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FINAL PROJECT REPORT

BIOFUELS AND BIODIVERSITY IN CALIFORNIA

A Framework for Conducting aTrade-Off Analysis

Prepared for: California Energy Commission
Prepared by: University of California Santa Barbara

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PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

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Biofuels and Biodiversity in California: A Framework for Conducting a Trade-Off Analysis is the final report for the Biofuels and Biodiversity in California project (Contract Number 500-02-004, Work Authorization 078) conducted by the University of California, Santa Barbara. The information from this project contributes to Energy Research and Development Division's Energy-Related Environmental Research Program.

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ABSTRACT

Biofuels from agricultural and other types of biomass are an important part of California's strategy to reduce greenhouse gas emissions and dependence on foreign oil. Ongoing land conversion for agricultural and urban uses has already imperiled many animal species in the state. This study investigated the potential impacts on wildlife of shifts in agricultural activity to increase biomass production. The investigators applied knowledge of the suitability of California's agricultural landscapes for wildlife species to evaluate wildlife effects associated with plausible scenarios of expanded production of five potential biofuel crops: sweet sorghum, sugar beets, bermudagrass, canola, and safflower. Alternative, spatially explicit scenarios that minimized loss of habitat for a given level of biofuel production were generated. Trade-off analysis compared the marginal changes per unit of energy for transportation costs, wildlife, and water use. Sweet sorghum and sugar beets require three times less land area per gallon of gasoline equivalent than bermudagrass and five to six times less than canola and safflower. Canola and safflower scenarios had the largest impacts on wildlife but the greatest reduction in water use. The bermudagrass scenarios result in a slight overall improvement for wildlife over the current situation. Relatively minor redistribution of lands converted to biofuel could produce the same energy yield with much less impact on wildlife and a very small increase in transportation costs for any crop. This framework provides a means to systematically evaluate potential wildlife impacts of alternative biofuel crop production scenarios. The accuracy of the predicted impacts could be improved with additional field study of wildlife use of agricultural landscapes, especially habitats associated with biofuel crops.

Keywords: California Wildlife Habitat Relationships system, habitat suitability, geographic information system, Marxan, trade-off analysis, renewable energy, water demand, agroecosystem

Note: The results in this report differ slightly than those published in: Stoms, D. M., F. W. Davis, M. W. Jenner, T. M. Nogeire and S. R. Kaffka. 2012. Modeling wildlife and other trade-offs with biofuel crop production. *Global Change Biology—Bioenergy* 4: 330–341. The analysis in the journal article limited biofuel crops to existing cropland or pasture whereas the analysis in this report assumed that grasslands could also be converted to biofuel crops. The assumption in Stoms et al. (2012) is more consistent with the California Bioenergy Crop Adoption Model (Kaffka and Jenner 2010) on which the analysis was based.

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EXECUTIVE SUMMARY

Environmental, economic, and political concerns about the production and use of fossil fuels have led to a growing interest in biofuels nationally and in California. Substitution of biofuels for fossil fuels could in many cases reduce environmental impacts, such as anthropogenic greenhouse gas emissions. Environmental scientists have expressed concern, however, that widespread land use change to generate sufficient biomass feedstock to meet ambitious targets may have undesirable and unintended consequences on other social objectives, such as biodiversity, water quality and quantity, and ecosystem services. Despite the concern, there has been little quantitative analysis of the potential impacts of biofuel crop production on species' habitats and biodiversity.

In simple terms, conversion to biofuel crops on a particular site can follow three pathways. An existing food or forage crop can be grown instead as an energy crop; a food or forage crop can be replaced with a different, perhaps novel, energy crop; or nonagricultural land could be cultivated to produce an energy crop. The first pathway would have little impact on wildlife species unless there was a dramatic change in management practices such as the timing of harvest or use of crop residues. In contrast, the third pathway could engender large changes in vegetation and land management that would dramatically alter site suitability for many species. Species may also be sensitive to the kinds of changes in habitat structure found in the second pathway, such as from a low-growing pasture to a taller perennial grain crop. To begin to understand the potential effects of biofuel crop production on wildlife species, one needs to know what crops are currently grown and where, which lands and how much might be converted to biofuel crops, and how various species will respond to that conversion. For an area as large and diverse as California, the data requirements are significant. A new analytical framework is needed to model alternative scenarios of biofuel crop production and assess the effects.

This project provides a statewide perspective on potential effects of increased cultivation of biofuel crops on California's wildlife species and water use. The specific project objectives were to develop and implement an integrated framework for generating plausible scenarios of biofuel crop production, assess the effects of that production on wildlife and water use, and identify trade-offs between energy and environmental factors throughout California.

Integrated Framework

The authors developed a general five-step integrated framework and implemented it with various models and analytical approaches.

- Step 1: An agroeconomic model predicts the level of biofuel crop production and associated water demand at an assumed level of profit for subregions. Colleagues from UC Davis modeled five potential biofuel crops (sweet sorghum, sugar beets, bermudagrass, canola, and safflower) with their California Bioenergy Crop Adoption Model. Crop biomass yields were converted into gallons of gasoline equivalent for direct comparison of energy yields.

- Step 2: Lands are screened to determine which land units are available and suitable for biofuel crops.
- Step 3: Habitat suitability modeling estimates the landscape quality for a set of wildlife species for both current land use and potential biofuel crop production. This study modeled suitability for 53 wildlife Species of Special Concern based on the habitat suitability ratings from the California Wildlife Habitat Relationships system.
- Step 4: Scenario generation produces maps of where biofuel crops could be grown with the least total cost or with least loss of habitat suitability for the same biofuel production. The researchers used freely available conservation planning software, Marxan, to generate alternative spatially explicit scenarios of land use and crop cultivation based on data on potential biofuel yield, transportation costs, and water use.
- Step 5: Trade-off analysis compares effects on cost, wildlife, and water.

Results

Basic scenarios were designed to achieve production levels of biofuel predicted by the California Bioenergy Crop Adoption Model at the minimum transportation cost (referred to here as “Minimize Cost” scenarios). Alternative scenarios also minimized habitat loss while still meeting biofuel production levels (“Minimize Loss” scenarios). The Marxan model selected one-square mile tracts of land to meet these targets efficiently.

The sweet sorghum scenario was the largest potential source of biofuel given of its relatively high energy yield (in gallons of gasoline equivalent per acre). The bermudagrass scenario produced less than 1/10th the energy of the sweet sorghum scenario. The canola scenario, however, had the largest conversion of land (17.7 percent), despite a relatively low level of biofuel production.

The sugar crops, sweet sorghum and sugar beets, require less than 8 m^2 per gallon of gasoline equivalent on average; bermudagrass requires 26 m^2 ; and canola and safflower take 38 and 51 $m^{2,}$ respectively. The oil crops and bermudagrass have much lower biomass yields per acre than sugar crops, although this is partially offset by their higher energy content and conversion efficiencies. The difference in the land requirements for any given crop between the Minimize Cost and Minimize Loss scenarios was tiny compared to differences between crops. On the other hand, safflower (3 percent) and canola (nearly 6 percent) provided the largest reductions in water use, whereas total irrigation remained about the same with the other three crops.

Sweet sorghum and canola have the greatest number of species with larger losses of habitat suitability. Sugar beets, bermudagrass, and safflower in general have relatively low numbers of species with large impacts. Bermudagrass, which had the lowest biofuel production, causes no more than 2 percent loss for any of the species and benefits 25 species. There are trade-offs to be considered between the set of surrogates of biodiversity and individual species. For instance, safflower was relatively benign in its effects on wildlife collectively, but it had the largest negative impact on Stephens’ kangaroo rat.

Trade-Off Analysis of Biofuels, Biodiversity, and Water

The scenarios generate information about biofuel production, costs, and impacts. These were transformed into five criteria for the trade-off analysis: the percentage of California's ethanol or biodiesel targets, mean habitat suitability for the Species of Special Concern, mean transportation cost, water savings, and land requirements, with the latter three criteria on a per unit of energy basis. The authors evaluated the marginal cost and wildlife impact on a standardized energy basis for scenarios and for individual biorefineries. As expected, scenarios that attempt to reduce the impact of biofuel crop production on habitat suitability for the Species of Special Concern would cause an increase in the cost of transporting biomass to the least-cost biorefinery.

Sugar beets: could meet close to 50 percent of the ethanol target; largest cost of the five crops due to its relatively low energy efficiency; least amount of land required to produce one gallon of gasoline equivalent because high biomass yields overcome its lower energy density; moderate loss in habitat value; no change in water use.

Sweet sorghum: greatest potential toward achieving state biofuel targets based on the California Bioenergy Crop Adoption Model at the assumed $40 profit per acre; largest cost of the five crops due to relatively low energy efficiency; least amount of land required to produce one gallon of gasoline equivalent because high biomass yields overcome its lower energy density; relatively large loss of habitat value; slight reduction in water use.

Bermudagrass: could supply only 7 percent of state ethanol target; intermediate cost; intermediate land requirement per unit of energy; only crop with a positive net effect on habitat suitability, even in the Minimize Cost scenario, and great potential for better outcomes for wildlife with the Minimize Loss scenarios at very low increases in cost; slight reduction in water use.

Canola: close to 50 percent of the state's biodiesel target; along with safflower, by far the lowest transportation cost per unit of energy because of their high energy density in each ton of biomass; large land requirement; relatively large loss of habitat suitability but large potential to reduce those impacts with the Minimize Loss scenarios at very low increases in cost; large water savings.

Safflower: only about 20 percent of the state's biodiesel target; along with safflower, by far the lowest transportation cost per unit of energy because of their high energy density in each ton of biomass; requires the most land area per unit of energy; largest loss of habitat suitability per gallon of gasoline equivalent but has the largest potential to reduce those impacts with the Minimize Loss scenario at very low increases in cost; saves the most water.

Thus, no crop is superior, or inferior, in all criteria.

Just as it is possible to compare trade-offs between crop types, the trade-offs of cost and impact can be assessed for individual biorefineries. This comparison identified potential biorefineries that contribute disproportionately to either the costs or habitat suitability loss, or offer the greatest potential to reduce suitability loss and minimal cost.

Discussion

This report demonstrates a five-step integrated framework to assess fine-scale changes in biodiversity associated with expanded biofuel production across California's agroecosystems. Although the results are contingent upon the underlying assumptions and model outcomes are highly uncertain, the framework provides a means to systematically evaluate potential impacts of alternative production scenarios on wildlife. In principle other indicators could be incorporated where geographic variability influences environmental outcomes (such as soil carbon fluxes, nutrient fluxes) if appropriate data could be obtained.

The key inputs to the framework are:

- Location of hypothetical biorefineries, biomass yields, and water use.
- Rules or maps about which lands are suitable and available for biofuel crop production.
- A map of current wildlife habitats.
- A matrix of species-habitat suitability ratings.

Farmers are free to choose which crops to grow, including biofuel crops. If resource planners wish to improve the outcomes for wildlife, they are limited to incentive mechanisms for growers or refiners. Incentives could be provided through subsidies for biomass produced on farms known to have low wildlife impact, or permitting could be expedited for biorefineries with low overall wildlife impact. This study makes a preliminary attempt to inform such a program; substantially more analysis would be required that also incorporated many other economic, social, and environmental factors.

Concluding Remarks

This study is the first that systematically assesses the effects of growing biofuel crops on a set of individual wildlife species and water use. It provides California stakeholders with an approach for exploring the trade-offs for a range of scenarios with different bioenergy crops and yields, biorefinery locations, and levels of energy production. The results of the study are specific to the scenarios assessed and to the defined set of assumptions. Readers should not interpret these results as conclusive evidence to support or oppose any particular biofuel crop or biorefinery location. In addition, converting farms from food to energy crops causes food to be grown elsewhere and perhaps degrade habitat there; the indirect effects of this land use change were not incorporated in this study.

Application of the framework did not identify any large geographic areas where wildlife appears particularly vulnerable to conversion to biofuel crop production except on the grassland fringe of the Central Valley, which is probably not feasible to cultivate in any practical way. Agricultural lands in California have relatively low suitability for agroecosystem wildlife species. The choice of biofuel crop, however, does make some difference in the effects on wildlife that are already faced with many threats. For all five crops assessed in this study, relatively minor redistribution of lands allocated to biofuel could produce the same energy yield with much less impact on wildlife and at very small increases in transportation costs.

CHAPTER 1: Introduction

1.1 Problem Statement

Environmental, economic, and political concerns about the production and use of fossil fuels have prompted the nation (Energy Independence and Security Act of 2007) and the State of California (California Biomass Collaborative 2006) to set ambitious targets for biofuel production. A number of recent studies suggested that the substitution of biofuels for fossil fuels could in many cases reduce environmental impacts such as eutrophication, acidification, and ecotoxicity, and, most importantly, anthropogenic greenhouse gas (GHG) emissions (Sheehan et al. 2003, de Oliveira et al. 2005, Kim and Dale 2005, Hill et al. 2006, Tilman et al. 2006).

Environmental scientists have observed, however, that biofuels are generally the most land-intensive form of energy (McDonald et al. 2009). Widespread land use change to generate sufficient biomass feedstock to meet these ambitious targets may have undesirable and unintended consequences for biodiversity, water quality and quantity, and ecosystem services (Groom et al. 2008, Robertson et al. 2008, McDonald et al. 2009, Dominguez-Faus et al. 2009, Williams et al. 2009, Fingerman et al. 2010, and Dauber et al. 2010). There is also concern about the consequences on food security and prices if prime farmland is used to produce the biomass. Conversely, cultivating biofuel crops on marginal farmland raises concerns about increased fertilization and soil erosion. Thus there is a great deal of attention focused on planning for renewable biofuel production that is economically, socially, and environmentally sustainable. The types of biomass, and where and how they are grown and harvested, will strongly influence the sustainability of biofuels (Robertson et al. 2008).

Agriculture is one of the leading proximate drivers of biodiversity loss (Daily et al.2003). Nevertheless, agricultural, or "countryside," habitats are key to conserving biodiversity because all biodiversity cannot be conserved in protected areas alone (Brosi et al. 2006). Conservation practitioners are paying increasing attention to this important role for agroecosystems (Brosi et al. 2006). Despite the concern, there has been little quantitative analysis of the potential impacts of biofuel crop production on species habitats and biodiversity. All effects may not necessarily be negative. For example, planting perennial crops like switchgrass on degraded cropland was speculated to improve habitat quality for some species (Perlack et al. 2005). On the other hand, market forces for biofuel could make undisturbed habitat and retired lands (for example, farms enrolled in the Conservation Reserve Program [CRP]) attractive for conversion to energy crops. Cultivating these lands could be detrimental for many wildlife species (Meehan et al 2010). If production changes from a food crop to a biofuel energy crop, the effects on wildlife species would be harder to anticipate.

All wildlife species have specific habitat requirements for breeding, cover, and food. These requirements can be met in different types of habitats. Wildlife use agricultural habitats by foraging directly on crops, drinking irrigation water, foraging on crop residues (especially waterfowl), or foraging on insects and small mammals that are attracted to working landscapes. A species may nest in woodland but feed in neighboring farm fields. Switching to biofuel can affect any of these three requirements, either positively or negatively. For example, converting a tomato field to a dedicated energy grass may improve the suitability of the site for seed-eating birds and rodents, but reduce the suitability for some other species. The habitat factors most likely to be altered in working landscapes where biofuel crops are grown include changes in plant structure (grasses, shrubs, trees, annual versus perennial), water use, pesticides, invasiveness, and timing or method of harvesting (Fargione et al. 2009). Learning how to assess the impacts on wildlife from meeting society's need for low-carbon energy will require a better understanding of wildlife use of agricultural habitats associated with biofuel crops. Before policy makers and business leaders commit heavily to large-scale production of biofuels, they need to be informed about the potential impacts on biodiversity (Hanegraaf et al. 1998, Chan et al. 2004).

Assessing those impacts in the context of trade-offs with other social concerns would be an even greater contribution to policy makers and stakeholders. One of the primary obstacles to studying the trade-offs associated with biofuel crop production is the lack of a general framework that would allow these concerns to be consistently assessed (Robertson et al. 2008). The alternative futures approach illustrates the impact assessment framework, which has been applied to biodiversity assessment (White et al. 1997). Graham et al. (1996) used this framework in a biofuels context, although they only discussed the potential to assess impacts on wildlife but did not implement it. Impact assessment lets one compare a predetermined set of scenarios but does not generate optimal solutions. Conservation assessment frameworks, on the other hand, have been used to select areas to protect targeted amounts of biodiversity features (Margules and Pressey 2000), usually as the sole concern. On rare occasions, the opportunity costs of resource production and extraction that would be foregone due to conservation are considered in optimizing the conservation area network design (Polasky et al. 2008). In both frameworks, scenarios are developed to emphasize one social concern, and then the impacts on the other concerns can be assessed contingent upon the scenario. Overcoming the obstacle described by Robertson et al. (2008) will require integrating frameworks so that scenarios can be formulated that incorporate multiple concerns concurrently. Such a framework could evaluate policy options as well as assess trade-offs among social concerns.

These issues are particularly urgent in California. The state is rich in both agricultural habitats and species that use these habitats. Twenty-nine percent of the land in California is used for agriculture (9 percent in cropland, the rest in pasture and rangeland). Nearly half (46 percent) of the terrestrial vertebrate species in California use the state's agricultural lands, including 37 percent of protected species, 64 percent of birds, 47 percent of mammals, 21 percent of reptiles, and 30 percent of amphibians (Brosi et al. 2006). Human-dominated land use associated with agricultural and urban development have also destroyed and degraded habitat for a large number of wildlife species. There may be great potential for California agriculture to positively influence wildlife conservation or to nudge imperiled species closer to the brink depending on the choice of biofuel crops and where they are grown.

Current annual usage of ethanol is approximately 1 billion gallons, with another 4 million gallons of biodiesel (California Biomass Collaborative 2006), but more than 95 percent is produced out-of-state (California Energy Commission 2007). The Governor's Executive Order S-06-06 sets goals for increasing reliance on in-state production of biofuels, stipulating that California produce at least 20 percent of the biofuels consumed in the state by 2010, 40 percent by 2020, and 75 percent by 2050. With projected demand for gasoline that contains 5.7 percent ethanol by volume (E5.7), this target translates to roughly 900 million gallons of ethanol by 2050. For diesel fuel with five percent content of renewable fuel (B5), this amounts to 375 million gallons of biodiesel by 2050 (California Biomass Collaborative 2006).

It has been estimated that it would require 1.9 million acres of corn or 1.0 million acres of sugar beets plus 3.7 million acres of oil seed crops to meet these targets (California Biomass Collaborative 2006). To put this in context, California's current irrigated cropland occupies 9 million acres. Based on these early estimates, half of the state's irrigated crop land would be needed to meet targets with these biofuel crops. Such a massive conversion of the diverse agricultural economy of the state into vast monocultures would both displace food production and dramatically modify habitat structure and diversity. Several additional crops have recently been identified as candidates for large-scale biofuel production (Kaffka 2009) however; their potential impacts have not been studied.

1.2 Project Objectives

The goal of this project was to provide a state-wide perspective on potential effects of increased cultivation of biofuel crops on California's wildlife species and water use. The specific project objective was to develop an integrated framework for generating plausible scenarios of biofuel crop production, assess the effects of that production on wildlife and water use, and identify trade-offs between energy and environmental factors. We did this through an innovative adaptation of a popular conservation planning tool, Marxan (Ball et al. 2009). The framework is then applied in the state of California, USA, which allowed us to answer the following research questions:

- Which agricultural areas seem most vulnerable to reduction of habitat suitability from expanded biofuel crop production?
- How might habitat suitability for wildlife species of special concern change in response to plausible scenarios of production of biofuel crops?
- What are the implications of the biofuel scenarios on water use?
- How much flexibility exists to produce the same amount of biofuel energy with reduced impact on wildlife species? How much does this change increase transportation costs of hauling biomass to biorefineries?

The first three of these questions represent conventional impact assessment issues. If we optimize land use for biofuel crop production, what are the consequences? The final question gets into the planning and policy realm by exploring options for biofuel crop production that address other environmental concerns. Ideally, the constraints correspond to potential policy options that could be implemented to optimize for multiple social objectives.

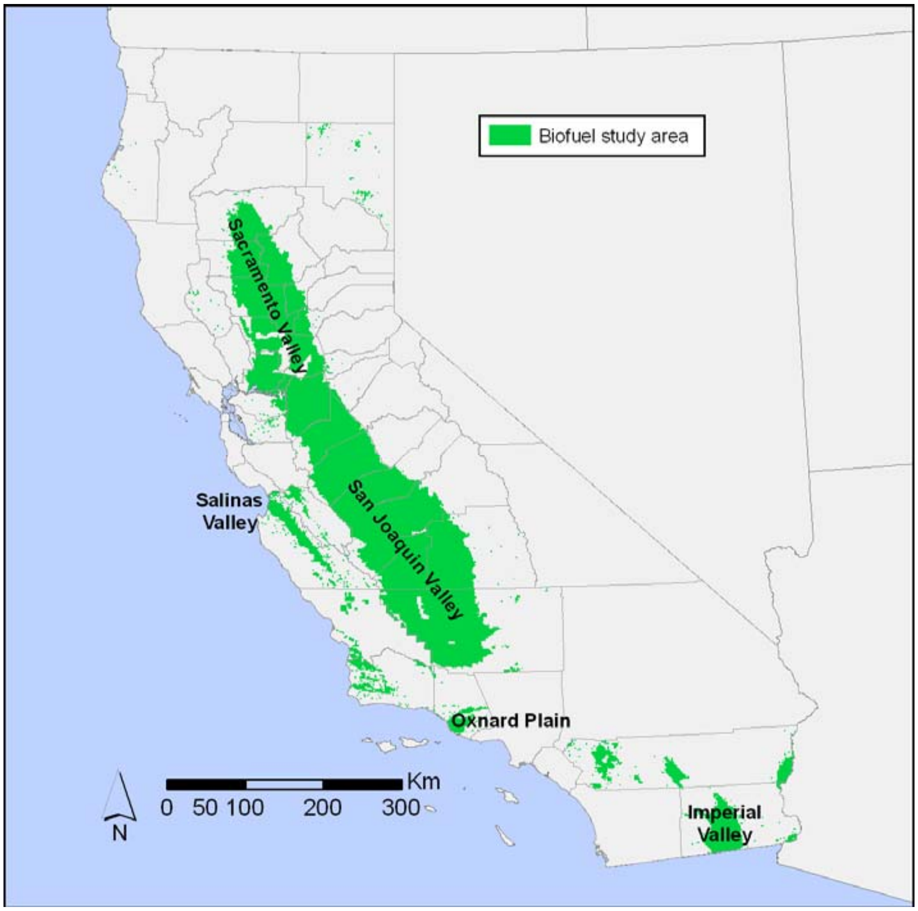
California makes an excellent study area because the state has a large demand for vehicle fuel, a globally-significant agricultural sector; high biodiversity documented with considerable data, and heated competition for water. Most of the arable land is already in production, often with irrigation because of California's Mediterranean climate of dry summers and rainy winters.

Some remnants of native habitats or rangeland persist, although these are often highly disturbed. As a result of the extreme loss of habitats in valleys in California, the state has an exceptional number of threatened and endangered animals.

This analysis was limited to the most important agroecosystem regions in the state. Specifically, the Central Valley (comprised of the San Joaquin and Sacramento Valleys), the Salinas Valley, and the Imperial Valley (Figure 1). We use "agroecosystem" as a general term that includes crop and pasture habitats plus the remnants of natural or semi-natural habitats within and adjoining those habitats.

Five crops are analyzed that have strong potential to become more widespread as biofuel feedstock crops in California—sweet sorghum (*Sorghum bicolor*) and sugar beets (*Beta vulgaris*) for fermentation-based ethanol, bermudagrass (*Cynodon dactylon*) for lignocellulosic ethanol, and oils from canola (*Brassica campestris*) and safflower (*Carthamus tinctorius*) for biodiesel (Williams et al. 2007, Kaffka 2009). This set of crops represents three types of feedstock—sugar, lignocellulosic, and oil—related to different refining technologies and that grow best in different settings. We would expect each to affect wildlife differently. Collaborators Steve Kaffka and Mark Jenner at the California Biomass Collaborative (CBC) developed an agroeconomic optimization model (California Bioenergy Crop Adoption Model) to identify the amount of land that might be converted from current crops to these five potential biofuel crops at specified levels of profit (Kaffka and Jenner 2010). We derive our scenarios from their results. Two potential feedstock crops, switch grass (*Panicum virgatum*) and sugar cane (*Saccharum* species) are often mentioned in national or international discussions of biofuels, but we have chosen not to analyze them in this study. Switch grass is considered a promising biomass feedstock east of the Rocky Mountains for lignocellulosic ethanol (Walsh et al. 2003, Wullschleger et al. 2010). At this point, however, it is not known if it can be grown at commercial scale in California (S. Kaffka, personal communication). Little is known about potential yields or prices or how wildlife species will adapt to it. Evidence also suggests that switch grass has high invasive potential in California (Barney and DiTomaso 2008). In light of the uncertainties about the crop and its wildlife effects, we excluded it from this analysis. We excluded sugar cane for similar reasons, even though it is grown in very small quantities in the Imperial Valley. We also did not analyze woody biomass or municipal solid waste in this study, although they will almost certainly be part of a comprehensive biomass feedstock portfolio.

Figure 1: California Agroecosystems Considered for Biofuel Crop Conversion in This Study



1.3 Organization of the Report

Chapter 2 describes the methods used to develop and implement an integrated framework for evaluating biofuel production scenarios. The framework brings together agroeconomic modeling of principal crops and potential biofuel crops, spatial analysis of available and suitable land, wildlife habitat suitability modeling, optimization modeling to generate spatially-explicit scenarios of crop production, and multicriteria trade-off analysis of social, economic, and environmental concerns such as biofuels costs, biodiversity, and water.

Chapter 3 reports the results of the trade-off analysis of scenarios for five potential biofuel crops.

Chapter 4 discusses the model and data uncertainties and opportunities to implement biofuel policy changes to minimize loss of wildlife habitat suitability.

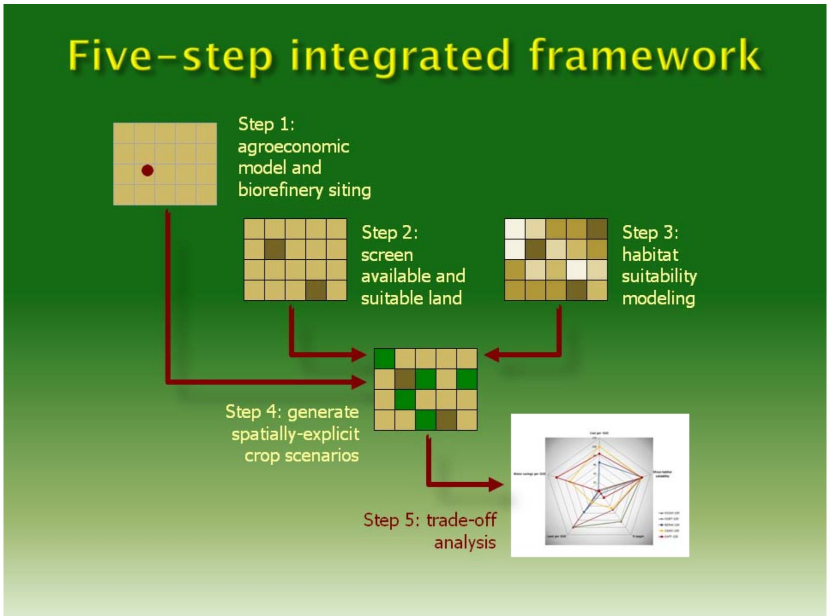
Chapter 5 answers the research questions posed and suggests future research directions. The appendices contain the technical details of the study, including a thorough literature review of wildlife use in Californian agricultural habitats.

CHAPTER 2:
Methods

The purpose of this study is to develop a methodology for predicting the potential effects of a scenario of biofuel crop production on wildlife species in California. We assume these effects are quantifiable from changes in habitat types (and hence on species-specific habitat suitability) at specific locations (such as 1 mi^2 sections of the Public Land Survey System, PLSS). This requires a spatially-explicit allocation of land from current habitat composition to a future state that includes commercial production of the biofuel feedstock in California's agroecosystem lands.

We developed an integrated five-step framework (Figure 2). Step 1: a whole-farm agroeconomic model predicts the level of biofuel crop production and associated water demand at an assumed level of profit within subregions that are relatively homogeneous in terms of climate and agronomic factors. Step 2: agroecosystem lands are screened to determine which land units are available and suitable for biofuel crops. Step 3: habitat suitability modeling estimates the landscape quality for a set of wildlife species for current land use and under biofuel crop production. Step 4: scenario generation produces spatially-explicit scenarios of biofuel crop production that minimizes the total cost to transport biomass to the nearest biorefinery. Alternative scenarios are also generated to minimize loss of habitat suitability. Step 5: trade-off analysis uses a multicriteria decision analysis of scenario effects on cost, wildlife, and water. This section describes the details of each step.

Figure 2: Flowchart of the Five Steps for Trade-Off Analysis of Biofuel Crops.



Details of Step 3 for Habitat Suitability Modeling can be seen in Figure 4.

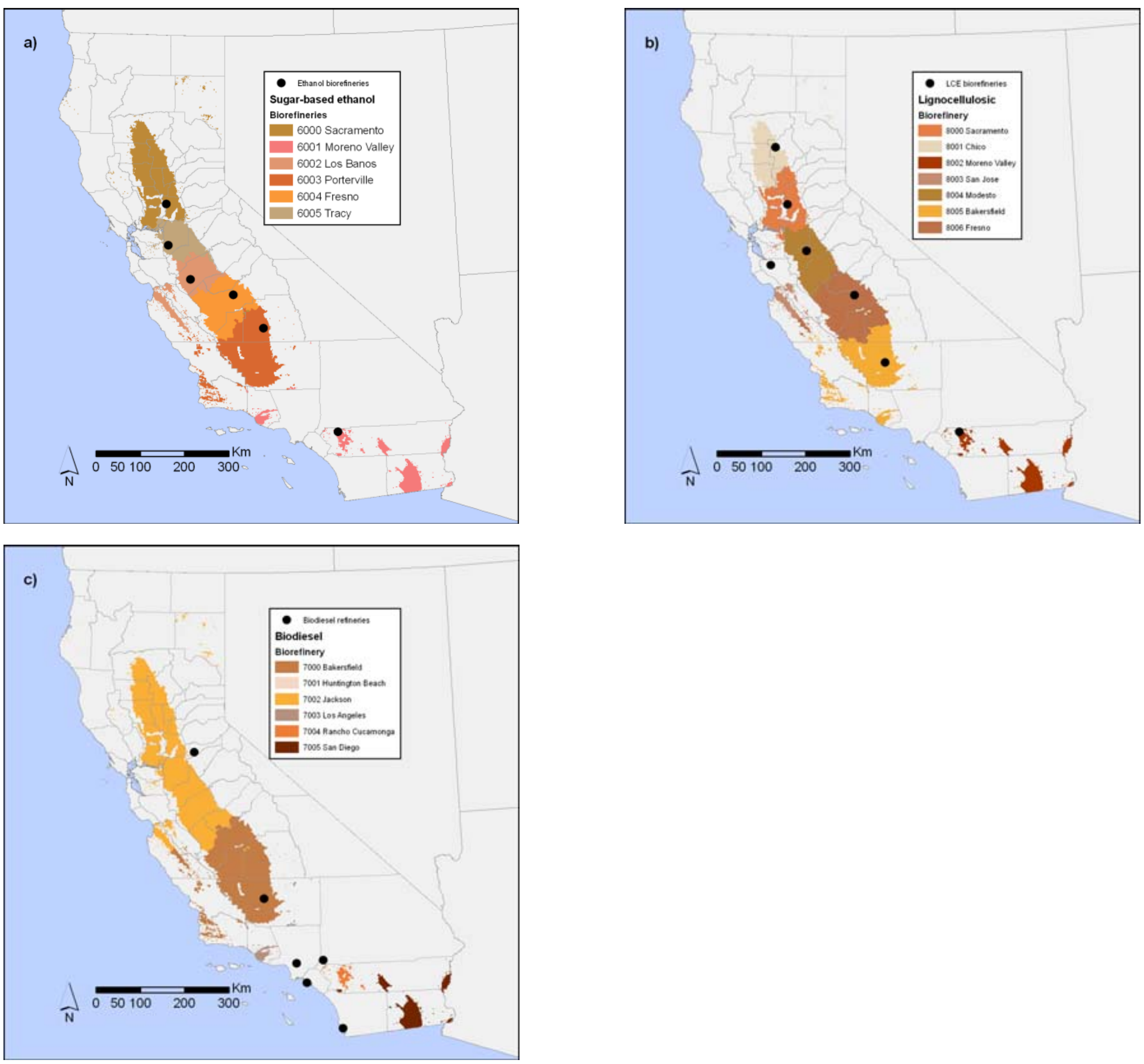
2.1 Biofuel Crop Production and Water Modeling

Five crops have strong potential to become more widespread as biofuel feedstock crops in California—sweet sorghum and sugar beets for fermentation-based ethanol, bermudagrass for lignocellulosic ethanol, and oils from canola and safflower for biodiesel (Williams et al. 2007, Kaffka 2009). Sweet sorghum is an annual grass that is much more water-efficient than corn (Reddy et al. 2007). It has higher sugar content than sugar cane or grain sorghum, whose acreage has been declining in California in recent years, and it is considered a better feedstock than sugar cane (Reddy et al. 2007). Sugar beets used to be widely grown in California in the past. The area planted has been greatly reduced, but yields per acre in the Imperial Valley are the highest in the world (Kaffka 2009). Bermudagrass is a fast-growing plant widely used for pasture in California, but if allowed to grow, it can be used as a biomass source. It is tolerant of salt-affected soils (Kaffka 2009). There is moderate risk that grass will invade disturbed habitats, particularly riparian scrub and desert washes in southern California (Cal-IPC 2006). Canola grows well here and can remediate selenium accumulation in the soils of the San Joaquin Valley (Kaffka 2009). It grows in winter during the rainy season and thus has relatively low irrigation needs. Safflower has long been the most widely grown oil-seed crop grown in California where it is well adapted to the semiarid climate and tolerant of salt-affected soils (Kaffka 2009). Thus this set of crops represents three types of feedstock—sugar, lignocellulosic, and oil—related to different refining technologies and that grow in different settings. Each provides some environmental benefits or can be grown on less productive soils where they would not compete with food crops.

Forecasting the allocation of lands is fraught with many uncertainties. Foremost among these uncertain factors is the infrastructure to produce biofuels from biomass feedstocks, which does not currently exist. Without this infrastructure, there will be no buyers of feedstock and therefore no growers. Conversely, without a reliable supply of feedstock, investors will not develop the biorefineries and distribution networks. Even assuming that the infrastructure will be built, we know little about future prices and yields of feedstock crops and the quantity that would be profitable to grow in competition with food crops. Bermudagrass is grown for pasture, canola and sweet sorghum are basically not grown commercially in California, and sugar beets and safflower are relatively minor crops in the state. None is currently used for biofuels, although there are proposals for bioenergy projects that will use sugar beets and sweet sorghum for feedstock.

Fortunately, two recent studies have modeled optimal feedstock supplies and infrastructure in California. We rely here on their results to generate spatially-explicit allocations of biofuel feedstocks for which to assess wildlife effects. For potential locations of biorefineries for ethanol and biodiesel, we adopt the findings of a recent study that optimized biorefinery location and capacity with respect to potential supply of biomass (Tittmann et al. 2008). The criteria for candidate locations of ethanol biorefineries were limited to cities greater than 10,000 people within 5 km of a railroad or 15 km of a marine terminal, or where a facility already occurred. For biodiesel facilities, the criteria were that a city has an existing petroleum refinery and is within 5 kilometers of a railroad or marine fuel terminal. The outcome of the study was a representative set of general locations around the state, primarily in large cities (Figure 3). Although the Tittmann et al. study did not model dedicated energy crops (except corn because it was already grown commercially in the state), the locations of potential biorefineries appears to be a plausible configuration for crop biomass as well. We selected a subset of locations for each refining technology that occur within the agricultural regions of the state. That is, we omitted locations associated primarily with forest biomass or municipal solid waste unless they also relied upon agricultural biomass feedstock. Tittmann et al. also calculated spatially-explicit transportation costs to move biomass from generalized locations (such as county centroids) through the road and railway network to their least-cost biorefinery site. We then extrapolated the transportation costs from county centroids to individual PLSS sections.

Figure 3: Locations of Hypothetical Biorefineries and Sources of Biomass for a) Sugar-Based Ethanol, b) Lignocellulosic Ethanol, and c) Oil-Based Biodiesel



Source: Derived from Tittmann et al. (2008)

The Tittmann et al. (2008) study used relatively coarse-scale data on biomass supplies and did not assess the five prospective energy crops. Therefore our collaborator, Steve Kaffka and colleagues, at the CBC developed an agroeconomic optimization model (California Bioenergy Crop Adoption Model) for the major crops of each region to identify the amount of land in each subregion that might be converted from current crops to potential biofuel crops (Kaffka and Jenner 2010). The model simulates current farm structure and economic conditions for farms producing annual or short-lived perennial crops on crop land in the state of California, and accounts for significant regional differences among farms. Its primary purpose is to identify the price and yield at which new bioenergy crops enter cropping systems, acreage amounts and locations for crop adoption, and which crop activities are displaced. First, CBC grouped the state's agricultural land into 45 clusters or subregions with relatively similar and consistent mixes of crops from 1998-2007 as documented by the DPR. This clustering process partitioned the primary physical, social, and economic variability of California's agricultural lands and allows more precise estimation of farm-level decision-making. PLSS sections are members of subregions, but the California Bioenergy Crop Adoption Model is at the resolution of the subregions. Note that sections within a subregion are not necessarily geographically contiguous but are nested within regions of the state. Enterprise budgets were developed for the dominant crops in each subregion and for five potential biofuel crops (sweet sorghum, sugar beets, bermudagrass, canola, and safflower analyzed individually). For each combination of crop price and yield, the California Bioenergy Crop Adoption Model projects the amount of land that would be converted for each crop in the subregion and the associated change in water consumption. CBC incorporated the substantial cost of irrigation water in the enterprise budgets. Furthermore, it was assumed that the current agricultural water-use levels were constrained by the existing use from historically grown crops. Therefore projections of biofuel crop production only permitted transfer of water between crops or a reduction in demand relative to current cropping patterns. Kaffka and Jenner (2010) explored a range of output prices, input costs, and crop yields that resulted in $20 and $40 per acre profits. For our analysis, we used the acreage amounts and water-use associated with a $40 per acre profit, which leads to the largest potential adoption of biofuel crop production that CBC investigated. The profit metrics are merely reference points. The actual profit would be determined by the prices offered by a biorefinery company. CBC modeled the entry of biofuel crops individually, rather than allowing them to compete with each other as well as with the current crops. Therefore our spatially-explicit scenarios are limited to a single biofuel crop.

It is more practical to compare effects on wildlife from alternative feedstocks and conversion technologies on a standard energy basis, rather than by acres converted or tons harvested. The biomass of each crop has a different energy density, and the corresponding conversion process has a different efficiency. Therefore, using standard conversion factors from the literature, we translated the land area and regional yield rates into potential farm-level yields of an energy-based unit of gallons of gasoline equivalent (GGE) (Table 1).

Multiplying the assumed crop yields by the acres of biofuel crops predicted by the California Bioenergy Crop Adoption Model determines biomass yield for each subregion. Converting biomass yield to biofuel yield in GGE with the conversion factors in Table 1 produces the statewide results in Table 2, whereas the breakdown for each crop-subregion combination can be found in Appendix A. The ranges of yield and water demand in Table 2 refer to the minimum and maximum values for individual subregions.

Table 1: Conversion Coefficients From Short Tons of Crop to GGE

Crop	Biofuel yield (gallons biofuel [EtOH or biodiesel]/ dry short ton feedstock yield)	Gasoline equivalent (gal-gasoline/ gal-biofuel [EtOH or biodiesel])	Conversion efficiency (GGE / dry short ton feedstock yield)
Sweet sorghum	25.9 [a]	0.67 [e]	17.3
Sugar beets	24.8 [b]	0.67 [e]	16.6
Bermudagrass	51.7 [c]	0.67 [e]	34.6
Canola	103.3 [d]	1.03 [e]	106.4
Safflower	64.5 [d]	1.03 [e]	66.4

[a] Reddy et al. 2007; [b] Williams et al. 2007; Shapouri et al. 2006; [c] Anderson et al. 2008; [d] Tyson et al. 2004; [e] Tittmann et al. 2008.

Table 2: Assumed Crop Yield, Predicted Area of Biofuel Crop Statewide, Calculated Biofuel Yield, Predicted Change in Water Demand, and Percentage of the Target Level of Biofuel Production

Crop	Range of yield (short tons per acre)	Predicted area converted (thousand acres)	Biofuel production (million GGE)	Range of change in water demand (thousand acre feet)	Percent of biofuel target
Sweet sorghum	30 - 32	847.0	453.9	-7.9 to 0	76% [a]
Sugar beets	30 - 42	538.5	281.9	0	47% [a]
Bermudagrass	3.2 - 6.4	244.6	38.2	-12.0 to 0	7% [a]
Canola	1.0 - 1.2	1,268.3	134.9	-167.2 to 0	47% [b]
Safflower	1.1 - 1.2	610.0	48.6	-157.2 to 0	18% [b]

Based On The California Bioenergy Crop Adoption Model.
[a] Williams et al. 2007; ethanol demand for E5.7 blend = 4.4 Gly^{-1}, with a target of 75% by 2050 under Executive Order S-06-06. Thus the target = 3.3 Gly^{-1}, which equals 584 MGGE.
[b] Williams et al. 2007; biodiesel demand for B5 blend = 1.41 Gly^{-1}, with a target of 75% by 2050 under Executive Order S-06-06. Thus the target = 1.1 Gly^{-1}, which is approximately 288 MGGE.

2.2 GIS Modeling of Available and Suitable Land for Biofuel Crops

We assumed that some factors would preclude the production of biofuel feedstocks, such as public or privately-protected lands, water bodies and wetlands, and existing urban development (Haughton et al. 2009). We also assumed that some agricultural types would not be converted to biofuels because of the large capital investment for the current use—orchards and vineyards. Lands that pass this filter we label as "available lands," which are common to all feedstock types. We also assumed that some lands were physically (and hence economically) unsuitable to produce biofuel crops. These unsuitable lands were characterized by habitat types associated with higher elevations, steeper slopes, wetlands, or extremely arid landscapes. Consequently only the agroecosystem habitat types in Table 3 were considered suitable for biofuel crops. The four semi-natural or natural habitat types, AGS, PGS, ASC, and VOW, primarily exist only as small remnants in the agroecosystem landscape. Consequently they tend to be essential habitat for many of the Species of Special Concern including listed threatened and endangered species. Some of this habitat is being formally protected through Multispecies Habitat Conservation Plans. To test the influence of our assumption that these habitats could be converted to biofuel crop production, we generated alternative scenarios for sweet sorghum that limited biofuel crops to the six agricultural habitat types.

Table 3: Habitat Types Assumed Suitable for Biofuel Crop Production

Habitat name	Habitat code
Dry Grain Crops	DGR
Irrigated Grain Crops	IGR
Irrigated Row and Field Crops	IRF
Irrigated Hayfield	IRH
Pasture	PAS
Rice	RIC
Annual Grassland	AGS
Alkali Desert Scrub	ASC
Perennial Grassland	PGS
Valley Oak Woodland	VOW

Our analysis required disaggregating the subregion-wide area of biofuel crop production to the individual PLSS sections so that habitat effects could be quantified. This allocation process will be described in the section on generating biofuel crop scenarios below.

2.3 Wildlife Habitat Suitability Modeling

To the extent that wildlife species prefer some habitat types more than others, conversion from existing agroecosystem habitats to those associated with biofuel crops will affect the overall suitability of the landscape, negatively for some species and positively for others. The framework requires modeling the potential effects of biofuel crop production on a relatively large number of wildlife species. The modeling needs to be sensitive to changes in habitat structure and function of various crop types. The California Wildlife Habitat Relationships (CWHR) database is a state-of-the-art information system about California's wildlife (http://www.dfg.ca.gov/biogeodata/cwhr/). CWHR, developed and maintained by the

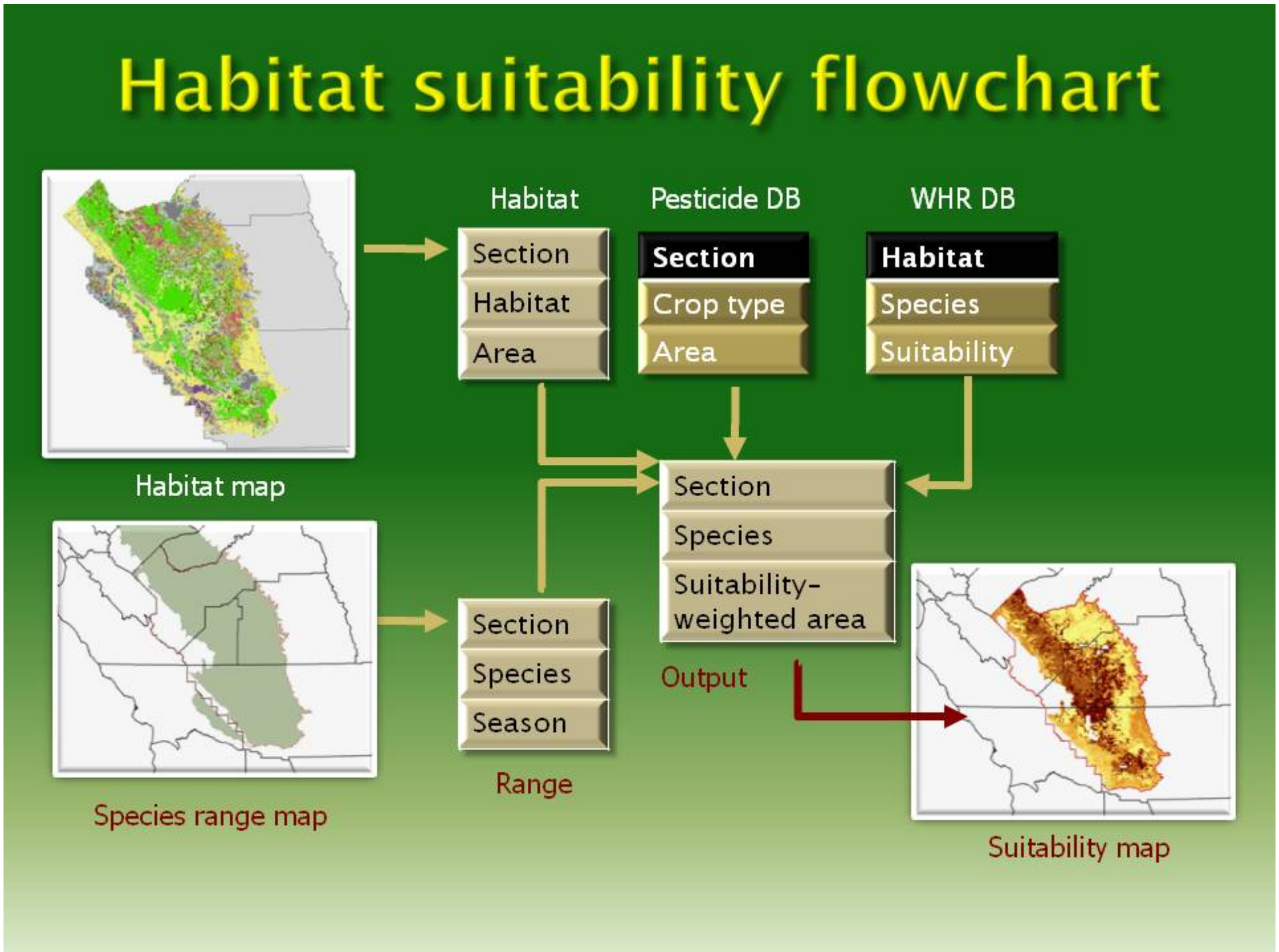
California Department of Fish and Game, contains life history, geographic range, habitat relationships, and management information on 695 species of amphibians, reptiles, birds, and mammals known to occur in the state. The core feature of CWHR is a set of habitat suitability ratings summarized in a species-by-habitat matrix. This matrix, compiled and revised by an interagency team of wildlife biologists, documents all available information on habitat affinities of terrestrial vertebrates to habitat types (Airola 1988). CWHR uses expert opinion to rate each habitat type as high, medium, low, or unsuitable for reproduction, cover, and feeding life history needs. CWHR classifies vegetation cover into 59 habitat types, including eight agricultural types (Mayer and Laudenslayer 1988 and updates at http://www.dfg.ca.gov/biogeodata/cwhr/wildlife_habitats.asp). The agricultural habitat types are general and were not rated specifically with biofuel crops in mind. For example, sugar beets are included in the Irrigated Row and Field Crop type, along with cotton, strawberries, tomatoes, and lettuce.

Modeling the suitability for each wildlife species involved the integration of a map of habitat types, a matrix of the suitability of each habitat type for each species, and maps of the species' geographic range (Figure 4). The CWHR system makes several assumptions (Airola 1988), and we adopt those assumptions for this study.

- Wildlife is a product of habitat. The ratings only evaluate the ***potential*** value of a habitat for a species.
- Habitat can be classified generically for all wildlife species based on vegetative cover.
- The suitability of habitat can be assigned a relative value. In preparing the species-habitat suitability matrix, biologists often had to extrapolate from habitats in other states or from similar species.
- The suitability of a habitat is uniform for a species throughout its range.
- If species require two or more habitats to be juxtaposed (such as, for breeding and feeding), the habitats were rated assuming the other habitats were available in the proper mix.
- All special habitat elements (such as, open water, prey, dead snags) that a species requires are assumed to be present when the suitability ratings were assigned.
- The size of the habitat patch was assumed to be adequate. The minimum resolution assumed by CWHR is 40 acres.

Agroecosystems occupy about one-sixth of the land area of California. For all spatial analyses in this study, we delineated the agroecosystems where biofuel crops were most likely a possibility by selecting one square-mile sections based on the Public Land Survey System (PLSS) where crops were reported to the California Department of Pesticide Regulation (DPR) in 2005. We added sections with other habitats that were interspersed or adjacent to those in the crops database to encompass a spatially continuous study area. This process yielded 25,715 sections (~16 percent of total state land area), which became the units of analysis.

Figure 4: Flowchart of Habitat Suitability Modeling Based on PLSS Sections



The core component of the California Wildlife Habitat Relationships (CWHR) system is a database compiled and revised by an interagency team of wildlife biologists to document all available information on habitat affinities of terrestrial vertebrates (Airola 1988). CWHR ranks each of the 59 habitat types as high, medium, low, or unsuitable for reproduction, cover, and feeding (see Table 4 for definitions of levels). Habitat types are further divided into size classes (such as height of canopy) and cover classes (such as percent canopy closure). The suitability ratings are assigned to each combination of type/size/cover or "stages". Our habitat map did not distinguish size and cover, only types, so we aggregated habitat suitability ratings for a habitat type as the highest rating of any stage of that type. The aggregated values for a sample of agroecosystem species and habitat types are shown in Table 5. We also interviewed experts and did a literature search to compile current knowledge of the habitat preferences of a subset of wildlife species, in particular for habitats associated with potential biofuel crops.

Table 4: Definition and Value of Habitat Suitability Levels

Habitat Suitability Level	Definition	Suitability index value
High	habitat is optimal for species occurrence; habitat can support relatively high population densities at high frequencies	1.00
Medium	habitat is suitable for species occurrence; habitat can support relatively moderate population densities at moderate frequencies	0.67
Low	habitat is marginal for species occurrence; habitat can support relatively low population densities at low frequencies	0.33
Unsuitable	habitat stage is unsuitable for species occurrence, and the species is not expected to reliably occur in the habitat	0.00

Source: California Department Of Fish And Game- California Interagency Wildlife Task Group 2008

Table 5: Sample of Habitat Suitability Matrix Based onCWHR for Some Species and Habitat Types

Species code	Common name	DGR	IGR	IRF	IRH	PAS	RIC	AGS	ASC	PGS	VOW
A001	California tiger salamander	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.33	0.67
A028	Western spadefoot	0.33	0.00	0.33	0.00	0.00	0.33	1.00	0.56	0.67	0.67
B121	Swainson’s Hawk	0.00	0.00	0.00	0.33	0.78	0.33	0.78	0.00	0.45	0.89
B150	Sandhill Crane	0.67	0.67	0.56	1.00	0.00	0.45	0.45	0.00	0.00	0.00
B173	Long-billed Curlew	0.67	0.00	0.00	1.00	0.00	0.33	0.67	0.00	0.67	0.00
B269	Burrowing Owl	0.00	0.00	0.00	1.00	1.00	0.45	1.00	1.00	1.00	1.00
M019	California leaf-nosed bat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00
M106	Giant kangaroo rat	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.67	0.00	0.00
M148	Kit fox	0.00	0.00	0.00	0.56	0.67	0.00	1.00	1.00	1.00	0.67
R019	Blunt-nosed leopard lizard	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	0.00	0.33

Habitat type names: DGR = Dry Grain Crops, IGR = Irrigated Grain Crops, IRF = Irrigated Row and Field Crops, IRH = Irrigated Hayfield, PAS = pasture, RIC = Rice Fields, AGS = Annual Grassland, ASC = Alkali Desert Scrub, PGS = Perennial Grassland, and VOW = Valley Oak Woodland. Values shown are the arithmetic mean of the suitability values for reproduction, cover, and feeding.

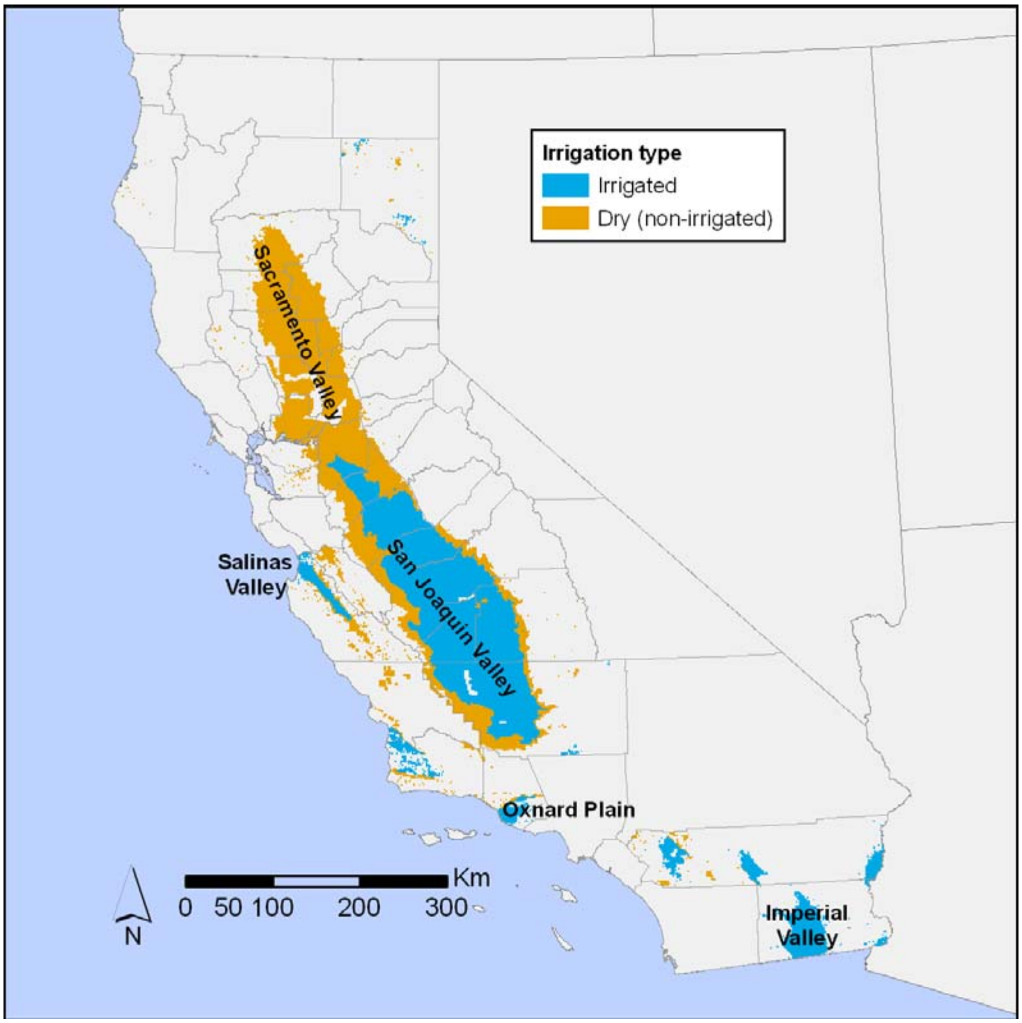
The CWHR system classifies vegetation cover into 59 habitat types, including eight agricultural types (Mayer and Laudenslayer 1988 and updates at http://www.dfg.ca.gov/biogeodata/cwhr/wildlife_habitats.asp). No single map of California portrays the distribution of all 59 types, particularly with the eight agricultural habitats needed for this analysis. Existing habitat types in each section were therefore derived from two sources—the recently updated land cover map from the Gap Analysis Program (GAP, Lennartz et al. 2009, http://www.gap.uidaho.edu/Portal/California/CAReGAP.html) and the DPR database of crop patterns.

The revised GAP land cover map of California was developed from 30 meter Landsat 7 ETM+ imagery circa 2000. The land cover schema employed NatureServe's Terrestrial Ecological Systems Classification framework for the conterminous United States (Comer et al. 2003). Ecological systems are defined as "groups of plant community types that tend to co-occur within landscapes with similar ecological processes, substrates and/or environmental gradients" (Comer et al. 2003). Developed and agricultural uses were taken from the National Land Cover Dataset (NLCD, Homer et al. 2004). NLCD simply divides agriculture into two classes, Hay/Pasture and Cultivated Crops. To make the GAP map compatible with the CWHR habitat classification, we cross-walked the ecological systems to habitat types based on the descriptions (and in some cases on the geographic areas where the class occurs).

Most conversion to biofuel crops is expected within existing agricultural habitats, so it is imperative to know their baseline distribution. Therefore we adapted the data from the DPR database as the most credible information at sufficient spatial resolution to subdivide the two agricultural types in the GAP land cover map. Since 1990, all of California's agricultural pesticide use must be reported monthly to county agricultural commissioners, who in turn report the data to the DPR (http://www.cdpr.ca.gov/docs/pur/purmain.htm). Reports are made at the parcel level, and also record the section from the Public Land Survey System of the field and the crop to which the pesticide is applied. Sections are generally one mile square, with some variation. The GIS group at the UC Kearney Agricultural Station processed the data from DPR for the period from 1999 - 2007. Crops were reclassified into habitat types based on the descriptions of habitats (Mayer and Laudenslayer 1988 and updates at http://www.dfg.ca.gov/biogeodata/cwhr/wildlife_habitats.asp#Agricultural) and a crosswalk between Department of Water Resources land use types and WHR habitat types (http://www.dfg.ca.gov/biogeodata/cwhr/pdfs/XDWRLandUse.pdf). The mapped area of Cultivated Crops and Hay/Pasture were allocated proportionally by the area of individual agricultural habitats.

The CWHR system subdivides grain and seed crop habitat depending on whether it is irrigated or dry-farmed. However, the database of crops by sections did not discriminate irrigated from non-irrigated grain crops. Given that there is a large difference in habitat suitability between dry and irrigated grain crop habitats, it was important to categorize grains by irrigation type. Based on expert knowledge of our collaborator, Steve Kaffka at UC Davis, and California Department of Water Resources land cover layers, we created a GIS layer of ECOMAP subsections labeled by dry versus irrigated practices for grain and seed crops (Figure 5). We assume that grain crops are irrigated in the San Joaquin Valley, the deserts, and selected valleys on the coast and in northern California; otherwise they are presumed non-irrigated. Grain and seed crops (barley, wheat, rye, oil seed crops, oats, rape (canola), safflower, sorghum, milo, soybeans, sudangrass, and sunflower) were allocated to the dry or irrigated habitat type based on their geographic location. Corn was assumed to always be grown with irrigation. We presume row and field crops are irrigated, even in the Sacramento Valley.

Figure 5: Map Of PLSS Sections Where Either Dry (Non-Irrigated) or Irrigated Farming Was Assumed to Be the Dominant Practice for Grains (Except Corn) and Oilseed Crops



In addition to finding suitable habitat, species are also constrained in their distribution by a variety of other factors. These factors collectively are represented spatially as a range map that depicts the biogeographic boundaries of the "normal" occupancy by the species. The CWHR system has developed range maps for all species in their database (available at http://www.dfg.ca.gov/biogeodata/cwhr/cwhr_downloads.asp#CWHR_GIS_Data). Range maps represent the maximum, current geographic extent of each species within California at a scale of

1:1,000,000 (http://www.dfg.ca.gov/biogeodata/cwhr/downloads/GIS/cwhr_gis.xml). Range maps were used as a filter on the habitat map such that a habitat patch is considered suitable if it is within the geographic range of the species and the CWHR habitat suitability matrix rates the habitat type as suitable.

2.4 Selection of Wildlife Species for Analysis

As mentioned above, CWHR documents 695 wildlife species. Many of these species inhabit landscapes outside of any area that could be plausibly allocated to growing biofuel crops. Such species will not be affected by any of our biofuel scenarios and are not modeled in this study. For this study, we selected four subsets of species for different parts of the analysis. The largest group included all agroecosystem species. We screened the full set of species in the CWHR 8.2 database to determine which might be vulnerable to a change in habitat area and suitability if biofuel crops were produced. The first screening level was based on the range maps: a species was added to the list of agroecosystem species if its range overlapped with the primary agricultural regions of the state (such as, Sacramento Valley, San Joaquin Valley, Imperial Valley, and South and Central coasts such as Salinas Valley, Oxnard Plain, and San Diego, Figure 1). A species was included if the CWHR habitat suitability matrix determined that the agricultural habitats or other habitats associated with agroecosystems (such as annual grassland, alkali desert scrub, and Valley oak woodland) were suitable. The screening process identified 216 out of California's 695 species in CWHR (Appendix B).

California identifies Species of Special Concern that are either federally listed as threatened or endangered, meet the State definition for listing but have not yet been listed, have experienced rapid population declines or range restrictions, or have naturally small populations that are highly susceptible to risk factors (Comrack et al. 2008). Fifty-three agroecosystem species are on state lists of Species of Special Concern and may be vulnerable to a change in habitat area and suitability if biofuel crops were produced in California's agroecosystems (Appendix B). The Species of Special Concern are important for management because they are already vulnerable from past impacts such as habitat loss, overhunting, and other stressors. Harvested species, on the other hand, are important because of their contribution to recreation and lifestyle. Changes in habitat prompted by conversion to biofuel crops could enhance or degrade habitat quality for 34 harvested species found in agroecosystems (Parisi et al. 2008, listed here in Appendix B). Two-thirds of the harvested species are waterfowl (ducks and geese), six are upland game bird species, and seven are mammals including both carnivores and ungulates.

CWHR was developed using generalized habitat types that are not crop-specific (except for Rice). We wanted to determine if sufficient field-based information was available to refine the habitat suitability ratings for specific biofuel crop types. As it was not practical to review literature for all 216 agroecosystem species and multiple habitat types, we identified a list of "focal" species to learn in detail about how they use different crop types and how they respond to management practices that are relevant to biofuel production (Appendix B). With help from wildlife experts working in agroecosystems and in specific taxonomic groups, we chose these species to represent a range of characteristics and concerns:

- Distribution (local, endemic, statewide, continent-wide; and locally common vs. rare (and potentially of concern) throughout range)
- Management: species of conservation concern, hunting interest
- Taxonomic groups
- Functional groups (example given wading birds, fossorial animals, granivores, insectivores, ground-nesters)
- Species that do not use crops but occur in grassland habitats that could be converted to biofuel production (California tiger salamander, Grasshopper Sparrow).

2.5 Assessment of Habitat Suitability

If all agroecosystem habitats had identical suitability ratings in CWHR, the amount, location, or choice of biofuel crop would generate the same results. To quantify the relative importance of agroecosystem habitat types for wildlife, we tallied the number of the 216 agroecosystem species with high, medium, low, or unsuitable ratings in each habitat type. We also calculated the dissimilarity between each pair of the ten habitat types to identify where large wildlife effects might be expected. This analysis was performed in the free statistical software R using the vegdist function in the vegan package with the Horn-Morisita dissimilarity index. The suitability scores were used as proxies for abundance of each of the 53 Species of Special Concern in the ten agroecosystem habitat types.

We calculated a suitability score for each PLSS section as an area-weighted suitability rating of the constituent habitat types for reproduction, cover, and feeding separately and then averaged these three for an overall suitability score per agroecosystem species. These averages were also determined for three subsets of the agroecosystem species: focal species, Species of Special Concern, and harvested species (Appendix B). Finally, the total number of species with suitable habitat (score greater than zero) was calculated for each section to map geographic patterns of species density (species per square mile) within California's agricultural landscapes.

The five biofuel feedstock crops belong to four distinct habitat types (Table 6:). The grain and oilseed crops can be grown with or without irrigation depending on the region of the state as described in Chapter 2.

Rather than conducting a trade-off analysis of the full set of 216 agroecosystem species, we restricted the analysis to the 53 agroecosystem species classified by the state as Species of Special Concern (Comrack et al. 2008). These species might be especially vulnerable to a change in habitat area and suitability if biofuel crops were produced in California's agroecosystems (Appendix B). If the section was available for biofuel crop conversion and its habitat types were suitable for conversion (Table 3), a similar score of suitability-weighted species density was calculated using the habitat suitability of each biofuel crop type. The net effect of converting to biofuel crop habitats reflects differences in species assemblages and suitability ratings between current crops and biofuel crops.

Table 6: Habitat Types Associated With Biofuel Feedstock Crops

Crop	Habitat name	Habitat code
Sweet sorghum	Dry/Irrigated Grain Crops[b]	DGR/IGR
Sugar beets	Irrigated Row and Field Crops	IRF
Bermudagrass	Irrigated Hayfield[a]	IRH
Canola	Dry/Irrigated Grain Crops[b]	DGR/IGR
Safflower	Dry/Irrigated Grain Crops[b]	DGR/IGR

[a] Bermudagrass is classified as Pasture in CWHR when it is grazed, but we assumed that for biofuel it would be grown tall and harvested, more like an alfalfa habitat type. Hence, IRH.
[b] Canola is grown in the winter rainy season. Safflower and sweet sorghum can be farmed without irrigation in northern parts of the state (Figure 5). The same rules applied in assigning it to Dry or Irrigated Grain Crops as were used in assigning other small grains based on expert knowledge.

2.6 Generating Spatially Explicit Biofuel Crop Production Scenarios

Scenario modeling for this study must allocate land units based on resource production, inputs to production, and biodiversity effects. An appropriate model is not readily available. Models for biodiversity come from the area of systematic conservation planning. These models identify a nominal network of potential conservation areas that efficiently meet representation targets for the biodiversity features of interest (Margules and Pressey 2000). In our study, biodiversity should be assessed in terms of persistence across the whole landscape and not simply on protected areas (Polasky et al. 2008, Ferrier and Drielsma 2010). Crop production modeling integrates agronomic production factors with socioeconomic processes to identify the sites where a crop is highly likely to be grown at a given market price (Bryan et al. 2008 and 2010, Scheffran and BenDor 2009, Hellmann and Verburg 2011). The effects on other social objectives such as biodiversity are generally not considered.

The California Bioenergy Crop Adoption Model predicted land conversions to biofuel crops at a subregional scale. Modeling wildlife impacts required a higher spatial resolution of habitat change at the scale of the 25,715 individual PLSS sections. Neither the conservation planning nor agricultural modeling approaches by themselves provide the integrated framework needed to consistently assess trade-offs (Robertson et al. 2008). Polasky et al. (2008) presented a modeling approach that integrated biodiversity and economic models to maximize net present value of market goods and services from several land uses. Wilson et al. (2010) examined the protection of species within production landscapes by applying a related conservation tool, Marxan with Zones. They classified the study area into eight combinations of land use, conservation status, and forest cover. Each zone's contribution to conservation for forest-dependent species was assigned. Although this study took a whole landscape perspective, the objective was still solely on biodiversity conservation. There were no targets for timber production, for instance. Kiesecker et al. (2009) used Marxan to select sites that could offset impacts on biodiversity from energy development. In this case, the energy project was already designed, and the objective was to select sites outside the project boundary with at least the habitat area the project would directly impact. Thus the objective was a net neutral or positive outcome, at least in terms of area of protection being equal or greater than the area lost. However, that study did not consider alternative sites for the energy development project that would minimize the need for offset sites. This reactive approach is appropriate where the resource is limited to a specific location, the permitting process is far along, and the loss of habitats is known in advance. In the case of biofuels, with many individual decision makers and flexibility in where the resource (and which one) could be produced, we needed a more proactive framework as described here. Developing a customized model was beyond the scope of this project. Therefore we adapted a conservation planning tool (Marxan) to generate alternative spatially-explicit scenarios of land use and crop cultivation based on data on biofuel yield, transportation costs, and water use.

Marxan is a commonly used software tool in conservation planning. It uses a simulated annealing with iterative improvement algorithm to select a set of planning units for a conservation area network (Ball et al. 2009). In Marxan terminology, the things to be protected (such as species) are called features and the total amount (such as area, number of occurrences) of each feature to be protected is a target. A set of selected planning units or sites is called a solution. For the tool to find a solution, it needs to know the amount of each feature that occurs in planning units as well as the cost to protect the site. Planners can also pre-assign the status of planning units, where some units are either "locked in" or "locked out" of solutions. Because simulated annealing is a stochastic heuristic approach, Marxan typically generates many potential solutions and can either identify the best solution from all runs or can sum the number of solutions in which a planning unit was selected.

Our objective, however, was not to design a conservation area network, but to account for the effects on persistence of wildlife in the whole landscape (Ferrier and Drielsma 2010) of growing a specified amount of biofuel feedstock and conversely to determine the increase in cost of meeting the feedstock targets with minimal loss of wildlife habitat value. This required several adaptations of the conventional data inputs for Marxan. The first adaptation was to include biofuel yield and water as "features" along with wildlife species. This allowed the tracking of production and consumption levels, respectively, and setting biofuel production targets as model constraints. Moreover, we subdivided potential feedstock supplies into geographically-distinct "cropsheds" that could supply feedstock to the potential biorefinery with the least transportation cost (Figure 3). Targets were set for biofuel yields for each crop subregion. In other words, biofuel yield from each subregion was tracked as a separate feature. Modest targets for each biorefinery were also applied.

In conventional conservation planning, each planning unit can contribute the amount of each feature it contains towards the conservation targets. If not selected for the network, the planning unit is assigned no conservation value. For this biofuel adaptation, we needed to account for the amount of species habitat suitability in for planning units (such as PLSS sections) both if they were selected for biofuel crop production not. This required two adaptations. Rather than storing the current amount of features in the input tables, we stored the net change between the current amount and the amount that would result if the planning unit were converted to biofuel crops. Summing these amounts of all selected planning units would give the total change in amount (level of persistence) for each feature, which could be positive for some species depending on the current habitat type and which crop was planted for biofuel. However, to account for the total amount of features resulting from a biofuel scenario, we created a dummy planning unit with the current amount of each species (but with zero biofuel and water amounts), and locked the status of this unit into all solutions. Marxan would then sum the current total amount with the total net changes in selected planning units to determine the future amount of habitat suitability for each species.

Habitat suitability analysis requires high spatial resolution. The limit on resolution for this analysis was the crop data from DPR, based on the 1 mi^2 PLSS sections. Therefore the 25,715 sections of California's agroecosystems became the planning units, and all other data were aggregated to this level. Input tables were compiled for Marxan analysis from the biofuel, water, costs, and wildlife modeling. For determining the wildlife amounts by planning unit, a new database of habitat types was created for each feedstock type assuming all available, suitable, and economically viable areas were converted to biofuel crops. The wildlife modeling process was then repeated for these new habitat configurations. The habitat suitability value for biofuel crop production was subtracted from the current suitability value for each species. The net changes for each Species of Special Concern were then used as the "amounts" in Marxan. Potential biofuel yield was calculated as the product of the available and suitable area of crop conversion and the crop yield per acre used in the California Bioenergy Crop Adoption Model for the subregion containing the section. Similarly, potential change in water demand in a section was prorated from the California Bioenergy Crop Adoption Model outputs. The cost of selecting a planning unit for biofuel crop production was the transportation cost associated with hauling the biomass yield over the least-cost distance to a potential biorefinery. Because the biofuel crop yields are different and the biorefineries to process the biomass vary by the type of crop, the transportation costs of a section can be quite different between crop types.

We generated basic crop allocation scenarios based on the three alternative biofuel conversion technologies. Each basic scenario minimizes transportation costs subject to meeting the biofuel production levels in crop subregions derived from the California Bioenergy Crop Adoption Model results at the $40 per acre profit benchmark (listed in Appendix A). Initial results indicated that sweet sorghum was slightly more cost-effective than sugar beets in every PLSS section and that canola was usually more cost-effective than safflower because of their slightly higher yields and superior conversion efficiencies. Therefore rather than analyzing scenarios with mixtures of crops, we elected to generate scenarios for each crop individually. Variations to the basic scenarios address wildlife conservation and sensitivity analysis of the weights (Table 7).

Table 7: Biofuel Crop Scenarios

	Technology 1: Sugar crops to ethanol	Technology 2: Lignocellulosic biomass crops to ethanol	Technology 3: Oil crops to biodiesel
Crops	Sweet sorghum (ssgm) Sugar beets (ssgm)	Bermudagrass (berm)	Canola (cano) Safflower (saff)
Potential biorefinery	Dry mill ethanol	LCE ethanol	FAME/FAME2/FT diesel

	Technology 1: Sugar crops to ethanol	Technology 2: Lignocellulosic biomass crops to ethanol	Technology 3: Oil crops to biodiesel
sites (Tittmann et al. 2008)—see Figure 3			
Scenarios			
Minimize transportation cost ("Minimize Cost")	ssgm1_0, sgbt1_0	berm1_0	cano1_0, saff1_0
Minimize habitat suitability loss ("Minimize Loss")	ssgm1_100, sgbt1_100	berm1_100	cano1_100, saff1_100
Sensitivity analysis of weights on "Minimize Loss"	ssgm1_25, ssgm1_50, ssgm1_1000,		
Limit biofuel crops to existing crop and pasture land for Minimize Cost and Minimize Loss	ssgm2_0, ssgm2_100		

Note: The abbreviated names of scenarios are used throughout the report.

To discourage loss of habitat suitability associated with biofuel production, variations to the basic scenarios were analyzed in which a weighted-"cost" of suitability loss was added to the transportation cost. It was expected that these scenarios would find solutions with greater overall transportation costs but less negative impact on wildlife. We tested sensitivity to the arbitrary penalty weight by varying it from small to very large values to inform the trade-off analysis. The final variation recognized the conservation value of remnants of natural/semi-natural habitats (annual and perennial grasslands, alkali desert scrub, and Valley oak woodland) in California's agroecosystems. In many areas within the state, the habitats are being protected through habitat conservation planning for listed species. For the sweet sorghum feedstock, we therefore ran the minimum cost and minimum habitat loss scenarios where these four habitat types were considered unsuitable for conversion to crops.

2.7 Trade-Off Analysis

The scenarios generate information about biofuel production, costs, and impacts. That information needs to be manipulated and evaluated to compare the five biofuel crops and the trade-offs among criteria. Because the crops have different fuel characteristics, including total energy production, it is necessary to standardize some of the criteria. For instance, we evaluated the marginal cost and wildlife impact on a per-GGE basis for scenarios and of individual biorefineries. In addition to the effects of the total biofuel production achieved by each scenario, we derived an "efficiency frontier" (Polasky et al. 2008) of the cumulative production and effects of the individual biorefineries. This assessment identifies which biorefineries are associated either with large per-GGE costs or large impacts on wildlife habitat suitability.

Five criteria were standardized for the trade-off analysis: mean transportation cost per GGE, percent of the statewide ethanol or biodiesel targets (Williams et al. 2007), mean habitat suitability for the Species of Special Concern, water savings per GGE, and land requirements per GGE. Impacts were also assessed for individual Species of Special Concern and the four natural/semi-natural habitat types.

To this point, the scenarios examined were all based on the same set of assumptions. The basic scenarios were based strictly on minimizing transportation costs, with no influence by possible habitat loss. The Minimize Loss scenarios all added a weighted loss value to artificially increase the "cost" used in Marxan. In all cases the weight was arbitrarily set at 100. The implicit weight on loss for the Minimize Cost scenarios was zero. Using just two values generates trade-off curves with just two points, but does not give us the shape of the efficiency frontier. A sensitivity analysis of the weights could answer two questions: how much more improvement in habitat suitability is possible with higher weight (at what cost)? And could a similar reduction in habitat suitability loss be achieved at less cost? Therefore new scenarios were generated in Marxan with weights set at 25, 50, and 1000. As the purpose of this sensitivity analysis was to demonstrate the capabilities of the framework, new scenarios were only generated for sweet sorghum.

The scenario options that attempted to Minimize Loss of habitat suitability added a penalty cost proportional to the net loss was a method of convenience. There is no specific policy mechanism such as economic incentives or regulation to achieve those specific results. However, land use planning under state and federal endangered species laws may provide an alternative basis for generating scenarios. Many local authorities are developing Natural Community Conservation Plans (state) and/or Habitat Conservation Plans (federal) to ensure adequate conservation of listed species and Species of Special Concern that depend on remnants of natural or semi-natural habitats. Such plans often could conserve remnant habitat patches. We generated Minimize Cost and Minimize Loss scenarios for sweet sorghum that declared these habitat types to be unavailable for biofuel production. Only existing agricultural land could be converted to biofuel crops.

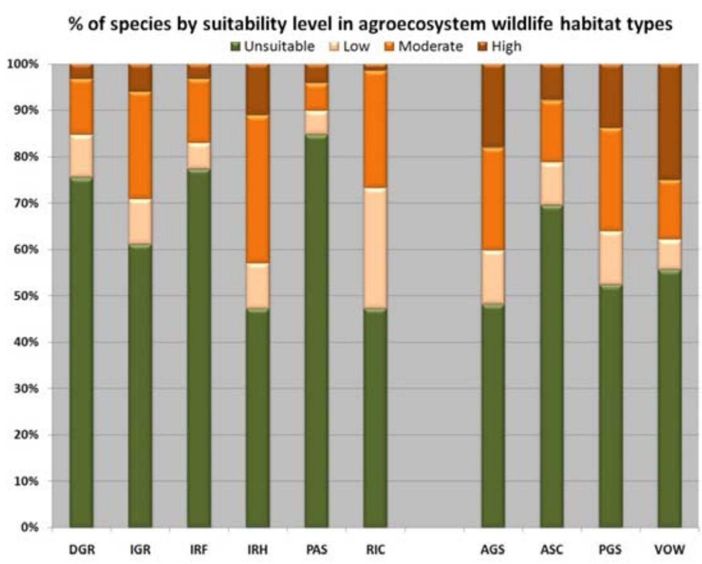
The Species of Special Concern are important for management because they have already suffered habitat loss, overhunting, and other stressors. Harvested or game species, on the other hand, are managed by the State of California for hunting. Changes in habitat prompted by conversion to biofuel crops could enhance or degrade habitat quality for the 34 harvested species (Parisi et al. 2008, listed in Appendix B). Two-thirds of the harvested species are waterfowl (ducks and geese), six are other birds, and seven are mammals including both carnivores and ungulates. Effects on harvest or game species were assessed for the basic Minimize Cost scenario for each biofuel crop and summarized as the number of species at different levels of habitat suitability loss or gain.

CHAPTER 3: Results

3.1 Suitability of Habitat Types for Wildlife Species

Agroecosystem habitats are definitely not created equal with respect to wildlife (Figure 6). Habitat types on the left side of the chart are agricultural types, whereas those on the right are natural or semi-natural habitats that intersperse or border agricultural lands in California. In general the agricultural habitat types are unsuitable for more agroecosystem species than their native counterparts and have high suitability for fewer species. Two distinctive exceptions are the Irrigated Hayfield (IRH) and Rice (RIC) types, which are suitable for more than half of the species. Irrigated Grain Crops (IGR) are more suitable habitat overall than Dry Grain Crops (DGR) and Irrigated Row and Field Crops (IRF). The chart suggests that in general, converting native habitats to biofuel crops will reduce overall habitat suitability. Similarly converting IRH or IGR to another habitat type to grow biofuel feedstock will tend to lower habitat suitability. On the other hand, converting Pasture (PAS) to one of the biofuel habitats would tend to benefit more wildlife species. These results do not account for differences in the ranges of species, only the habitat type. Therefore the effects of converting habitats may vary from place to place within the state.

Figure 6: Chart of Percentage of the 216 Agroecosystem Species in Suitability Classes for CWHR Habitat Types



Habitat type names: DGR = Dry Grain Crops, IGR = Irrigated Grain Crops, IRF = Irrigated Row and Field Crops, IRH = Irrigated Hayfield, PAS = pasture, RIC = Rice Fields, AGS = Annual Grassland, ASC = Alkali Desert Scrub, PGS = Perennial Grassland, and VOW = Valley Oak Woodland.

An alternative visualization of this kind of data is to add up the suitability scores associated with the four suitability levels for a set of species. For the 53 Species of Special Concern annual and perennial grassland types have the highest total suitability (Table 8). Irrigated Hayfield has the highest overall suitability of any of the agricultural habitat types and is actually higher than Valley Oak Woodland and Alkali Desert Scrub. Remember that the set of species are those associated with agroecosystems and not all species with affinity for the woodland and scrub habitat types. Converting any other agricultural habitat to bermudagrass would tend to increase overall suitability, although perhaps with a loss for some individual species. Dry Grain Crops and Irrigated Row and Field Crops have the lowest overall suitability. Note that these summed scores are for generic habitat types statewide, irrespective of geographic location. Some areas of suitable habitat lie outside a species geographic range, so the actual sum of scores in any particular location is likely to be less than the statewide score.

Table 8: Suitability-Weighted Species Richness Scores for Agroecosystem Habitats Based on the 53 Species of Special Concern

Habitat type	Suitability-weighted richness
DGR	4.33
IGR	8.55
IRF	5.89
IRH	13.89
PAS	7.88
RIC	9.98
AGS	24.45
ASC	11.68
PGS	19.11
VOW	12.67

Habitat type names: DGR = Dry Grain Crops, IGR = Irrigated Grain Crops, IRF = Irrigated Row and Field Crops, IRH = Irrigated Hayfield, PAS = pasture, RIC = Rice Fields, AGS = Annual Grassland, ASC = Alkali Desert Scrub, PGS = Perennial Grassland, and VOW = Valley Oak Woodland.

Large dissimilarity index values indicate more distinct assemblages of species between the two habitats (Table 9:) where larger effects of biofuel crop production would likely occur. Pasture (PAS) stands out as being highly dissimilar to other agricultural habitats, and Dry Grain Crops are dissimilar to Irrigated Row and Field Crops. The grassland, woodland, and desert scrub habitats are moderately to highly dissimilar to the habitats associated with biofuel crops, except that grasslands are more similar to Irrigated Hayfields associated with bermudagrass than to other agricultural types.

Table 9: Dissimilarity Index Scores Between CWHR Habitat Types of the California Agroecosystems

Habitat type	DGR	IGR	IRF	IRH	PAS	RIC	AGS	ASC	PGS	VOW
DGR	0.00									
IGR	0.57	0.00								
IRF	0.74	0.23	0.00							
IRH	0.43	0.27	0.39	0.00						
PAS	0.96	0.99	1.00	0.68	0.00					
RIC	0.70	0.47	0.47	0.33	0.72	0.00				
AGS	0.65	0.64	0.65	0.37	0.56	0.49	0.00			
ASC	0.87	0.96	0.94	0.73	0.52	0.76	0.46	0.00		
PGS	0.63	0.60	0.62	0.30	0.50	0.50	0.10	0.52	0.00	
VOW	0.79	0.93	0.90	0.63	0.38	0.49	0.31	0.49	0.34	0.00

Habitat type names: DGR = Dry Grain Crops, IGR = Irrigated Grain Crops, IRF = Irrigated Row and Field Crops, IRH = Irrigated Hayfield, PAS = pasture, RIC = Rice Fields, AGS = Annual Grassland, ASC = Alkali Desert Scrub, PGS = Perennial Grassland, and VOW = Valley Oak Woodland. Score = 0 means two habitats are totally similar, 1 means totally dissimilar.

Based on our literature review we proposed some relatively minor changes to the original CWHR for the set of focal species. Our panel of wildlife experts reviewed those proposed modifications. For the focal species there was sufficient data to suggest splitting three biofuel crops from their original generic habitat type (in parentheses) and assigned habitat suitability ratings for each focal species: corn (Irrigated Grain Crops), sweet sorghum (Dry or Irrigated Grain Crops), and high-density hay grasses (Irrigated Hayfield). We did not find sufficient information in the literature review to separate sugar beets from other row crops, or oilseed crops from other grains. Details of the results of the literature review, including management implications, and of a validation of the modeled suitability scores versus field-collected abundance data is provided in Appendix C.

When the habitat suitability modeling is applied spatially, the average suitability-weighted species density in sections was lowest for reproduction and generally highest for feeding for all groups of species (Table 10). This finding supports our expectation that many species forage in agricultural fields but may build dens, nests, or burrows in other nearby habitat patches. Most species in the study do not occur in all regions of the state. On average only 69 species out of 216 (32 percent) find suitable habitat in a section. Over half of the focal species occur in the average section, compared to only 23 percent of the Species of Special Concern. The latter tend to be rare and have less overlap, and the former were chosen as representative agroecosystem species, so this result should be expected. Species of concern have the lowest average suitability of any of the groups. Harvested species are distributed in a similar manner as the agroecosystem species, with about one-third occurring in sections on average. This group, however, has slightly higher suitability values for cover than for feeding whereas all other groups had highest suitability for feeding.

Table 10: Summary of Average Suitability-Weighted Species Density for Groups of Species

Suitability Indicator	All agroecosystem species (216)	Focal species (32)	Species of Special Concern (53)	Harvested species (34)
Reproduction	23.0	7.6	3.2	4.9
Cover	28.7	8.0	4.7	6.1
Feeding	32.3	9.3	5.4	5.5
Overall (average of suitability for reproduction, cover, and feeding)	28.0	8.3	4.4	5.1
Density (species per square mile)	68.6 (32%)	16.3 (51%)	12.2 (23%)	12.0 (34%)

3.2 Wildlife Biodiversity Patterns in California's Agroecosystems

The spatial patterns of predicted species density (# species/sq. mile) and suitability-weighted species richness are similar for all four groups of species, so only the results for the full set of agroecosystem species are presented here. The highest predicted density of agroecosystem wildlife species was 146 species per square mile. Species density is systematically higher in the Sacramento Valley and Imperial Valley than the San Joaquin Valley because of larger species pools in those areas (based on range maps) (Figure 7). Suitability of agricultural habitat types is lower than neighboring grasslands, so that sections with a mixture of croplands and grassland around the edges of the Central Valley have highest predicted species densities. Coastal agricultural areas such as the Salinas Valley and the Oxnard Plain have relatively low species densities. Species density shows the number of potential species in a section but not how suitable the habitat is for them. Suitability-weighted species density combines density with suitability scores as an index (Figure 8). The Sacramento Valley tends to have higher suitability-weighted species density than the San Joaquin Valley. Coastal agricultural areas such as the Salinas Valley and the Oxnard Plain also tend to have low suitability-weighted species densities.

Figure 7: Potential Number of Terrestrial Vertebrate Species Per Square Mile Section (Species Density) Based on Geographic Range Maps, Mapped Land Use/Land Cover, and CWHR Habitat Suitability Ratings

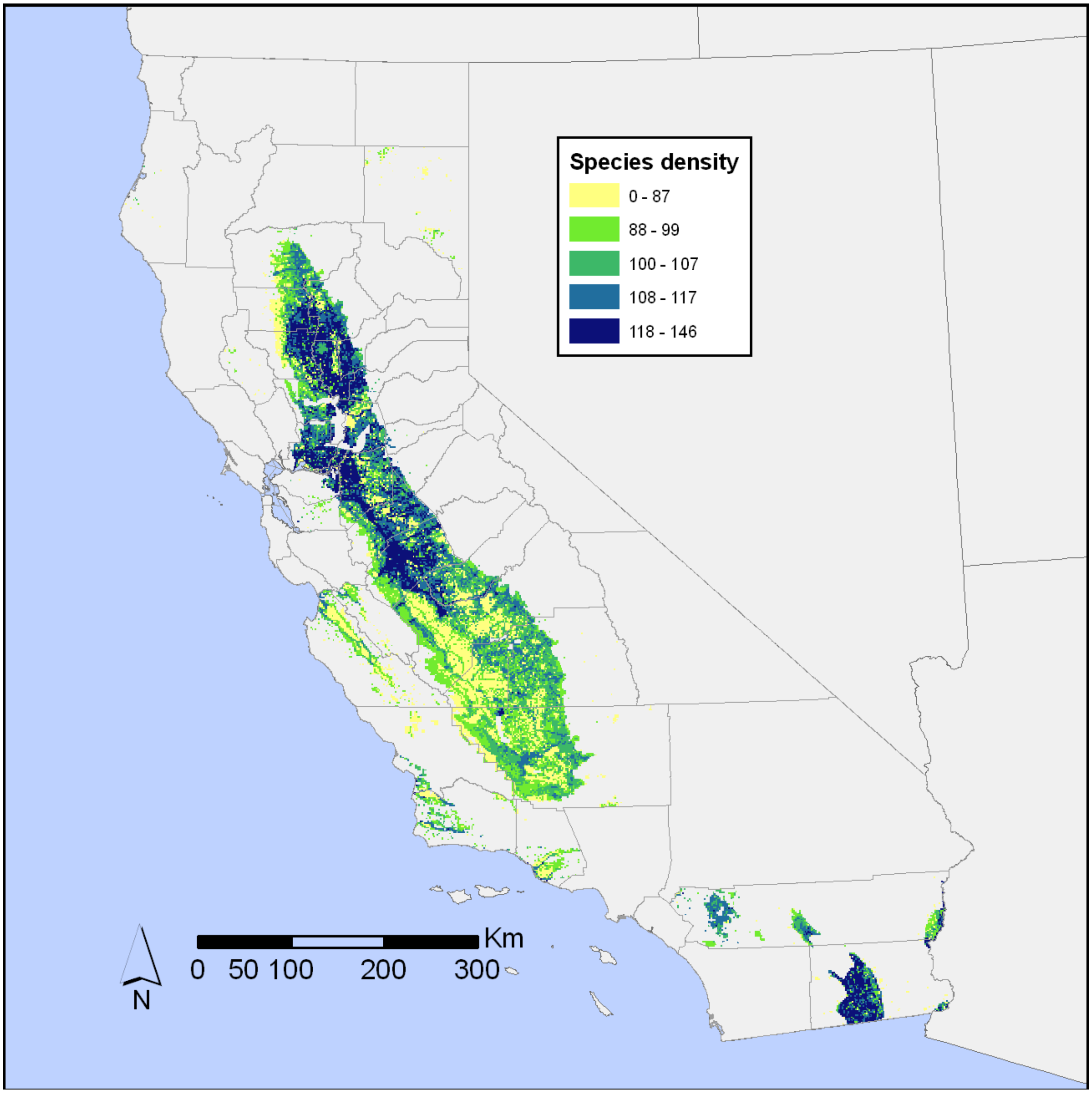
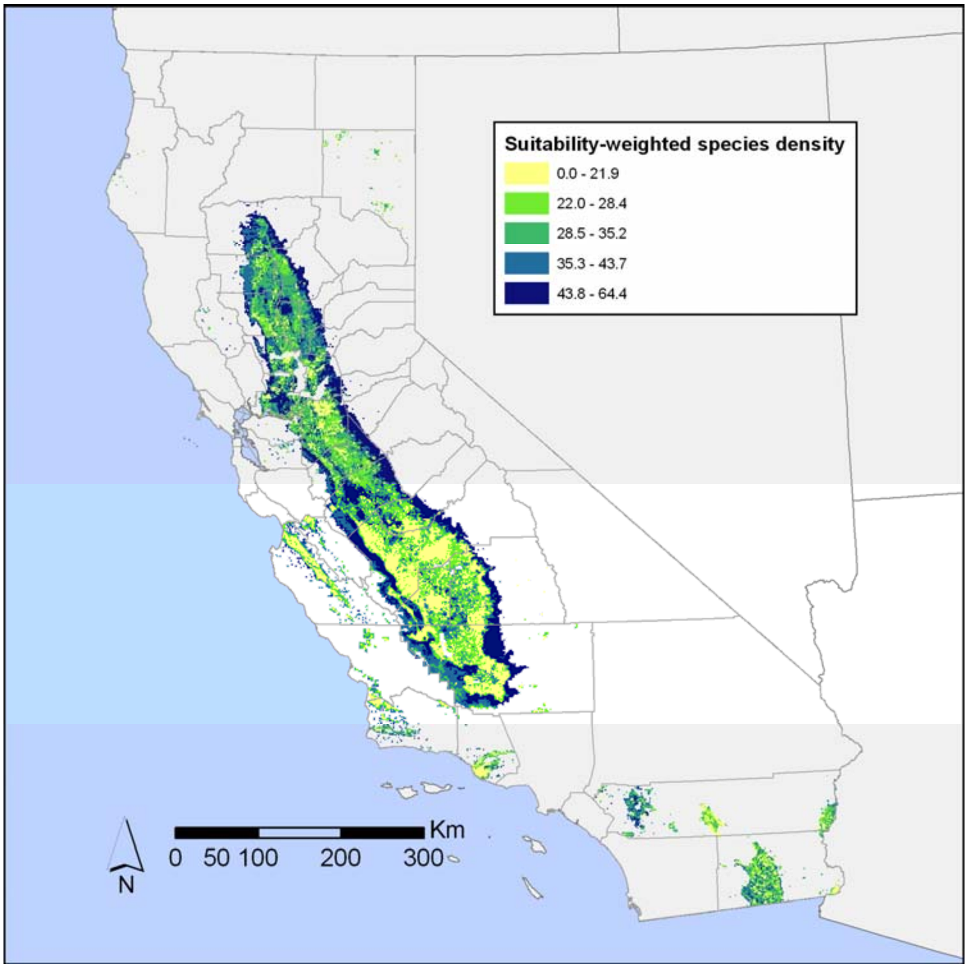


Figure 8: Map of Suitability-Weighted Species Density for Agroecosystem Species by Section Based on Geographic Range Maps, Mapped Land Use/Land Cover, and CWHR Habitat Suitability Ratings



3.3 Areas of Potential Conflict Between Biofuel Crop Production and Habitat Suitability

The effects on wildlife Species of Special Concern will depend substantially on where biofuel crops would be produced because of the variety of species ranges and habitat associations (Figure 9a). The edge of the Central Valley where cropland transitions into grassland has relatively high suitability-weighted species richness. The northern end of the Sacramento Valley also tends to be high. The magnitude of potential effects, however, depends not only on current values but also on the habitat type of the biofuel crop to be grown. Panels b-f in Figure 9 indicate the potential effects of the five biofuel crops if each available and suitable section were converted. The largest impacts for all five crops would occur in the grassland fringe of the Sacramento and San Joaquin Valleys. The general pattern of potential effects are quite similar for the two sugar crops—sweet sorghum (b) and sugar beets (c) even though they represent different habitat types. Bermudagrass would have large areas in the Sacramento and southern

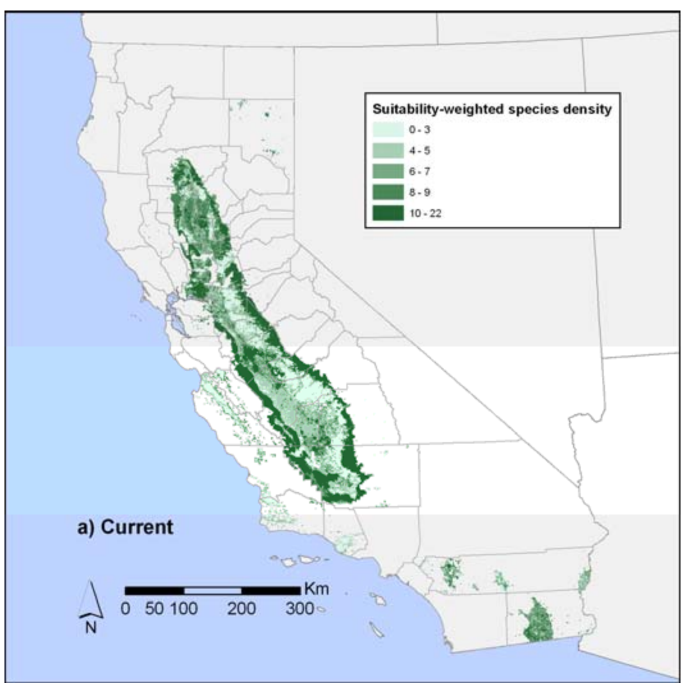
San Joaquin Valleys and in the Imperial Valley where the effects would generate an overall increase in habitat suitability (d). There is a large area in the northern San Joaquin Valley with no predicted change in suitability because the California Bioenergy Crop Adoption Model predicted no conversion to bermudagrass there at the $40 per acre profit benchmark. Canola (e) and safflower (f) are assigned to the same habitat type (DGR or IGR depending on the assumptions about irrigation) and conversion to these crops is predicted to have nearly identical effects, with some positive effects scattered throughout the agroecosystem.

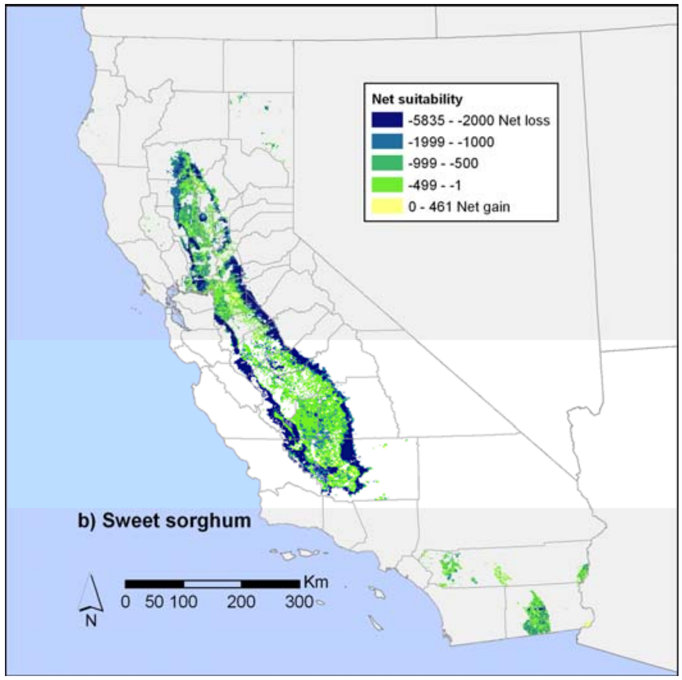
3.4 Biofuel Crop Scenarios

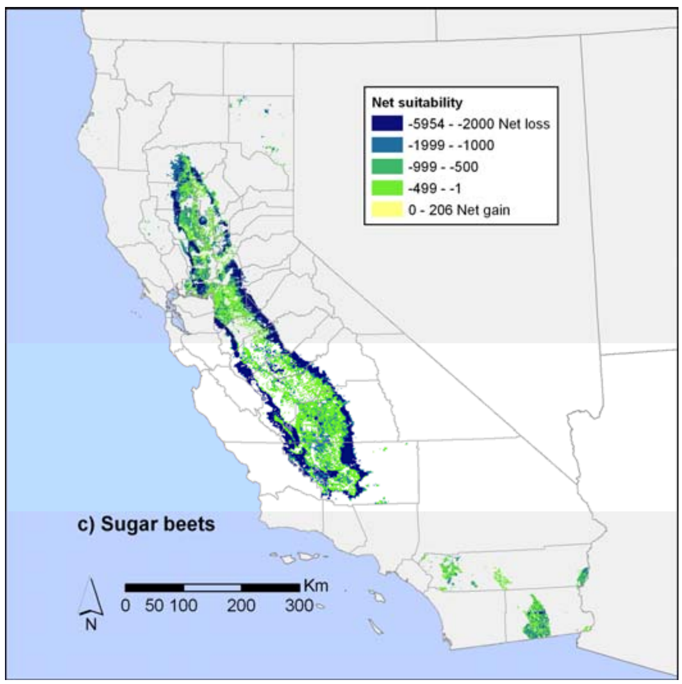
The results of the basic scenarios that minimized transportation costs for each crop type are summarized in

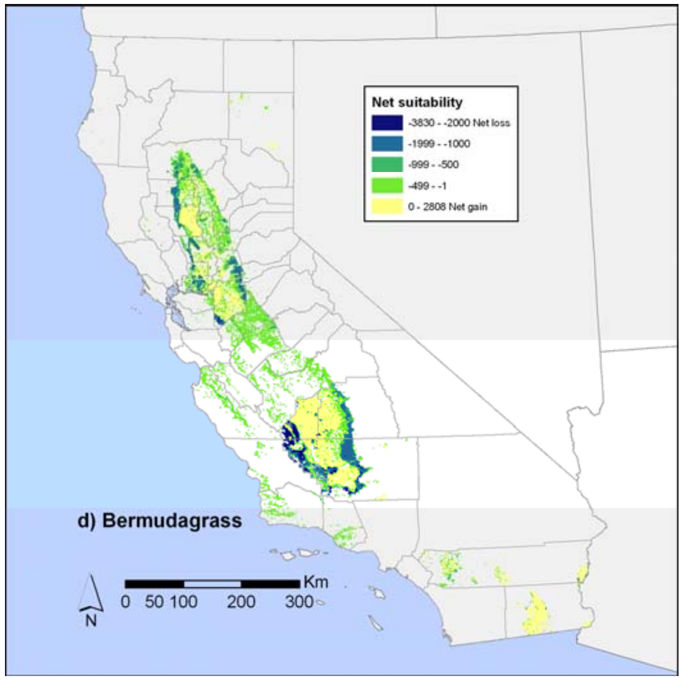
Table 11: (maps in Appendix D). Based on the predicted crop conversion by the California Bioenergy Crop Adoption Model, sweet sorghum could produce more GGEs of biofuel than the other four potential crops. The bermudagrass scenario produced less than 1/10th the energy of the sweet sorghum scenario. On the other hand, bermudagrass was the only scenario to have a positive, albeit very small, effect on overall habitat suitability. The canola scenario, however, had the largest net impact on suitability and the largest conversion of land (17.7 percent), despite a relatively low level of biofuel production. Canola could potentially reduce demand for irrigation water by more than 5 percent.

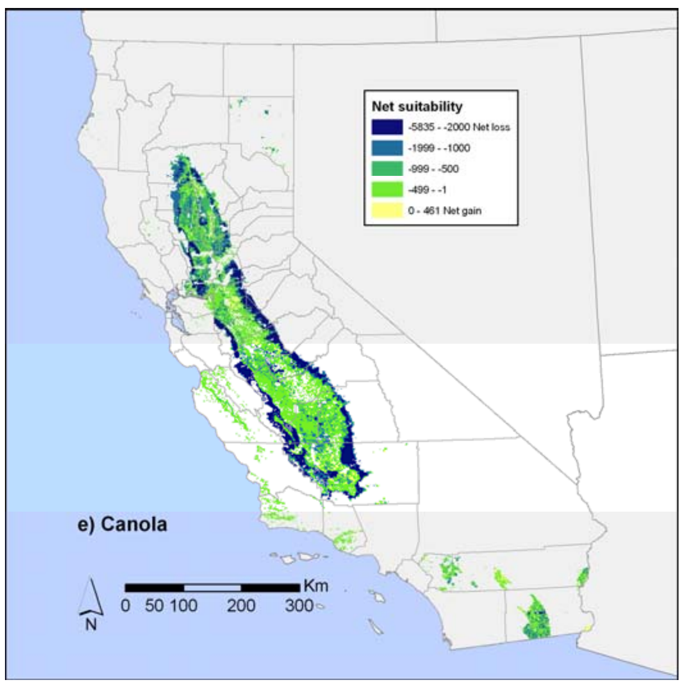
Figure 9: Suitability-Weighted Species Density for all 53 Species of Special Concern. a) Current. Net Change in Suitability-Weighted Species Density If Section Were Converted to: b) Sweet Sorghum, c) Sugar Beets, d) Bermudagrass, e) Canola, and f) Safflower.




Net suitability
-5835 - -2000 Net loss
-1999 - -1000
-999 - -500
-499 - -1
0 - 461 Net gain
b) Sweet sorghum
Km
0 50 100 200 300
N


Net suitability
-5954 - -2000 Net loss
-1999 - -1000
-999 - -500
-499 - -1
0 - 206 Net gain
c) Sugar beets
Km
0 50 100 200 300
N


Net suitability
-3830 - -2000 Net loss
-1999 - -1000
-999 - -500
-499 - -1
0 - 2808 Net gain
d) Bermudagrass
Km
0 50 100 200 300
N


Net suitability
-5835 - -2000 Net loss
-1999 - -1000
-999 - -500
-499 - -1
0 - 461 Net gain
e) Canola
Km
0 50 100 200 300
N

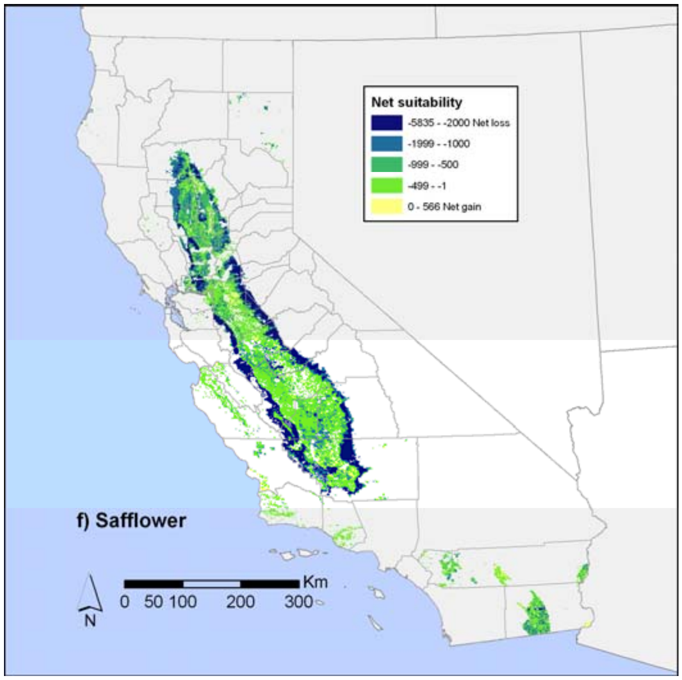


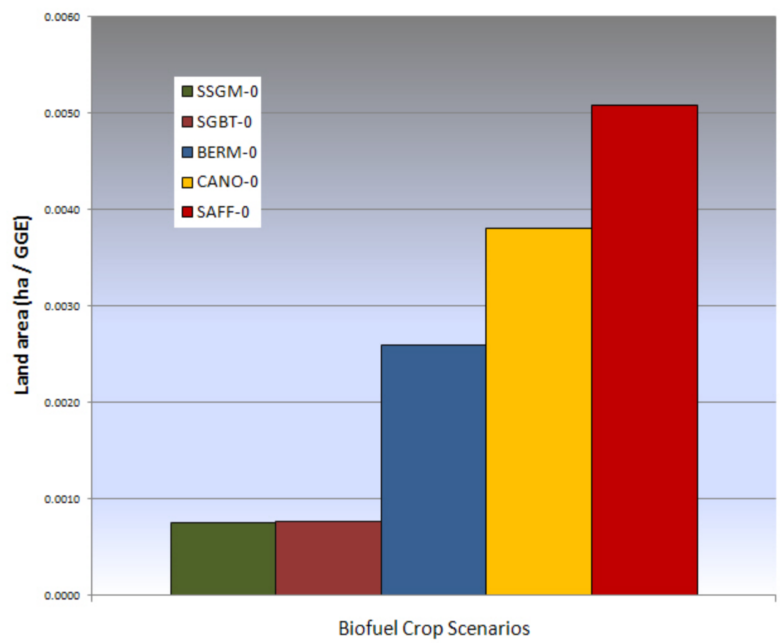
Table 11: Summary Results of Basic "Minimize Cost" Biofuel Crop Scenarios.

	Sweet sorghum (ssgm1-0)	Sugar beets (sgbt1-0)	Bermudagrass (berm1-0)	Canola (cano1-0)	Safflower (saff1-0)
Total biofuel production (million GGE)	492.1	299.6	38.2	136.1	51.1
Total net change in habitat suitability	-4.4%	-2.9%	+0.1%	-5.3%	-2.4%
Total land area converted to biofuel crop in thousand ha (% of available/suitable land for crop)	372.6 (12.7%)	228.3 (7.5%)	99.1 (4.5%)	517.7 (10.5%)	260.1 (6.5%)
Total net change in water demand in thousand acre-feet (% of all irrigation)	-15.1 (-0.1%)	0 (0%)	-12.0 (-0.1%)	-1,040.2 (-5.7%)	-566.3 (-3.0%)

3.5 Relative Effects on Land Use, Water Consumption, and Habitat Suitability From Growing Biofuel Crops

The California Bioenergy Crop Adoption Model predicted the amount of land converted to biofuel crop production for each crop type at the $40 per acre profit benchmark (Table 2). As a result, the total land area converted to biofuels in the scenarios varies by crop as does the total energy yield in GGE. Therefore, comparing the land requirement on an energy basis (per GGE) is more informative. The sugar crops, sweet sorghum and sugar beets, require less than 8 m^2 (0.0008 hectares) per GGE on average (1323 GGE/hectare) (Figure 10). Bermudagrass requires 26 m^2 per GGE (385 GGE/hectare), and canola and safflower take 38 and 51 m^2 (263 and 197 GGE/hectare) respectively. The oil crops and bermudagrass have much lower biomass yields per acre than sugar crops, although this is partially offset by their higher energy content and conversion efficiencies. There was virtually no difference in the land requirements for any given crop between the Minimize Cost and Minimize Loss scenarios so only the minimize-cost option is shown here.

Figure 10: Land Area Required to Produce One GGE by Crop Type in the Minimize Cost Scenarios

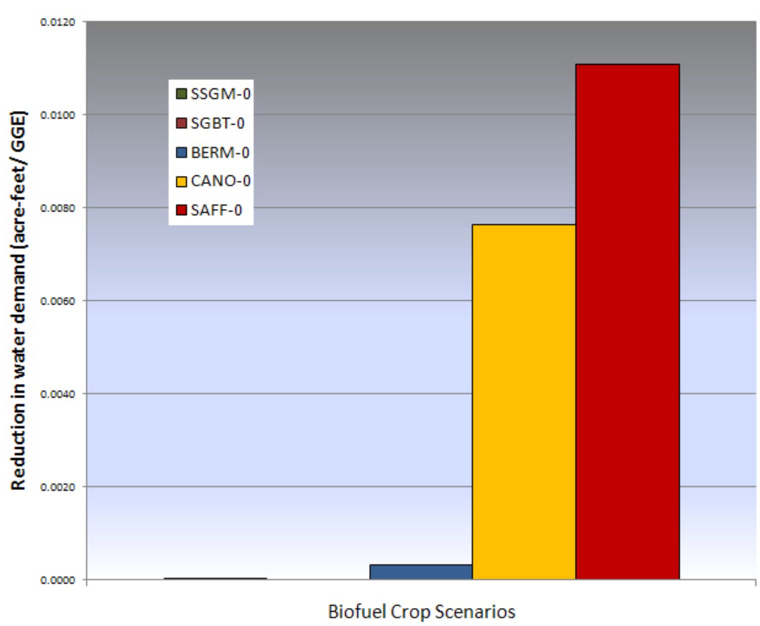


ssgm = sweet sorghum, sgbt = sugar beets, berm = bermudagrass, cano = canola, saff = safflower.

By similar logic, the crops can be compared by the amount of reduction in water demand for irrigation per GGE produced (Figure 11). The California Bioenergy Crop Adoption Model was constrained to allow no more than the current volume of water for irrigation in allocating land area to biofuel crops. Sugar beets provided no reduction in irrigation. That is, the water from existing crops that would be converted would be fully transferred to sugar beets in that biofuel scenario. For sweet sorghum and bermudagrass, reductions were only predicted in a few crop subregions, so the average reduction per GGE was quite small. Canola had the largest overall reduction in acre-feet of water at nearly 6 percent of current statewide irrigation. However, on a per GGE basis, the reduction was more modest than for safflower. These two oil crops require little irrigation, and canola is a winter crop that can be largely rain-fed. Moreover the water reduction would occur in a majority of crop subregions throughout the state (Appendix A).

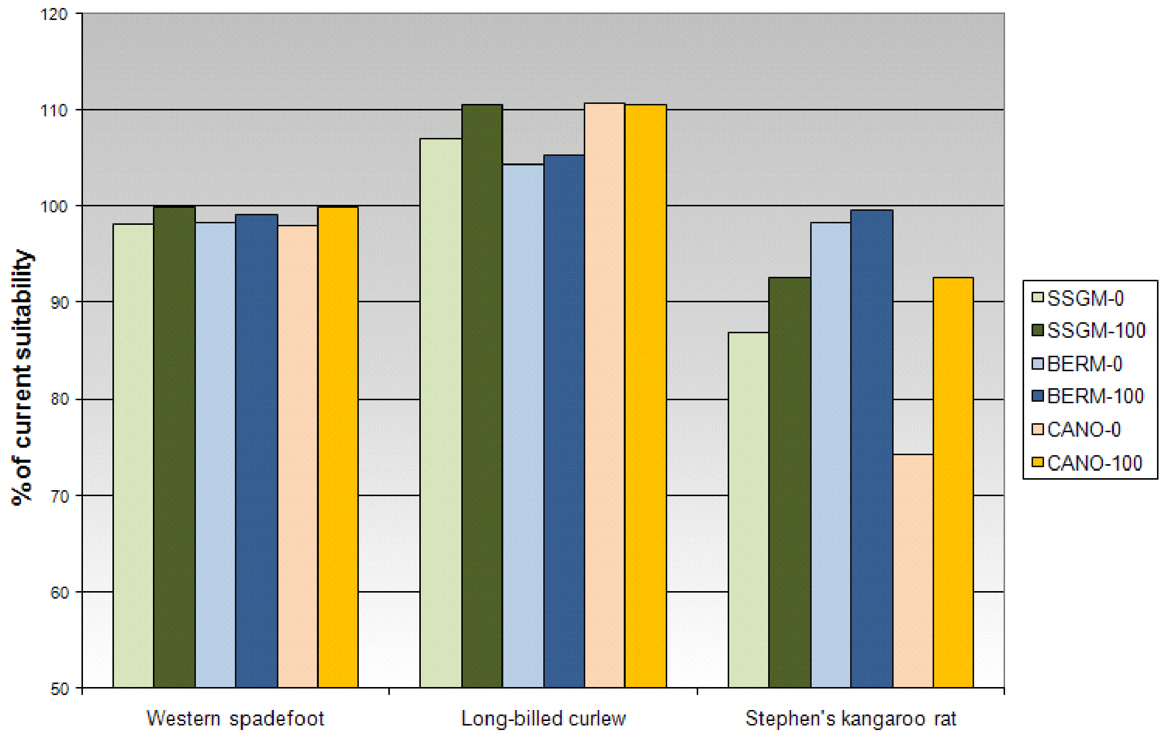
In addition to assessing cumulative changes in habitat suitability for the set of species, the analysis provides details about the net changes in suitability statewide for the individual species. A sample of species and scenarios are shown in Figure 12. For the Western spadefoot toad, the Minimize Cost scenarios cause a very small loss in overall suitability, and the Minimize Loss scenarios reduce that amount close to zero. The Long-billed Curlew is one of the species that would appear to benefit under any scenario with any biofuel crop. It likes cropland as part of its wintering range. On the other hand, the Stephens' kangaroo rat, a listed species whose small range in southern California has been drastically reduced by urban development and agriculture, appears to be highly vulnerable to habitat conversion to some biofuel crops. Canola could reduce suitability by over 25 percent in the associated Minimize Cost scenario, although in the Minimize Loss scenario, reduction would be less than 8 percent. Converting to safflower would be even more impactful for this species. Of the 53 Species of Special Concern, Stephens' kangaroo rat is by far the most sensitive to choice of biofuel crop scenario, ranging from virtually no change (bermudagrass in Minimize Loss scenario) to over 30 percent reduction (safflower in the Minimize Cost scenario)

Figure 11: Reduction in Water Demand to Produce One GGE by Crop Type in the Minimize Cost Scenarios



ssgm = sweet sorghum, sgbt = sugar beets, berm = bermudagrass, cano = canola, saff = safflower

Figure 12: Total Habitat Suitability for Selected Species Under the Minimize Cost (-0) and Minimize Loss (-100) Scenarios Relative to Current Conditions.



ssgm = sweet sorghum, berm = bermudagrass, cano = canola

The effects on species can be viewed collectively as well. Effects on these species were assessed for the basic Minimize Cost scenario for each biofuel crop and summarized as the number of species at different levels of habitat suitability loss or gain (Table 12). Sweet sorghum and canola scenarios had the greatest number of species with larger losses (>10 percent) of habitat suitability. Sugar beets, bermudagrass, and safflower scenarios in general had relatively low numbers of species with large impacts. The bermudagrass scenario causes no more than 2 percent loss for any of the species and benefits 25 species. Remember though that bermudagrass scenario converted much less land and produced less energy than the other biofuel crops in the modeling (Table 2). Bermudagrass is also rated as moderate risk for invasion in California, particularly in disturbed riparian areas (Cal-IPC 2006) and thus may have additional consequences not captured by the habitat suitability modeling. Note also that even though safflower was relatively benign in its effects on wildlife collectively, it had the largest negative impact on Stephens' kangaroo rat. Thus there are trade-offs to be considered between biodiversity, or the set of surrogates, and individual species.

Table 12: Number of Species of Special Concern by Level of Change in Habitat Suitability for Minimize Cost Biofuel Crop Scenarios

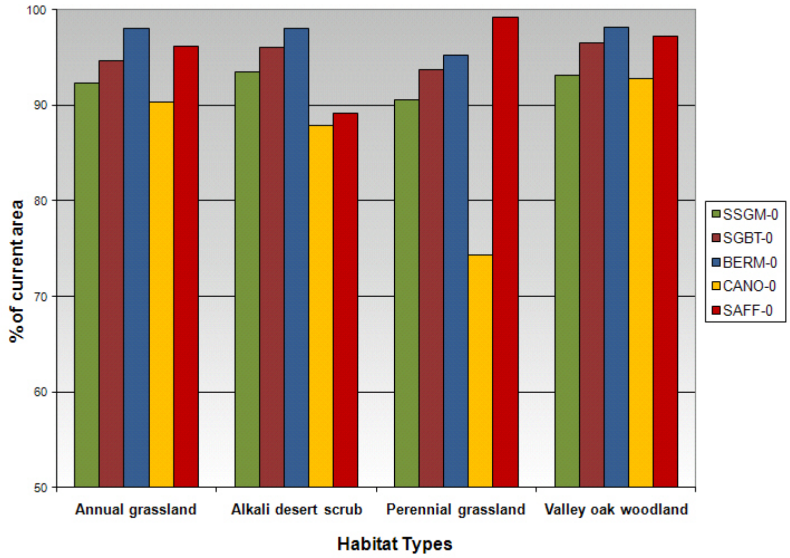
Percent change	SSGM	SGBT	BERM	CANO	SAFF
> 10% loss	5	1	0	8	3
7.5 – 10% loss	7	0	0	11	1
5 – 7.5% loss	12	6	0	11	6
2.5 – 5% loss	9	18	0	4	17
0 – 2.5% loss	9	16	28	7	14
0 – 10.7% gain	11	12	25	12	12
Total number of species	53	53	53	53	53

ssgm = sweet sorghum, sgbt = sugar beets, berm = bermudagrass, cano = canola, saff = safflower.

Besides this collective view across all Species of Special Concern, there are interesting patterns for individual species. Most of the large effects (>10 percent loss or a positive gain) occurred for the birds. Effects on all amphibian and reptile species and most mammals were negative but less extreme. Stephens' kangaroo rat was the only mammal with >10 percent loss, which occurred with all crops except bermudagrass where the loss was less than 2 percent. Kit fox was the only mammal with a positive gain, although this effect only occurred in the bermudagrass scenario. Fulvous Whistling-Duck and Vermillion Flycatcher had >10 percent in all the grain crop scenarios (sweet sorghum, canola, and safflower), although they had positive gains in the sugar beets and bermudagrass scenarios. One group of birds gained habitat suitability in all biofuel scenarios except for sugar beets—Northern Harrier, Sandhill Crane, Long-Billed Curlew, Loggerhead Shrike, Vesper Sparrow, and Tricolored Blackbird.

In addition to simple conversions from one crop to another, the scenarios selected some natural/semi-natural habitat for conversion as well. These habitat remnants of pre-European settlement conditions are valuable not only to the Species of Special Concern but also to many other species that depend on them for nesting habitat or cover. The integrated framework also tracks net loss of habitat area for the four non-agricultural habitat types (annual and perennial grasslands, alkali desert scrub, and Valley oak woodland). Canola would reduce these habitat types the most of any of the five biofuel crops modeled, and bermudagrass would cause the least (although it also produces the least biofuel). Perennial grassland tends to have the greatest percentage loss, except with safflower that retains almost all of this habitat type. Alkali desert scrub has the lowest overall suitability for Species of Special Concern (Table 8) of the four natural/semi-natural habitat types. Consequently it often suffered greater losses under the Minimize Loss scenarios than it did under the corresponding Minimize Cost scenarios. In other words, all else being equal, Marxan selected sections with alkali desert scrub for conversion rather than the other three types.

Figure 13: Net Loss of Natural/Seminatural Habitat Types Under the Minimize Cost Scenarios



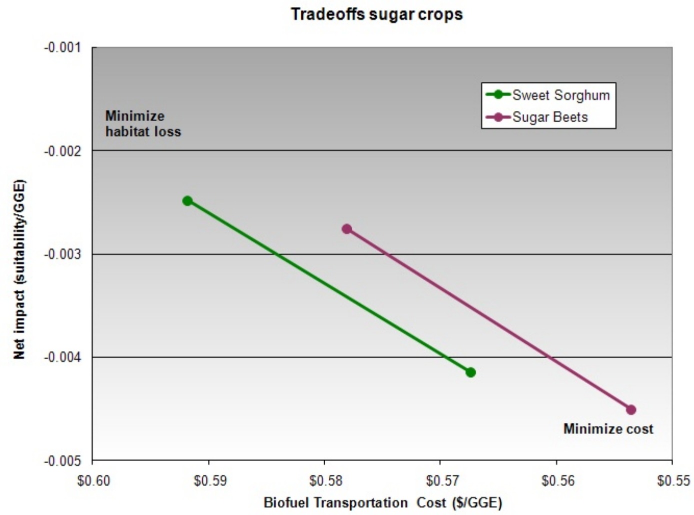
ssgm = sweet sorghum, sgbt = sugar beets, berm = bermudagrass, cano = canola, saff = safflower

Land use for energy crops competes with food production. Our framework in its current state does not track losses in food production by crop. The California Bioenergy Crop Adoption Model does predict at the crop subregion scale the net change in area harvested for major crops. We can, however, track the area of food production converted to biofuels for each scenario. For all five biofuel crops, approximately half of the land converted comes from the four food habitat types—dry grain crops, irrigated grain crops, irrigated row and field crops, and rice fields. In the Minimize Loss scenarios, this fraction that comes from food crop habitats rises to 2/3 for sweet sorghum, sugar beets, and bermudagrass and over 80 percent for canola and safflower. Irrigated row and field cropland would suffer the largest losses in land area to produce canola (up to 25 percent of the current total) and sweet sorghum (up to 13 percent).

3.6 Trade-Offs Between Transportation Cost, Wildlife Habitat, and Water Consumption

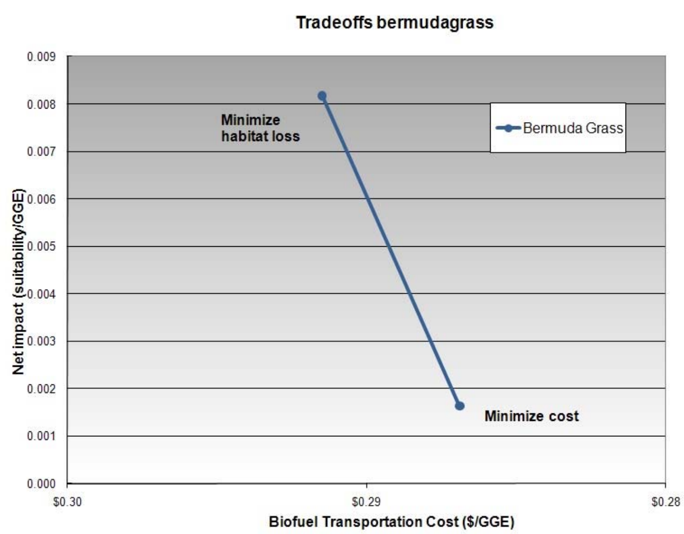
As expected, scenarios that attempt to reduce the impact of biofuel crop production on habitat suitability for the Species of Special Concern would cause an increase in the cost of transporting the biomass to the least-cost biorefinery. For sweet sorghum, the cost would increase about 4 percent from $0.57 to $0.59 per GGE whereas the loss of habitat suitability could be reduced 40 percent (Figure 14). The graph is drawn such that cost gets better (such as lower) moving to the right, and habitat impacts get better (such as less loss or more gain) moving up the vertical axis. The points at the lower right end of each line represent the basic Minimize Cost scenarios for each crop. The points on the upper left end represent the Minimize Loss scenarios. The trade-offs are nearly identical for sugar beets, but the cost is approximately $0.01 per GGE less for sugar beets while the net impact is slightly greater.

Figure 14: Trade-Offs Between Cost and Net Impact on Habitat Suitability Per GGE for Sugar Crops, Sweet Sorghum, and Sugar Beets



The results for bermudagrass are quite different than those for the sugar crops in several ways (Figure 15). First, the transportation cost for bermudagrass is one-half of that for the two sugar crops. This lower cost is primarily due to the higher energy content of bermudagrass so that less biomass needs to be transported to produce each GGE of fuel. The second major difference is that the effect on habitat suitability overall is positive. Even the Minimize Cost scenario has a slight positive effect on suitability. This positive effect increases rapidly if minimizing habitat suitability loss is also emphasized with very little increase in cost.

Figure 15: Trade-Offs Between Cost and Net Impact on Habitat Suitability Per GGE for Bermudagrass



Results for the biodiesel oil crops are similar in general pattern. Both canola and safflower would cost approximately $0.01 per GGE more to reduce habitat suitability loss, but the reduction would be 50 percent and 72 percent respectively (Figure 16). Canola has dramatically lower transportation costs than safflower because of its greater GGE yield per short ton of biomass (Table 1). The analysis predicts that canola's net impact would be less than safflower's in the Minimize Cost case but greater in the Minimize Loss scenario. The oil crops, despite very low biomass yields relative to the sugar crops have a higher energy density, making the transportation costs very low. Costs for canola average $0.11 per GGE and $0.19 for safflower. Because the biomass yields are lower, producing one GGE converts more habitat than the sugar crops, so the net impact of the oil crops is much greater.

Placing all five crops on a single trade-off graph makes it easier to visualize the relationships between them. The sugar crops on the far left of Figure 17 have the largest costs of the five crops because of their relatively low energy efficiency. The oil crops have the lowest costs, but also the greatest loss of habitat suitability per GGE. However, the oil crops have the largest potential to reduce those impacts with the Minimize Loss scenarios. Bermudagrass has an intermediate cost but is the only crop with a positive net effect on habitat suitability, even in the Minimize Cost scenario. The oil crops and bermudagrass all have great potential for better outcomes for wildlife with the Minimize Loss scenarios at very low increases in cost. This finding is partially due to the relatively low biofuel production for these crops that the California Bioenergy Crop Adoption Model predicted, especially bermudagrass, relative to the sugar crops. Bermudagrass requires less than 5 percent of the available and suitable agroecosystem land to achieve its target whereas sweet sorghum requires almost 13 percent. Thus there is more flexibility to redistribute bermudagrass to satisfy other social objectives such as wildlife conservation and yet be cost-effective.

Figure 16: Trade-Offs Between Cost and Net Impact on Habitat Suitability Per GGE for Oil Crops, Canola and Safflower

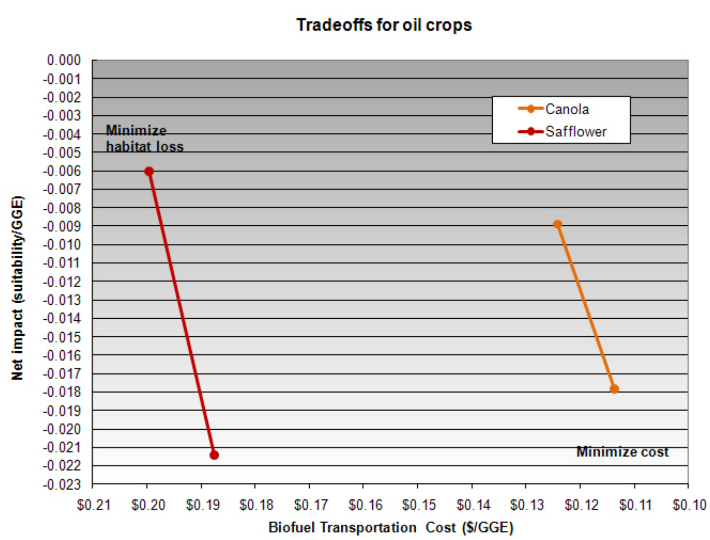
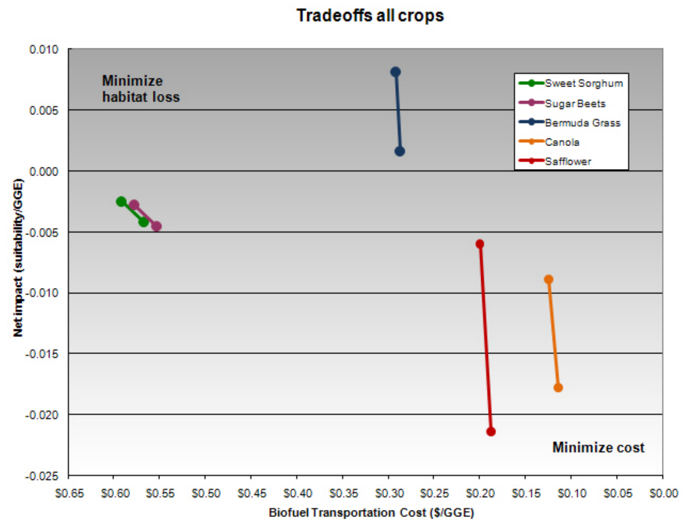
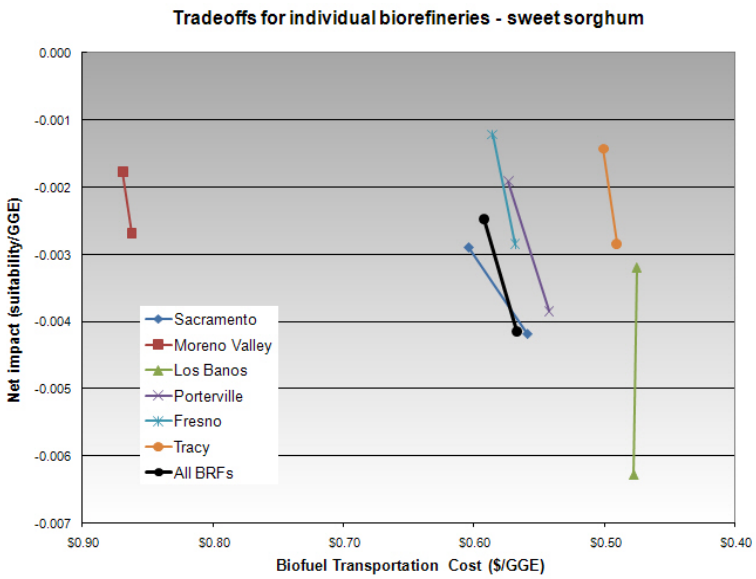


Figure 17: Trade-Offs Between Cost and Net Impact on Habitat Suitability Per GGE for All Five Biofuel Crops



Just as it is possible to compare trade-offs between crop types, the trade-offs of cost and impact can be assessed for individual biorefineries. This comparison can identify any potential biorefineries that contribute disproportionately to either the costs or habitat suitability loss, or offer the greatest potential to reduce suitability loss and minimal cost. For example, Figure 18 displays these trade-offs for the Minimize Cost and Minimize Loss scenarios for sweet sorghum. Given these scenarios, and all the assumptions about the locations of the biorefineries and associated transportation costs, several of the trade-off curves are very similar to the curve for the aggregate of all biorefineries (black line). On the other hand, the curve for Moreno Valley, which would receive biomass from southern California, has relatively low impacts but an extremely high transportation cost per GGE. This hypothetical site might be a candidate for relocation to reduce costs, because the feedstock sources tend to have lower impact than other areas of California. In contrast the Los Banos site in central California has the greatest associated impact on suitability in the Minimize Cost scenario. However, it also has the longest curve indicating the greatest potential for mitigation by redistributing the sources of biomass to less impactful planning units. In this particular case, the average cost could actually decrease slightly as well.

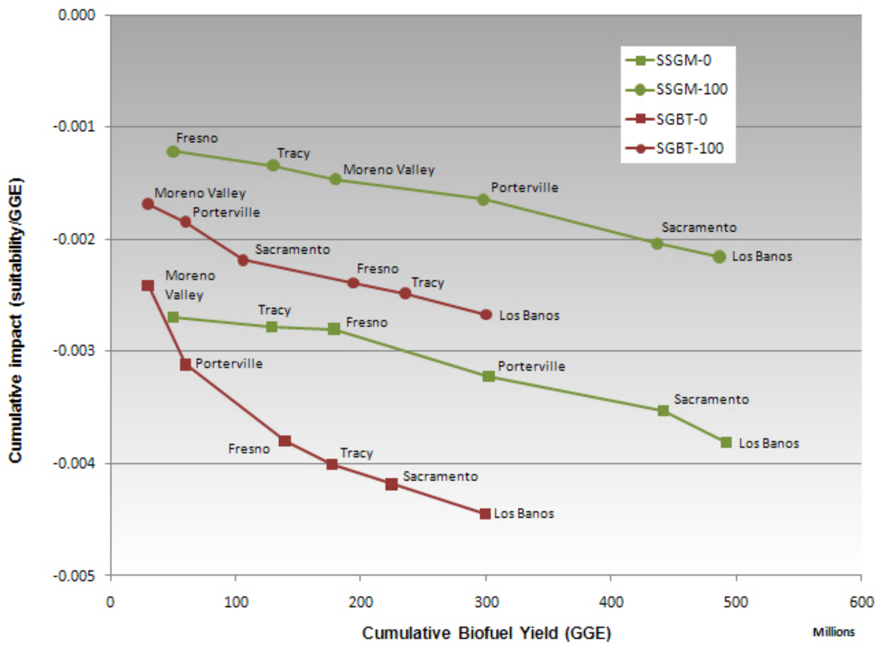
Figure 18: Trade-Offs for Individual Biorefineries for the Sweet Sorghum Scenarios



Note: For locations of these hypothetical biorefineries, refer to Figure 3a.

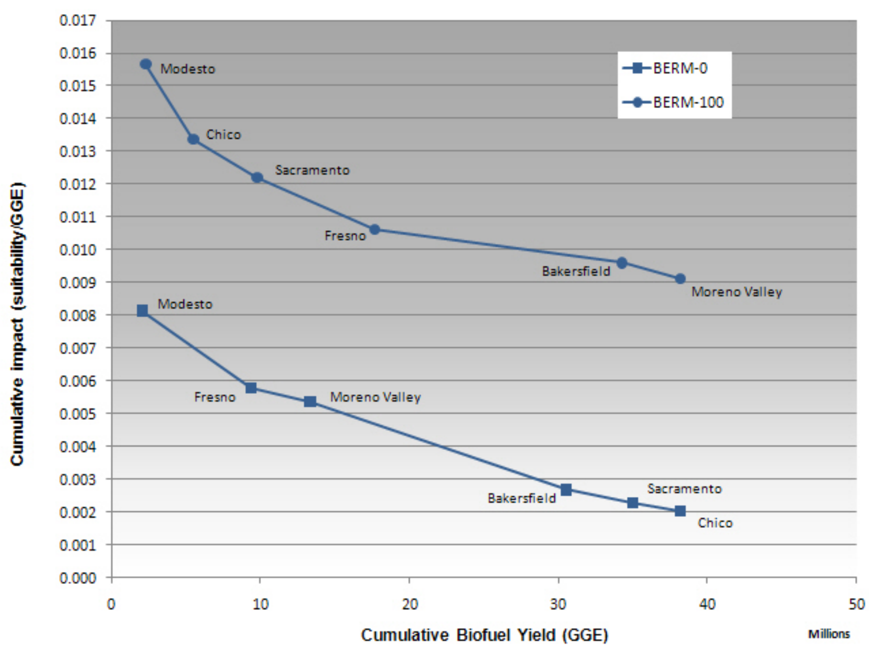
Whereas the previous graph examined the relative trade-off between cost and impact on a per GGE basis, it is also possible to generate an "efficiency frontier" (Polasky et al. 2008) of the cumulative yields and effects of the individual biorefineries. The biorefineries were sorted from lowest to highest impact per GGE for each scenario. In Figure 19 as the curves move from left to right, each point represents the addition of another biorefinery and its biofuel yield and the change in impact of including it. The point on the right end of the curve corresponds to the total biofuel yield of the scenario and the impact per GGE of that yield. Note that the curves for sugar beets are shorter than those for sweet sorghum because the total biofuel yield from sugar beets is predicted to be considerably less. In these scenarios, the Moreno Valley site tends to have very low impact, and the Los Banos site is consistently the least efficient in terms of wildlife habitat suitability. In general the sites in the northern half of the state tend to be associated with the most impact on wildlife habitat for the sugar crops. For bermudagrass, the order of the lignocellulosic biorefinery sites is dramatically switched between the Minimize Cost and Minimize Loss scenarios (Figure 20). The southern sites have the lowest impacts in the Minimize Cost scenario, but the northern sites become the least impactful in the Minimize Loss scenarios. Note that the x-axis scale is roughly an order of magnitude smaller than the axis for sugar crops because the California Bioenergy Crop Adoption Model predicted low land conversion to bermudagrass. The y-axis for bermudagrass indicates positive effects for all biorefineries, whereas the axis is negative for sugar crops. Again, we repeat that these results are the interpretation of the particular scenarios that were analyzed, contingent upon all the assumptions embedded within them.

Figure 19: Cumulative Trade-Off Curve for Sugar Crops of Impact Versus Biofuel Production



ssgm = sweet sorghum, sgbt = sugar beets; Minimize Cost = -0, Minimize Loss = -100.

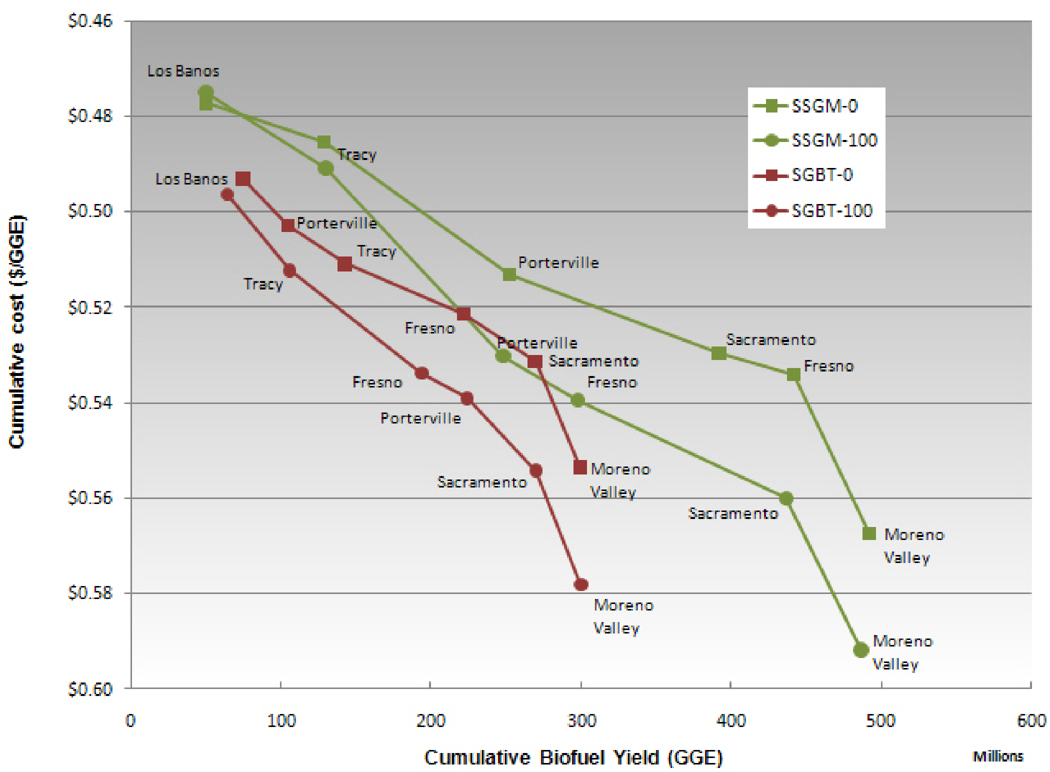
Figure 20: Cumulative Trade-Off Curve for Bermudagrass of Impact Versus Biofuel Production



berm = bermudagrass; Minimize Cost = -0, Minimize Loss = -100.

The cumulative cost of adding each individual biorefinery can be analyzed relative to cumulative biofuel yield in a similar manner (Figure 21). In this case, the hypothetical biorefineries were sorted by their average transportation cost per GGE. For both scenarios for both sugar crops, the Los Banos site offers the lowest cost per GGE whereas the Moreno Valley site in southern California was consistently the most expensive (as seen also in Figure 18). The Sacramento site also tends to be costly. Sacramento is the destination for a large area covering most of the Sacramento Valley, and Moreno Valley receives biomass from the Imperial Valley and elsewhere in southern California, so both are associated with long hauling distances.

Figure 21: Cumulative Trade-Off Curve for Sugar Crops of Cost Versus Biofuel Production

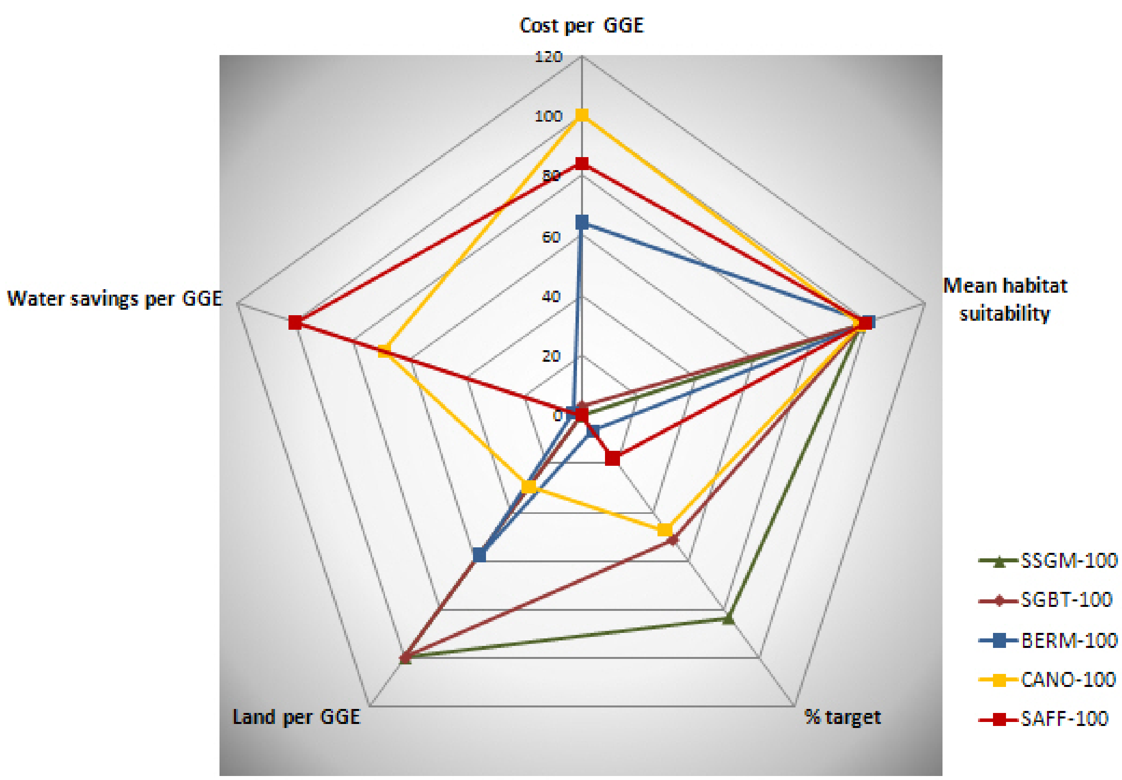


ssgm = sweet sorghum, sgbt = sugar beets; Minimize Cost = -0, Minimize Loss = -100

One way to visually compare the costs and benefits of the five biofuel crops is through a spidergram that portrays the relative performance on five criteria (Figure 22).Performance was standardized so that the values for all criteria range from 100 (best) to 0 (worst). The level of biofuel production could be measured in absolute terms relative to the state targets for ethanol and biodiesel (Williams et al. 2007). Similarly, mean habitat suitability is measured in absolute terms relative to current conditions. The other three criteria were scaled in relative terms to the best performer of the crops. The results shown here are for the Minimize Loss scenarios, but the

Minimize Cost results are very similar. The oil crops, canola and safflower, have by far the lowest transportation costs per GGE because of their high energy density in each ton of biomass. The sugar crops, sweet sorghum and sugar beets, are the most expensive. All five crops retain at least 97 percent of current habitat suitability. Sweet sorghum has the greatest potential toward achieving state biofuel targets with over 80 percent based on the California Bioenergy Crop Adoption Model at the $40 per acre benchmark. Sugar beets and canola are close to 50 percent of the ethanol and biodiesel targets respectively. At the assumed price, bermudagrass could only supply 7 percent of the state target. The high biomass yields for the sugar crops overcome their lower energy density so that the land required to produce one GGE is by far the least. Safflower requires the most land area, but saves the most water per GGE. The other crops save very little water, or in the case of sugar beets, save none. Because of the way water was constrained in the California Bioenergy Crop Adoption Model, no crops could increase the amount of water required for irrigation.

Figure 22: Spidergram of Trade-Offs Between Criteria for the Five Biofuel Crops in the Minimize Loss Scenarios

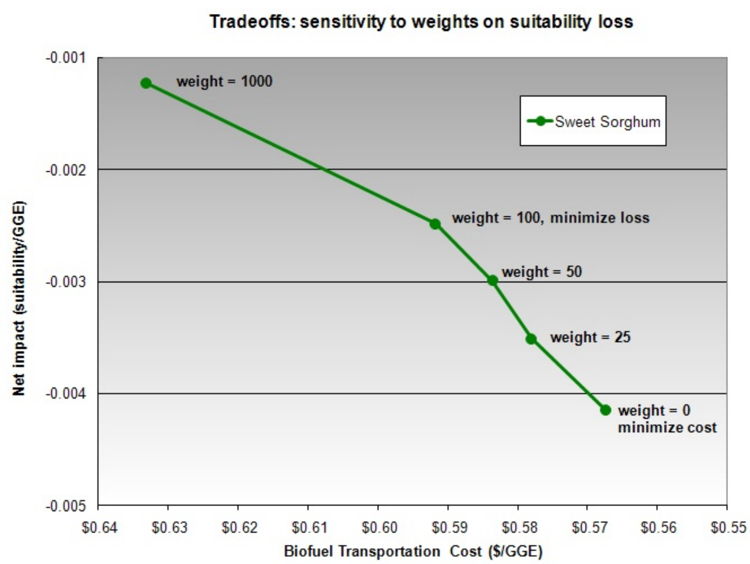


ssgm = sweet sorghum, sgbt = sugar beets, berm = bermudagrass, cano = canola, saff = safflower.

3.7 Sensitivity of Results to Habitat Suitability Weights

Additional scenarios were generated in Marxan for sweet sorghum with weights set at 25, 50, and 1000 to test the sensitivity of the results to the choice of weights and to determine the shape of the efficiency frontier. These additional points were added to the original trade-off curve. With a weight of 1000, the impact on habitat suitability is dramatically reduced by 70 percent from the base case, but cost also increases 12 percent or $0.07 per GGE (Figure 23). From the set of weights tested, weights greater than 100 provide less wildlife improvement per unit of cost than for weights below 100, or diminishing returns. For weights between 0 and 100, there is no clear inflection point to identify the optimal trade-off. That is, the curve is essentially straight through this range with a linear response of suitability to changes in cost.

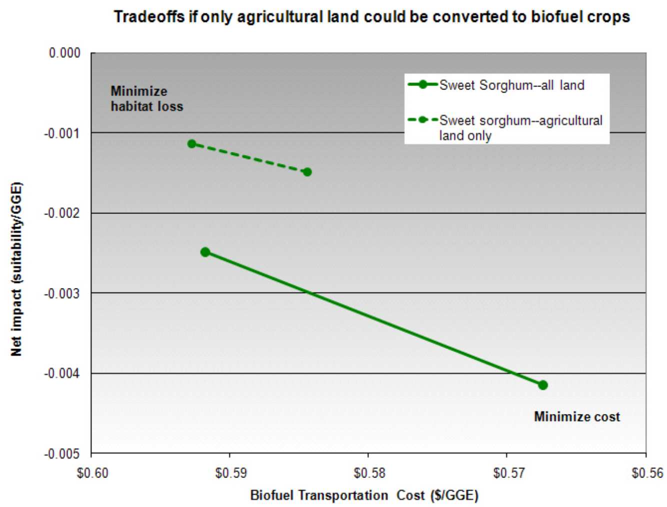
Figure 23: Trade-Off Sensitivity to Weights on Habitat Suitability Loss for Sweet Sorghum



3.8 Sensitivity of Results to Assumptions About Land Suitability for Biofuel Crops

We generated Minimize Cost and Minimize Loss scenarios for sweet sorghum that declared remnant patches of natural or semi-natural habitats to be unavailable for biofuel production. Only existing agricultural land could be converted to biofuel crops (Figure 24). Comparing the Minimize Cost scenarios, precluding natural habitats would increase the cost by 3 percent while reducing habitat loss 64 percent. In other words, the Minimize Cost scenario on agricultural land has less cost and better wildlife effects than the Minimize Loss scenario on all land. Even further improvement in the net impact factor is possible through the Minimize Loss scenario on agricultural land with virtually no increase in cost relative to the all land scenario.

Figure 24: Trade-Offs Between Cost And Wildlife Impact With Different Rules for Biofuel Crop Suitability



3.9 Effects on Harvested Wildlife Species

Effects on harvest or game species were assessed for the basic Minimize Cost scenario for each biofuel crop and summarized as the number of species at different levels of habitat suitability loss or gain. Sweet sorghum and canola degraded habitat suitability more than 10 percent for seven and six harvested species, respectively (Table 13:). These were primarily geese, Fulvous Whistling-Duck, and Cinnamon Teal. These same species benefited in the bermudagrass scenario. Biofuel crops, with the exception of sugar beets, improved habitat suitability for most harvested duck species, Ring-Necked Pheasant, and elk. Bermudagrass as Irrigated Hayfield improved habitat suitability for 20 harvested species, including most of the mammals. In general the impacts on waterfowl were the most sensitive of the harvested species to the type of biofuel crop.

Table 13: Number of Harvested Species by Level of Change in Habitat Suitability for Minimize Cost Biofuel Crop Scenarios

Percent change	SSGM	SGBT	BERM	CANO	SAFF
> 10% loss	7	0	0	6	1
7.5 – 10% loss	2	0	0	3	0
5 – 7.5% loss	2	7	0	4	4
2.5 – 5% loss	3	5	0	2	6
0 – 2.5% loss	12	17	14	11	15
0 – 6.4% gain	8	5	20	8	8
Total number of species	34	34	34	34	34

ssgm = sweet sorghum, sgbt = sugar beets, berm = bermudagrass, cano = canola, saff = safflower

CHAPTER 4: Discussion

4.1 Prototyping an Integrated Framework for Trade-Off Analysis

Robertson et al. (2008) called for an integrated framework to assess trade-offs between biofuel production and other environmental objectives beyond the conventional factors of greenhouse gas emissions and fossil energy use. Many attempts are either coarse-scale assessments of land use transformation or occupancy that cannot address biodiversity impacts in any detail (McDonald et al. 2009). At the other end of the spectrum, site-specific assessments can be based on detailed information about biodiversity and agricultural management, but results are difficult to extrapolate. As the geographic scope increases, it becomes more difficult to predict the behavior of thousands of farmers when faced with potential decisions about switching to biofuel crops. This report demonstrates a five-step integrated framework to assess fine-scale changes in biodiversity associated with expanded biofuel production across California's agroecosystems. Although the results are contingent upon the underlying assumptions (discussed below) and model outcomes are highly uncertain, the framework provides a means to systematically evaluate potential wildlife impacts of alternative production scenarios. The framework also permits exploring the relative range of wildlife responses to determine whether the magnitude of impacts should raise alarm. The use of scenarios is an accepted approach to explore what-if situations in highly uncertain future projections, but does not provide definitive answers about which crop is best or what level of production is sustainable.

The initial steps generate the input data for needed to generate spatially-explicit scenarios so that impacts could be assessed. One key element in the process was the application of a widely-used and publicly-available conservation planning tool, Marxan. With some innovative adaptations to the model inputs, we were able to assess trade-offs between the cost of transporting biofuel crop biomass to a set of hypothetical biorefineries versus the impacts to a suite of wildlife species and on water demand. In principle other indicators could be incorporated where geographic variability influences environmental outcomes (such as soil carbon fluxes, nutrient fluxes) if appropriate data could be obtained.

Marxan was a useful tool for generating scenarios. We could not adapt Marxan to permit direct trade-off analysis between costs and wildlife impact in a systematic manner by setting dual objectives and varying the weights. Instead, Marxan is designed to Minimize Cost to achieve (conservation) targets. In one Marxan adaptation, Klein et al. (2008) use fishing activity as the cost, but did not set specific targets for fishing yield. Polasky et al. (2008) calculated biodiversity scores for varying levels of economic activity (net present value combined from several resources). In our case, however, the objective was to assess the impact of a given target level of biofuel production while minimizing the transportation cost. Conceptually, the adaptation to Marxan's data model was to use the net change in habitat suitability if converted to biofuel crops rather than the current level of suitability or "amount" of habitat. In this instance, there is no logical basis to set conservation targets for wildlife species. How much habitat suitability is enough for a species? Our work-around solution was to add a penalty to the cost values for each planning unit that was proportional to the total net loss in habitat suitability if that unit were selected for biofuel crop production. The penalty was weighted, allowing Marxan to generate alternative scenarios that favored more or less habitat retention with an associated change in overall transportation costs. Admittedly, this approach is rather ad hoc and lacks subtle control of the trade-off analysis. Perhaps an ideal tool for generating scenarios would be a multi-resource allocation model that sets objectives or constraints for each resource (such as crop production, habitat) and minimizes the cost to achieve them. This kind of tool has been used for decades in multiple-use forest planning (Church et al. 1998), but they are not publicly-available and would be complicated to parameterize for biofuels. Similar tools for land use allocation (Ligmann-Zielinska et al. 2008) are currently research tools and also not available.

The framework was integrated in the sense that all three primary social objectives (biofuel, biodiversity, and water) were modeled. The framework loosely couples agroeconomic modeling, GIS analysis, habitat suitability modeling, generating scenarios, and trade-off analyses were performed serially with separate tools. Several computer scripts were written to share data between these tools. Marxan has a further advantage in that it can be used to assess full or partial scenarios generated externally. For instance, a pre-defined scenario for biofuel crop production might identify the land sections to where a crop should be grown. These sections would be pre-allocated or "locked-in" in Marxan so that they were forced into the solutions. In this situation, Marxan would merely tally the effects on habitat suitability and water use. Conversely, biodiversity conservation stakeholders might design a scenario of sections to be preserved. These could be "locked-out" of any Marxan solutions to determine the effect of conservation.

4.2 Model Uncertainties and Limitations

As emphasized throughout this chapter, the results and any conclusions about impacts, trade-offs, or which biomass crops are most sustainable are all contingent upon the large number of assumptions made at each of the five steps in the framework. Here we summarize the major assumptions that could be tested further.

4.2.1 Agroeconomic Biofuel Crop Modeling

- Hypothetical biorefineries would be located as modeled by Tittmann et al. (2008). These locations determine transportation costs.
- Crop prices, input costs, biomass yields, and water use assumed for the enterprise budgets in the California Bioenergy Crop Adoption Model (Kaffka and Jenner 2010). In general, the five modeled biofuel crops are not currently grown commercially in large quantities in California so the future values of these parameters are unknown. The CBC study conducted a sensitivity analysis of these parameters. We assumed that crop price at the farmgate and transportation costs from farmgate to biorefinery were independent. In practice, costs would influence price and therefore supply of biomass.
- In the California Bioenergy Crop Adoption Model, it was assumed that total water use in a crop subregion would remain constant even with economic demand pressure for more biomass for biofuel.

- The crop modeling assumed no future changes in climate that could alter the potential distribution of suitability or yield for crops and the availability of water for irrigation.
- Conversion efficiencies of biomass to energy were based on values in the literature for current technology. Gains in efficiency from technological advances would reduce biomass requirements and hence the land area to produce it.

4.2.2 GIS Modeling of Available and Suitable Land for Biofuel Crops

- Orchards and vineyards, because of the large capital investments, would not be available for conversion to biofuel crops. Recently, however, some orchards have been taken out in response to drought and the economic recession.

4.2.3 Wildlife Habitat Suitability Modeling

- All the assumptions of the CWHR system listed in the Wildlife Habitat Suitability Modeling section.
- Our translation of the land cover map from GAP and supplemented with the DPR database for 2005 accurately portrays the current configuration of wildlife habitats.
- Bermudagrass grown for biofuel feedstock was assigned to the Irrigated Hayfield habitat type was based on the assumption that it would be grown and harvested like alfalfa. Currently it is used for pasture and kept short by grazing.
- The habitat suitability analysis was limited to changes in habitat types, based on canopy structure. We ignored differences in management practices that might also affect habitat quality for individual species, such as use of pesticides or timing of planting or harvesting relative to timing of species' life history events such as nesting. We also ignored that growing crops repeatedly in the same field can cause declines in yields over time from disease, pests, or nutrient depletion. Farmers generally rotate what crops they plant every few years to avoid these effects. Our results could be viewed as a snapshot for a single year, whereas the cropping pattern and its wildlife effects would be a dynamic shifting of crops across the landscape from year to year.
- Patch size of suitable habitat was assumed to be sufficient to sustain breeding pairs. If the minimum viable patch area were known for all species, it would be possible to use the number of breeding pairs as the metric rather than area-weighted suitability (Polasky et al. 2008).
- Best management practices for most crops suggest a rotation with other crops over time to maintain soil fertility and disrupt cycles of pests and diseases. We believe that the dynamics of crop activity, and therefore of habitat types, generally occurs between fields within farms. Our landscape scale modeling of habitat suitability should be relatively insensitive to crop rotations.
- In the absence of farm-level information about irrigation practices, we generalized the distribution of dryland farming for grain crops to specific subregions in the state that expert knowledge had identified where non-irrigated farming was the primary practice.

4.2.4 Generating Spatially Explicit Biofuel Crop Production Scenarios

- Farmers' decision making is assumed to be based solely on maximizing profit. If the Marxan model selects a farm for conversion to biofuel crop production based on cost and/or wildlife impacts, the farmer is assumed to convert the available and suitable land.
- The five biofuel crops could provide some of the feedstock needed to operate a large biorefinery, but if the agroeconomic model did not predict sufficient land and therefore biomass yield to fully supply a biorefinery, we assumed that other sources would be available to meet the remaining demand (for example, forest residues, agricultural residues, municipal solid wastes).

4.2.5 Trade-Off Analysis

- We assumed there were no indirect effects of transitioning from food crops to energy crops. That is, we did not take into account any global increases in crop prices in response to reduction of crop land in California. These price increases would likely induce landowners abroad to clear native habitats to fill the void, with consequent effects on biodiversity (Searchinger et al. 2008).
- Wildlife effects were allocated entirely to the production of biofuel in this study. There are often co-products generated in association with biofuels, such as animal feed or chemicals. A major challenge in determining impacts of renewable energy has been to standardize methods for allocating impacts to these co-products (Halleux et al. 2008). On the other hand, some processes for lignocellulosic ethanol burn part of the biomass to generate energy for the conversion. In that case, less transportation fuel would be produced, but the wildlife and water impacts would be the same as modeled in our study.

Biofuels have been promoted as an antidote to some of the ills associated with fossil fuels—greenhouse gas emissions, energy insecurity, and foreign policy issues. As investigations on biofuels have progressed, certain potential drawbacks have emerged—water quality, indirect land use (Searchinger et al. 2008, and Lapola et al. 2010), and food security. Our study has focused solely on effects on wildlife and water use associated with five biofuel crops. Any conclusions or policy decisions about adopting certain crops should consider the full suite of impacts in a trade-off analysis.

4.2.6 Opportunities for Policy Changes to Minimize Wildlife Habitat Suitability Loss

For the scenarios that attempted to minimize loss of habitat suitability, we applied an arbitrary penalty cost proportional to the loss. In practice, the choice to switch to growing biofuel crops would be made by thousands of farm owners based on the financial rewards and costs. Our penalty cost would not be a consideration for these decision makers as it was simply a modeling convenience. Resource planners have two policy tools at their disposal—incentives or land use regulations. Incentives could be provided through subsidies to growers or refiners for biomass produced on farms with low wildlife impact. Perhaps low impact zones could be established in advance so that growers would know who was eligible for subsidies. Our results found that in general there are no large areas of low impact. Rather net suitability from biofuel crop production is very heterogeneous spatially and depends in part on what crops are currently being grown. Farmers who already grow crops with high wildlife impacts would have an advantage over those with higher quality habitats. A second form of incentive could expedite permitting for biorefineries with low overall wildlife impact. A trade-off analysis similar to Figure 18 could inform the decision about which biorefineries qualify. Our results are a very preliminary attempt to inform such a decision process; substantially more study would be required. Other economic, social, and environmental factors would also have a role.

State planners have very little authority to regulate land use in the United States. That authority is primarily vested at the local governmental level. It seems unlikely that all the agricultural counties in California would develop consistent zoning and land use to preserve wildlife habitat in areas where biofuel crops could be grown. However, many listed species and other Species of Special Concern depend on remnants of natural or semi-natural habitats. Further habitat loss for these species is regulated under state and federal endangered species laws. Many local authorities are developing Natural Community Conservation Plans (state) and/or Habitat Conservation Plans (federal) to ensure adequate conservation of these species and their habitat requirements. Such plans could conserve the remnant habitat patches. In our limited analysis (Figure 24), excluding these habitat types from conversion to sweet sorghum produced superior outcomes.

CHAPTER 5: Conclusions

We remind the reader that the purpose of this study was to develop a framework for assessing potential effects of biofuel crop production on the state's wildlife species. With that framework, we generated and assessed the effects on and trade-offs between criteria for a small set of plausible scenarios. Each of the five steps in the process is contingent on many assumptions, limitations and best available information. The results, and any conclusions based upon them, should therefore be viewed as indicative of the type and magnitude of effects but not as a definitive basis for judging crop types, biorefinery locations, or biofuel policies. With those caveats in mind, we answer the research questions posed in Chapter 1, identify promising future research directions, and summarize the benefits of the framework for the people of California.

5.1 Answers to Research Questions

5.1.1 Which Agricultural Areas Seem Most Vulnerable to Reduction of Habitat Suitability From Expanded Biofuel Crop Production?

Vulnerability, in terms of potential net loss of habitat suitability, depends on the biofuel crop and on the suitability of the current habitat types. We found (Figure 8 and Figure 9) that agroecosystem lands provide relatively low suitability for wildlife. They are most suitable for feeding habitat. Wildlife tends to rely on adjacent patches of natural habitat for reproductive habitat. If these remnant patches are converted to biofuel crops, the ability of the entire landscape to support wildlife diminishes. The biofuel crops vary somewhat in the geographic areas where the California Bioenergy Crop Adoption Model predicted them to be economically viable at the $40 per acre benchmark. The current pattern of habitat types varies at such a fine grain that we did not identify any large contiguous areas that seem particularly vulnerable from any of the five biofuel crops studied. The one exception for all crops is the band of grassland and other habitat ringing the agricultural lands, particularly surrounding the Central Valley (Figure 9). Some of this land may be too hilly to cultivate or irrigate anyway. Moreover these grasslands are already a significant conservation priority for a number of organizations.

5.1.2 How Might Habitat Suitability of Wildlife Species of Special Concern Change in Response to Plausible Scenarios of Production of Biofuel Crops?

Our findings show that the choice of biofuel crop matters for wildlife. The scenarios based on the area of land predicted to be converted to each biofuel crop at a given price (level of profit). Based on the agroeconomic modeling, the scenarios varied from converting 100,000 hectares to bermudagrass up to over 500,000 hectares for canola. The biofuel energy yields also vary because of biomass yields and conversion efficiencies. On a per unit energy basis, sweet sorghum and sugar beets require three times less area than bermudagrass and 5-6 times less than canola and safflower. The aggregate change for all 53 Species of Special Concern ranged from a 5 percent loss of total suitability in the agroecosystems statewide with canola to a slight increase of 0.1 percent for bermudagrass if it was grown like alfalfa hay. It is also considered a moderately invasive plant, particularly in disturbed riparian scrub and desert washes in southern California (Cal-IPC 2006). Because the area affected varies by crop, the aggregate changes in suitability are difficult to compare directly. Again comparing net effects on a per GGE basis, canola and safflower have the highest negative impact, sweet sorghum and sugar beets are nearly identical at a medium impact, and bermudagrass has a small positive net gain in suitability.

Aggregate measures of biodiversity mask the fact that in these scenarios, some species had more dramatic losses in suitability than the average. Although a 5 percent loss may sound insignificant, this would be on top of the substantial losses in habitat quantity and quality from the original cultivation and settlement of California's natural habitats.

5.1.3 What are the Implications of the Biofuel Scenarios on Water Use?

The California Bioenergy Crop Adoption Model was constrained to allow no more than the current volume of water for irrigation in allocating land area to biofuel crops. Sugar beets provided no reduction in irrigation. That is, the water from existing crops that would be converted would be fully transferred to sugar beets in that biofuel scenario. For sweet sorghum and bermudagrass, reductions were only predicted in a few crop subregions, so the average reduction per GGE was quite small. Canola had the largest overall reduction in acre-feet of water at nearly 6 percent of current statewide irrigation. However, on a per GGE basis, the reduction was more modest than for safflower. These two oil crops require little irrigation, and canola is a winter crop that can be largely rain-fed. Moreover the water reduction would occur more widely throughout the state.

5.1.4 How Much Flexibility Exists to Produce the Same Amount of Biofuel Energy With Reduced Impact on Wildlife Species? How Much Does this Change Increase Transportation Costs of Hauling Biomass to Biorefineries?

Despite the large area of land conversion to biofuel crops in the scenarios, there is still enough flexibility such that a relatively slight relocation of farms producing biomass could dramatically reduce wildlife impacts. We found this result for all crops, but especially for canola and safflower. It is encouraging that in these scenarios the trade-off in transportation cost was relatively small compared to large gains in habitat suitability. We originally anticipated that the changes in crop-growing areas for the sake of wildlife would involve large-scale shifts, perhaps to different counties. However, the fine-scale heterogeneity in crop habitats, combined with the geographic constraints imposed by the locations of hypothetical biorefineries, generated a very minor reconfiguration in our scenarios. Probably the most significant large-scale shifts in crop locations to benefit wildlife would be associated with a different configuration of biorefineries.

As expected, scenarios that attempt to reduce the impact of biofuel crop production on habitat suitability for the Species of Special Concern would cause an increase in the cost of transporting biomass to the least-cost biorefinery. From our rough estimates of transportation costs, the increase ranges from $0.005 per GGE for bermudagrass, $0.01 per GGE for oil crops, and $0.025 for sugar crops. The California Bioenergy Crop Adoption Model predicted low production levels for bermudagrass, relative to the sugar and oil crops. Thus there is more flexibility to redistribute bermudagrass to satisfy other social objectives such as wildlife conservation and yet be just as cost-effective as when minimizing cost alone.

5.2 Future Research Directions

Assessing biodiversity impacts from renewable energy production poses a number of methodological challenges. Researchers in life cycle assessment have endeavored to develop methods for incorporating biodiversity as an indicator in their impact assessment methods. Biofuel crops in particular have been a promising product system because of the large-scale changes in land use and habitats involved in commercial scale production. Geyer et al. (2010a and b) proposed a methodology based on similar wildlife habitat suitability modeling that was used in this study. The Geyer study was a proof-of-concept using simplistic biofuel crop scenarios. The National Science Foundation has recently funded a project to develop biodiversity impact indicators for life cycle impact assessment for which we intend to use the wildlife habitat suitability modeling from the CEC-funded project. The new project will also evaluate methods to incorporate connectivity and patch size considerations into the basic habitat suitability approach.

Our review of the scientific literature and expert knowledge highlighted the dearth of information about how wildlife species, particularly non-pest species, use agroecosystem habitats. Two new trends motivate the compilation of new information about agroecosystem habitats: the growing awareness of the importance of working landscapes in conservation strategies (Daily et al. 2003, Polasky et al. 2008) and the rising demand for energy from biomass from these landscapes. Some potential biofuel crops may create novel habitats beyond the scope of the current version of CWHR. We recommend that some of the governmental funding to promote biofuel production be allocated to additional field studies of wildlife use in biofuel crop habitats, with an initial emphasis on Species of Special Concern.

The trade-off analysis reported here was based on a set of spatially-explicit scenarios of biofuel crop production that in turn were based on outputs of the California Bioenergy Crop Adoption Model. Kaffka and Jenner (2010) conducted a sensitivity analysis of the price and crop yield factors and showed a wide range in land area in response to changes in these key assumptions. In our study, we did not pursue the sensitivity of wildlife impacts to these variations in land allocations, but we recommend this be done before any policy decisions are made regarding crop types or biorefinery locations. We can speculate on what such a sensitivity analysis might find. If yields are higher than the values used in our study, less land and thus less habitat area would be converted to achieve the same biofuel production levels. However, higher yields might also make biofuel crops more profitable and lead to more land conversion and potential to produce greater biofuel yields. For some crop types though, water availability may restrain the expansion of land conversion to biofuel crops. A sensitivity analysis of the price and yield assumptions would modify the apparent precision of the points in the trade-off curves into ellipses of uncertainty.

Some studies have excluded prime farmland from consideration for growing biofuel crops to avoid conflicts with food production (Lovett et al. 2009). We did not evaluate this option in this study. The framework could readily accommodate this variation, however, either by masking prime farmland as "unsuitable" for biofuel crops (Step 2) or by locking-out sections with prime farmland in the Marxan scenario runs (Step 4). The area of food-producing prime farmland converted to biofuel production could be added as another criterion in the trade-off analysis. Because prime farmland is quite widespread in the study area, we would expect that scenarios that retained it for food production would increase the amount of natural/semi-natural habitat to be converted. Consequently preserving food production would have to be traded-off with biodiversity loss.

Biodiversity and water use are just two of many possible environmental concerns associated with biofuel crop production. The framework could be expanded to incorporate a suite of ecosystem services to be optimized concurrently (Zhang et al. 2010). Some studies have suggested that conversion of food-producing land to energy crops will lead to displacement of food production, perhaps to tropical forests (Searchinger et al. 2008). Estimates of the GHG emissions associated with this indirect land use change have been controversial because of the challenges in identifying spatially-explicit locations for the displacement. Although biodiversity would also be impacted by indirect land use change, it is an even greater challenge to model the effects than those on GHG emissions because biodiversity is so critically linked to location.

Recent studies of potential impacts of climate change have indicated that California agriculture may be vulnerable to dramatic changes by mid-century (Hayhoe et al. 2004). Climate is a major driver in determining what crops can be grown profitably in a region. Changes in precipitation would alter the availability of water for irrigation. Despite using 2050 biofuel targets to assess scenarios, the current study did not consider how future climate change might affect crop suitability or range shifts in wildlife species. As adopting policies to promote biofuel production in-state is a long-term enterprise, it would be prudent to extend the crop and habitat suitability modeling to explore the potential interactions of climate change with both crops and wildlife.

5.3 Benefits From This Research to the People of California

The urgency for mitigation actions in response to climate change and energy security prompted state policy to stimulate the rapid development of biofuel production capacity with in-state feedstock supplies (Governor's Executive Order S-06-06, California Biomass Collaborative 2006). These are certainly essential components of sustainability, but they are not the only dimensions. Among the many other environmental concerns associated with biofuel crop production, biodiversity and water use are particularly noteworthy in a region of such high diversity and competition for water as California. If meeting energy goals conflicts with endangered species regulations or with existing demands for water, biofuel production may be derailed. An integrated analytical framework is needed to model the trade-offs between biofuel production and biodiversity and water use. Several frameworks have recently appeared that integrate economics, agronomics, and land use to generate spatially-explicit scenarios (Scheffran and BenDor 2009, Bryan et al. 2010, Zhang et al. 2010, Hellmann and Verburg 2011). These frameworks have been successful in assessing some trade-offs. To our knowledge, our framework in this study is the first that systematically assesses the effects on a set of individual wildlife species and water use. The framework provides California stakeholders with a tool for exploring a range of scenarios for different bioenergy crops and yields, biorefinery locations, target levels of production, and rules determining the availability and suitability of land for biofuel crops. We hope such a framework will allow Californians to find a sustainable balance between potentially-competing social values and objectives.

GLOSSARY

Acronym	Definition
AGS	Annual Grassland
ASC	Alkali Desert Scrub
BBS	Breeding Bird Survey
CBC	California Biomass Collaborative
CDF&FP	California Department of Forestry and Fire Protection
CRP	Conservation Reserve Program
CWHR	California Wildlife Habitat Relationships
DDT	Dichlorodiphenyltrichloroethane
DPR	California Department of Pesticide Regulation
DWR	California Department of Water Resources
GAP	Gap Analysis Program
GHG	Greenhouse Gas
GGE	Gallons of gasoline equivalent
GIS	Geographic Information System
LCA	Life Cycle Assessment
NLCD	National Land Cover Dataset
PGS	Perennial Grassland
PLSS	Public Land Survey System
VOW	Valley Oak Woodland
UCD	University of California Davis
UCSB	University of California Santa Barbara

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APPENDIX A:
Results of Agroeconomic Modeling of Crop Yields, Land Area, Biofuel Production, and Water Use By Crop Subregion

Sweet Sorghum

Cluster	Short tons per acre	Acres	Total GGE	Net acre feet water
NCA1	32.0	169,821	94,012,906	0
NCA2	32.0	17,228	9,537,421	0
NCA3	32.0	0	0	0
NCA4	32.0	51,820	28,687,552	0
NCA5	32.0	9,825	5,439,120	0
NCA6	32.0	9,591	5,309,578	0
NCA7	32.0	19,970	11,055,392	0
NCA8	32.0	31,219	17,282,838	0
NCA9	32.0	15,245	8,439,632	0
NCA99*	32.0	70,106	38,810,804	0
CEN1	31.0	0	0	0
CEN2	31.0	0	0	0
CEN3	31.0	23,422	12,561,219	0
CEN4	31.0	0	0	0
CEN5	31.0	0	0	0
CEN6	31.0	15,249	8,178,039	0
CEN7	31.0	0	0	0
CEN8	31.0	0	0	0
CEN9	31.0	0	0	0
CEN99*	30.0	7,511	3,898,413	0
SSJ1	30.0	78,704	40,847,376	0
SSJ2	30.0	28,969	15,034,911	0
SSJ3	30.0	82,312	42,719,928	0
SSJ4	30.0	6,839	3,549,441	0
SSJ5	30.0	27,423	14,232,537	0
SSJ6	30.0	0	0	0
SSJ7	30.0	14,506	7,528,614	0
SSJ8	30.0	20,045	10,403,355	0
SSJ99*	30.0	56,412	29,277,782	0
SCA1	30.0	19,967	10,362,873	-7,865
SCA2	30.0	0	0	0
SCA3	30.0	14,826	7,694,694	-6,303

Cluster	Short tons per acre	Acres	Total GGE	Net acre feet water
SCA4	30.0	33,631	17,454,489	0
SCA5	30.0	7,614	3,951,666	0
SCA6	30.0	11,176	5,800,344	0
SCA99*	30.0	3,542	1,838,241	0
COA1	31.0	0	0	0
COA2	31.0	0	0	0
COA3	31.0	0	0	0
COA4	31.0	0	0	0
COA5	31.0	0	0	0
COA6	31.0	0	0	0
COA7	31.0	0	0	0
COA8	31.0	0	0	0
COA9	31.0	0	0	0
COA10	31.0	0	0	0
COA11	31.0	0	0	0
COA12	31.0	0	0	0
COA13	31.0	0	0	0
COA99*	31.0	0	0	0
Total		**846,973**	**453,909,163**	**-14,168**

Sugar Beets

Subregion	Short tons per acre	Acres	Total GGE	Net acre feet water
NCA1	30.0	79,618	39,649,764	0
NCA2	30.0	3,185	1,586,130	0
NCA3	30.0	0	0	0
NCA4	30.0	11,452	5,703,096	0
NCA5	30.0	875	435,750	0
NCA6	30.0	3,654	1,819,692	0
NCA7	30.0	12,452	6,201,096	0
NCA8	30.0	3,833	1,908,834	0
NCA9	30.0	4,443	2,212,614	0
NCA99*	30.0	25,802	12,849,603	0
CEN1	30.0	0	0	0
CEN2	30.0	156,019	77,697,462	0
CEN3	30.0	80,469	40,073,562	0
CEN4	30.0	0	0	0

Subregion	Short tons per acre	Acres	Total GGE	Net acre feet water
CEN5	30.0	0	0	0
CEN6	30.0	34,807	17,333,886	0
CEN7	30.0	0	0	0
CEN8	30.0	0	0	0
CEN9	30.0	0	0	0
CEN99*	30.0	52,696	26,242,559	0
SSJ1	42.0	26,437	18,431,876	0
SSJ2	42.0	9,267	6,460,952	0
SSJ3	42.0	745	519,414	0
SSJ4	42.0	2,422	1,688,618	0
SSJ5	42.0	335	233,562	0
SSJ6	42.0	0	0	0
SSJ7	42.0	2,423	1,689,316	0
SSJ8	42.0	160	111,552	0
SSJ99*	42.0	9,109	6,350,812	0
SCA1	42.0	514	358,361	0
SCA2	42.0	0	0	0
SCA3	42.0	12,231	8,527,453	0
SCA4	42.0	2,772	1,932,638	0
SCA5	42.0	534	372,305	0
SCA6	42.0	1,522	1,061,138	0
SCA99*	42.0	714	497,568	0
COA1	30.0	0	0	0
COA2	30.0	0	0	0
COA3	30.0	0	0	0
COA4	30.0	0	0	0
COA5	30.0	0	0	0
COA6	30.0	0	0	0
COA7	30.0	0	0	0
COA8	30.0	0	0	0
COA9	30.0	0	0	0
COA10	30.0	0	0	0
COA11	30.0	0	0	0
COA12	30.0	0	0	0
COA13	30.0	0	0	0
COA99*	30.0	0	0	0
Total		**538,490**	**281,949,614**	**0**

Bermudagrass

Subregion	Short tons per acre	Acres	Total GGE	Net acre feet water
NCA1	3.2	48,994	5,424,616	0
NCA2	3.2	4,310	477,203	0
NCA3	3.2	0	0	0
NCA4	3.2	8,204	908,347	0
NCA5	3.2	3,251	359,951	0
NCA6	3.2	0	0	0
NCA7	3.2	0	0	0
NCA8	3.2	7,779	861,291	0
NCA9	3.2	0	0	0
NCA99*	3.2	15,661	1,733,966	0
CEN1	4.5	0	0	0
CEN2	4.5	0	0	0
CEN3	4.5	0	0	0
CEN4	4.5	0	0	0
CEN5	4.5	0	0	0
CEN6	4.5	0	0	0
CEN7	4.5	0	0	0
CEN8	4.5	0	0	0
CEN9	4.5	0	0	0
CEN99*	4.5	0	0	0
SSJ1	5.1	36,632	6,464,083	0
SSJ2	5.1	12,949	2,284,981	-11,979
SSJ3	5.1	34,607	6,106,751	0
SSJ4	5.1	3,245	572,613	0
SSJ5	5.1	11,923	2,103,933	0
SSJ6	5.1	0	0	0
SSJ7	5.1	4,260	751,720	0
SSJ8	5.1	10,226	1,804,480	0
SSJ99*	5.1	24,815	4,378,836	0
SCA1	6.4	1,406	311,345	0
SCA2	6.4	0	0	0
SCA3	6.4	12,453	2,757,592	0
SCA4	6.4	1,239	274,364	0
SCA5	6.4	0	0	0
SCA6	6.4	1,940	429,594	0
SCA99*	6.4	692	153,223	0
COA1	4.5	0	0	0
COA2	4.5	0	0	0
COA3	4.5	0	0	0

Subregion	Short tons per acre	Acres	Total GGE	Net acre feet water
COA4	4.5	0	0	0
COA5	4.5	0	0	0
COA6	4.5	0	0	0
COA7	4.5	0	0	0
COA8	4.5	0	0	0
COA9	4.5	0	0	0
COA10	4.5	0	0	0
COA11	4.5	0	0	0
COA12	4.5	0	0	0
COA13	4.5	0	0	0
COA99*	4.5	0	0	0
Total		**244,586**	**38,158,886**	**-11,979**

Canola

Subregion	Short tons per acre	Acres	Total GGE	Net acre feet water
NCA1	1.0	232,559	24,744,244	-148,446
NCA2	1.0	20,578	2,189,499	-16,623
NCA3	1.0	7,068	752,035	0
NCA4	1.0	58,577	6,232,593	-31,644
NCA5	1.0	11,897	1,265,841	-11,454
NCA6	1.0	8,379	891,526	0
NCA7	1.0	17,870	1,901,368	-14,565
NCA8	1.0	39,059	4,155,878	-29,298
NCA9	1.0	15,711	1,671,650	-11,044
NCA99*	1.0	88,885	9,457,338	0
CEN1	1.0	81,042	8,622,869	-124,291
CEN2	1.0	41,243	4,388,255	0
CEN3	1.0	15,388	1,637,283	0
CEN4	1.0	0	0	0
CEN5	1.0	0	0	0
CEN6	1.0	9,980	1,061,872	0
CEN7	1.0	27,058	2,878,971	-36,604
CEN8	1.0	1,131	120,338	0
CEN9	1.0	0	0	0
CEN99*	1.0	34,155	3,634,120	0
SSJ1	1.0	111,408	11,853,811	-130,429

Subregion	Short tons per acre	Acres	Total GGE	Net acre feet water
SSJ2	1.0	39,757	4,230,145	-50,046
SSJ3	1.0	99,797	10,618,401	-167,168
SSJ4	1.0	6,775	720,860	-13,257
SSJ5	1.0	28,846	3,069,214	-54,739
SSJ6	1.0	50	5,320	0
SSJ7	1.0	19,203	2,043,199	-28,245
SSJ8	1.0	49,693	5,287,335	-19,006
SSJ99*	1.0	77,497	8,245,682	0
SCA1	1.0	30,909	3,288,718	-29,985
SCA2	1.0	459	48,838	0
SCA3	1.0	14,819	1,576,742	-48,236
SCA4	1.0	44,651	4,750,866	-52,909
SCA5	1.0	11,882	1,264,245	-6,644
SCA6	1.0	17,060	1,815,184	-9,515
SCA99*	1.0	4,864	517,577	0
COA1	1.2	0	0	0
COA2	1.2	0	0	0
COA3	1.2	0	0	0
COA4	1.2	0	0	0
COA5	1.2	0	0	0
COA6	1.2	0	0	0
COA7	1.2	0	0	0
COA8	1.2	0	0	0
COA9	1.2	0	0	0
COA10	1.2	0	0	0
COA11	1.2	0	0	0
COA12	1.2	0	0	0
COA13	1.2	0	0	0
COA99*	1.2	0	0	0
Total		**1,268,250**	**134,941,817**	**-1,034,148**

Safflower

Subregion	Short tons per acre	Acres	Total GGE	Net acre feet water
NCA1	1.2	3,592	286,211	0
NCA2	1.2	1,336	106,452	0
NCA3	1.2	6,981	556,246	0
NCA4	1.2	1,722	137,209	0
NCA5	1.2	655	52,190	0
NCA6	1.2	309	24,621	0
NCA7	1.2	2,027	161,511	0
NCA8	1.2	1,757	139,998	0
NCA9	1.2	838	66,772	0
NCA99*	1.2	4,149	330,585	0
CEN1	1.2	81,307	6,478,542	-157,195
CEN2	1.2	37,240	2,967,283	0
CEN3	1.2	13,501	1,075,760	0
CEN4	1.2	0	0	0
CEN5	1.2	0	0	0
CEN6	1.2	8,711	694,092	0
CEN7	1.2	27,618	2,200,602	-48,972
CEN8	1.2	682	54,342	0
CEN9	1.2	0	0	0
CEN99*	1.2	32,838	2,616,512	0
SSJ1	1.2	113,730	9,062,006	-89,062
SSJ2	1.2	40,728	3,245,207	-35,371
SSJ3	1.2	1,704	135,775	0
SSJ4	1.2	6,930	552,182	-10,835
SSJ5	1.2	29,687	2,365,460	-44,547
SSJ6	1.2	63	5,020	0
SSJ7	1.2	20,005	1,593,998	-21,649
SSJ8	1.2	960	76,493	0
SSJ99*	1.2	46,605	3,713,480	0
SCA1	1.2	30,606	2,438,686	-28,417
SCA2	1.2	450	35,856	0
SCA3	1.2	14,784	1,177,989	-47,406
SCA4	1.2	44,473	3,543,609	-50,903
SCA5	1.2	11,796	939,905	-6,003
SCA6	1.2	16,959	1,351,293	-8,619
SCA99*	1.2	4,836	385,295	0
COA1	1.1	0	0	0
COA2	1.1	0	0	0
COA3	1.1	0	0	0

Subregion	Short tons per acre	Acres	Total GGE	Net acre feet water
COA4	1.1	0	0	0
COA5	1.1	0	0	0
COA6	1.1	0	0	0
COA7	1.1	0	0	0
COA8	1.1	393	28,705	0
COA9	1.1	0	0	0
COA10	1.1	0	0	0
COA11	1.1	0	0	0
COA12	1.1	0	0	0
COA13	1.1	0	0	0
COA99*	1.1	75	5,452	0
Total		**610,046**	**48,605,341**	**-548,979**

* Subregions numbered 99 in each region represent agroecosystem sections not included in the DPR database for which we extrapolated area from other subregions in the region. The number of sections in subregion 99 was multiplied by the average area predicted per section to be converted in the other subregions of the region and then reduced to 25 percent as a conservative assumption. Sections were included in subregion 99 if they were farmland where pesticides had not been registered and reported to DPR or were natural or semi-natural habitat.

APPENDIX B: California's Agroecosystem Species and Subsets of Focal Species, Species of Special Concern, and Harvested Species

Focal Species: with help from experts in agroecosystems and in specific taxonomic groups, we chose a set of focal species to represent a range of characteristics and concerns:

- Distribution (local, endemic, statewide, continent-wide; and locally common vs. rare (and potentially of concern) throughout range)
- Management: species of conservation concern, hunting interest
- Taxonomic groups
- Functional groups (such as wading birds, fossorial animals, granivores, insectivores, ground-nesters)
- Species that do not use crops but occur in grassland habitats that could be converted to biofuel production.

Species of Special Concern: The State of California identifies these species that are either federally listed as threatened or endangered, meet the State definition for listing but have not yet been listed, have experienced rapid population declines or range restrictions, or have naturally small populations that are highly susceptible to risk factors (Comrack et al. 2008).

Harvested Species: The State of California manages these game species for hunting (Parisi et al. 2008). Therefore maintaining their habitats is important for the recreational opportunities they provide.

WHR Code	Common Name	Scientific Name	Focal species	Species of Special Concern	Harvested species
A001	CALIFORNIA TIGER SALAMANDER	*Ambystoma californiense*	●	●	
A014	CALIFORNIA SLENDER SALAMANDER	*Batrachoseps attenuatus*	●		
A028	WESTERN SPADEFOOT	*Spea hammondii*		●	
A030	COLORADO RIVER TOAD	*Bufo alvarius*		●	
A032	WESTERN TOAD	*Bufo boreas*	●		
A034	WOODHOUSE'S TOAD	*Bufo woodhousii*			
A036	RED-SPOTTED TOAD	*Bufo punctatus*			
A037	GREAT PLAINS TOAD	*Bufo cognatus*			
A047	EASTERN TIGER SALAMANDER	*Ambystoma tigrinum*			

WHR Code	Common Name	Scientific Name	Focal species	Species of Special Concern	Harvested species
A056	GABILAN MTNS SLENDER SALAMANDER	*Batrachoseps gavilanensis*			
B006	PIED-BILLED GREBE	*Podilymbus podiceps*			
B009	EARED GREBE	*Podiceps nigricollis*			
B010	WESTERN GREBE	*Aechmophorus occidentalis*			
B042	AMERICAN WHITE PELICAN	*Pelecanus erythrorhynchos*		●	
B044	DOUBLE-CRESTED CORMORANT	*Phalacrocorax auritus*			
B049	AMERICAN BITTERN	*Botaurus lentiginosus*			
B050	LEAST BITTERN	*Ixobrychus exilis*		●	
B052	GREAT EGRET	*Ardea alba*			
B053	SNOWY EGRET	*Egretta thula*			
B057	CATTLE EGRET	*Bubulcus ibis*			
B058	GREEN HERON	*Butorides virescens*			
B059	BLACK-CROWNED NIGHT HERON	*Nycticorax nycticorax*			
B062	WHITE-FACED IBIS	*Plegadis chihi*	●	●	
B065	FULVOUS WHISTLING-DUCK	*Dendrocygna bicolor*		●	●
B067	TUNDRA SWAN	*Cygnus columbianus*			
B070	GREATER WHITE-FRONTED GOOSE	*Anser albifrons*		●	●
B071	SNOW GOOSE	*Chen caerulescens*			●
B072	ROSS' S GOOSE	*Chen rossii*			●
B075	CANADA GOOSE	*Branta canadensis*			●
B076	WOOD DUCK	*Aix sponsa*			●
B079	MALLARD	*Anas platyrhynchos*	●		●
B080	NORTHERN PINTAIL	*Anas acuta*			●
B082	BLUE-WINGED TEAL	*Anas discors*			●
B083	CINNAMON TEAL	*Anas cyanoptera*	●		●
B084	NORTHERN SHOVELER	*Anas clypeata*			●
B085	GADWALL	*Anas strepera*			●

WHR Code	Common Name	Scientific Name	Focal species	Species of Special Concern	Harvested species
B086	EURASIAN WIGEON	*Anas penelope*			●
B087	AMERICAN WIGEON	*Anas americana*			●
B089	CANVASBACK	*Aythya valisineria*			●
B090	REDHEAD	*Aythya americana*		●	●
B093	GREATER SCAUP	*Aythya marila*			●
B101	COMMON GOLDENEYE	*Bucephala clangula*			●
B102	BARROW'S GOLDENEYE	*Bucephala islandica*			
B105	COMMON MERGANSER	*Mergus merganser*			●
B106	RED-BREASTED MERGANSER	*Mergus serrator*			●
B107	RUDDY DUCK	*Oxyura jamaicensis*			●
B111	WHITE-TAILED KITE	*Elanus leucurus*	●		
B113	BALD EAGLE	*Haliaeetus leucocephalus*		●	
B114	NORTHERN HARRIER	*Circus cyaneus*	●	●	
B119	RED-SHOULDERED HAWK	*Buteo lineatus*			
B121	SWAINSON'S HAWK	*Buteo swainsoni*		●	
B124	FERRUGINOUS HAWK	*Buteo regalis*		●	
B125	ROUGH-LEGGED HAWK	*Buteo lagopus*		●	
B133	RING-NECKED PHEASANT	*Phasianus colchicus*	●		●
B139	GAMBEL'S QUAIL	*Callipepla gambelii*			●
B140	CALIFORNIA QUAIL	*Callipepla californica*	●		●
B145	VIRGINIA RAIL	*Rallus limicola*			
B148	COMMON MOORHEN	*Gallinula chloropus*			●
B150	SANDHILL CRANE	*Grus canadensis*		●	
B151	BLACK-BELLIED PLOVER	*Pluvialis squatarola*			
B154	SNOWY PLOVER	*Charadrius alexandrinus*		●	

WHR Code	Common Name	Scientific Name	Focal species	Species of Special Concern	Harvested species
B159	MOUNTAIN PLOVER	*Charadrius montanus*		●	
B163	BLACK-NECKED STILT	*Himantopus mexicanus*			
B164	AMERICAN AVOCET	*Recurvirostra americana*			
B165	GREATER YELLOWLEGS	*Tringa melanoleuca*			
B166	LESSER YELLOWLEGS	*Tringa flavipes*			
B168	WILLET	*Tringa semipalmata*			
B170	SPOTTED SANDPIPER	*Actitis macularius*			
B173	LONG-BILLED CURLEW	*Numenius americanus*	●	●	
B176	MARBLED GODWIT	*Limosa fedoa*			
B183	WESTERN SANDPIPER	*Calidris mauri*			
B185	LEAST SANDPIPER	*Calidris minutilla*			
B191	DUNLIN	*Calidris alpina*			
B196	SHORT-BILLED DOWITCHER	*Limnodromus griseus*			
B197	LONG-BILLED DOWITCHER	*Limnodromus scolopaceus*			
B213	MEW GULL	*Larus canus*			
B214	RING-BILLED GULL	*Larus delawarensis*			
B215	CALIFORNIA GULL	*Larus californicus*		●	
B216	HERRING GULL	*Larus argentatus*			
B219	YELLOW-FOOTED GULL	*Larus livens*			
B221	GLAUCOUS-WINGED GULL	*Larus glaucescens*			
B226	GULL-BILLED TERN	*Gelochelidon nilotica*		●	
B233	FORSTER'S TERN	*Sterna forsteri*			
B235	BLACK TERN	*Chlidonias niger*		●	
B254	WHITE-WINGED DOVE	*Zenaida asiatica*			●
B257	COMMON GROUND-DOVE	*Columbina passerina*			
B259	YELLOW-BILLED CUCKOO	*Coccyzus americanus*		●	
B260	GREATER ROADRUNNER	*Geococcyx californianus*			
B264	WESTERN SCREECH OWL	*Megascops kennicottii*			
B269	BURROWING OWL	*Athene cunicularia*	●	●	

WHR Code	Common Name	Scientific Name	Focal species	Species of Special Concern	Harvested species
B273	SHORT-EARED OWL	*Asio flammeus*		●	
B275	LESSER NIGHTHAWK	*Chordeiles acutipennis*			
B286	BLACK-CHINNED HUMMINGBIRD	*Archilochus alexandri*			
B287	ANNA'S HUMMINGBIRD	*Calypte anna*			
B294	LEWIS' S WOODPECKER	*Melanerpes lewis*			
B296	ACORN WOODPECKER	*Melanerpes formicivorus*			
B297	GILA WOODPECKER	*Melanerpes uropygialis*		●	
B298	RED-NAPED SAPSUCKER	*Sphyrapicus nuchalis*			
B301	LADDER-BACKED WOODPECKER	*Picoides scalaris*			
B302	NUTTALL'S WOODPECKER	*Picoides nuttallii*			
B321	BLACK PHOEBE	*Sayornis nigricans*			
B323	SAY'S PHOEBE	*Sayornis saya*			
B324	VERMILION FLYCATCHER	*Pyrocephalus rubinus*		●	
B326	ASH-THROATED FLYCATCHER	*Myiarchus cinerascens*			
B333	WESTERN KINGBIRD	*Tyrannus verticalis*			
B337	HORNED LARK	*Eremophila alpestris*			
B339	TREE SWALLOW	*Tachycineta bicolor*			
B340	VIOLET-GREEN SWALLOW	*Tachycineta thalassina*			
B341	NORTHERN ROUGH-WINGED SWALLOW	*Stelgidopteryx serripennis*			
B342	BANK SWALLOW	*Riparia riparia*		●	
B343	CLIFF SWALLOW	*Petrochelidon pyrrhonota*			
B344	BARN SWALLOW	*Hirundo rustica*			
B348	WESTERN SCRUB-JAY	*Aphelocoma californica*			
B352	YELLOW-BILLED MAGPIE	*Pica nuttalli*			
B353	AMERICAN CROW	*Corvus brachyrhynchos*			●
B358	OAK TITMOUSE	*Baeolophus inornatus*			
B359	VERDIN	*Auriparus flaviceps*			
B360	BUSHTIT	*Psaltriparus minimus*			
B365	CACTUS WREN	*Campylorhynchus*		●	

WHR Code	Common Name	Scientific Name	Focal species	Species of Special Concern	Harvested species
		brunneicapillus			
B369	HOUSE WREN	*Troglodytes aedon*			
B372	MARSH WREN	*Cistothorus palustris*			
B377	BLUE-GRAY GNATCATCHER	*Polioptila caerulea*			
B380	WESTERN BLUEBIRD	*Sialia mexicana*	●		
B381	MOUNTAIN BLUEBIRD	*Sialia currucoides*			
B386	HERMIT THRUSH	*Catharus guttatus*			
B390	VARIED THRUSH	*Ixoreus naevius*			
B391	WRENTIT	*Chamaea fasciata*			
B393	NORTHERN MOCKINGBIRD	*Mimus polyglottos*			
B394	SAGE THRASHER	*Oreoscoptes montanus*			
B399	CRISSAL THRASHER	*Toxostoma crissale*		●	
B407	CEDAR WAXWING	*Bombycilla cedrorum*			
B409	NORTHERN SHRIKE	*Lanius excubitor*			
B410	LOGGERHEAD SHRIKE	*Lanius ludovicianus*		●	
B425	ORANGE-CROWNED WARBLER	*Vermivora celata*			
B461	COMMON YELLOWTHROAT	*Geothlypis trichas*		●	
B475	BLACK-HEADED GROSBEAK	*Pheucticus melanocephalus*			
B476	BLUE GROSBEAK	*Passerina caerulea*			
B477	LAZULI BUNTING	*Passerina amoena*			
B483	SPOTTED TOWHEE	*Pipilo maculatus*			
B484	CALIFORNIA TOWHEE	*Pipilo crissalis*			
B485	ABERT'S TOWHEE	*Pipilo aberti*			
B491	BREWER'S SPARROW	*Spizella breweri*			
B494	VESPER SPARROW	*Pooecetes gramineus*		●	
B495	LARK SPARROW	*Chondestes grammacus*			
B496	BLACK-THROATED SPARROW	*Amphispiza bilineata*			
B499	SAVANNAH SPARROW	*Passerculus sandwichensis*		●	
B501	GRASSHOPPER SPARROW	*Ammodramus savannarum*	●	●	
B509	GOLDEN-CROWNED	*Zonotrichia atricapilla*			

WHR Code	Common Name	Scientific Name	Focal species	Species of Special Concern	Harvested species
	SPARROW				
B514	LAPLAND LONGSPUR	*Calcarius lapponicus*			
B519	RED-WINGED BLACKBIRD	*Agelaius phoeniceus*	●		
B520	TRICOLORED BLACKBIRD	*Agelaius tricolor*	●	●	
B521	WESTERN MEADOWLARK	*Sturnella neglecta*	●		
B522	YELLOW-HEADED BLACKBIRD	*Xanthocephalus xanthocephalus*		●	
B525	GREAT-TAILED GRACKLE	*Quiscalus mexicanus*			
B530	HOODED ORIOLE	*Icterus cucullatus*			
B543	LESSER GOLDFINCH	*Carduelis psaltria*			
B545	AMERICAN GOLDFINCH	*Carduelis tristis*			
B548	CLARK'S GREBE	*Aechmophorus clarkii*			
B620	HARRIS' S HAWK	*Parabuteo unicinctus*			
B629	PACIFIC GOLDEN-PLOVER	*Pluvialis fulva*			
B648	BAIRD'S SANDPIPER	*Calidris bairdii*			
B649	PECTORAL SANDPIPER	*Calidris melanotos*			
B773	AMERICAN REDSTART	*Setophaga ruticilla*			
B798	WHITE-THROATED SPARROW	*Zonotrichia albicollis*			
B809	INDIGO BUNTING	*Passerina cyanea*			
B864	CACKLING GOOSE	*Branta hutchinsii*			
M006	ORNATE SHREW	*Sorex ornatus*		●	
M019	CALIFORNIA LEAF-NOSED BAT	*Macrotus californicus*		●	
M028	CALIFORNIA MYOTIS	*Myotis californicus*	●		
M033	WESTERN RED BAT	*Lasiurus blossevillii*	●		
M035	WESTERN YELLOW BAT	*Lasiurus xanthinus*			
M039	BRAZILIAN FREE-TAILED BAT	*Tadarida brasiliensis*	●		
M040	POCKETED FREE-TAILED BAT	*Nyctinomops femorosaccus*		●	
M047	DESERT COTTONTAIL	*Sylvilagus audubonii*			●
M068	NELSON'S ANTELOPE	*Ammospermophilus*		●	

WHR Code	Common Name	Scientific Name	Focal species	Species of Special Concern	Harvested species
	SQUIRREL	*nelsoni*			
M072	CALIFORNIA GROUND SQUIRREL	*Spermophilus beecheyi*	●		
M074	ROUND-TAILED GROUND SQUIRREL	*Spermophilus tereticaudus*		●	
M086	LITTLE POCKET MOUSE	*Perognathus longimembris*		●	
M087	SAN JOAQUIN POCKET MOUSE	*Perognathus inornatus*		●	
M104	HEERMANN'S KANGAROO RAT	*Dipodomys heermanni*			
M105	CALIFORNIA KANGAROO RAT	*Dipodomys californicus*	●		
M106	GIANT KANGAROO RAT	*Dipodomys ingens*		●	
M108	STEPHENS' KANGAROO RAT	*Dipodomys stephensi*		●	
M111	FRESNO KANGAROO RAT	*Dipodomys nitratoides*		●	
M112	AMERICAN BEAVER	*Castor canadensis*			
M122	SOUTHERN GRASSHOPPER MOUSE	*Onychomys torridus*		●	
M123	HISPID COTTON RAT	*Sigmodon hispidus*	●		
M125	WHITE-THROATED WOODRAT	*Neotoma albigula*			
M134	CALIFORNIA VOLE	*Microtus californicus*	●		
M139	COMMON MUSKRAT	*Ondatra zibethicus*			
M146	COYOTE	*Canis latrans*			●
M148	KIT FOX	*Vulpes macrotis*	●	●	
M149	GRAY FOX	*Urocyon cinereoargenteus*	●		●
M166	BOBCAT	*Lynx rufus*	●		●
M177	ELK	*Cervus elaphus*			●
M181	MULE DEER	*Odocoileus hemionus*	●		●
M182	PRONGHORN	*Antilocapra americana*			●
R004	WESTERN POND TURTLE	*Actinemys marmorata*	●	●	

WHR Code	Common Name	Scientific Name	Focal species	Species of Special Concern	Harvested species
R008	WESTERN BANDED GECKO	*Coleonyx variegatus*			
R010	DESERT IGUANA	*Dipsosaurus dorsalis*			
R012	ZEBRATAIL LIZARD	*Callisaurus draconoides*			
R014	COACHELLA VALLEY FRINGE-TOED LIZARD	*Uma inornata*		●	
R018	LONG-NOSED LEOPARD LIZARD	*Gambelia wislizenii*			
R019	BLUNT-NOSED LEOPARD LIZARD	*Gambelia sila*	●	●	
R020	DESERT SPINY LIZARD	*Sceloporus magister*			
R024	SIDE-BLOTCHED LIZARD	*Uta stansburiana*			
R030	DESERT HORNED LIZARD	*Phrynosoma platyrhinos*			
R039	WESTERN WHIPTAIL	*Aspidoscelis tigris*			
R050	SPOTTED LEAFNOSE SNAKE	*Phyllorhynchus decurtatus*			
R052	COACHWHIP	*Masticophis flagellum*		●	
R055	WESTERN PATCHNOSE SNAKE	*Salvadora hexalepis*			
R056	GLOSSY SNAKE	*Arizona elegans*			
R057	GOPHER SNAKE	*Pituophis catenifer*	●		
R060	LONGNOSE SNAKE	*Rhinocheilus lecontei*			
R065	CHECKERED GARTER SNAKE	*Thamnophis marcianus*			
R079	GIANT GARTER SNAKE	*Thamnophis gigas*	●	●	

APPENDIX C: Wildlife in California's Agroecosystems: Determining Habitat Suitability to Assess Impact of Biofuel Crop Production

Methods

Habitat Suitability Ratings for Current Agricultural Habitat Types and For Potential Biofuel Crops

Literature Review of Agroecosystem Habitat Use by Focal Wildlife Species

We interviewed experts and did a literature search to compile current knowledge of how the 32 focal species associate with relevant agricultural ecosystems in California. We incorporated data from the Midwest (where more research has been done on wildlife in agriculture, and in biofuel crops in particular) when the same or closely related species used crop types relevant to California, although we prioritized California-specific information. When little or no information was available, we also considered data from closely related species. To identify experts, we started with recognized experts in California agroecosystems, and then asked at the end of each interview who else we should contact. For the literature search, we did broad searches:

> *TS=((wildlife OR biodiversity OR vertebrate OR bird OR mammal OR reptile OR amphibian) AND California AND (habitat OR use OR abundance) AND (biofuel* OR bioenergy OR agricultur* OR corn OR safflower OR beet* OR sorghum OR sugar OR canola OR "bermudagrass" OR "reed canary grass" OR switchgrass));*

and also combined agricultural, biofuel, and specific crops with each species name (common and Latin):

> *TS=("species name inserted here" AND (biofuel* OR bioenergy OR agricultur* OR cropland OR corn OR safflower OR beet* OR sorghum OR sugar OR canola OR "bermudagrass" OR "reed canary grass" OR switchgrass))*.

If we found compelling evidence to change suitability ratings, we proposed changes to the original CWHR, which were then reviewed by our panel of wildlife experts. It is important to note that our revisions are biased towards inclusion. Data are usually presented telling that a given species was found in a certain crop type, but we rarely found studies indicating that a certain crop type was searched but that a given species was never found in that crop type (with the exception of Best et al.1995).

Addition of Biofuel Crop Habitat Types

We added three new habitat types that are subtypes of existing CWHR agricultural habitat types: corn, sweet sorghum, and high-density hay grasses. We did not find sufficient information in the literature review to separate sugar beets from other row crops, and oilseed crops from other grains.

We based the initial habitat suitability ratings for our new crop types on the corresponding original CWHR habitat type. Then we modified the ratings as we found more information on specific crops. Corn is from the Irrigated Grain habitat type of the current CWHR, and sweet sorghum is from the "irrigated grain crop" type. Several potential high-density hay grasses (*Panicum virgatum* (switchgrass), *Miscanthus giganteus*, *Phalaris arundinacea* (reed canary grass), *Cynodon dactylon* (bermudagrass)), however, are not currently grown for biofuel in California and do not map readily into the CWHR habitat types. For these new high-density hay grasses, the closest existing CWHR habitat type is "irrigated hayfield" whose suitability ratings are based primarily on alfalfa. We expect high-density grasses grown for hay to function differently from alfalfa, but this is our nearest approximation. Sugar cane, which is currently grown in the Imperial Valley on a small scale, does not correspond to any of the existing CWHR types. We did not model sugar cane because we found no information on wildlife use in sugar cane in California and only scare information on wildlife in sugar cane elsewhere. We expect, however, that sugar cane would be good habitat for blackbirds and two rat species present in California: *Rattus norvegicus and R. rattus*. Red-winged Blackbirds roost in sugar cane (Yasukawa and Searcy 1995), and rats (*R. exulans, R. norvegicus and R. rattus*) are a universal control problem in sugar cane (Tobin et al. 1990). We would also expect that sugar cane would not support a large diversity of songbirds; a study in Panama found that sugar cane (along with introduced pine) supported the fewest number of bird species of any modified habitat (Petit et al. 1999).

Comparison of Predictions of Suitability (CWHR Vs. MCWHR)

We compared the ratings in the original CWHR habitat suitability matrix to our updated and revised ratings (mCWHR) based on the literature review and interviews with wildlife experts using a (matched-pairs) paired t-test (JMP, SAS Inst., N.C. 2010).

Using only the mCWHR values for 32 focal species, we compared the habitat value of the different agriculture types, and compared these between species of concern and other species. For habitats with multiple stages (rice, deciduous orchard, and evergreen orchard), we used the maximum value for that habitat type, as in Brosi et al. (2006), because we are interested in the potential habitat value of a given habitat type.

Validating Wildlife Habitat Suitability Ratings

We checked our mCWHR ratings against two sources of field data for birds (no databases for other taxa were available). First, we used the report from extensive field surveys conducted in agricultural fields for the Imperial Irrigation District (IID, ERA 2008) for the four species and three crop types that overlapped with our study. This survey was conducted by driving along transects throughout the Imperial Valley, and noting the number of individuals of each focal bird species, as well as crop conditions in the field at the time of the survey. A χ^2 test was used to measure the significance of association between each species and each crop type. We calculated the coefficient of determination (R^2) between z-scores (both significant and non-significant) and our mCWHR ratings.

As a second test of the habitat ratings, we compared mapped habitat suitability to local abundance from North American Breeding Bird Survey (BBS) data. BBS data are based on 3-minute point counts every 0.5 mi. along 25 mile routes surveyed annually by observers coordinated by the U.S. Geological Survey (http://www.pwrc.usgs.gov/BBS/, Sauer et al. 2007, USGS Patuxent Wildlife Research Center 2009). Because the BBS is not well suited to abundance estimation for wading birds, shorebirds, or raptors (White and Hurlbert 2010), we limited our analysis to the following eight species within our list of focal species: California Quail, Grasshopper Sparrow, Red-winged Blackbird, Ring-necked Pheasant, Tricolored Blackbird, Western Bluebird, Western Meadowlark and Burrowing Owl. The Burrowing Owl was our exception to excluding raptors, because Burrowing Owls are readily visible from roadsides (S. Rothstein, personal communication).

The BBS only occurs during the breeding season, when species are likely to more strongly tied to breeding territory. We therefore used only suitability for reproduction for this analysis, and ignored suitability for foraging and cover. We first checked that variation in counts of each species from the Breeding Bird Survey did not vary significantly by year. Next, we examined crop habitats and corresponding predicted suitability during the time period from 2000-2007 (2003 was not included because of problems with data formatting). Using the annual DPR data on acres of each crop type in each section, we modeled habitat suitability across each BBS route for each year. Each BBS route was buffered by 0.25 miles on either side of the route, because this was the area nominally surveyed (Sauer et al. 2007). We area-weighted the sections that overlap the buffered BBS routes: this method assumes that the different habitat types within a section are spread evenly throughout the section, but, given the scale of the data, this assumption was necessary and we don't expect it to introduce systematic error. We tested for trends in habitat suitability over the 7-year period using linear regression, to determine whether any routes would provide temporal variation which could then be compared to temporal variation in bird counts. Next, we examined whether the bird counts along routes were predicted by the habitat suitability along that route.

Results

Habitat Suitability Ratings for Current Agricultural Habitat Types and for Potential Biofuel Crops

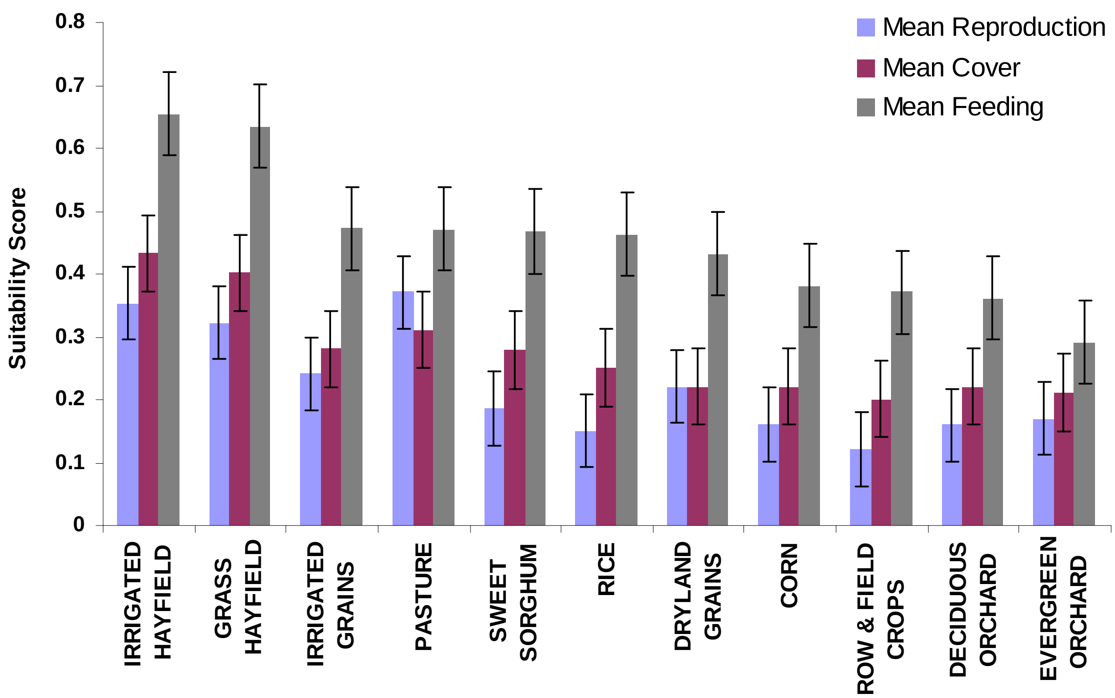
Literature Review of Agroecosystem Habitat Use by Focal Wildlife Species

We added new categories for crops with potential for renewable energy. We also added to and changed existing CWHR rankings through literature search and expert opinion.

Using our new suitability values, we assessed the relative suitability of different agricultural habitat types for wildlife (Figure C-1).

Suitability rankings are higher for feeding than for reproduction or cover, and this is generally true for agroecosystems (but not native habitats) in California (Brosi et al. 2006). Brosi et al. (2006) also found slight negative correlation in agricultural habitats between reproduction and feeding.

Figure C- 1: Mean Of Suitability Scores for Each Agroecosystem



With No Suitability = 0; Low = 0.33; Med = .66, And High =1

Comparison of Predictions of Suitability (CWHR Vs. MCWHR)

Although the majority of habitat suitability ratings in mCWHR did not change from the original CWHR ratings, a small number were uprated (for example, a "low" score was adjusted to a "medium" score) and a similar number were downrated (Table C-1). The number of changes was greatest for the feeding category, and the difference between the original and modified CWHR was significant ($p > |t| = 0.0022$). The changes for cover were less dramatic ($p > |t| = 0.097$), and were not significant for reproduction ($p > |t| = 0.71$). The full set of modifications in ratings is shown in Table C-2.

Table C-1: Number of Times the Suitability Ranking for a Species Was Downrated, Unchanged, or Uprated for the 32 Focal Species (352 Rankings)

	R	C	F
Uprated: mCWHR>CWHR	30 (9%)	21 (6%)	45 (13%)
Unchanged	298 (85%)	317 (90%)	284 (81%)
Downrated: mCWHR<CWHR	24 (7%)	14 (4%)	23 (7%)

Table C-2: Changes in Habitat Suitability Ratings Based on Literature Review

					CWHR			Modified CWHR	
Species Name	Habitat Name	Size	Stage	Repro	Cover	Feed	mRepro	mCover	mFeed
CALIFORNIA TIGER SALAMANDER	PASTURE						M	M	M
CALIFORNIA SLENDER SALAMANDER	PASTURE						L	L	L
CALIFORNIA SLENDER SALAMANDER	RICE	1	A (non-flooded)	L	L	L			
CALIFORNIA SLENDER SALAMANDER	RICE	1	B (non-flooded)	L	L	L			
WESTERN TOAD	GRASS HAYFIELD			H	M	M		M	M
WESTERN TOAD	CORN			L	L	L		L	L
WESTERN TOAD	DRYLAND GRAIN CROPS			L	L	L		L	L
WESTERN TOAD	IRRIGATED GRAIN CROPS			L	L	L		L	L
WESTERN TOAD	IRRIGATED HAYFIELD			H	M	M		M	M
WESTERN TOAD	IRRIGATED ROW AND FIELD CROPS			L	L	L		L	L
WESTERN TOAD	SWEET SORGHUM			L	L	L		L	L
NORTHERN LEOPARD	CORN			L	L	L		L	L

Species Name	Habitat Name	Size	Stage	CWHR Repro	 Cover	 Feed	Modified CWHR mRepro	 mCover	 mFeed
FROG									
NORTHERN LEOPARD FROG	IRRIGATED GRAIN CROPS			L	L	L		L	L
NORTHERN LEOPARD FROG	IRRIGATED ROW AND FIELD CROPS			L	L	L		L	L
NORTHERN LEOPARD FROG	SWEET SORGHUM			L	L	L		L	L
MALLARD	CORN			H	H	H	L		
MALLARD	DRYLAND GRAIN CROPS						L		M
MALLARD	PASTURE						M		
MALLARD	RICE	1	A (non-flooded)		L	M	M	M	M
MALLARD	RICE	1	B (non-flooded)		L	M	M	M	M
MALLARD	RICE	2	M	L	L	M	H	H	H
MALLARD	RICE	2	D	L	L	M	H	H	H
CINNAMON TEAL	RICE	1	B (non-flooded)		M	M	M	M	L
CINNAMON TEAL	RICE	2	M (flooded)		L	L	M	H	H
CINNAMON TEAL	RICE	2	D (flooded)		L	L	M	H	H
WHITE-TAILED KITE	CORN				M	H		L	M
WHITE-TAILED KITE	PASTURE						L		L
NORTHERN HARRIER	GRASS HAYFIELD			H	H	H	M	M	M
NORTHERN HARRIER	CORN			H	H	H	H	H	M
NORTHERN HARRIER	IRRIGATED ROW AND FIELD CROPS						L	L	L
NORTHERN HARRIER	PASTURE						M	L	M
RING-NECKED	GRASS			H	H	H	M	M	M

Species Name	Habitat Name	Size	Stage	CWHR Repro	CWHR Cover	CWHR Feed	Modified CWHR mRepro	Modified CWHR mCover	Modified CWHR mFeed
PHEASANT	HAYFIELD								
RING-NECKED PHEASANT	CORN			H	H	H	L	M	M
RING-NECKED PHEASANT	PASTURE						L		L
RING-NECKED PHEASANT	SWEET SORGHUM			H	H	H	L	M	M
LONG-BILLED CURLEW	PASTURE						L	L	L
BURROWING OWL	GRASS HAYFIELD			H	H	H	L	M	M
BURROWING OWL	DRYLAND GRAIN CROPS								L
BURROWING OWL	IRRIGATED GRAIN CROPS								L
BURROWING OWL	IRRIGATED ROW AND FIELD CROPS						L	L	L
WESTERN BLUEBIRD	DECIDUOUS ORCHARD	2	Young Trees		L	M	L	L	M
WESTERN BLUEBIRD	DECIDUOUS ORCHARD	3	Mature Trees		L	M	L	L	M
WESTERN BLUEBIRD	EVERGREEN ORCHARD	2	Young Trees				L		
WESTERN BLUEBIRD	EVERGREEN ORCHARD	3	Mature Trees				L		
GRASSHOPPE R SPARROW	CORN								L
GRASSHOPPE R SPARROW	DRYLAND GRAIN CROPS								L
GRASSHOPPE R SPARROW	IRRIGATED GRAIN CROPS								L
GRASSHOPPE R SPARROW	IRRIGATED HAYFIELD			L	L	L	M	M	M
GRASSHOPPE R SPARROW	PASTURE						M	M	M
GRASSHOPPE	SWEET								L

Species Name	Habitat Name	Size	Stage	Repro	CWHR Cover	Feed	mRepro	Modified CWHR mCover	mFeed
R SPARROW	SORGHUM								
RED-WINGED BLACKBIRD	CORN						M	M	M
RED-WINGED BLACKBIRD	DRYLAND GRAIN CROPS						L		M
RED-WINGED BLACKBIRD	IRRIGATED GRAIN CROPS						L		M
RED-WINGED BLACKBIRD	PASTURE						L		L
RED-WINGED BLACKBIRD	SWEET SORGHUM								M
TRICOLORED BLACKBIRD	DRYLAND GRAIN CROPS					H	H		H
TRICOLORED BLACKBIRD	EVERGREEN ORCHARD	3	Mature Trees				L		L
TRICOLORED BLACKBIRD	IRRIGATED GRAIN CROPS						H		H
TRICOLORED BLACKBIRD	IRRIGATED ROW AND FIELD CROPS					H			L
TRICOLORED BLACKBIRD	PASTURE								M
WESTERN MEADOWLARK	GRASS HAYFIELD			H	H	H	M	M	M
WESTERN MEADOWLARK	CORN			L	L	L			
WESTERN MEADOWLARK	IRRIGATED ROW AND FIELD CROPS								L
WESTERN MEADOWLARK	PASTURE						H	H	H
CALIFORNIA MYOTIS	DECIDUOUS ORCHARD	1	Seedling/ Sapling Tree			M			L
CALIFORNIA MYOTIS	DECIDUOUS ORCHARD	2	Young Trees						M
CALIFORNIA	DECIDUOUS	3	Mature				L	L	M

Species Name	Habitat Name	Size	Stage	CWHR Repro	CWHR Cover	CWHR Feed	Modified CWHR mRepro	Modified CWHR mCover	Modified CWHR mFeed
MYOTIS	ORCHARD		Trees						
CALIFORNIA MYOTIS	DRYLAND GRAIN CROPS					M			L
CALIFORNIA MYOTIS	EVERGREEN ORCHARD	1	Seedling/ Sapling Tree			M			L
CALIFORNIA MYOTIS	EVERGREEN ORCHARD	2	Young Trees						M
CALIFORNIA MYOTIS	EVERGREEN ORCHARD	3	Mature Trees				L	L	M
CALIFORNIA MYOTIS	IRRIGATED GRAIN CROPS					M			L
CALIFORNIA MYOTIS	IRRIGATED HAYFIELD					M			L
CALIFORNIA MYOTIS	PASTURE					M			H
CALIFORNIA MYOTIS	RICE	2	S (flooded)			L			H
CALIFORNIA MYOTIS	RICE	2	M (flooded)			L			H
CALIFORNIA MYOTIS	RICE	2	D (flooded)			L			H
CALIFORNIA MYOTIS	SWEET SORGHUM					M			L
WESTERN RED BAT	GRASS HAYFIELD					M			
WESTERN RED BAT	DECIDUOUS ORCHARD	1	Seedling/ Sapling Tree						L
WESTERN RED BAT	DECIDUOUS ORCHARD	2	Young Trees				L	L	M
WESTERN RED BAT	DECIDUOUS ORCHARD	3	Mature Trees				L	L	H
WESTERN RED BAT	EVERGREEN ORCHARD	1	Seedling/ Sapling Tree						L
WESTERN RED BAT	EVERGREEN ORCHARD	2	Young Trees				L	L	M

Species Name	Habitat Name	Size	Stage	Repro	CWHR Cover	Feed	mRepro	Modified CWHR mCover	mFeed
WESTERN RED BAT	EVERGREEN ORCHARD	3	Mature Trees				H	H	H
WESTERN RED BAT	IRRIGATED HAYFIELD					M			L
WESTERN RED BAT	PASTURE					M			L
WESTERN RED BAT	RICE	1	A (non-flooded)			M			L
WESTERN RED BAT	RICE	1	B (non-flooded)			M			L
BRAZILIAN FREE-TAILED BAT	GRASS HAYFIELD					L			M
BRAZILIAN FREE-TAILED BAT	CORN					L			M
BRAZILIAN FREE-TAILED BAT	DECIDUOUS ORCHARD	1	Seedling/ Sapling Tree			L			L
BRAZILIAN FREE-TAILED BAT	DECIDUOUS ORCHARD	2	Young Trees						M
BRAZILIAN FREE-TAILED BAT	DECIDUOUS ORCHARD	3	Mature Trees						H
BRAZILIAN FREE-TAILED BAT	EVERGREEN ORCHARD	1	Seedling/ Sapling Tree			L			L
BRAZILIAN FREE-TAILED BAT	EVERGREEN ORCHARD	2	Young Trees						M
BRAZILIAN FREE-TAILED BAT	EVERGREEN ORCHARD	3	Mature Trees						H
BRAZILIAN FREE-TAILED BAT	IRRIGATED ROW AND FIELD CROPS					L			M
BRAZILIAN FREE-TAILED BAT	PASTURE					L			M
BRAZILIAN FREE-TAILED	RICE	2	S (flooded)			L			H

Species Name	Habitat Name	Size	Stage	CWHR Repro	CWHR Cover	CWHR Feed	Modified CWHR mRepro	Modified CWHR mCover	Modified CWHR mFeed
BAT									
BRAZILIAN FREE-TAILED BAT	RICE	2	M (flooded)			L			H
BRAZILIAN FREE-TAILED BAT	RICE	2	D (flooded)			L			H
CALIFORNIA GROUND SQUIRREL	CORN			M	M	H		L	L
CALIFORNIA GROUND SQUIRREL	DECIDUOUS ORCHARD	2	Young Trees				M	M	M
CALIFORNIA GROUND SQUIRREL	DECIDUOUS ORCHARD	3	Mature Trees				M	M	M
CALIFORNIA GROUND SQUIRREL	EVERGREEN ORCHARD	2	Young Trees				M	M	M
CALIFORNIA GROUND SQUIRREL	EVERGREEN ORCHARD	3	Mature Trees				M	M	M
CALIFORNIA GROUND SQUIRREL	IRRIGATED GRAIN CROPS			M	M	H		M	H
CALIFORNIA GROUND SQUIRREL	IRRIGATED HAYFIELD			M	M	H		L	M
CALIFORNIA GROUND SQUIRREL	IRRIGATED ROW AND FIELD CROPS			M	M	H		M	H
CALIFORNIA GROUND SQUIRREL	RICE	1	A (non-flooded)	M	M	M		M	M
CALIFORNIA GROUND SQUIRREL	RICE	1	B (non-flooded)	M	M	M		M	M
CALIFORNIA GROUND SQUIRREL	SWEET SORGHUM			M	M	H		M	H
HISPID COTTON RAT	IRRIGATED HAYFIELD			H	H	H	M	M	M

Species Name	Habitat Name	Size	Stage	Repro	CWHR Cover	Feed	mRepro	Modified CWHR mCover	mFeed
HISPID COTTON RAT	PASTURE			H	H	H	M	M	M
CALIFORNIA VOLE	GRASS HAYFIELD						H	H	H
CALIFORNIA VOLE	IRRIGATED HAYFIELD			M	M	H	H	H	H
KIT FOX	DECIDUOUS ORCHARD	2	Young Trees					L	L
KIT FOX	DECIDUOUS ORCHARD	3	Mature Trees					L	L
KIT FOX	IRRIGATED ROW AND FIELD CROPS								L
GRAY FOX	EVERGREEN ORCHARD	2	Young Trees					M	M
GRAY FOX	EVERGREEN ORCHARD	3	Mature Trees					M	M
BOBCAT	EVERGREEN ORCHARD	2	Young Trees						L
BOBCAT	EVERGREEN ORCHARD	3	Mature Trees						L
MULE DEER	EVERGREEN ORCHARD	2	Young Trees						M
MULE DEER	EVERGREEN ORCHARD	3	Mature Trees						M
BLUNT-NOSED LEOPARD LIZARD	PASTURE							L	L

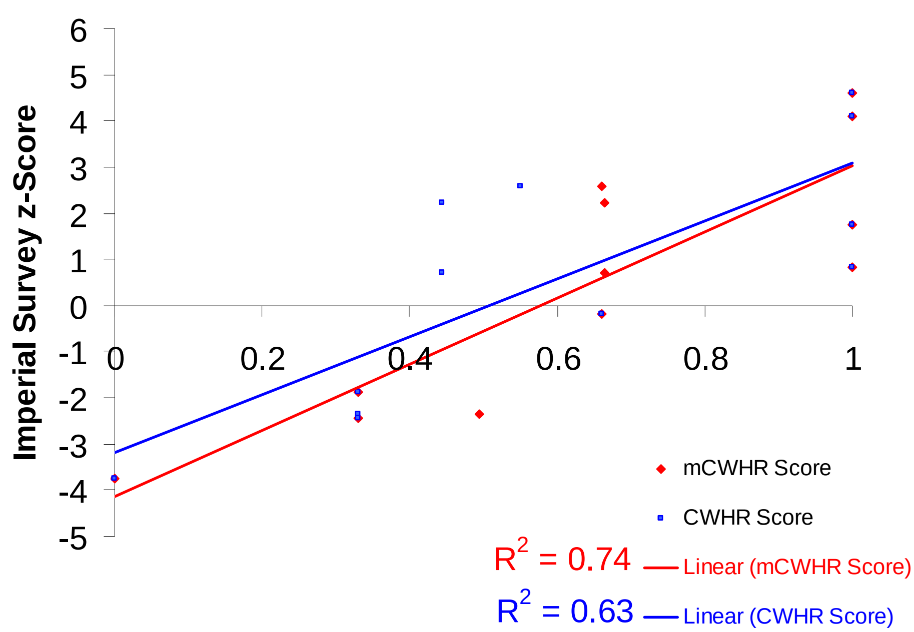
We modeled suitability at the section-level to determine how the differences between CWHR and mCWHR affect modeled suitability across the species ranges and the existing habitat. We compared the average suitability across the three life history stages (to compare whether habitats were *useful to* populations), the minimum of the life history stages (to compare whether habitats could actually *sustain* populations), and each of the life history stages (reproduction, cover and feeding) between CWHR and mCWHR. We found that a few species lost or gained a significant percentage of their habitat suitability, but for most focal species and in aggregate, the changes were not great. The species whose modeled suitability was at least 1 percent lower in mCWHR (in at least one metric, usually multiple) were Hispid cotton rat, California ground squirrel, Western toad and Ring-necked Pheasant. The species whose modeled suitability was at least 1 percent greater in mCWHR were California vole, Long-billed Curlew, kit fox, Burrowing

Owl, Red-winged Blackbird, Brazilian free-tailed bat, Northern Harrier, White-faced Ibis, Grasshopper Sparrow, Western red bat, Western Meadowlark, and Cinnamon Teal. Species which showed gains in some metrics and losses in others were the Tricolored Blackbird, California myotis and Mallard.

Validating Wildlife Habitat Suitability Ratings

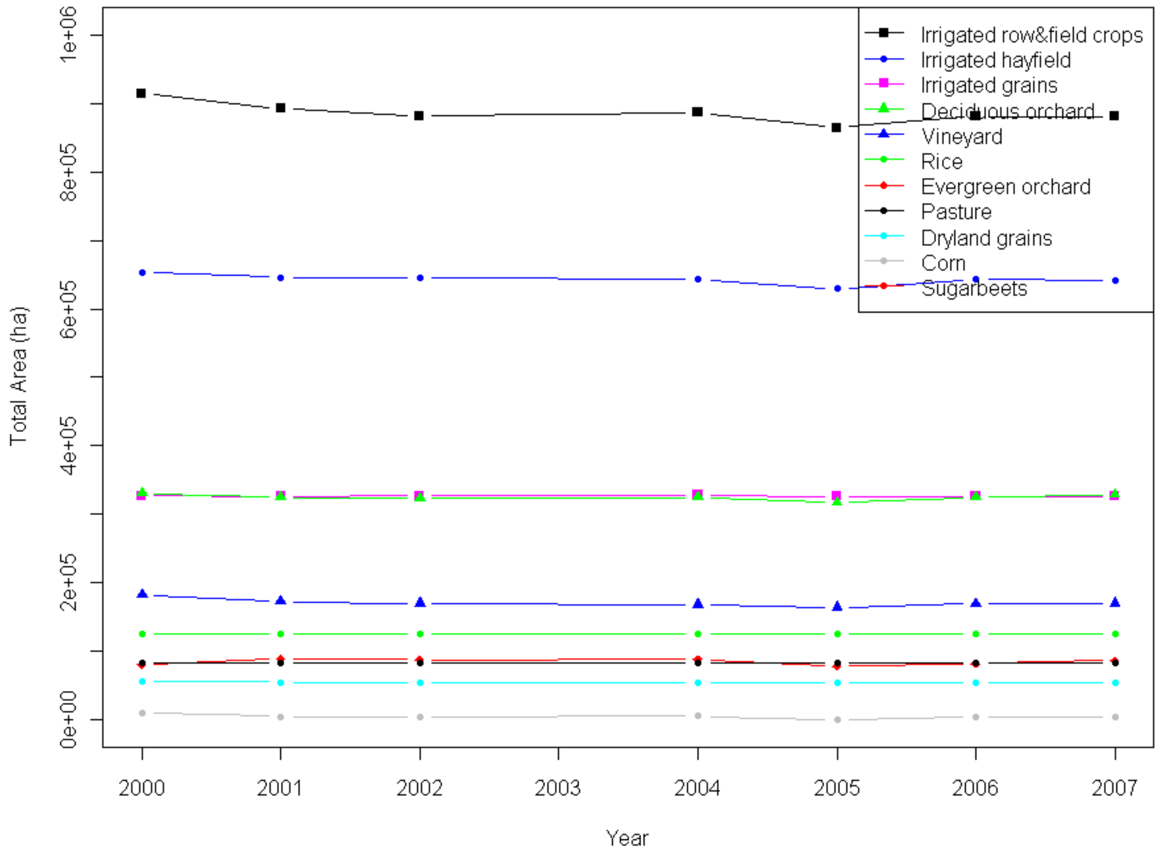
When we checked our CWHR suitability values (average of cover and feeding) against the z-scores for four species in the IID report (Figure C-2), we found a high degree of association (R^2=0.69). The association between the mCWHR values and the IID data was even more pronounced (R^2=0.74), which we expect because the nine modifications to the CHWR for these four species were based partially on the IID report.

Figure C- 2: Relationship Between Habitat Suitability Scores fromCWHR and MCWHR Modeling and Z-Scores for the Imperial Survey



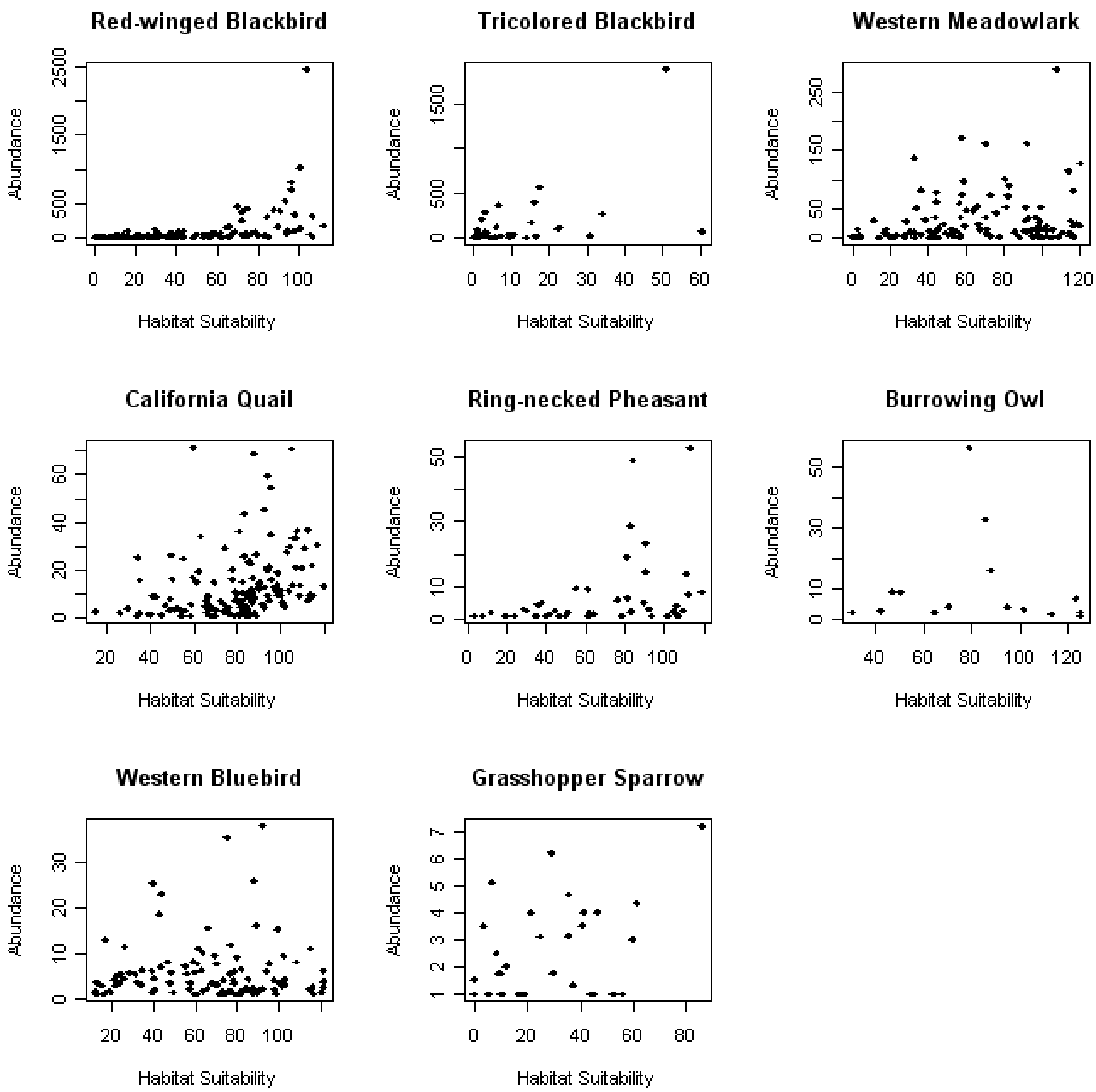
The amount of crops in each of our categories also did not vary by year (for example, from a grain crop to an orchard), (Figure C-3, ANOVA, R project, P > F = 0.992). As we would expect given this result, the predicted suitability also did not vary by year for reproduction, cover, or feeding (ANOVA, R project, P > F = 0.903 (reproduction), = 0.872 (cover), = 0.790 (feeding)). Suitability for reproduction varied according to species but not according to route (linear regression, R project, whole model p<0.001), while suitability for cover and feeding varied according to both species and route (linear regression, R project, whole model p<0.001).

Figure C- 3: Area in Each Crop Type Along BBS Routes by Year



We found that species counts from the BBS did not vary systematically by year, and instead varied only by species (linear regression, R project, whole-model p<0.001). Suitability along routes partially explained variance in the counts of species Figure C-4), and although the degree of association was low (R^2= 0.071), it was a significant effect, providing further support for CWHR (linear regression, R project, whole model p<0.001).

Figure C- 4: Habitat Suitability as Measured by Habitat Maps and MCWHR Rankings Versus Abundance



Management Implications

With rare exceptions for some pest species, we do not know much about wildlife use of agricultural lands. The wildlife effects of expanded biofuels production will be species-specific and will depend on management practices (Groom et al 2008). Our predictions of wildlife habitat use based on habitat type only tell a fraction of the story: to more accurately predict the changes that will occur as we produce more biofuels, we need to consider management practices. Some management practices that would benefit wildlife would cost farmers, and may therefore need to be subsidized. Other practices are free or even beneficial to farmers.

In this section, we summarize the lessons learned from our literature review and expert interviews on how biofuels production may influence our focal species. We gathered information on effects on focal species, but these species were particularly chosen to represent a range of management concerns, therefore we expect these concerns to be broadly applicable.

The most critical management practices to consider are water management, harvest timing, tilling, and treatment of field margins and other surrounding features. Pest management and pesticide application, landscape context, lighting, fencing, and management of domestic pets are also influential.

In addition to the changes in management that we expect from changing between crop types, crops grown for fuel are treated differently than crops grown for food. Most importantly, contamination with fecal matter and other animal matter is not a concern for biofuel crops, so pest management strategies and other practices to exclude wildlife from croplands will be different. In addition, some biofuel crops will require less fertilization and irrigation (Bies 2006).

Water Management

The presence of water attracts wildlife to agriculture and is often the chief reason a species will use croplands. Wetland-dependent species used to be numerous in California's Central Valley because wetlands were numerous. These species now depend on irrigated agriculture, especially flood-irrigated crops like rice. Water is also present in irrigation ditches, troughs, and ponds, and its presence is indirectly felt through the relatively lush environment created by irrigated crops. Substituting non-irrigated for irrigated crops, or reducing the amount of flood-irrigated crops grown, will have impacts for wildlife.

Standing water is probably the most influential water feature in agricultural landscapes. Long-billed Curlews, for example, use flooded fields, drainage ditches, and farm ponds, in addition to non-flooded fields (Dugger and Dugger 2002). Ponds (especially within pastures) and waterways/irrigation ditches are very important for amphibians (R. Fisher, personal communication). Giant garter snakes feed in remnant wetlands, rice fields, and irrigation and drainage canals (Wylie and Amarello 2008, R. Fisher, M. Jennings, personal communications). Other animals drink water directly: some bat species swoop in and drink water from pools and troughs, so netting or other obstructions can be dangerous.

Irrigation ditches and right-of-ways are a particular landscape feature used by species in California. A majority of California's Burrowing Owl population is in the Imperial Valley, where owls nest along irrigation ditches (DeSante et al. 2004, Rosenberg and Haley 2004). The Imperial Irrigation District, which manages most of the ditches on which the owls depend, manage for sustaining the owl population by such methods as flagging and avoiding burrows when mowing around ditches (B. Wilcox, Imperial Irrigation District, personal communication). San Joaquin kit fox also live along irrigation right-of-ways (Cypher 2010).

Flooded fields attract their own suite of wildlife, including Northern Harrier (ERA 2008, MacWhirter and Bildstein 1996), White-faced Ibis (Cogswell 1977), and Cinnamon Teal (Gammonley 1996). Flooding of fields also kills non-mobile organisms, including California vole (Whisson and Salmon 2008, R. Baldwin, D. Kelt, and D. Van Vuren, personal communications) and California ground squirrels (Marsh 1998, D. Van Vuren, personal communication), and destroys burrows for other organisms, including California ground squirrel. Flood irrigation can help control pest species, but can also have a negative impact on species of concern

Irrigation changes the value of crops to wildlife, even when standing water is not left in the field. Irrigated fields encourage insects, which in turn form a prey base for many species. Irrigated crops provide insect prey for many species, including Cinnamon Teal (in irrigated hay, J. Eadie, personal communication), and White-faced Ibis (Bray and Klebenow 1988), although the ibis seem to prefer fields with standing water (ERA 2008). Irrigated agriculture can support large rodent populations, particularly the California vole, which is an important prey item for Northern Harriers in California (Davis and Niemela 2008).

Another aspect of water in agriculture is timing. Rather than natural flow regimes and natural storage in wetlands, we now store water in reservoirs and have a less dynamic water regime. This may benefit some species (for example, insectivores, which have a steadier stream of prey base), but may hurt other species, like migrating waterfowl dependent on seasonally inundated wetlands. Irrigated agriculture lowers the water table, which lowers nest success for Red-winged Blackbirds (Gallion 2008).

Harvest, Mowing, and Grazing

Both the timing, intensity and pattern of harvest (mowing) and grazing can affect wildlife. This will be especially important for timing the mowing of grass hay crops. An important wildlife-friendly management practice for biofuel production is to postpone harvest until after ground-nesting birds have fledged from their nests (Bies 2006, Fargione et al. 2009). Strip harvesting – harvesting only some parts of the field or only some fields within a landscape mosaic – will leave habitat for cover for species that need it, and this has been identified as an important practice for biofuel crop production in the U.S. Midwest (Bies 2006, Roth et al. 2005). Leaving crop residues can also have important impacts: crop residues are an important cover and food source for ground-feeding birds, such as Sharp-tailed Grouse, pheasants, mourning doves, and turkey (Bies 2006). Northern Harriers nest on the ground, so in hay crops, delaying haying and plowing until after nestlings have fledged (ca. mid July) will increase their success (Davis and Niemela 2008). Blackbirds and Long-billed Curlews will also be negatively impacted by poorly timed harvest of hay grasses.

Another wildlife-friendly practice that has proved successful and easy to implement is flagging burrows to avoid them when mowing. This would help burrows of Burrowing Owls, nests of Northern Harrier, dens of San Joaquin kit fox, and eggs of Western pond turtle, as these species frequently nests in areas which are mowed and mowing can destroy their burrows (example given Haug et al. 1993, Davis and Niemela 2008, Warrick et al. 2007, and M. Jennings, personal communication).

Some species need open spaces in which to hunt, and therefore prefer mowed or overgrazed pasture. These species include Burrowing Owls (Gervais et al. 2008) and blunt-nosed leopard lizards (R. Fisher, personal communication). Other species can only use pasture when it is ungrazed or lightly grazed, such as Northern Harrier (MacWhirter and Bildstein 1996, Davis and Niemela 2008), and still others prefer a moderate amount of grazing (California ground squirrel, Marsh 1998).

Tilling

Most cropland in California is currently tilled, including 98 percent of annual crops in the Central Valley (Mitchell et al. 2007). Some biofuel crops, however, do not require tilling, so changing to these crops would have a big impact on wildlife. Most high-density grasses grown for biofuels, such as switchgrass, are not normally tilled. Other biofuel crops may require tilling or discing, but this could occur at a different time of year from food crops, which will influence wildlife by disturbing underground burrows at a different point during different species' life cycles.

In addition to its other purposes, tilling can be an important non-toxic pest management strategy for California ground squirrel and other rodent pests, but like any practice which reduces rodent populations, by destroying burrows, it will reduce populations of both the fossorial animals themselves and the animals that depend on them for food or depend on their burrows for shelter.

Tilling can be used to reduce pest populations, or can be timed to not kill certain populations. Many species will be reduced or completely absent from tilled fields, including kangaroo rats (D. Kelt, personal communication), Hispid cotton rat (D. Van Vuren, personal communication), California ground squirrel (Marsh 1998, D. Van Vuren, personal communication), California vole, and Red-winged Blackbird (Gallion 2008).

Tilling also destroys the burrows of non-pest or even beneficial wildlife, including any reptile or amphibian with low movement ability (D. Van Vuren, U.C. Davis, personal communication). And when tilling destroys burrows, this negatively impacts species which depend on pre-existing burrows. In California, several species depend on the burrows of California ground squirrel, including California Tiger Salamanders (US Fish and Wildlife Service 2003), Burrowing Owl, and San Joaquin kit fox.

In addition to these effects, tilling will increase erosion, which could have indirect effects on wildlife, especially downstream aquatic wildlife.

Crop Density

Different crops are planted and grown at different densities. Hay grasses grown for biofuels, for example, are often planted at very high density. The density at which crops are planted will affect a variety of species. For example, Western toads are very adaptable (M. Jennings, personal communication) and are perhaps the amphibian that will use agriculture the most (R. Fisher, personal communication), but they will not use crops which are too dense (R. Fisher, personal communication). Switchgrass is often planted at too high a density to allow use by Western toad (R. Fisher, personal communication). Kangaroo rats also aren't expected to do well in switchgrass because it is too dense (Kelt, personal communication), and tall or dense crops such as corn discourage ground squirrels (D. Van Vuren, personal communication). Vegetation density is the most important factor in determining which bird species used Miscanthus versus reed canary grass (Semere and Slater 2007). California voles and Hispid cotton rat, on the other hand, may do very well in dense grasses and alfalfa (D. Van Vuren, personal communication).

Field Margins, Habitat Fragments, and Landscape Context

Field margins, hedgerows, shelterbelts, edges of irrigation ditches, and other habitat fragments in agricultural landscapes can support high species diversity. Treatment of these habitat fragments varies widely. Areas of unharvested land near or in fields improves habitat for wildlife in farmland landscapes (Fargione et al. 2009). We expect that when farmers grow biofuel rather than food, they will not have fewer concerns about wildlife using these habitats and contaminating crops. Therefore growers may be more likely to leave these habitats undisturbed.

Many species forage in agriculture, but also depend on fragments of non-cultivated land. For example, Burrowing Owls nest along irrigation ditches and roads, San Joaquin kit fox nest along irrigation right-of-ways (Warrick et al. 2007), and songbirds use field margins (Benton et al. 2003). Both Burrowing Owls (Gervais et al. 2003) and kit fox (Warrick et al. 2007) forage in nearby agricultural fields, even though they won't use burrows directly in fields. Burrowing Owls in agricultural areas showed little or no selection for cover types: instead, they chose foraging location determined by distance to their burrow (Gervais et al. 2003, Gervais et al. 2008, Rosenberg and Haley 2004). In southern California, bobcats use was higher in areas near avocado orchards than in wildlands (Nogeire et al. *unpublished data*). A comprehensive survey of birds in agricultural landscapes in Iowa found high species abundance in wooded fencerows, railroad rights-of-way, farmstead shelterbelts and grassed waterways (Best et al. 1995). White-tailed Kites forage over a variety of agricultural lands, including pasture and other crops (Dunk 1995, ERA 2008). To roost, however, they usually require small stands of trees, although they are occasionally observed roosting in orchards or in open fields on the ground (Dunk 1995). Ring-necked Pheasants use a variety of agricultural habitats, but prefer heterogeneous landscapes (Giudice and Ratti 2001).

Bats also forage over agricultural fields but rest in surrounding features. California myotis, for example, feed over a variety of agricultural habitats (CWHR) but need trees, rocky crevices, caves, mines, or buildings to form colonies (Long et al. 2006). For bats, the most important elements of agricultural habitats are insect communities and structure. When changing between crop types, two of the three most important elements are inclusion versus removal of hedgerows and lines of trees, and changing patterns of buildings near the fields (the third is which insects are available and how much they are controlled, as discussed below) (R. Long, U.C. Extension Specialist, personal communication).

Some species require different types of agricultural to meet different life-history requirements. Mallards, for example, need wetland habitat for feeding and upland habitat for nesting, and these habitats should be fairly near to each other (J. Fleskes, USGS Western Ecological Research

Center, personal communication). Although they require these two landscape features, they can nest in a wide variety of habitat types, including alfalfa, pastures, cropland, grasslands, and wetlands, provided that cover is sufficient (Drilling et al. 2002). Another example is mule deer: in California, mule deer use alfalfa (and sometimes cause serious damage), but only when there is cover habitat nearby (Whisson and Salmon 2008). In general, we can expect that wildlife will benefit from more heterogeneity in agricultural landscapes (Benton et al. 2003) and especially in landscape where biofuels are produced on a large scale (Fletcher et al. 2010).

Other species don't use crop fields at all, and persist in agricultural landscapes entirely in non-cultivated lands. Most amphibians don't use crop fields, but they will persist in field margins (R. Fisher, USGS & UCSD, personal communication). California tiger salamanders are also sometimes found crossing through non-intensive, often bare dirt (fallow) agricultural fields in the Salinas and Sonoma Valleys during winter migration (R. Fisher, personal communication). California slender salamanders don't directly use crop fields, but they may use crop margins: for example, willows or other vegetation along a stream adjacent to crops (R. Fisher, M. Jennings, personal communication). They may use pasture as long as there are some downed logs, trees, rocks, or ground litter (C. Davidson, San Francisco State University, and R. Fisher, personal communications). Blunt-nosed leopard lizards generally won't use agriculture, but may use fallow fields or open space along irrigation systems.

Pest Management

Many of our focal species depend on prey that are considered pests to farmers, and therefore will be influenced by the type and intensity of pest management. The primary effects of pesticide management are secondary effects of pesticides and reduced prey base (either insect or rodent). Use of pesticides instead of alternative methods is expected to reduce habitat value for wildlife (Fargione et al. 2009).

Ground squirrels are a keystone species of California agroecosystems. They are also a key pest species across the state. The management of California ground squirrels ripples throughout wildlife communities, so their management in biofuel crops will be especially important. Reducing ground squirrel populations by any methods will negatively impact the populations of species which depend on their burrows (example given California tiger salamander, US Fish and Wildlife Service 2003) or depend on the ground squirrels for food, as described above. But the method of ground squirrel control is even more important. Ground squirrels are often poisoned, and this has been linked with non-target poisoning of several carnivore species, including San Joaquin kit fox and bobcat (Cypher 2010, Riley et al. 2007).

Pesticides have direct impacts on wildlife mortality and morbidity either through direct exposure (in example toads, coyotes, some birds) or through eating contaminated food (animals that eat rodents or insects). Pesticides also have indirect impacts by reducing prey base of rodents and insects. Wildlife will benefit from reduced pesticide use and use of less noxious pesticides and pest management.

Pesticides will have a large effect on all amphibians, but especially toads, because they sit directly on the soil and pesticides will be incorporated via their brood patch, and because they may be on the field very soon after pesticide is applied. The effects could be lethal or sub-lethal, and could also be indirect, through the effect of reduced insect prey (M. Jennings, California Academy of Sciences, personal communication).

Gopher snakes, for example, are habitat generalists, and will use many types of habitat as long as prey is available (M. Jennings, R. Fisher, personal communication).

Many bats are insectivorous. In general, bats prefer to forage in places where they will always find food, so crops with annual fluctuations are less favorable then perennial crops such as orchards or perennial grasses (R. Long, personal communication). The preferred food of Western red bats is moths, which are agricultural pests (R. Long et al. 2006). Mexican free-tailed bats also eat mostly moths, many of which are agricultural pests (Bat Conservation International 2009).

Burrowing owl association with agriculture is possibly due to greater availability of prey items in agricultural fields (Moulton et al. 2006). Burrowing Owls are dependent on burrowing mammals both as a source of burrows and as a prominent prey item. Rodent control measures, particularly those aimed at California ground squirrels, are thus detrimental to burrowing owl populations. Pesticides may be decreasing reproduction rates for Burrowing Owls (Gervais et al. 2000)

Northern Harriers were highly affected by dichlorodiphenyltrichloroethane (DDT), therefore other pesticides are possibly of concern (Davis and Niemela 2008). Overgrazing, haying, agricultural intensification, and rodenticide application degrade habitat by reducing small mammal prey (Davis and Niemela 2008).

Western Bluebirds are primarily insectivorous during the breeding season. Red-winged Blackbirds are infamous for their consumption of grains, which is often damaging to crops and would therefore reduce yields of biofuel crops, but their breeding diet is almost entirely insects (Gallion 2008).

Lighting, Fencing, and Domestic Pets

Appropriate lighting and fencing will keep wildlife away from areas where it is undesirable and will not disturb wildlife in other areas. Keeping domestic dogs and cats inside at night will keep them from scaring or attacking wildlife. Keeping livestock, poultry, dogs and cats inside at night will prevent them from being attacked by wildlife, which in turn will reduce human-wildlife conflicts. These wildlife-friendly practices apply to all agriculture, and we do not expect biofuel crops to have any particular differences.

APPENDIX D:
Maps of Biofuel Crop Scenarios

Figure D- 1: Minimize Cost Scenario for Sweet Sorghum (ssgm1-0)

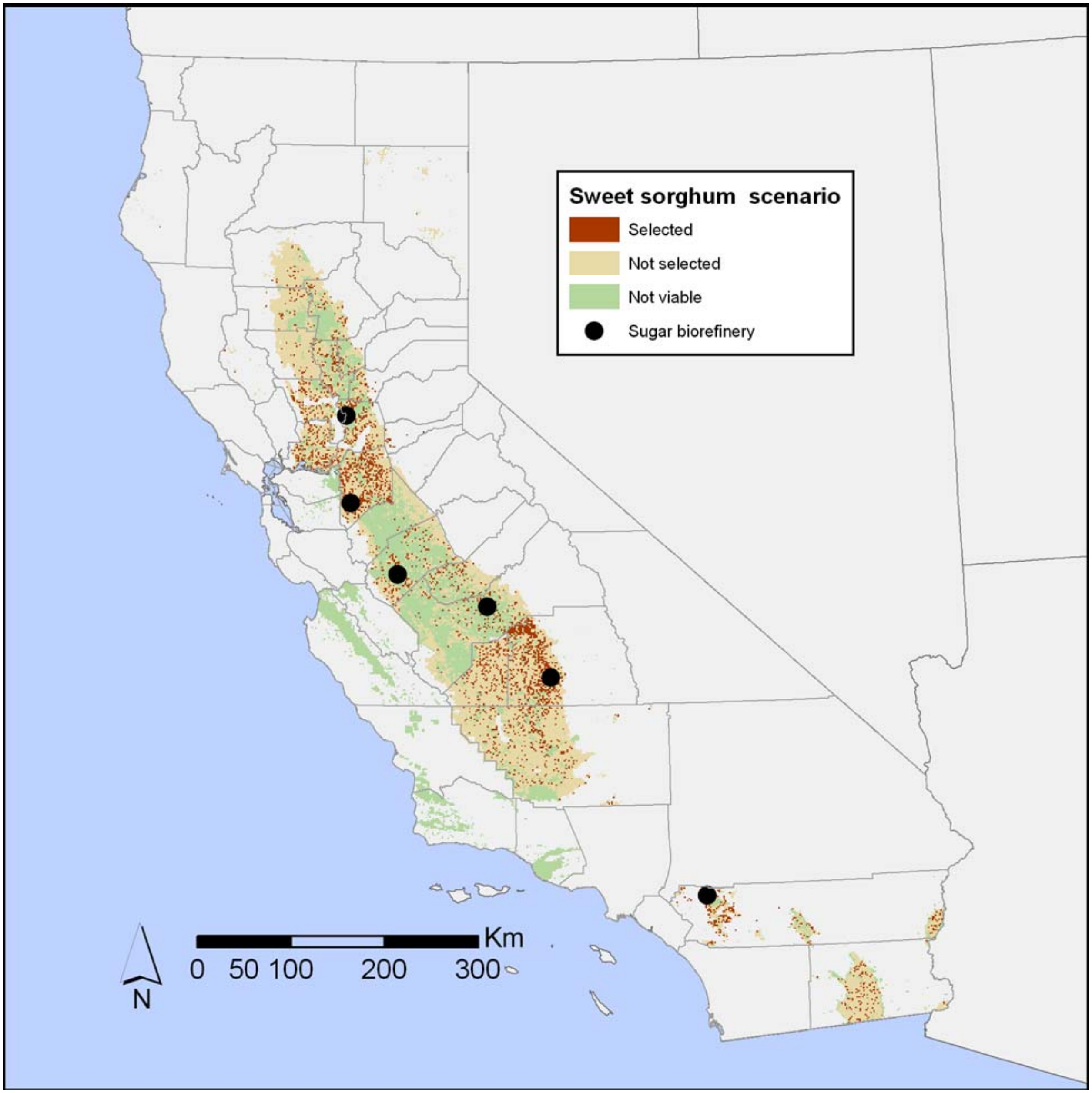


Figure D- 2: Minimize Loss Scenario for Sweet Sorghum That Minimizes Loss of Habitat Suitability (ssgm1-100)

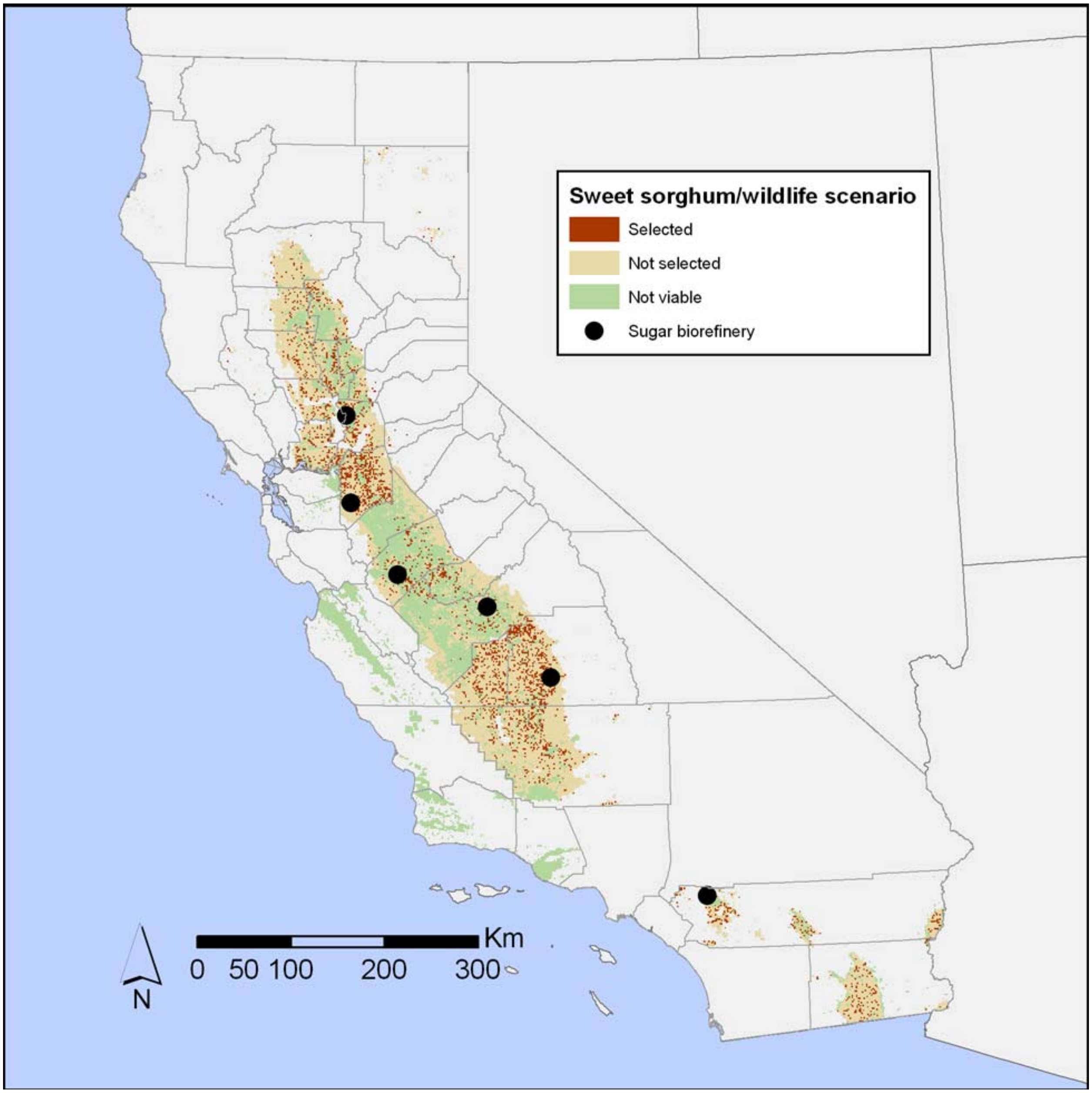


Figure D- 3: Minimize Cost Scenario for Sweet Sorghum Where Conversion Is Limited to Existing Agricultural Land (ssgm2-0)

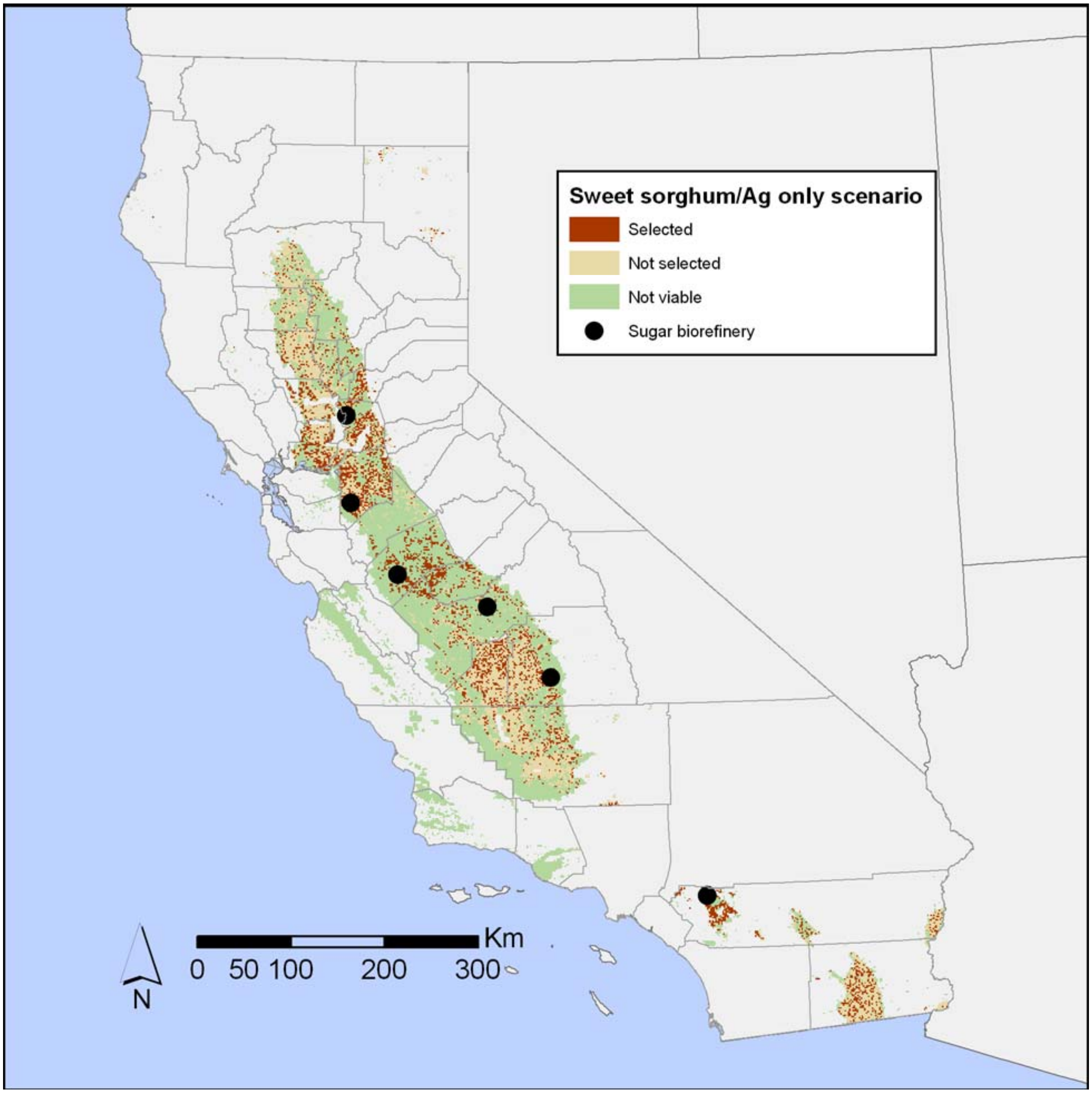


Figure D- 4: Minimize Cost Scenario for Sugar Beets (sgbt1-0)

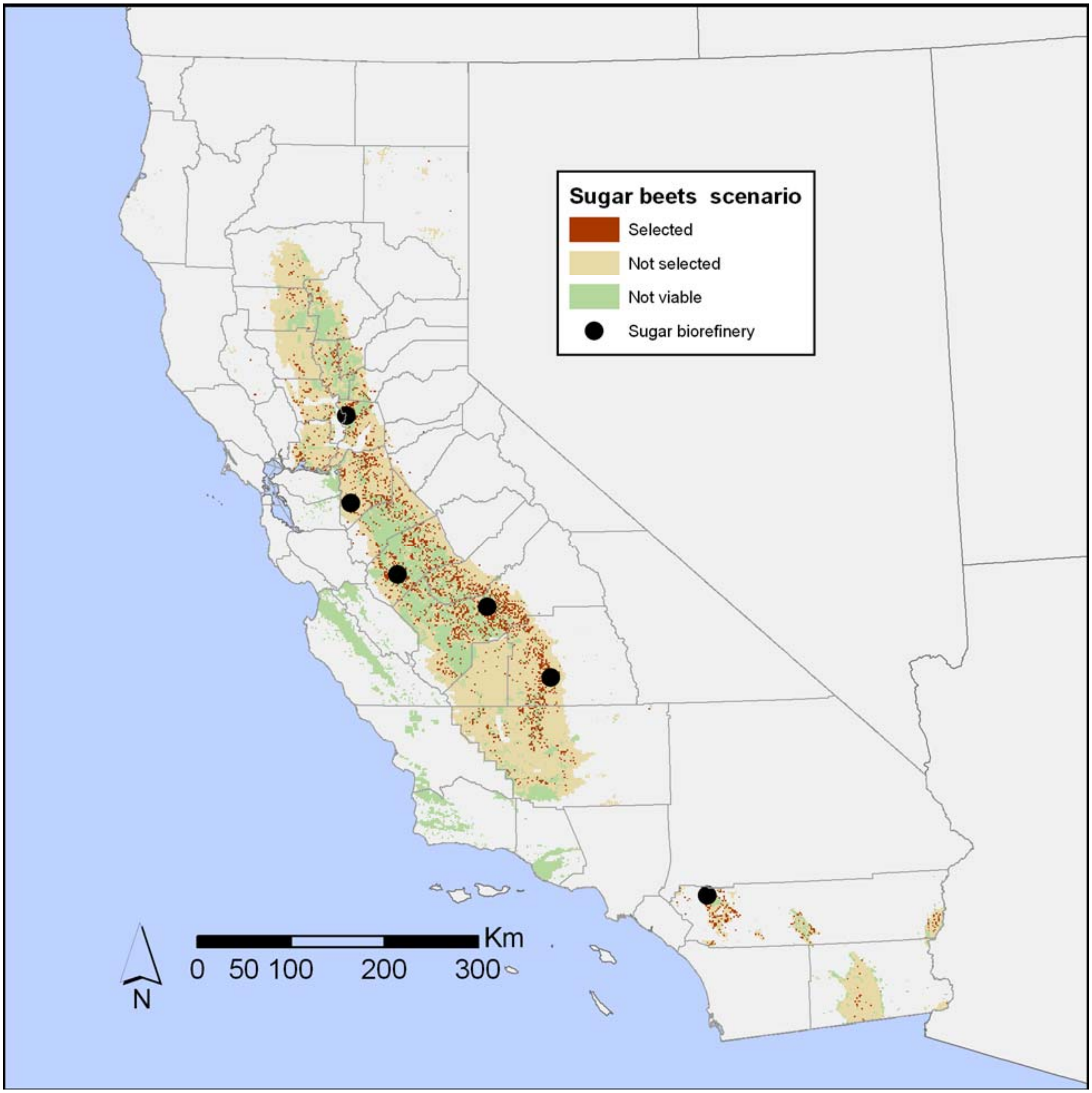


Figure D- 5: Minimize Loss Scenario for Sugar Beets That Minimizes Loss of Habitat Suitability (sbgt1-100)

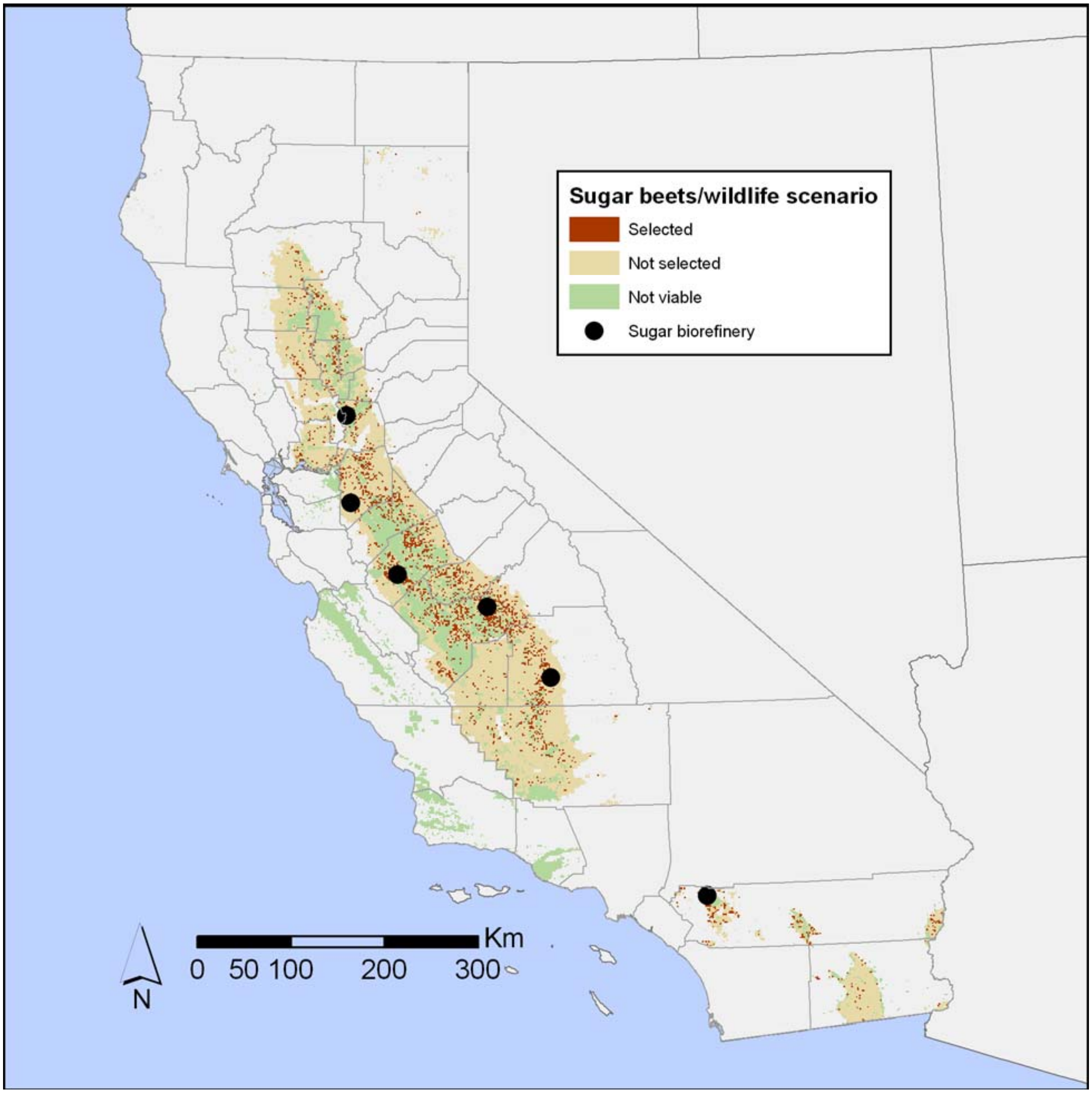


Figure D- 6: Minimize Cost Scenario for Bermudagrass (berm1-0)

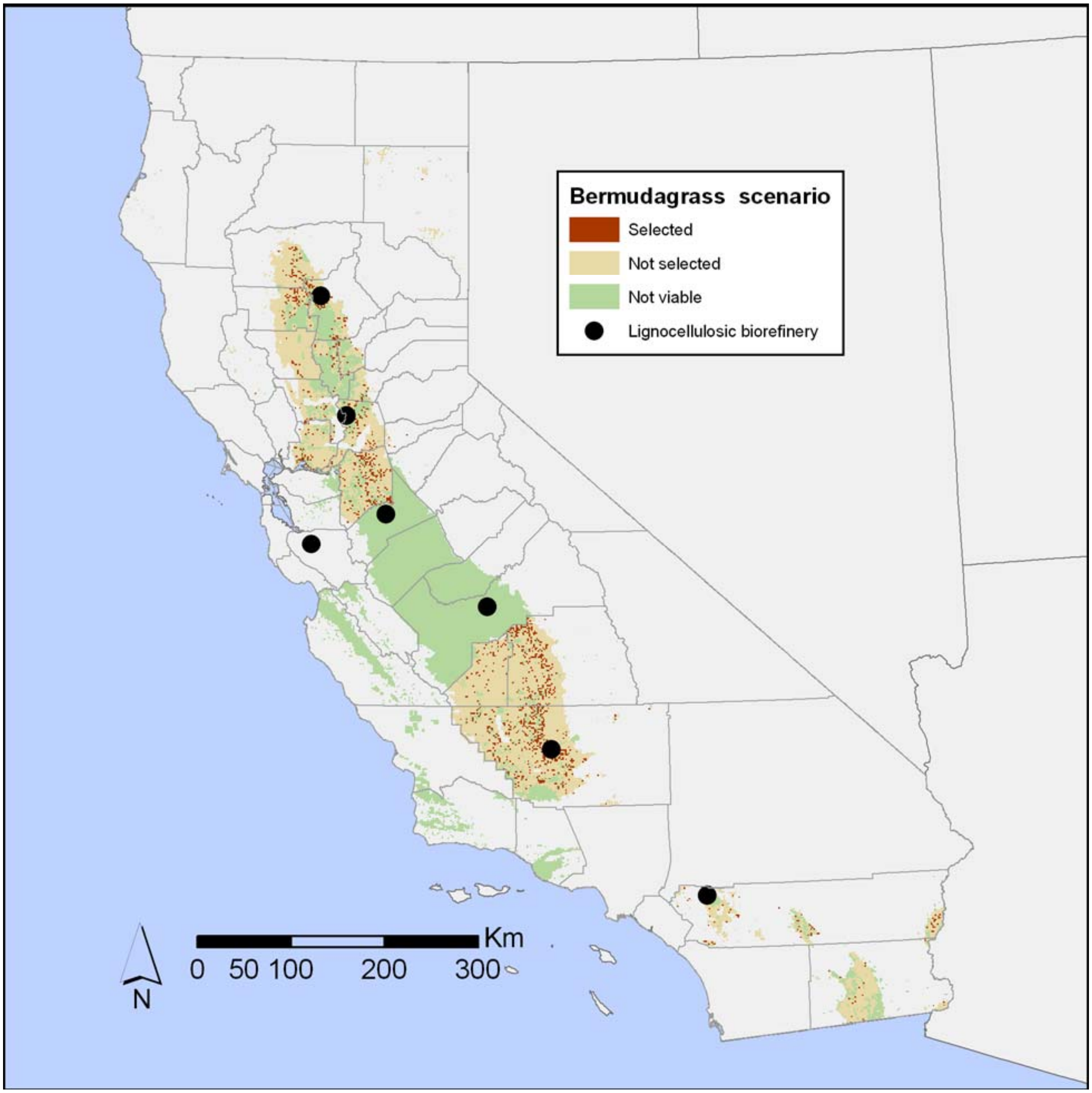


Figure D- 7: Minimize Loss Scenario for Bermudagrass That Minimizes Loss of Habitat Suitability (berm1-100)

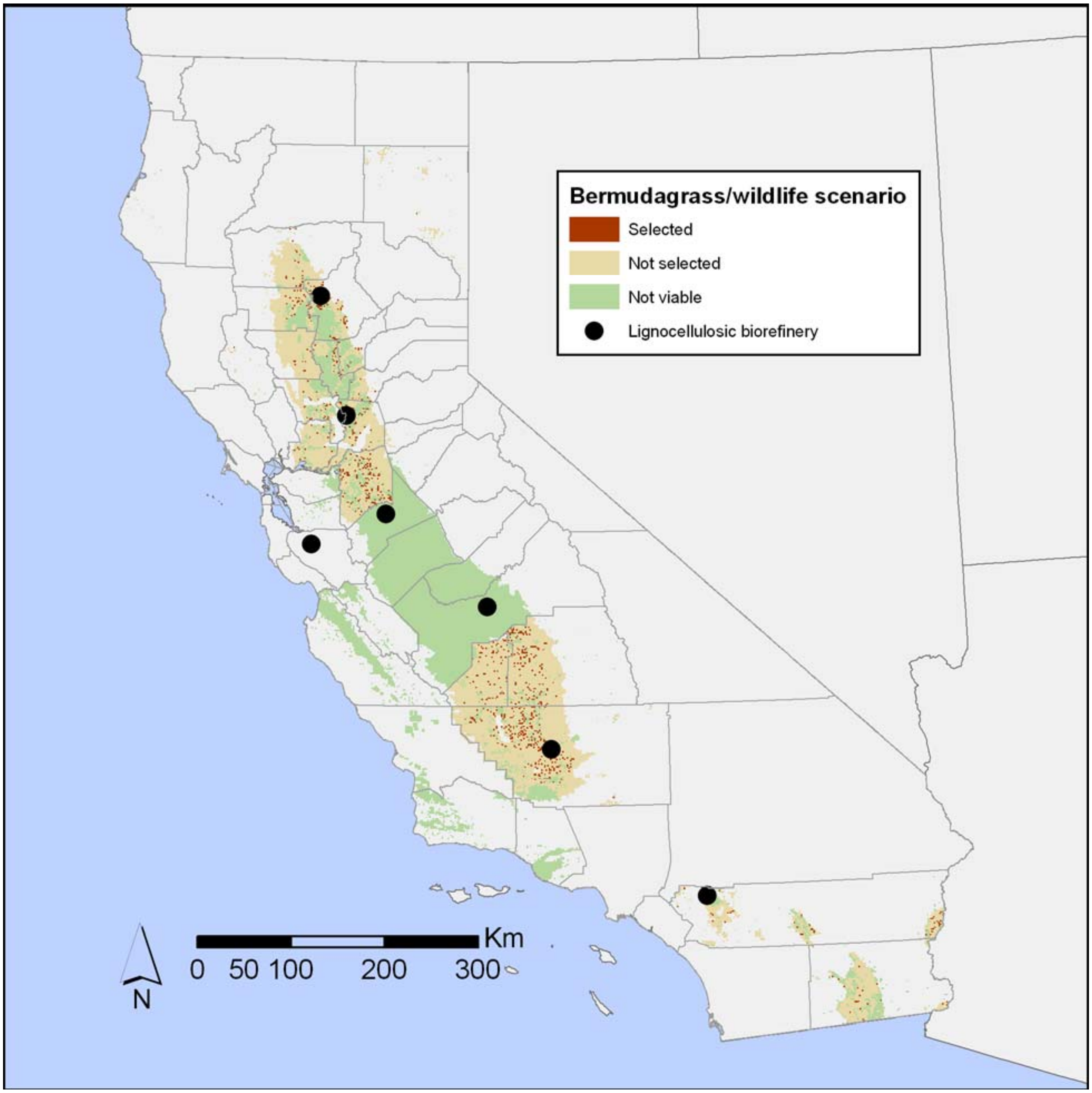


Figure D- 8: Minimize Cost Scenario for Canola (cano1-0)

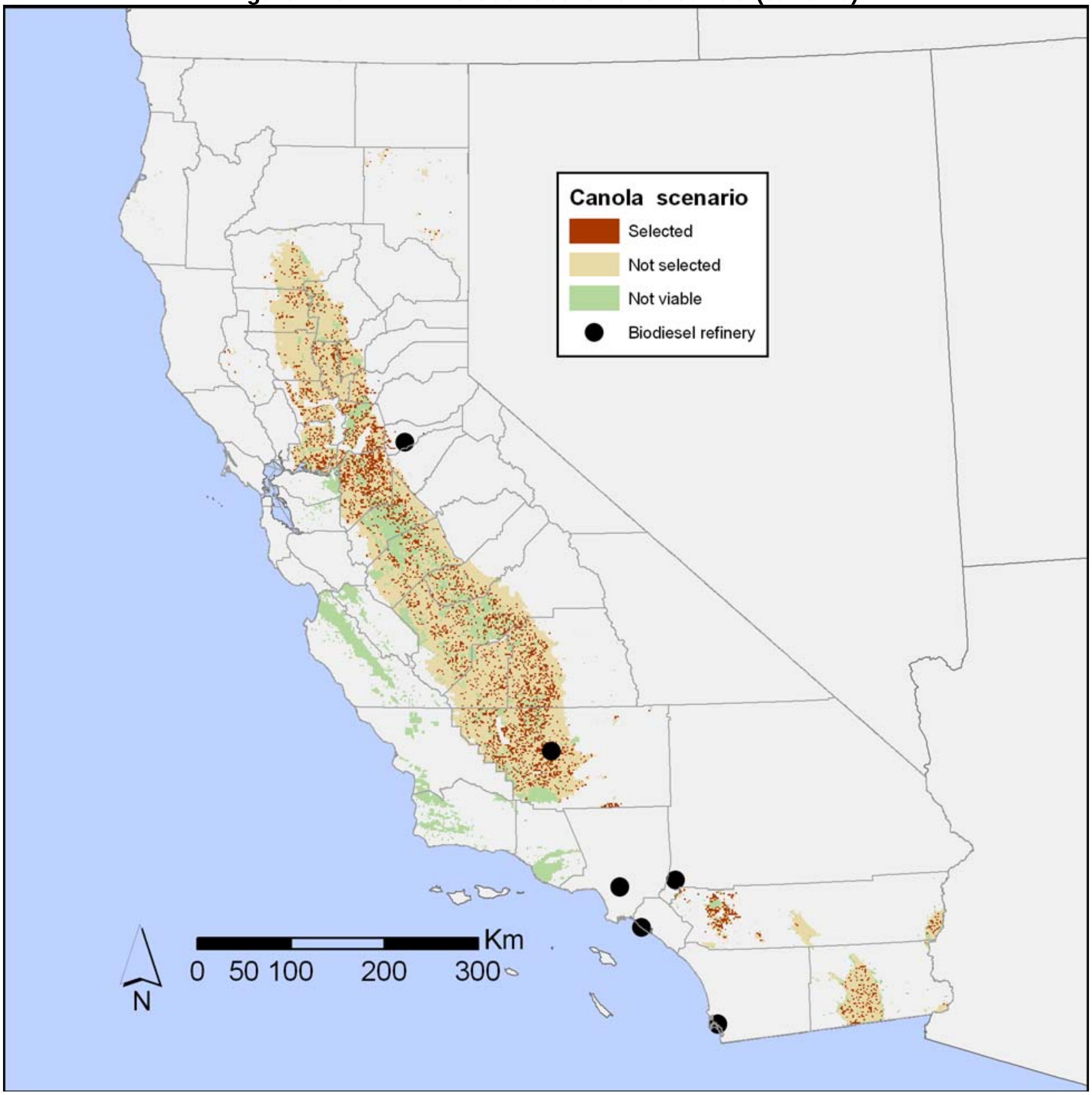


Figure D- 9: Minimize Loss Scenario for Canola That Minimizes Loss of Habitat Suitability (cano1-100)

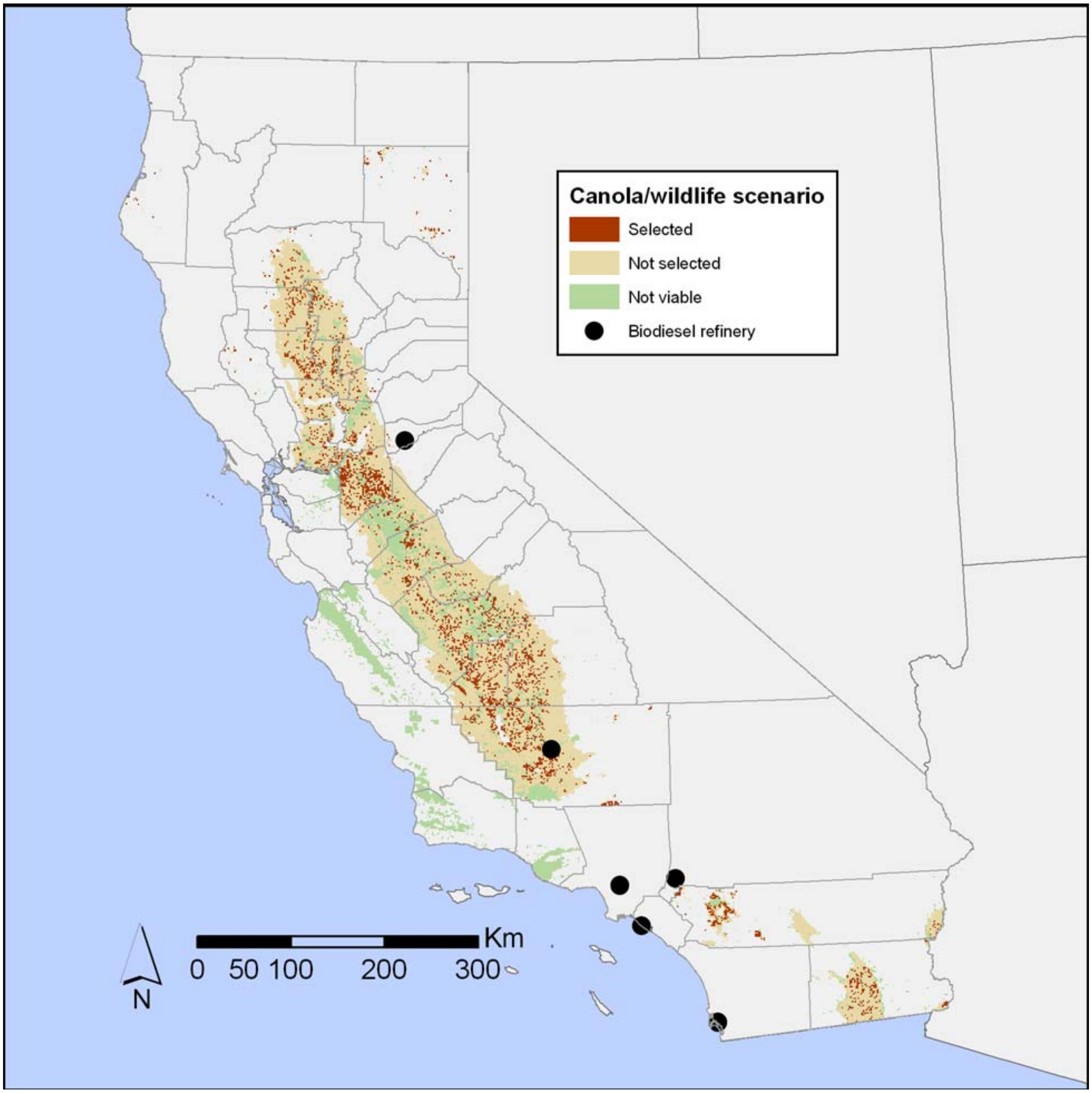


Figure D- 10: Minimize Cost Scenario for Safflower (saff1-0)

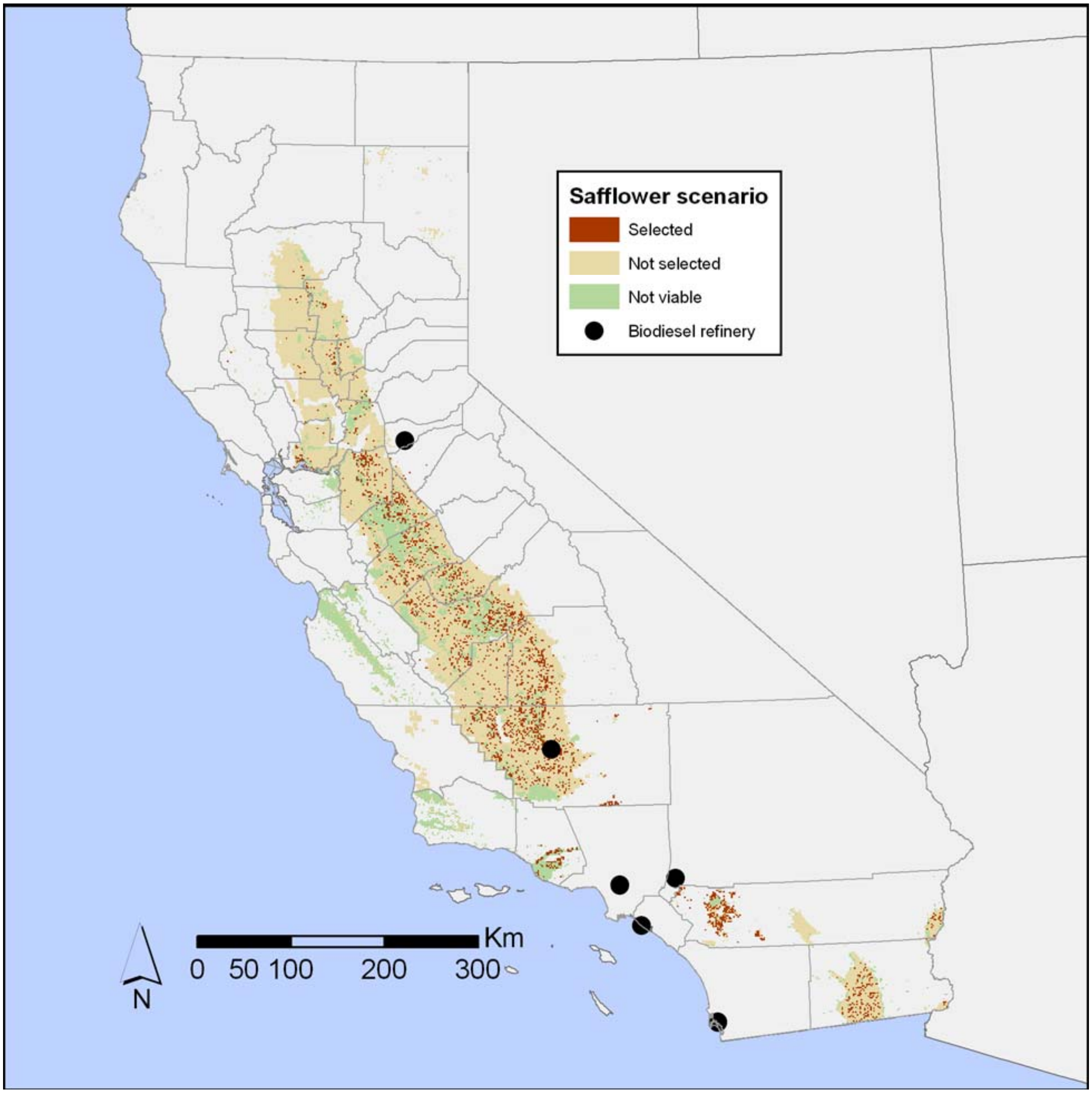


Figure D- 11: Minimize Loss Scenario for Safflower That Minimizes Loss of Habitat Suitability (saff1-100)