.**

730 Scenario with lowest percent value shown in **bold** font; highest value in **bold italics**. Shaded rows indicate species that were not
 731 affected by any change of crops.

WHR Code	Scientific Name	Common Name	Current suitability-weighted area	Sugar Beets MC	Sugar Beets ML	Bermuda grass MC	Bermuda grass ML	Canola MC	Canola ML
A001	<i>Ambystoma californiense</i>	CALIFORNIA TIGER SALAMANDER	873,587	100.0	100.0	99.6	99.6	99.3	99.8
A028	<i>Spea hammondi</i>	WESTERN SPADEFOOT	2,389,987	101.5	101.3	99.3	99.3	103.1	102.3
A030	<i>Bufo alvarius</i>	COLORADO RIVER TOAD	9,278	100.0	100.0	100.0	100.0	100.0	100.0
B042	<i>Pelecanus erythrorhynchos</i>	AMERICAN WHITE PELICAN	70,976	97.1	97.8	99.4	99.3	93.9	98.7
B050	<i>Ixobrychus exilis</i>	LEAST BITTERN	104,963	98.6	99.1	99.6	99.5	96.6	99.4
B062	<i>Plegadis chihi</i>	WHITE-FACED IBIS	153,750	100.1	100.2	100.7	100.7	89.1	89.9
B065	<i>Dendrocygna bicolor</i>	FULVOUS WHISTLING-DUCK	174,114	100.0	100.1	100.1	100.0	79.3	84.1
B070	<i>Anser albifrons</i>	GREATER WHITE-FRONTED GOOSE	1,813,954	99.0	99.2	100.8	100.7	86.5	87.9
B090	<i>Aythya americana</i>	REDHEAD	162,928	98.2	98.6	99.7	99.6	96.2	99.3
B113	<i>Haliaeetus leucocephalus</i>	BALD EAGLE	386,616	99.7	99.8	98.9	99.0	98.0	99.3
B114	<i>Circus cyaneus</i>	NORTHERN HARRIER	3,582,494	96.8	97.2	101.3	101.3	106.7	108.6
B121	<i>Buteo swainsoni</i>	SWAINSON'S HAWK	1,433,143	98.4	98.8	101.3	101.4	96.5	98.5
B124	<i>Buteo regalis</i>	FERRUGINOUS HAWK	1,182,864	98.0	98.5	101.9	102.0	94.7	97.7
B125	<i>Buteo lagopus</i>	ROUGH-LEGGED HAWK	1,202,194	98.4	98.8	101.1	101.2	95.8	98.1
B150	<i>Grus canadensis</i>	SANDHILL CRANE	1,873,265	98.7	99.0	101.7	101.6	100.0	101.5
B154	<i>Charadrius alexandrinus</i>	SNOWY PLOVER	9,551	100.0	100.0	100.0	100.0	100.0	100.0
B159	<i>Charadrius montanus</i>	MOUNTAIN PLOVER	996,437	100.3	100.2	100.1	100.1	84.6	85.8
B173	<i>Numenius americanus</i>	LONG-BILLED CURLEW	1,160,369	96.0	97.2	105.8	105.6	113.9	119.7

WHR Code	Scientific Name	Common Name	Current suitability-weighted area	Sugar Beets MC	Sugar Beets ML	Bermuda grass MC	Bermuda grass ML	Canola MC	Canola ML
B215	<i>Larus californicus</i>	CALIFORNIA GULL	2,278,729	100.4	100.4	100.2	100.2	86.9	87.0
B226	<i>Gelochelidon nilotica</i>	GULL-BILLED TERN	570	100.0	100.0	100.0	100.0	91.3	100.0
B235	<i>Chlidonias niger</i>	BLACK TERN	334,237	92.7	93.6	101.1	101.2	84.4	90.4
B259	<i>Coccyzus americanus</i>	YELLOW-BILLED CUCKOO	49,466	100.0	100.0	99.7	99.3	100.0	100.0
B269	<i>Athene cunicularia</i>	BURROWING OWL	3,229,015	98.1	98.7	102.5	102.5	95.3	98.2
B273	<i>Asio flammeus</i>	SHORT-EARED OWL	3,200,176	100.3	100.3	100.1	100.1	89.7	89.9
B297	<i>Melanerpes uropygialis</i>	GILA WOODPECKER	44,819	100.0	100.0	100.0	100.0	100.0	100.0
B324	<i>Pyrocephalus rubinus</i>	VERMILION FLYCATCHER	19,217	95.3	95.0	101.5	104.8	89.2	95.7
B342	<i>Riparia riparia</i>	BANK SWALLOW	239,940	100.8	100.7	100.6	100.2	92.6	93.5
B365	<i>Campylorhynchus brunneicapillus</i>	CACTUS WREN	136,256	100.0	100.0	100.0	100.0	100.0	100.0
B399	<i>Toxostoma crissale</i>	CRISSAL THRASHER	35,338	100.0	100.0	100.0	100.0	100.0	100.0
B410	<i>Lanius ludovicianus</i>	LOGGERHEAD SHRIKE	2,512,099	98.8	99.1	101.3	101.3	105.9	107.7
B461	<i>Geothlypis trichas</i>	COMMON YELLOWTHROAT	1,496,061	100.0	100.0	99.4	99.5	99.2	99.6
B494	<i>Pooecetes gramineus</i>	VESPER SPARROW	610,932	98.8	99.0	101.1	101.1	104.5	107.0
B499	<i>Passerculus sandwichensis</i>	SAVANNAH SPARROW	2,609,165	98.4	98.8	102.0	102.1	100.3	102.5
B501	<i>Ammodramus savannarum</i>	GRASSHOPPER SPARROW	1,339,773	99.2	99.4	101.2	101.2	98.6	99.5
B520	<i>Agelaius tricolor</i>	TRICOLORED BLACKBIRD	1,645,387	100.1	100.0	99.6	99.7	99.8	100.1
B522	<i>Xanthocephalus xanthocephalus</i>	YELLOW-HEADED BLACKBIRD	608,921	95.5	96.2	101.7	101.7	90.0	93.7
M006	<i>Sorex ornatus</i>	ORNATE SHREW	964,556	99.8	99.9	99.2	99.4	98.6	99.5
M019	<i>Macrotus californicus</i>	CALIFORNIA LEAF-NOSED BAT	29,431	100.0	100.0	100.0	100.0	100.0	100.0
M040	<i>Nyctinomops femorosaccus</i>	POCKETED FREE-TAILED BAT	33,804	100.0	100.0	100.0	100.0	100.0	100.0
M068	<i>Ammospermophilus nelsoni</i>	NELSON'S ANTELOPE SQUIRREL	286,288	100.0	100.0	99.9	99.9	99.7	99.9
M074	<i>Spermophilus tereticaudus</i>	ROUND-TAILED GROUND SQUIRREL	67,531	99.5	99.7	99.1	99.5	94.4	93.3
M086	<i>Perognathus longimembris</i>	LITTLE POCKET MOUSE	94,534	100.0	100.0	100.0	100.0	100.0	100.0
M087	<i>Perognathus inornatus</i>	SAN JOAQUIN POCKET	1,274,922	99.5	99.6	99.8	99.8	99.2	99.5

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WHR Code	Scientific Name	Common Name	Current suitability-weighted area	Sugar Beets MC	Sugar Beets ML	Bermuda grass MC	Bermuda grass ML	Canola MC	Canola ML
		MOUSE							
M106	<i>Dipodomys ingens</i>	GIANT KANGAROO RAT	381,353	100.0	100.0	100.0	100.0	100.0	100.0
M108	<i>Dipodomys stephensi</i>	STEPHENS' KANGAROO RAT	17,843	100.0	100.0	100.0	100.0	100.0	100.0
M111	<i>Dipodomys nitratooides</i>	FRESNO KANGAROO RAT	333,761	99.9	99.9	99.9	99.9	99.7	99.9
M122	<i>Onychomys torridus</i>	SOUTHERN GRASSHOPPER MOUSE	572,573	100.0	100.0	99.9	100.0	100.0	100.0
M148	<i>Vulpes macrotis</i>	KIT FOX	1,144,848	98.7	99.1	101.9	102.0	96.1	98.8
R004	<i>Actinemys marmorata</i>	WESTERN POND TURTLE	1,675,450	99.8	99.8	99.4	99.5	98.8	99.5
R014	<i>Uma inornata</i>	COACHELLA VALLEY FRINGE-TOED LIZARD	12,805	100.0	100.0	100.0	100.0	100.0	100.0
R019	<i>Gambelia sila</i>	BLUNT-NOSED LEOPARD LIZARD	494,020	100.0	100.0	99.9	99.9	99.9	99.9
R052	<i>Masticophis flagellum</i>	COACHWHIP	342,817	100.0	100.0	99.8	99.9	99.1	99.3
R079	<i>Thamnophis gigas</i>	GIANT GARTER SNAKE	411,319	98.7	99.1	98.8	98.6	96.9	98.9
	Total or Average		46,108,425	99.0	99.2	100.8	100.8	97.8	99.2
	Minimum			92.7	93.6	98.8	98.6	79.3	84.1
	Maximum			101.5	101.3	105.8	105.6	113.9	119.7

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