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RESEARCH

Quantifying Trade-Offs Among Ecosystem Services, Biodiversity, and Agricultural Returns in an Agriculturally Dominated Landscape Under Future Land-Management Scenarios

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ABSTRACT

Change in land use in agriculturally dominated areas is often assumed to provide positive benefits for land-owners and financial agricultural returns at the expense of biodiversity and other ecosystem services. For an agriculturally dominated area in the Central Valley of California we quantify the trade-offs among ecosystem services, biodiversity, and the financial returns from agricultural lands. We do this by evaluating three different landscape management scenarios projected to 2050 compared to the current baseline: habitat restoration, urbanization, and enhanced agriculture. The restoration scenario benefited carbon storage services and increased landscape suitability for birds, and also decreased ecosystem disservices (nitrous oxide emissions, nitrogen leaching), although there was a trade-off in slightly lower financial agricultural returns. Under the urbanization scenario, carbon storage, suitability for birds, and agricultural returns were negatively affected. A scenario which enhanced agriculture, tailored to the needs of a key species of conservation concern (Swainson's Hawk, *Buteo swainsoni*), presented the most potential for trade-offs. This scenario benefitted carbon storage and increased landscape suitability for the Swainson's Hawk as well as 15 other focal bird species. However, this scenario increased ecosystem disservices. These spatially explicit results, generated at a scale relevant to land management decision-makers in the Central Valley, provide valuable insight into managing for multiple benefits in the landscape and an approach for assessing future land-management decisions.

KEY WORDS

Agricultural valuation, biodiversity, carbon, Central Valley, nitrogen, restoration, Swainson's Hawk (*Buteo swainsoni*), urbanization

INTRODUCTION

Intact natural landscapes provide ecosystem functions that result in numerous ecosystem goods and services from which humans benefit, including carbon storage, flood protection, and maintenance of species life cycles (Daily 1997; MEA 2003). However, many of these services are diminished in landscapes that have been converted for agricultural purposes. The provisioning services of these food-production landscapes are clear, and there is increasing recognition that agricultural landscapes can continue to supply or maintain other vital ecosystem services if well managed. These include flood mitigation and carbon storage (regulating services), pollination (supporting services), and wildlife habitat (MEA 2003; Scherr and McNeely 2008). Maintaining ecosystem functions to optimize these multiple services in agricultural landscapes is particularly important, given that cropland and pasture currently occupy ~40% of the earth's land surface, with increases predicted to support a growing global population (Asner et al. 2004; Alexandratos and Bruinsma 2012).

In the past, agricultural production was characterized by growing one or more crops in the same place. Crop rotation would provide inputs of nitrogen, and suppress insects and weeds by breaking their life cycles, yielding modest but stable agricultural inputs (Altieri 1992). However, this link between ecology and agriculture has become strained over the past few decades a a result of mechanization, new crop varieties, development of agrochemicals, as well as political and economic forces associated with regional agriculture's supplying international markets (Altieri 1992). This has led to concerns about the long-term sustainability of food-production systems, and the influence of these practices on the ecosystem services provided to people.

An increasing number of studies show how creating diverse agricultural landscapes, through patches of remnant or revegetated native habitat on farmland, even on a small scale, can provide important habitat for native flora and fauna, as well as benefit farm productivity in unexpected ways (Kremen et al. 2012). For example, fields with uncultivated margins have higher plant and moth diversity as well as more diverse soil macrofauna (Pickett and Bugg 1998; Smith et al. 2008; Merckx et al. 2009). Hedgerows have been associated with higher bird and moth diversity, provide movement corridors for fauna and host natural enemies that control agricultural pests (Swinton et al. 2006). In addition, remnant areas close to agricultural areas improve pollination services with positive consequences for crop yields (Greenleaf and Kremen 2006; Morandin and Winston 2006; Kohler et al. 2008; Ricketts et al. 2008).

Furthermore, agricultural lands store carbon through remnant native vegetation (Williams et al. 2011) and from the crops cultivated, particularly annual row crops because of their dense planting (Brown et al. 2004). Similarly below-ground biomass could be increased by introducing cover crops with deeper roots to increase below-ground biomass while food is still produced (Kane 2015). Other ecosystem services from certain types of agriculture include aesthetic landscapes (e.g., vineyards or rolling pastures), farm tourism (e.g., self-pick berry and apple farms, corn mazes, and farm-animal petting zoos), and the preservation of rural lifestyles (Swinton et al. 2007; Zhang et al. 2007).

Agriculture can also be the source of ecosystem disservices such as habitat loss and pesticide poisoning of non-targeted species (Zhang et al. 2007; Power 2010), while soil and nutrient runoff result in losses of soil carbon (Olson et al. 2016). The effect of these disservices ranges from the local scale (e.g., drinking water quality and loss of natural habitat) to the regional scale (e.g., air and odor pollution and contamination of groundwater from the dairy industry in California), to the global scale (e.g., global warming) (Dale and Polasky 2007; Power 2010). For example, 20% of the N fertilizer applied in agricultural systems globally moves to aquatic ecosystems (Galloway et al. 2004). Agricultural production practices in California, which produces roughly half of the fruits, nuts, and vegetables for the U.S, has resulted in widespread nitrate contamination of groundwater aquifers (Rosenstock et al. 2014).

An emerging body of literature focuses on spatially quantifying ecosystem services and comparing these with patterns of biodiversity across the landscape and agricultural land returns (Broody et al. 2005; Chan et al. 2006; Nelson et al. 2008, 2009; Egoh et al. 2009; Polasky et al. 2011; Goldstein et al. 2012). For example, Nelson et al. (2009) assessed

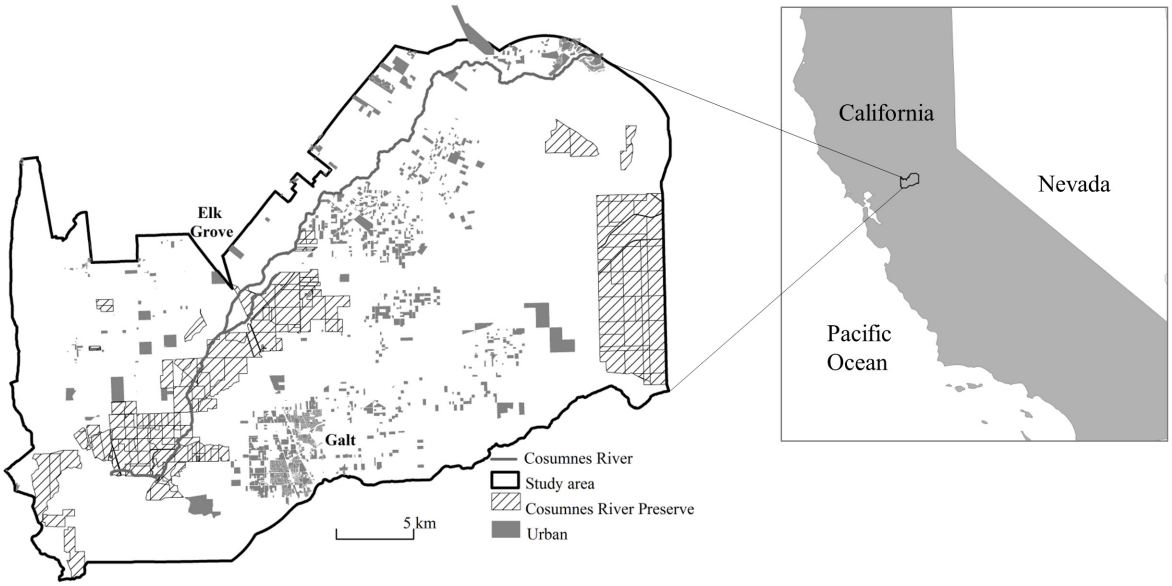

Figure 1 Map of Cosumnes River study area, central California, USA

these three components under alternative land-use trajectories in the Willamette Basin, Oregon. The study found that a conservation scenario which resulted in high scores for ecosystem services also had high scores for biodiversity, while a development scenario had higher returns to land-owners but lower levels of biodiversity conservation and ecosystem services. Polasky et al. (2011) in an assessment of land-use alternatives over a 10-year period in Minnesota found a lack of concordance—the scenarios that created the greatest annual net returns to land-owners also had the lowest social benefits. Agricultural expansion was found to reduce stored carbon, negatively affect water quality, and reduce habitat quality for biodiversity and forest songbirds. The present study has elements similar to Nelson et al. (2009) and Polasky et al. (2011). It is conducted at the parcel spatial scale, it is forward looking to 2050, and it addresses ecosystem services and disservices along with biodiversity and financial returns from agriculture.

In this study, we examine the assumption that land use change in agriculturally dominated areas provides positive benefits for land-owners and financial agricultural returns at the expense of biodiversity and other ecosystem services, such as carbon storage. We do this by quantifying carbon storage, landscape suitability for birds, ecosystem disservices, and financial returns from agriculture within an area of the Central Valley of California. We ask how these change by 2050 under three alternative scenarios: restoration, urbanization, and enhanced agriculture tailored to the needs of a key species of conservation concern, the Swainson's Hawk.

MATERIALS AND METHODS

Study Area

The study area spans a 72,188-ha area in the Central Valley that includes the Cosumnes River Preserve and surrounding lands up to 50 m in elevation, encompassing lands owned privately, by state and federal government, or by non-profit organizations including The Nature Conservancy (TNC) (Figure 1). Historically, this area was dominated by native grassland, valley oak woodland and savanna, and riparian forest along the once-perennial Cosumnes River. However, conversion to agriculture has resulted in a landscape where only small patches of natural habitat remain. Many of these remnant natural areas are currently experiencing conversion to urban land use from the rapidly growing adjacent cities. Although some of these natural areas are habitat for state- and federally-listed threatened and

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endangered species and, consequently, development of these lands has resulted in mitigation funding to compensate for habitat losses of imperiled species. Currently, natural vegetation covers 44% (or 31,892 ha) of the study area, based on a vegetation map of the Delta (2007) developed by the California Department of Fish and Wildlife (CDFW) in addition to project-based vegetation mapping. The urban and developed footprint, which currently covers 9% of the study area, has increased by 35% over the last decade (Farmland Mapping and Monitoring Program [FMMP] data 1998–2008). Urban expansion associated with cities at the northern and southern edges of the study area (Elk Grove and Galt, respectively) continues to exert development pressure on remaining natural and agricultural lands. Today, the river channel is lined with agricultural levees, and adjacent floodplains are used largely for crops (Constantine et al. 2003), with agriculture covering 46% of the study area.

Agricultural activity in the study area, compared to large-scale agriculture in many other parts of California, has a high diversity of crops across many small parcels. Our agricultural land-use scenario represents an enhanced agriculture which favors compatible crops that are commonly the targets for mitigating habitat loss for the imperiled Swainson's Hawk (*Buteo swainsoni*) through mitigation funding. This scenario is reasonable, given that the region is highly suitable for Swainson's Hawk nesting and foraging, supporting one of the highest concentrations of birds in the Pacific Flyway. Because *B. swainsoni* is a species of concern, priority has been placed on managing the landscape for its persistence. Both governmental and non-governmental land managers currently engage in a number of practices intended to boost populations of avian species of concern, for example, paying farmers to flood fallow fields to provide habitat for migrating waterfowl. Given their conservation priority status, it is possible that management agencies might also pay farmers to enhance habitat for improved outcomes for the Swainson's Hawk. The widespread use of conservation easements within the study area provides the mechanism (enforceable contract which stipulates types of compatible uses) and the means (financial payments) to accomplish an enhanced agricultural scenario. The Yolo County Habitat Conservation Plan / Natural Community Conservation Plan is one such policy that points toward management for this species.

The Swainson's Hawk can also be a valuable focal species because of its dependence on tree canopy nesting sites and nearby open-country foraging habitat. Many other raptors, riparian species, and migratory birds also depend on these ecosystem traits. The Swainson's Hawk is able to forage in specific types of agriculture (Bechard 1982; Woodbridge 1985). In particular, alfalfa (*Medicago sativa*) is a valuable resource because it is a perennial crop that continually supports high populations of prey (rodents) whose availability peaks during monthly irrigation and harvesting events. Other crops, such as beet and tomato fields, are also hunted regularly during harvest, though crops such as rice or vineyards are not significantly utilized (Estep 1989; Swolgaard et al. 2008). The same crop associations are true for a number of other species. Alfalfa, in particular, is considered important habitat for other migratory birds, including shorebirds like Long-Billed Curlew (*Numenius americanus*) and White-Faced Ibis (*Plegadis chihi*), both of which are species of conservation concern.

The Swainson's Hawk responds well to protection and restoration of riparian forest habitats (used for nesting), within an agricultural landscape that is used for foraging (Estep 1989). Thus, a varying matrix of natural riparian habitat and different forms of agriculture can reasonably be expected to significantly affect the value of the landscape for this species. The potential for multi-species benefits from single species mitigation or management is rarely evaluated; therefore, we include an assessment of the ramifications of these land-use scenarios for 15 other focal bird species identified by the California Partners in Flight program (*http://www.prbo.org/calpif/plans.html*). These are a suite of species whose requirements (1) define different spatial attributes, habitat characteristics, and management regimes, and (2) represent healthy habitats within our focal landscape (Chase and Geupel 2005).

We conducted this study at the parcel scale ($\sim 10^{0-2}$ ha), which is meaningful because land-management decisions for agricultural practices are made at this scale and only a few ecosystem services quantification studies have been conducted at this

scale (exceptions include Nelson et al. 2008). The average size of parcels in the study area that grow alfalfa, grain, orchard, rice, row crop, or vineyard was 3.88 ha (and 4.19 ha with the inclusion of pasture). To assess the changes over time among carbon storage, landscape suitability for birds, ecosystem disservices, and returns from agriculture with each of our management scenarios, we first developed a snapshot of the current land cover in the study area. We mapped urban areas (rural to high-density residential, industrial, and retail classes) using information from the Sacramento Area Council of Governments (SACOG) data from 2005, with a minimum mapping unit of five acres (2.02 ha) for urban areas and ten acres (4.04 ha) for rural areas. We defined agricultural land cover data from the CDFW's Delta vegetation map and from the California Department of Water Resources (CDWR) (most recent data from 2000), with a minimum mapping unit of 10 acres (4.04 ha). The agricultural data were grouped into seven primary classes (alfalfa, grains, orchard, pasture, rice, row crops, and vineyard). These were considered sufficiently distinct from each other in terms of foraging value for Swainson's Hawk. In addition to these agricultural classes, we used four natural vegetation classes (grassland, shrubland, wetland, and riparian forest) along with developed/urban and water (Table 1). These land-cover types were intersected with land-owner parcels for the study area (SACOG 2005). In cases where a parcel contained more than one land use type, the parcel was split into the respective classes to retain this detail. These resultant land- cover data represent the contemporary baseline condition (hereafter baseline) from which we measured changes resulting from the landscape management scenarios. We conducted spatial analysis in ESRI ArcMap version 10.3, in Universal Transverse Mercator (Zone 10) projection with North American Datum 1983.

Table 1 Area (ha) and proportion of each land-use class under baseline (current) conditions and the three management scenarios implemented for the Cosumnes River study area, central California, USA

Land use	Baseline	Restoration	Enhanced agricultural	Urban
Row crop	9,596	9,019	18,334	9,170
Pasture	8,343	8,168	13,266	7,550
Vineyard	8,292	8,149	8,292	7,972
Grain	4,278	4,113	6,773	3,835
Alfalfa	1,349	1,349	1,714	1,176
Orchard	658	658	658	642
Rice	408	121	408	408
Agricutural total	32,924 (46%)	31,577 (44%)	49,445 (68%)	30,754 (43%)
Grassland	28,153	24,059	12,322	25,424
Riparian forest	2,639	8,726	2,639	2,526
Shrubland	112	32	37	111
Wetland	987	557	373	798
Natural total	31,892 (44%)	33,375 (46%)	15,371 (21%)	28,859 (40%)
Developed / Urban	6,369 (9%)	6,369 (9%)	6,369 (9%)	11,643 (16%)
Water	1,003 (1%)	866 (1%)	1,003 (1%)	932 (1%)
Total	72,188	72,188	72,188	72,188

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MANAGEMENT SCENARIOS

We consulted with management stakeholders at the Cosumnes River Preserve to develop three management scenarios to simulate potential changes in the current landscape: extensive restoration, urbanization, and enhanced agriculture designed to benefit the Swainson's Hawk. The stakeholders consisted primarily of the Preserve Partners—a consortium of federal, state, and local agencies—in addition to non-profits such as TNC and Ducks Unlimited. The management scenarios were developed with reference to the Preserve Management Plan (2008), created by the Preserve Partners through a 2-year planning process (*http://www.cosumnes.org/about_crp/CH%201%20-%202.pdf*). The management plan gathered information from the public (including local farmers, ranchers, and environmental interests), the Preserve Partners, local municipalities, and other groups. We used a time-frame of ~30 years to 2050 (see Urbanization scenario below). We considered each of the scenarios in isolation; for example, landscape-wide restoration does not account for development, nor urbanization for set-asides for wildlife. For parcels not affected by the management scenario, we assumed a static landscape with no change of land use occurring, as much of the land has remained pastoral for ~150 years before present.

1. Restoration Scenario

The objective of this scenario was to maximize restoration of agricultural lands to natural riparian habitat, focusing on areas of specific soil type and proximity to the river, based on an analysis in the Management Plan. In addition, Preserve goals, as set forth in the Management Plan, support maximizing the restoration of riparian habitat in the Cosumnes corridor. We applied six decision rules that relate the location of each parcel to existing landscape features. A parcel received a high likelihood of being restored if: (1) the parcel was currently within the Cosumnes River Preserve lands; (2) was managed for other conservation purposes (California Protected Areas Database version 1.6, 2011); (3) was within a historical riparian corridor; (4) was within 1 km of standing water; (5) was within 1 km of grassland, shrubland, or wetland; or (6) was within 1 km of riparian forest. The 1-km distance threshold was set to be inclusive of remnant riparian forest within the Preserve, coupled with the assumption that areas within this threshold are practical targets for restoration. If a parcel fell within any one of these six categories, it was given a score of one. Scores were summed for each of the six rules, and a composite score was given to each parcel.

Using the composite score, the upper quartile of all parcels with a score greater than one, weighted by area, were designated to be restored. We tested for multicollinearity using the variance inflation factor (VIF), which did not indicate substantial multicollinearity of the six decision rule variables (1.6). We filtered the final layer of restorable parcels to exclude existing urban areas. The restoration of these parcels was to grassland or riparian forest, which was assigned based on the potential natural vegetation (mapped by Kuchler 1976). We did not consider areas defined by Kuchler as subtidal marsh within the study area for future restoration because of the current lack of feasibility; consequently, parcels remained under current land cover (typically irrigated pasture or rice farms).

2. Urbanization Scenario

The objective of this scenario was to represent a realistic growth outcome for the area projected to 2050. We assigned parcels as urban in 2050 based on whether they were currently urban or projected to become urban using the Preferred Blueprint Scenario for 2050 (SACOG 2005). SACOG generated the blueprint to help guide local government in growth and transportation planning through 2050 throughout the six-county region. This Preferred Blueprint Scenario (adopted in December 2004) promotes compact, mixed-use development and more transit choices as an alternative to low-density development (*http://www.sacregionblueprint.org/adopted/*). We filtered the final layer of potentially urbanized parcels by extracting current protected areas and areas of riparian forest, which are unlikely to be developed because they are within the 100-year floodplain. This provided the land cover data necessary to make projections in ecosystem services and disservices for 2050.

3. Enhanced Agriculture Scenario

The objective of this scenario was to maximize high-quality foraging habitat for the Swainson's Hawk, and was developed based upon the literature and experience of the authors. A parcel received a high likelihood of being Swainson's Hawk-friendly agriculture if it was designated as or within 1.25 km of alfalfa, grain, pasture, or row crop (Estep 1989). (Vineyards, orchard, and rice were not considered favorable.) We selected all non-protected parcels of natural vegetation, such as grasslands, within 1.25 km of existing fields under these four agricultural types to identify parcels available for conversion to agricultural types favorable to Swainson's Hawk. For practical reasons, certain agricultural types were not considered for conversion. For example, vineyards, given their high economic value (Table 2), are unlikely to be converted; vineyard expansion remains a dominant trend for the region (Viers et al. 2013). We filtered the final layer of potentially enhanced parcels to exclude riparian forest and existing urban areas. Using the composite score, we converted the upper quartile of all parcels for these rules from existing land use to the four agriculture types more favorable for Swainson's Hawk foraging. These types were randomly allocated in proportion to the number of parcels in which they currently occur: alfalfa 5%, grain 20%, pasture 45%, and row crop 30%. As with the restoration scenario, we tested for multicollinearity using the VIF, which indicated the model (1.2) did not have substantial multicollinearity of the variables.

Quantifying Ecosystem Services and Disservices, Biodiversity Value, and Agricultural Returns

The three landscape management scenarios provided the basis for calculating changes in carbon storage, biodiversity value, ecosystem disservices, and financial returns, based on the difference between current and projected land-cover types within each parcel.

1. Carbon Storage

We quantified the amount of carbon stored within three different land-cover types based on readily available data and literature: agricultural crops (above- and below-ground); natural, non-forest vegetation types (above- and below-ground, with the exception of above-ground for wetlands); and forest types (above-ground only) (Table 3). We did not include soil carbon storage in this analysis, nor do we account for carbon storage associated with natural habitat within urban areas. We assumed that these steady-state estimates apply to all locations, and that changes in land cover would increase or decrease carbon storage to a new steady state. We calculated differences in carbon storage between the scenarios.

Above- and below-ground carbon storage for standing agricultural crops (alfalfa, grains, pasture, rice, row crops, and vineyard) was based on a

Table 2 Estimated value (US$, 2011 data) of seven agricultural crop types under baseline (current) conditions and under three alternative management scenarios at the Cosumnes River study area, central California, USA

Crop type	Baseline	Restoration	Enhanced agricultural	Urban
Row crop	$89,338,987	$83,966,955	$170,690,098	$85,368,819
Vineyard	$70,045,676	$68,838,517	$70,045,676	$67,342,337
Orchard	$9,039,777	$9,039,777	$9,039,777	$8,822,104
Pasture	$5,865,021	$5,742,191	$9,325,829	$5,307,753
Grain	$4,526,020	$4,351,132	$7,166,007	$4,057,718
Alfalfa	$4,117,692	$4,117,692	$5,231,764	$3,591,675
Rice	$1,032,929	$307,200	$1,032,929	$1,032,929
Total	$183,966,102	$176,363,464	$272,532,080	$175,523,334
Change from baseline		-4%	48%	-5%

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Table 3 Estimates of ecosystem services and disservices, and the type of carbon included in the measurement (to the extent it can be deduced from the literature source)

	Ecosystem service or disservice			
Land cover type	**Nitrogen leaching (kg N ha^{-1})**	**Nitrous oxide (kg N_2O ha^{-1})**	**Carbon (tons C ha^{-1})**	**Carbon type estimate**
Alfalfa	0.00	0.00	7.0	above and below ground
Grains	48.01	2.81	7.1	above and below ground
Rice	22.50	0.69	10.4	above and below ground
Row Crop	164.76	2.93	35.9	above and below ground
Orchard	69.52	2.03	3.8	above and below ground
Vineyard	16.70	0.61	1.8	above and below ground
Pasture	4.49	0.20	3.50	above and below ground
Grassland	n/a	n/a	3.50	above and below ground
Shrubland	n/a	n/a	30.00	above and below ground
Wetland	n/a	n/a	4.10	assume above ground only
Salix Riparian Forest	n/a	n/a	79.7	above ground
Populus Riparian Forest	n/a	n/a	49.8	above ground
Oak Riparian Forest	n/a	n/a	132.0	above ground
Urban	n/a	n/a	n/a	n/a

study by Kroodsma and Field (2006) (Table 3). We divided the yield (in 2000) by the harvest index (the proportion of the biomass harvested) for each crop, and then multiplied the result by 0.45 as the proportion of biomass assumed to be carbon (Penman et al. 2003) to estimate Mg (metric ton) C ha^{-1}. For row crops not included in Kroodsma and Field (2006), we estimated it using the National Agricultural Statistics Service yield data from the year 2000 (*http://www.nass.usda.gov/Data_and_Statistics/index.php*) and the average harvest index for all row crops (from Kroodsma and Field 2006). We estimated carbon storage for orchards by assuming the mid-point of the crop's lifespan, multiplying this by wood accumulated (g cm^{-2} yr^{-1}) (Kroodsma and Field 2006), and again multiplying by 0.45 to provide Mg C ha^{-1}. For perennial crops not listed in Kroodsma and Field (2006), we used the mid-point of the average lifespan (25 years) and the average wood-accumulation estimates for crops within the same category as defined by the CDWR. For our broad categories of grains, orchards and row crops, we calculated an average value of Mg C ha^{-1} based on data available for each crop type within the category. We multiplied the area (ha) of each of the seven agricultural classes in the study area by the estimated carbon to provide total Mg C ha^{-1} (see Table 3).

Carbon storage for non-forest natural vegetation types used estimates from the literature: pasture, grassland, and shrubland (Brown et al. 2004) (above- and below-ground carbon), and freshwater emergent wetlands (Rodosta 2009). We divided forested vegetation types into three main types of riparian forest: valley oak (*Quercus lobata*), Fremont cottonwood (*Populus fremontii*), and willow (*Salix* spp.) (UC Davis, unpublished data, but follows Viers et al. 2012). We improved the estimates of carbon storage (above ground only) associated with these types of riparian forest with plot data collected on the Cosumnes Preserve. Plot data included the measurement of all trees >10 cm diameter at breast height (dbh) within a 0.04-ha plot (2005 riparian monitoring data from TNC), applied allometric equations to calculate the amount of above-ground carbon (Pillsbury and Kirkley 1984; Jenkins et al. 2004), and summed these amounts to report a total Mg C ha^{-1} for riparian forests (see Table 3). These are in line with other estimates of live biomass from riparian studies in California (e.g., Matzek et al. 2015). Using this variety of techniques, we assigned

a coarse estimate of total Mg C ha^{-1} for each parcel in the study area (Figure 2). Since this compilation of varied data includes a mix of both above- and below-ground carbon estimates for different classes (see Table 3), our estimates need to be considered conservative.

2. *Biodiversity: Swainson's Hawk and Other Focal Bird Species*

We assessed the effect of different landscape management scenarios on the Swainson's Hawk and also on a suite of 15 focal bird species. First, we used Boosted Regression Trees (BRT) modeling techniques to fit the baseline land-cover data to presence and absence points of Swainson's Hawk nest locations. We used known nest locations, identified using comprehensive field surveys of the area (Estep 2007, 2008), to generate presence points (n = 212). We generated absence points by randomly placing (n = 177) pseudo-absence points within the study area. We used 75% of the points to train the landscape suitability model, and 25% to test the predictive ability of those points. We generated models by calculating the proportion of each land-use type contained within a 25-ha square that surrounded each presence and absence point. This threshold utilized research which found that 50% of Swainson's Hawk foraging occurs within 25 to 86 ha of nest sites (Babcock 1995). We also tested model sensitivity using a 100-ha core area, and noted no significant changes n model results.

Once we fitted the current land-cover type to the Swainson's Hawk nest presence and absence data, we used the BRT to spatially project the probability of landscape suitability onto each of the three future scenarios. We assessed model performance using area under curve (AUC) of the receiver operating characteristic (ROC) curve scores (R Core Team 2013). We converted model results to raster grids (50 m ×

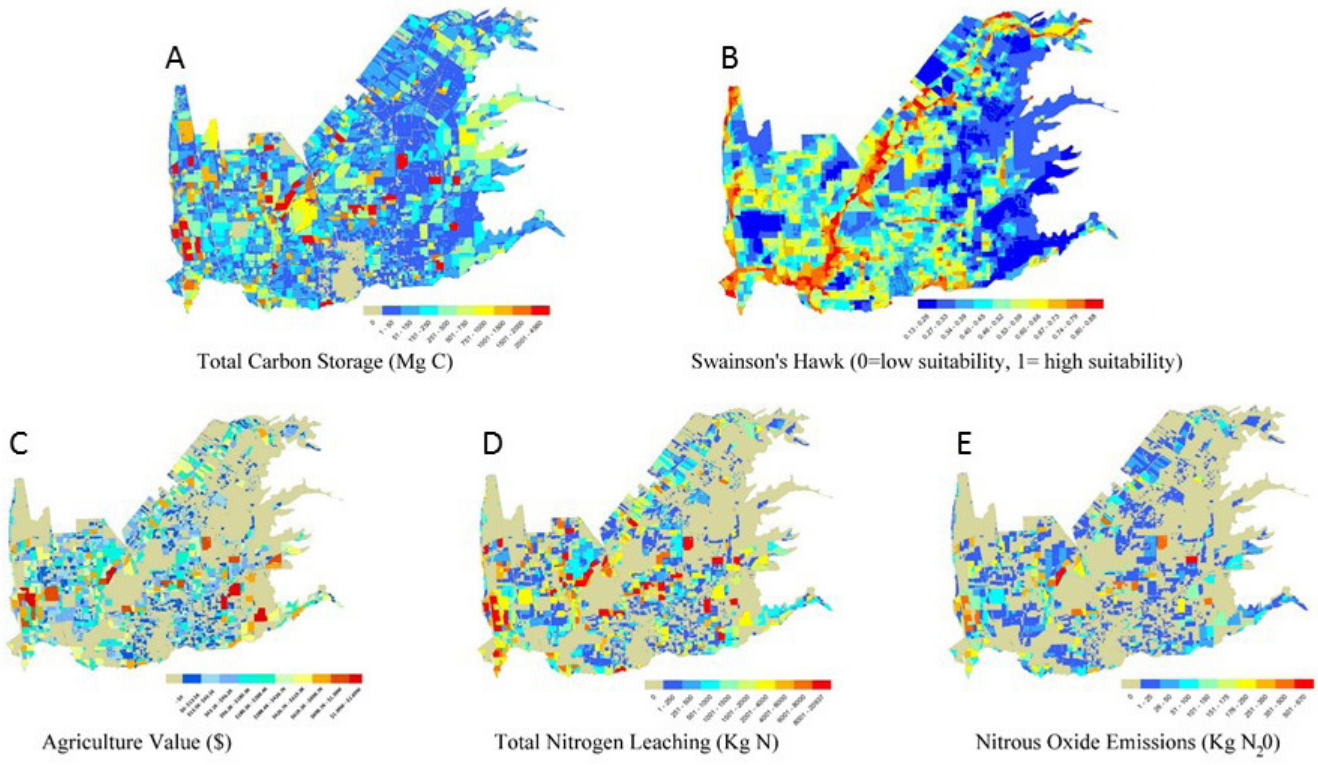

Figure 2 Baseline (current) patterns of total carbon storage (per year) (**A**), landscape suitability for the Swainson's Hawk (**B**), estimated annual financial returns from agricultural crops at the Cosumnes River Preserve shown by ownership parcels (**C**), and the ecosystem disservices of nitrogen leaching (**D**), and nitrous oxide emissions (**E**) per year. The patterns for 15 focal bird species are not shown.

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50 m) and assigned each parcel a landscape suitability score (for the current and each of the alternative management scenarios) based on the average score of all grid cells contained within a parcel (values ranged from zero to one, with one being most suitable, Figure 2).

Second, we assessed the effects of the three management scenarios relative to baseline on a suite of 15 other focal bird species identified as indicator species for natural habitats in the Central Valley (CVJV 2006) (Table 4). In contrast to the Swainson's Hawk approach, we used existing suitability models developed for each of these focal species in the Central Valley, with suitability scores ranging from zero to one (Jongsomjit et al. 2007). We assigned suitability values to our baseline and three alternative scenario parcels using two steps. First, we estimated the average suitability for each bird species within each of our land-cover types (e.g., grassland or riparian forest) by overlaying the spatial suitability surfaces (Jongsomjit et al. 2007) onto our land-cover data and calculating the area-weighted average suitability of each land-cover type for each bird species (Table 4). Second, we assigned an area-weighted suitability value for each of the 15 species to each parcel in our baseline and future management scenarios, according to the parcel's land-cover type. Based on these scores, we calculated the average suitability score for each landscape scenario across all 15 focal bird species, using a 5% increase or decrease as the threshold for meaningful change.

3. Nitrous Oxide Emission and Nitrogen Leaching

We calculated nitrous oxide emissions for the agricultural land-use types in a manner consistent with International Panel on Climate Change Tier-1 guidelines (IPCC 2006). The key input parameter was nitrogen fertilizer use. We acquired estimates of nitrogen fertilizer application rates from a

Table 4 Landscape suitability scores for 15 focal bird species at the Cosumnes River study area, central California, USA. Baseline (current conditions) gives the average suitability value for each species across all land-cover types. Resto (Restoration), En Ag (Enhanced Agriculture), and Urban columns indicate how this average value changes under each of the three management scenarios. Percent change (% Chg) columns indicate the percent change between current baseline conditions and each of the three scenarios. Figures in bold are ≥5% change.

Common name	Scientific name	Baseline	Resto	En Ag	Urban	% Chg Resto	% Chg En Ag	% Chg Urban
Acorn Woodpecker	*Melanerpes formicivorus*	7.81	8.32	7.72	7.73	**7**	–1	–1
Ash-throated Flycatcher	*Myiarchus cinerascens*	10.49	11.04	10.43	10.27	**5**	–1	–2
Black-Headed Grosbeak	*Pheucticus melanocephalus*	10.21	11.66	10.35	10.02	**14**	1	–2
Blue Grosbeak	*Passerina caerulea*	7.43	7.92	7.61	7.20	7	2	–3
Common Yellowthroat	*Geothlypis trichas*	13.55	13.73	13.85	13.49	1	2	0
Lark Sparrow	*Chondestes grammacus*	4.79	4.87	4.87	4.61	2	2	–4
Nuttall's Woodpecker	*Picoides nuttallii*	10.42	11.82	10.40	10.19	**13**	0	–2
Oak Titmouse	*Baeolophus inornatus*	7.85	8.89	7.83	7.67	**13**	0	–2
Song Sparrow	Melospiza melodia	9.74	9.68	9.73	10.02	–1	0	3
Spotted Towhee	*Pipilo maculatus*	19.27	20.06	19.27	18.78	4	0	–3
Western Bluebird	*Sialia mexicana*	8.36	8.58	8.37	8.04	3	0	–4
Western Meadowlark	*Sturnella neglecta*	32.23	31.95	32.59	32.33	–1	1	0
Yellow-Breasted Chat	*Icteria virens*	4.45	4.94	4.41	4.65	**11**	–1	5
Yellow-Billed Magpie	*Pica nuttalli*	14.42	15.33	14.67	14.37	**6**	2	0
Yellow Warbler	*Dendroica petechia*	5.47	5.97	5.52	5.30	**9**	1	–3
Average		11.10	11.65	11.17	10.98	5%	1%	–1%

compilation of California data (Rosenstock et al. 2013, 2014) and summarized these by our seven agricultural types (see Table 4). For grain, orchard, pasture, and row crops, which contain multiple types of crops, we averaged emission rates of these individual crops to provide a single figure for the class. We used IPCC emissions factors to convert nitrogen fertilizer application to nitrous oxide emissions. This was 1% of nitrogen fertilizer applied for all crop groups except rice, for which we used an emissions factor of 0.3% (lower because emissions are reduced under the anaerobic soil conditions caused by flooding in rice systems) (IPCC 2006). We excluded estimates for alfalfa since this crop rarely receives inorganic nitrogen fertilizer application and only accounts for a small proportion of the study area (2%). For each parcel, we estimated the amount of nitrous oxide emissions per year (kg N_2O) under baseline (Figure 2) and the three alternative management scenarios based on the land use type(s) within each parcel.

We calculated the amount of nitrate–nitrogen leaching for the agricultural land types based on the difference between nutrient inputs and nutrient losses. We compiled nutrient inputs from crop-specific fertilization rates (e.g., from USDA chemical use surveys) and based nutrient losses on the amount of nitrogen harvested in crops (N tonnage from crop-specific dry matter, the USDA Crop Nutrient Tool, and the 2002–2007 crop-specific average statewide tonnage; see (Liptzin and Dahlgren 2016; Rosenstock et al. 2014) (Table 3). We assumed atmospheric losses to be 10% of the fertilization rate, which is a conservative estimate developed to reflect the total N gaseous emissions (N_2O, NH_3, N_2, and NO_x) (Rosenstock et al. 2014). We assumed all surplus nitrogen was leached from soil into the groundwater in the form of nitrate (NO_3), and for crops where the nitrogen harvested exceeds the nitrogen inputs, we assumed leaching loss was zero. As with emissions, we estimated the amount of nitrogen currently leached per year (kg N ha^{-1}) for each parcel (Figure 2) and for the three alternative scenarios.

4. Agricultural Returns: Commodity Valuation

We calculated the annual revenue per hectare for different crops within the study using the Sacramento County Crop Report for 2011 (*http://www.agcomm.saccounty.net/Pages/CropandLivestockReports.aspx*). Where necessary, we assigned crop types in the report to the seven agricultural land-cover types used in this study, and took the median value to estimate the annual revenue per hectare (US$ ha^{-1}, Figure 2). Given the difficulty of predicting changes in commodity values in the future, our valuation estimates for 2050 used the same 2011 relative assessment without a discount rate.

RESULTS

Influence of Management Scenarios on Land-Use Type

Natural vegetation increased slightly in the restoration scenario from a baseline of 44% (31,892 ha) to 46% of the study area, and decreased in the urban and enhanced agriculture scenarios to 40% and 21%, respectively (Table 1). Under baseline conditions, natural vegetation consisted primarily of grassland in the eastern portion of the study area (39%), and riparian forest along the Cosumnes River accounts for 4%. Cover of riparian forest increased to 12% under the restoration scenario (Table 1).

Under baseline conditions, agricultural land use comprised 46% (32,924 ha) of the study area. Vineyard, pasture, and row crops make up approximately a quarter each of this agricultural area, followed by grains (13%), while alfalfa, rice, and orchards accounted for less than 4% each. Under the enhanced agriculture scenario, the agricultural footprint increased to 68% of the study area, and is reduced slightly in the restoration and urban scenarios to 44% and 43%, respectively. The developed/urban class accounted for 9% (6,369 ha) of the study area under baseline, and increased in the urban scenario to 16% (11,643 ha) of the study area by 2050 (Table 1).

Influence of Management Scenario on Carbon Storage, Biodiversity Conservation, Ecosystem Disservices, and Valuation of Agricultural Returns

1. Carbon Storage

The total amount of carbon stored on the landscape under baseline conditions was ~784,000 Mg C ha^{-1} (Figure 2), with the majority stored in row crops

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(47%), riparian forests (28%), and grassland (13%). Carbon storage in other agricultural classes was less than 4%. Carbon storage increased by 83% from baseline in the restoration scenario to ~1.4 million Mg C ha^{-1}, largely associated with a 4-fold increase in carbon stored in riparian forests (Figure 3). Areas adjacent to the Cosumnes River and its tributaries became increasingly important for this ecosystem service (Figure 4). In the restored landscape, the carbon stored in riparian forests accounted for 63% of the total, with proportionally less harbored in row crops and grasslands compared to baseline. In the enhanced agriculture scenario, carbon storage increased by 12% from baseline to 879,000 Mg C ha^{-1} (Figure 2), with parcels that harbor increased carbon storage scattered throughout the study area (Figure 4). Compared to baseline, the proportion of carbon stored in row crops increased slightly, from 47% to 53% of all carbon stored in the study area, while the proportion of carbon stored in vegetation classes such as riparian forest and grasslands decreased by ~4% each. In the urban scenario, carbon storage decreased from baseline by 6% to ~740,000 Mg C ha^{-1} (Figure 3).

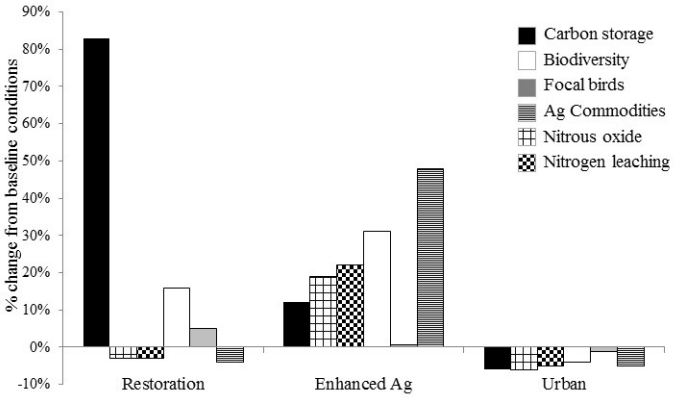

Figure 3 Summary of percent change from baseline (current) conditions under the three management scenarios. Positive changes in carbon storage and biodiversity indicate improvements relative to current conditions, and negative changes indicate a decline. For nitrous oxide and nitrogen leaching, a positive change indicates a worse state relative to current conditions because of the negative effect of these on other services (e.g., water quality and air pollution). Data indicate: carbon = % change in Mg C ha^{-1}; Swainson's Hawk = % change in suitable habitat; focal birds = % change in suitable habitat for 15 bird species; nitrous oxide = % change in kg N_2O; nitrogen leaching = % change in kg N; and agricultural value = % change in revenue from agricultural crops.

2. *Biodiversity: Swainson's Hawk and Other Focal Bird Species*

The AUC score for the BRT model performance was 0.672 (a score of 0.5 would indicate the model was no better than random, and a value of 1 would indicate perfect model performance). Variables with the highest relative importance for predicting Swainson's Hawk nest sites included riparian forest, row crops, pasture, grassland, vineyards, and urban/developed areas. We found a positive relationship between nest sites and the proportion of riparian forest, row crops, pasture, and grassland within the surrounding 25-ha landscape, and a generally negative relationship with vineyards and urban/developed areas, matching expectations based on field surveys of habitat use.

Baseline conditions showed areas adjacent to the Cosumnes River had the highest suitability for Swainson's Hawk (Figure 2). The predicted landscape suitability for Swainson's Hawk changed substantially from baseline under each of the three management scenarios. It increased the most under the enhanced agriculture scenario (31% more area classified as suitable), followed by the restoration scenario (16%) (Figure 3). Parcels close to the Cosumnes River became more suitable in the restoration scenario, and parcels throughout the study area became more suitable under the enhanced agriculture scenario (Figure 4). As might be expected, landscape suitability declined under the urban scenario (–4%) (Figure 3).

The average suitability of each land-use scenario as calculated for each of the 15 focal bird species showed subtle changes. Average suitability across all species increased under the restoration scenario by 5% and increased slightly under the enhanced agriculture scenario (1%), but overall suitability declined by 1% in the urban scenario (Figure 3 and Table 4). In addition, using a 5% change threshold, the restoration land-use scenario resulted in a more suitable landscape for nine out of the 15 bird species. One species, the Yellow-Breasted Chat (*Icteria virens*), experienced a 5% increase in suitability under the urban scenario, and no species experienced an

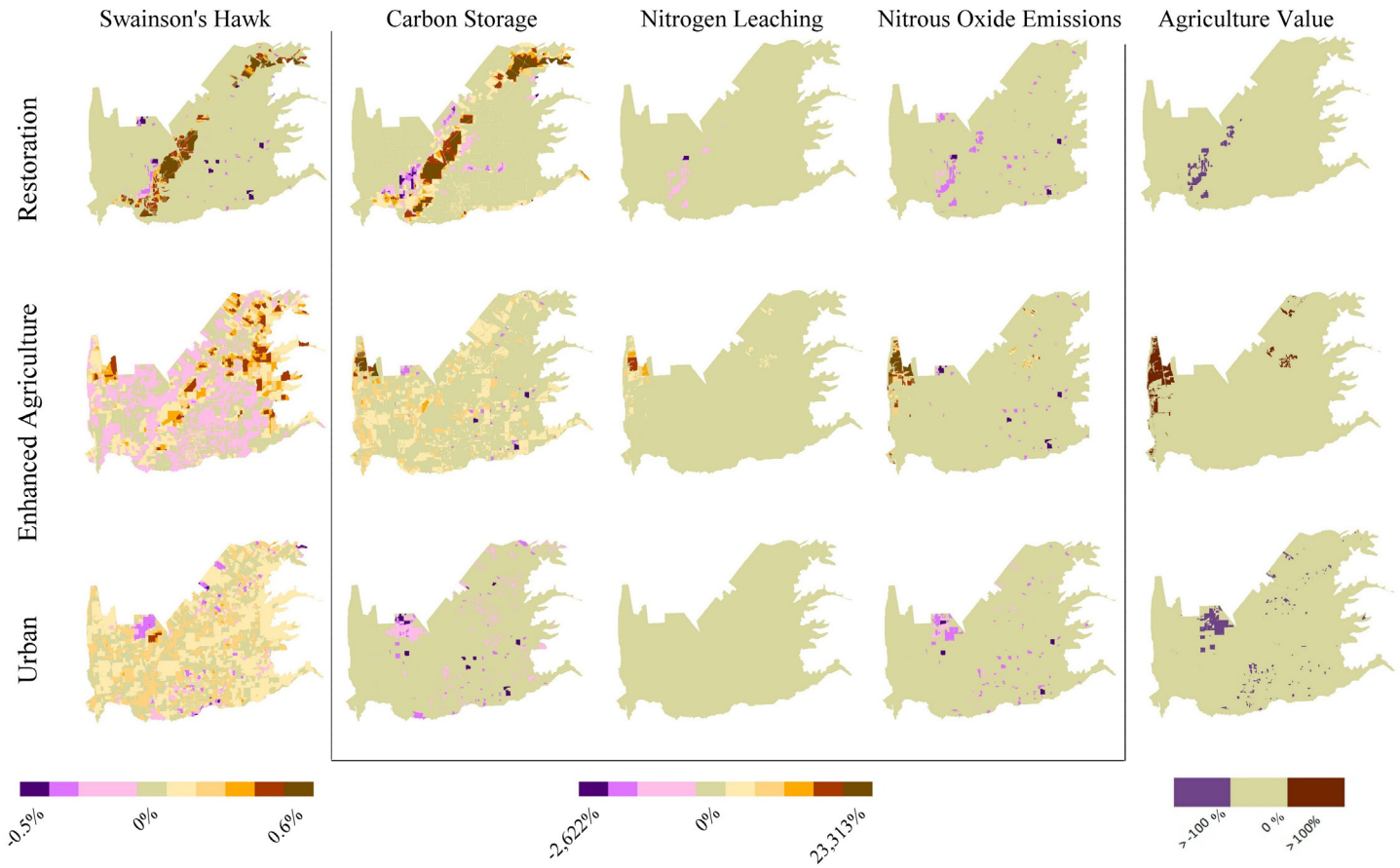

Figure 4 Maps showing change in ecosystem services from baseline (current) conditions to 2050 across the Cosumnes River Preserve by land-owner parcel for the restoration, enhanced agriculture, and urbanization scenarios. Colors indicate the magnitude of change (%): for Swainson's Hawk (biodiversity), carbon storage, and agricultural value, browns and reds represent an enhancement of these ecosystem services, and pink and purple shades represent a decrease (results for 15 focal bird species are not shown.) For nitrogen leaching and nitrous oxide emissions, browns and reds represent an increase in these disservices; pink and purple shades represent a decline and, consequently, an improvement to the environment. For all services, beige represents no change. The legend for carbon storage, nitrogen leaching, and nitrous oxide emissions maps, which appear within the black box, is shared.

increase or decrease in suitability exceeding 5% in the enhanced agriculture scenario.

3. Nitrous Oxide Emission and Nitrogen Leaching

The total amount of nitrous oxide emission associated with baseline agriculture in the study area is approximately 50,506 kg N_2O. Row crops had the highest N_2O emissions, accounting for 60% (~30,000 kg N_2O) of the baseline emissions. The next highest emissions were associated with grain (~12,000 kg N_2O or 24% of total) and vineyards (~5,000 kg N_2O or 10%), while pasture, orchards, and rice were less than 3%. The total amount of nitrates leached from agricultural lands is approximately 2.1 million kg N. Patterns of nitrogen leaching were similar to nitrous oxide emissions, with row crops ranking highest (approximately 1.7 million kg N, 79% of the total), followed by grain (~0.2 million kg N or 10%) and vineyards (~0.14 million kg N or 7%). Again, pasture, orchard, and rice comprised less than 2% of the total. Areas of high leaching and emissions under baseline were scattered throughout the agricultural lands of the study area (Figure 2).

In the enhanced agriculture scenario, total N_2O emissions and nitrate leaching in the study area increased by about 20%, concentrated in the northwest area (Figure 4). Nitrous oxide emissions

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increased to approximately 60,000 kg N_2O, and nitrate leaching to 2.6 million kg N (Figure 3). Similar to baseline conditions, row crops accounted for the greatest proportion of emissions and leaching. In the restoration scenario where agricultural lands were replaced by natural vegetation, total N_2O emissions and nitrate leaching decreased by 3% (approximately 49,000 kg N_2O and 2 million kg N; Figure 3), mostly in close proximity to the Cosumnes River (Figure 4). There was also an approximate 5% decrease in these figures in the urban scenario as agricultural land is developed; N_2O emissions decreased to around 48,000 kg N_2O and nitrate leaching to 2 million kg N, respectively (Figure 3). Patterns of emissions and leaching among types of agriculture are similar to baseline across both the restored and urbanized landscapes.

4. Agricultural Commodity Valuation

The total agricultural commodity value of the study area under baseline was ~$184 million (2011 figures), with a handful of high-value parcels scattered throughout the study area (Figure 2). Row crops accounted for almost half of this value (~$89 million or 49%), followed by vineyards (~$70 million or 38%) (Table 2). Agricultural types favored by the Swainson's Hawk such as alfalfa, grains, and pasture each accounted for less than 3%. Under the enhanced agricultural scenario, revenue increased by 48% to ~$273 million (Figure 3 and Table 2), with revenues from row crops accounting for an even higher proportion of the total revenue (63%). The restoration scenario resulted in a 4% decrease in agricultural revenue (to ~$176 million), while the urbanization scenario resulted in a 5% decrease (Figure 3 and Table 2).

DISCUSSION

Our analysis examined a highly productive agricultural landscape and quantified how different land-management scenarios compared in terms of carbon storage, biodiversity values, ecosystem disservices, and agricultural returns at the parcel scale. More specifically, we looked at the trade-offs under different land-use change scenarios, and evaluated whether positive benefits in financial agricultural returns were at the expense of biodiversity and other services. Underlain by the projected changes in land-cover types in 2050, our estimates indicated that the restoration scenario had multiple positive benefits from a conservation and environmental management perspective, similar to the conservation scenario generated by Nelson et al. (2009). Restoration yielded substantial positive outcomes for carbon storage (which increased 83% from baseline) and habitat for Swanson's Hawk, as well as 15 other focal bird species (16% and 5%, respectively). Concurrently, ecosystem disservices (nitrate oxide emissions and nitrate leaching) decreased (–3%), and agricultural returns also decreased (–4%) (Figure 3). Furthermore, the amount of agricultural land in the study area only decreased slightly (–2%) under the restoration scenario. At the other extreme, urbanization had consistently negative effects on the landscape, and resulted in decreased carbon storage (–6%) and landscape suitability for all bird species (–1% for the 15 focal species and –2% for the Swanson's hawk, specifically), along with a loss in financial agricultural returns (–5%). The only positive effect from a conservation and environmental management perspective was the reduction in nitrous oxide and nitrogen leaching (~ –5%) (Figure 3). From a land-use planning viewpoint, however, these relatively negative effects of expanding the urban footprint would need to be examined in the context of alternatives for meeting the housing needs of local cities (e.g., urban infill and increased urban housing densities).

The enhanced agriculture scenario was developed based on favoring the kinds of crops commonly protected or expanded as part of Swainson's Hawk conservation and mitigation efforts. Although managing for a single species is not ideal, in some cases (as here) it is a necessity because mitigation for habitat loss or affected protected species demands it. In other cases, a single-species approach might be pursued by management if a keystone species is identified. Either way, evaluating the effect of this strategy on ecosystem services and disservices, agricultural returns, and potential multi-species benefits is valuable for management. By 2050, we estimated that the enhanced agricultural landscape had a highly positive effect on Swanson's Hawk habitat value (31%), higher even than the restoration scenario (Figure 3). Landscape suitability for the

15 focal bird species also increased marginally, i.e., favorable crop types for the Swanson' hawk were also more suitable for some of these bird species. Agricultural returns increased by almost 50%. In contrast to other studies (e.g., Polasky et al. 2011), we found carbon storage benefitted as well (12% increase), owing to a replacement of grasslands with row crops, pastures, grains, and alfalfa with higher levels of carbon storage (Table 1 and 4). However, these gains came at a cost, with increases in nitrous oxide emissions and nitrogen leaching by about one-fifth (Figure 3).

The approach and scenarios used in this study provide a framework which can be adaptively modified in the future to inform land utilization. Clearly, many different or complex management scenarios could be explored. Our intent was to evaluate a range of feasible options to demonstrate the effects of major restoration on the one hand to urban growth on the other, with the enhanced agriculture scenario in the middle. One future modification, for example, would be to optimize the configuration of native and adjacent agricultural land in the restoration scenario to increase connectivity across the landscape. Alternatively, future analyses could also account for carbon storage in urban green spaces, or the value of retaining mature trees to provide nesting habitat for a listed species in the urban scenario. In addition, other services such as groundwater could be assessed, which is particularly relevant given the recently implemented Sustainable Groundwater Management Act, or recreation, given the high visitation rates of the study area.

To improve estimates of ecosystem services associated with agricultural areas, better information is needed on crop rotations over time (currently, the amount of agricultural land types for 2050 is projected based on the current proportion of types in the study area). The study area also harbors a few registered organic farms and some contracted organic production, such as rice cultivation. Future modifications of our approach could incorporate organic land management, given the association between organic practices and decreased ecosystem disservices. Although cultivation is largely conventional, compared to many parts of California it is highly diversified, with many different types of crops across small parcels. This spatial configuration makes farmscaping practices (the planting of trees, shrubs, and grasses to create diverse habitats for ecosystem services, including pest control and pollination) and buffer habitats a realistic option, which, in turn, can substantially affect carbon storage and biodiversity in agricultural lands (Pickett and Bugg 1998; Brodt et al. 2009). Estimates of the focal ecosystem services could also be improved by additional data, for example, including below-ground carbon storage estimates for the forest class, estimates of soil carbon, or nitrous oxide emissions for natural habitats.

Our findings using the 15 focal bird species, although subtle, indicated that management actions for the Swainson's Hawk yielded benefits for other bird species; however, it would be useful to assess how well this was reflected in other taxonomic groups. A number of studies from central California indicate that insects might respond similarly to the restoration scenario. For example, insectary hedgerows favor beneficial insects over pests by a ratio of three to one (Long 2001), with the highest numbers of insects correlated with the length of flowering period. Another study found that pollination by native bees depended on the proportion of natural habitat within 1 to 2.5 km from the farm site (Kremen et al. 2002). The authors compared rates of pollination of watermelon in Yolo County, California and found that farms with ≤1% natural habitat within 1 km experienced greatly reduced diversity and abundance of native bees compared to farms with ≥30% natural habitat within 1 km, meaning that pollination services by native bees had to be supplemented by imported colonies of European honey bees.

This study represents one of the few ecosystem services studies conducted at a spatial scale that is relevant to the on-the-ground decision-making of land managers, county planners, and conservation practitioners. Using parcels instead of pixels (albeit with a higher resolution) is useful because changes such as cropping patterns or fertilizer application occurs by these units. The identification of parcels that exhibit consistent, beneficial changes in carbon and biodiversity from baseline conditions across all scenarios may represent focal areas for targeted protection that constitute "no regrets" opportunities for conservation investment. In contrast, conflicted parcels that harbor both beneficial services and disservices might require land-owners and

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municipalities to work together to develop a management strategy that optimizes the value for beneficial ecosystem services.

CONCLUSION

To make trade-offs transparent to decision-makers, and inform choices about best land use in this agriculturally dominated landscape that has high potential for achieving multiple objectives for both agriculture and conservation, it is essential to understand ecosystem services and disservices from agriculture, implications for conserving habitat for biodiversity, and financial returns (Dale and Polasky 2007). Land use change in agriculturally dominated areas is often assumed to lead to benefits for landowners and agricultural returns, but negatively affect biodiversity and ecosystem services. That the restoration scenario resulted in a relatively minor decrease in agricultural financial returns, and that carbon storage increased under the enhanced agricultural scenario, are notable findings to present to decision makers.

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