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Analysis

Valuing ecosystem and economic services across land-use scenarios in the Prairie Pothole Region of the Dakotas, USA

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ABSTRACT

This study uses biophysical values derived for the Prairie Pothole Region (PPR) of North and South Dakota, in conjunction with value transfer methods, to assess environmental and economic tradeoffs under different policy-relevant land-use scenarios over a 20-year period. The ecosystem service valuation is carried out by comparing the biophysical and economic values of three focal services (i.e. carbon sequestration, reduction in sedimentation, and waterfowl production) across three focal land uses in the region [i.e. native prairie grasslands, lands enrolled in the Conservation Reserve and Wetlands Reserve Programs (CRP/WRP), and cropland]. This study finds that CRP/WRP lands cannot mitigate (hectare for hectare) the loss of native prairie from a social welfare standpoint. Land use scenarios where native prairie loss was minimized, and CRP/WRP lands were increased, provided the most societal benefit. The scenario modeling projected native prairie conversion to cropland over the next 20 years would result in a social welfare loss valued at over $4 billion when considering the study's three ecosystem services, and a net loss of about $3.4 billion when reductions in commodity production are accounted for.

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1. Introduction

Increases in domestic and international demands for food, fiber, and fuel have led to increased land conversion for agricultural production across the U.S. In the last few decades, conservation provisions have been introduced into U.S. agricultural policy to mitigate conversions and restore once native habitats and the respective ecosystem services they provide. Two of the most prominent conservation programs within the U.S. Farm Bill are the Conservation Reserve Program (CRP) and the Wetlands Reserve Program (WRP). These programs were engineered to establish long-term, resource-conserving covers on marginally productive farmland, and have conserved more than 12 million hectares nationwide each year since 1990 (Hart, 2006).

Ecosystem services have been described as the direct and indirect benefits people obtain from ecological systems (Millennium Ecosystem Assessment, 2003). This anthropocentric view has led to increased efforts to identify, quantify, and value ecosystem services. An economic perspective on ecosystems portrays them as natural assets providing a flow of goods and services (Daily et al., 2000; Turner et al., 2008). Once these goods and services are identified and quantified, they can be monetized to complete the valuation process (Murray et al., 2009). Complicating this last step is the fact that most of these goods and services are public and non-market. Identifying the economic value of these services is essential in revealing their societal value because this provides a common metric to facilitate comparisons across attributes and differing ecological scenarios in policy assessments (NRC, 2005). Programs such as the CRP and WRP are geared towards increasing the amount of ecosystem services provided through public investment. To foster ecosystem service markets the U.S. Department of Agriculture (USDA) announced the establishment of a new Office of Ecosystem Services and Markets (USDA, 2008; News Release No. 0307.08), now called "Office of Environmental Markets."

The objectives of this study are to (1) model and analyze the primary ecosystem and economic services across prominent land uses within the Prairie Pothole Region (PPR) of North and South Dakota, (2) illustrate and compare the societal values of agricultural products and ecosystem services produced under policy-relevant land-use change scenarios, and (3) explore the effectiveness of mitigating native prairie loss with conservation program lands. Conservation and natural resource managers have been criticized for focusing on a single economic sector, while trying to maximize a narrow set of objectives (Tallis and Polasky, 2009). By quantifying both ecosystem and economic services in the PPR and analyzing the tradeoffs between them, natural resource managers and policy makers can make more efficient, knowledgeable, and defensible decisions in a region described as

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"North America's most endangered ecosystem (Samson and Knopf, 1996)."

Numerous studies have been conducted to estimate the value of a range of ecosystem services using both stated and revealed preference techniques, as well as benefit transfer methodology. However, the integration of both biophysical and ecosystem service valuation data is a relatively new phenomenon (NRC, 2005; Troy and Wilson, 2006). Past integrated research has usually incorporated a descriptive spatial component [ex. Geographic Information Systems (GIS)] within the models used (Bockstael et al., 1995; Eade and Moran, 1996; Kreuter et al., 2001; Lant et al., 2004; Troy and Wilson, 2006; Zhao et al., 2003); whereby changes in ecosystem services and relative economic valuation are compared across various land uses and spatial patterns. However, few of these studies attempt to model future land-use predictions, and subsequent changes in ecosystem service values produced (see Nelson et al., 2009 for uncommon example).

Due to the complexity of both the ecological and economic valuation processes, most integrated research has been either broad-scale assessments of multiple services (Costanza et al., 1997; Troy and Wilson, 2006), or highly detailed functional analysis of a single ecosystem service at small geographical scales (Polasky et al., 2008; Smith, 2007). The broader approach is often criticized for its generality across habitat types, while the other is noted for lacking both the scope and scale for it to be relevant and applicable to policy scenarios (Nelson et al., 2009). Furthermore, few authors have compared the ecosystem service values generated to the opportunity costs of alternative land uses, such as agricultural production or urban development (see Jenkins et al., 2010; Nelson et al., 2009, and Polasky et al., 2008 for initial attempts).

There is a building body of literature estimating the non-market benefits of government-sponsored conservation programs. Much of the economic literature focuses on greenhouse gas mitigation and the potential for retired lands or altered agricultural operations to sequester carbon (Antle et al., 2007; Feng et al., 2004; Lal et al., 1999; Marland et al., 2001). Research has found that instituted market mechanisms and/or additional program payments for carbon sequestration have the potential to exceed the cost of land restoration and the opportunity cost of foregone agricultural production in some particular areas (Hansen, 2009; Jenkins et al., 2010; Lewandrowski et al., 2004). Far less research has been done on the economic value of native prairie grasslands and wetlands (see Hovde and Leitch (1994), and Hubbard (1988) for early examples).

In this study, we model changes to ecosystem and associated economic values across policy-relevant land-use change scenarios over the next 20 years within the PPR of North and South Dakota. This is accomplished by way of linking sound ecological field data and economic valuation within a single accounting metric. The study area was selected based on available scientific data and its unique and critical ecological makeup, as well as the region's vulnerability to future land-use change. Our analysis focuses on three ecosystem services; (1) carbon sequestration as it pertains to global climate regulation, (2) reduction in sedimentation relative to soil and water quality, and (3) waterfowl production in relation to the derived benefits associated with increases in duck populations. Biological and associated economic values are compared across three focal land uses found in the study region: (1) native prairie grasslands, (2) land enrolled in the CRP and WRP (CRP/WRP), and (3) cropland. Our study's findings provide insight into the impacts of the CRP/WRP and other conservation provisions that are currently in existence or up for consideration within the U.S. Farm Bill. Such accounting is critical to ensuring the continued funding of Federal conservation programs, as is required by the President's Budget and Performance Integration Initiative (Gleason et al., 2008). Importantly, this study will help determine economic and ecological tradeoffs in the PPR and the substitutability of retired croplands enrolled in conservation programs for native prairie grasslands that have experienced annual conversion rates approaching 3% in recent years (DU-EPF, 2009).

2. Methods

2.1. Study Area

The PPR is found within the Northern Great Plains, and covers approximately 900,000 km^2. The region extends all the way from the north-central United States, incorporating parts of Iowa, Minnesota, North Dakota, South Dakota, and Montana, to the south-central part of Canada, encompassing sections of Alberta, Saskatchewan, and Manitoba (Reference Fig. 1). For this study, we focus specifically on the PPR of North and South Dakota that is roughly defined by the area and state boundaries north and east of the Missouri River, covering approximately 224,000 km^2. The combination of interspersed grassland and wetland ecosystems within this region produces a highly valued bundle of ecosystem services. For example, the PPR has been referred to as the "Duck Factory," as it serves as the most important breeding ground for North American waterfowl, producing 50–80% of the continent's entire dabbling duck population on only 10% of the available nesting habitat (Batt et al., 1989; Ducks Unlimited, 2008). However, this same landscape provides necessary inputs for valuable agricultural production. North and South Dakota are more economically dependent on the agricultural sector than any other states in the country, with their annual agricultural products valued at around $6.5 billion (USDA-NASS, 2007a).

The vast network of agricultural operations interspersed among critical habitats has made the PPR an attractive area for farm conservation investment. The CRP and WRP are voluntary land retirement programs for agricultural landowners. Through the programs, landowners can receive annual rental payments and cost-share assistance to establish long-term, resource-conserving land cover. A majority of newly enrolled CRP hectares have been planted with a native grass and forbs mix over the last three years in the Dakotas (USDA-FSA, 2010). Contract periods for the CRP are typically between 10 and 15 years, whereas the WRP offers perpetual and 30-year conservation easements. At the end of 2008, both North and South Dakota ranked in the top ten states for land enrolled in the CRP, with a combined enrollment of nearly 1.7 million hectares (USDA-FSA). However, in a time of rising commodity prices, renewable energy mandates, and tightening federal allowances, along with the timing of CRP contract expirations, many experts fear that enrolled hectares are in a steep decline. In a recent Congressional report, North and South Dakota were noted as having the largest decreases in CRP lands in the country over the last few years (Cowan, 2009).

Remaining tracts of native prairie also remain vulnerable to the forces threatening CRP/WRP reenrollment. The recent push for renewable energy from biofuels and higher-than-average market prices for corn, with a growing portion of this crop being used as a bioenergy fuel feedstock, appear to be providing economic incentive to convert native prairie lands (Stubbs, 2007). With only a quarter of the original grasslands remaining in South Dakota, elevated conversion rates persist (Reynolds et al., 2006; Stephens et al., 2006). Similarly, previous estimates indicate more than 50 % of PPR wetlands in the U.S. have been drained or altered for purposes of agricultural production (Tiner, 1984).

2.2. Valuation Process

The valuation sequence is composed of four essential steps: (1) identify ecosystem services by land use, (2) quantify the biological values associated with those services down to annualized per-hectare values, (3) monetize those values using economic methods, and (4) track and sum the flux in those values as the number of hectares change in each land use scenario (Murray et al., 2009). By standardizing measurements into per-hectare values, we are able to compare ecosystem services and other land incomes at the regional scale. Once economic values are added, ecosystem service values can be summed and cross-tabulated by service and land use for each scenario (Troy and Wilson, 2006).

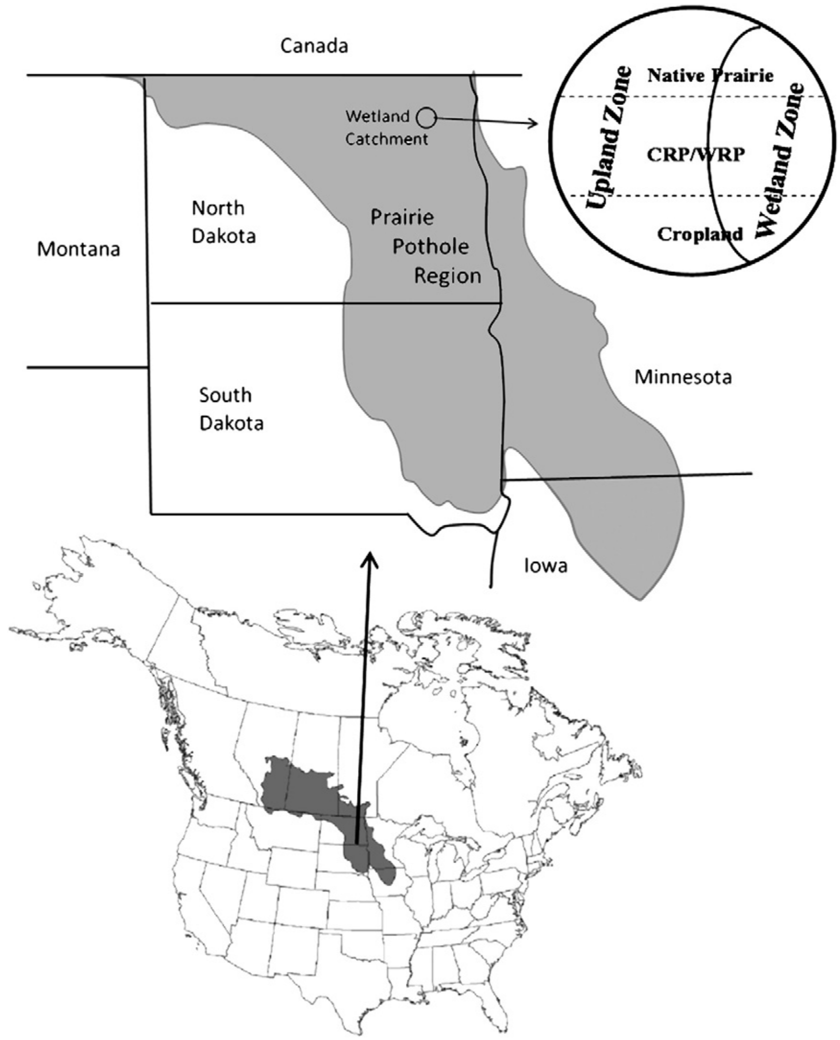

Fig. 1. Prairie Pothole Region in the Unites States, and illustration of a wetland catchment showing the three land cover types described by Gleason et al. (2008). Enlarged circle of wetland catchment is not an exact replica of land-use makeup, scale, or location."CRP/WRP" refers to lands enrolled in the Conservation Reserve Program and Wetland Reserve Program.

Biophysical values for our analysis were derived from a comprehensive reporting of ecosystem services in the PPR by Gleason et al. (2008), and supplemented by a waterfowl productivity evaluation report by Reynolds et al. (2007). Gleason et al.'s (2008) two-stage study consists of a comprehensive, stratified survey of 204 wetland catchments (wetland and surrounding uplands contributing runoff to the wetland) in 1997 and 270 catchments in 2004 as part of a USDA Conservation Effects Assessment Project (CEAP) effort in the PPR portion of the U.S. In their study, biophysical samples were taken in catchments containing temporary, seasonal, and semipermanent wetlands in hydrologically restored and non-drained restored catchments on CRP/WRP lands; drained and non-drained catchments on croplands; and native prairie catchments.[1]

Benefit transfer methods (as outlined in Rosenberger and Loomis, 2001) are used to monetize the non-market ecosystem services. Benefit transfer relies on previous economic studies to make inferences about the economic values of non-market goods and services at an alternative policy site. The reliability of the benefit transfer estimates is solely dependent on both the applicability of the study sites and the quality of the original benefit estimation (Wilson and Hoehn, 2006). In this study, we use value transfer as it encompasses the transfer of a single point benefit estimate. In conjunction with the biophysical flow data, we monetize three services within the region: carbon sequestration, reduction of sedimentation, and waterfowl production. Previous research done in other wetland dominated landscapes (Jenkins et al., 2010), along with the biological makeup of the PPR, suggests that the services included in our study are economically among the most valuable in the region.

Current land use estimates are needed as a baseline in order to determine the impact of land-use changes. The biophysical values used in our study were individualized for counties, physiographic regions (Missouri Coteau, Prairie Coteau, and Glaciated Plains),[2] Major Land Resource Areas (MLRA's), catchment zones (wetland and upland), and the three land uses (native prairie, cropland, CRP/WRP lands) (Reference Fig. 1). The geographical breakdown of the biological data is maintained in the accounting model. To derive land unit figures for each level of specificity, we relied on geospatial data-extracting software (ESRI ArcMap 9.2, 1999–2006). Regional boundaries for the PPR were overlaid to produce the exact hectares (and percentages) within the study area.

[1] Refer Gleason et al. (2008) for a detailed list of land-use treatment sample wetlands where they were subjected to.

[2] Due to limited data, Prairie Coteau acreage was lumped together with that of the Missouri Coteau given their similar ecological makeup. Where appropriate, biological data from these two physiographic regions were averaged together (reference Table 1).

Cultivated cropland and native prairie estimates were extracted from the most recent U.S. Fish and Wildlife Service (USFWS) Habitat and Population Evaluation Team (HAPET) land cover dataset (2002). CRP/WRP hectares were derived from 2007 USDA-Farm Service Agency (U.S. Department of Agriculture-Farm Service Agency (USDA-FSA), FY, 2007) CRP and Natural Resource Conservation Service (U.S. Department of Agriculture-Natural Resources Conservation Service (USDA-NRCS), FY, 2007) WRP cumulative enrollment datasets.

Land cover estimates were further refined to wetland and dry-land zones. We use data from the 1997 National Resources Inventory (NRI) (USDA, 2000) – a comprehensive database of wetlands inventoried on existing cropland – to estimate the proportion of wetlands on cultivated croplands within the region. Given the lack of similar data across the other two land uses, we prescribe the same proportion of wetlands to CRP/WRP lands and native prairie as was found for cropland (consistent with Gleason et al., 2008). This methodology presumes that if a wetland was in existence when inventoried as part of the NRI collection that it would remain in existence when enrolled into the CRP or WRP conservation programs. Employing the same wetland proportions to native prairie is likely conservative. Average wetland proportions are multiplied by the total area of each land use to estimate total hectares of wetlands. The remaining upland land cover both within and outside the catchment boundaries are grouped together and classified as the "dry-land" zone. Biophysical values derived for the upland zone of the catchment are assigned to all dry-land hectares.

Once calculated, biophysical changes and adjoining monetary values are coupled with percentages of each land use to aggregate up to regional estimates for each land-use change scenario compared to the baseline. Ecosystem service estimates are made proportional to land-use changes, and values found in the Gleason et al. (2008) study.

2.3. Biophysical Measurement of Ecosystem Services

2.3.1. Carbon Sequestration

Soil organic carbon (SOC) and vegetation organic carbon (VOC) contents were estimated separately for upland and wetland zones in each of the 270 catchments surveyed in the PPR (Gleason et al., 2008). SOC data collected for the upper 15 cm of the soil is used in estimating the soil carbon sequestration flow values. Previous work (Euliss et al., 2006) demonstrates that most differences in SOC among the land covers occur within this particular soil depth. Net fluxes of SOC are calculated using data for each specific physiographic region, dry-land and wetland zones, and land use.

To estimate potential carbon gains/losses from changing land cover, mean estimates supplied by the authors of Gleason et al. (2008) are coupled with historic sequestration/emission rates found in the literature. A relative timeline is produced when cited annual sequestration/emission rates are applied to the calculated net differences in SOC (Reference Table 1; a–c). For example, if the estimated net difference in SOC between CRP/WRP and cropland is 12 Mg,[3] and a sequestration rate of 0.75 Mg/ha/year is applied, the maximum restoration potential of 12 Mg (from retiring cropland) would be met uniformly in its entirety over the course of sixteen years (i.e. 12 ÷ 0.75 = 16). There would be a zero gain in years 17 to 20 in our timeline.

Three specific land cover changes are considered: (1) native prairie being converted to cropland, (2) CRP/WRP lands converted back to cropland, and (3) cropland becoming enrolled in the CRP/WRP. To calculate the carbon sequestration "benefit" of retiring cropland to CRP/WRP grasslands, we first calculate the sequestration potential of retired lands. It is common within the biological field to use mean estimates for native prairie as the maximum potential level for conserved CRP/WRP lands (Euliss et al., 2006; Gleason et al., 2005, 2008). In turn, mean estimates for cropland are subtracted from those of native prairie to arrive at the potential net gain from restoration (see Table 1-b). We employ a conservative constant sequestration rate of 0.5 Mg/ha/year to the carbon flow measurements until carbon is no longer sequestered (listed in Table 1-a) (Follett et al., 2001; Lewandrowski et al., 2004). This typical-loss assumption serves as a proxy for the actual path which likely has higher sequestration rates early on and lower rates later in the time path.

For converting native prairie to cropland, the steady-state averages for cropland are subtracted from those of native prairie. A study by Davidson and Ackerman (1993) reports that cultivation of previously untilled soils results in an average decrease in SOC of 30%, usually occurring entirely within the first 5 years. The net differences in mean estimates from Gleason et al., 2008 study are on par with those of Davidson and Ackerman. In turn, we calculate individual emission rates for both dry-land and wetland zones in each physiographic region by dividing the net difference between native prairie and cropland by five. For example, in one catchment the mean SOC estimates for native prairie and cropland were 64.76 Mg and 44.57 Mg, respectively, resulting in a net difference of 20.19 Mg (or 31%) (Table 1-b). The difference is then divided by five – as we assume it is entirely lost in the first five years – to arrive at an annual emission rate of 4.04 Mg/ha (Table 1-a). This estimation process produces SOC emission rates ranging from 1.22 Mg/ha/year to 4.04 Mg/ha/year when native prairie is converted to cropland, which are consistent with previous estimates made in the PPR (Euliss et al., 2006; Gleason et al., 2005).

To calculate the biophysical value of SOC lost from converting CRP/WRP lands back into cropland, we first calculate steady-state averages for CRP/WRP lands from which we can subtract mean estimates for cropland. The CRP/WRP SOC estimates from Gleason et al.'s (2008) study were

Table 1
Sequestration and emission rates of soil organic carbon (SOC), calculated net differences for SOC and vegetation organic carbon (VOC), and relative time period for sequestration/emission for possible land-use changes.

a) SOC		Sequestration (+)/emission (−) rates (Mg/ha/year)		
Region	Zone	CROP to CRP	CRP to CROP	NP to CROP
GP	UPL	+0.50	−1.00	−4.04
	WET	+0.50	−1.00	−1.47
MC/PC	UPL	+0.50	−1.00	−1.22
	WET	+0.50	−1.00	−2.63
b) SOC		**Mean net differences in SOC (Mg/ha)**		
Region	Zone	(+) CROP and CRP	(−) CRP and CROP	(−) NP and CROP
GP	UPL	20.19	5.00	20.19
	WET	7.36	5.00	7.36
MC/PC	UPL	6.12	5.00	6.12
	WET	13.16	5.00	13.16
c) SOC		**Time period for sequestration/leaching (years)**		
Region	Zone	CROP to CRP	CRP to CROP	NP to CROP
GP	UPL	40.39	5.00	5.00
	WET	14.73	5.00	5.00
MC/PC	UPL	12.24	5.00	5.00
	WET	26.32	5.00	5.00
d) VOC		**Mean net differences in VOC (Mg/ha)**		
Region	Zone	(+/−) CRP and CROP	(−) NP and CROP	(+/−) CRP and NP
GP	UPL	1.57	1.32	0.25
	WET	1.40	0.80	0.60
MC/PC	UPL	1.91	1.83	0.08
	WET	1.84	1.49	0.35

"CROP" stands for cropland, "CRP" stands for lands enrolled in the Conservation Reserve Program and Wetland Reserve Program; "NP" stands for Native Prairie; "GP" stands for Glaciated Plains; "MC/PC" stands for the Missouri and Prairie Coteau; "UPL" stands for the upland zone; "WET" stands for the wetland zone.

[3] The abbreviation Mg refers to megagram; 1 Mg is equivalent to 1 metric ton (or tonne), or 10^6 g. This paper employs Mg except in the context of monetizing carbon estimates, in which the standard abbreviation tCO_2e is used to refer to "metric tons of CO_2 equivalent."

deemed unusable, as values were inconsistently affected by the restoration age of the study sites, farming history, climate variations, soil type, etc. Given the contract structures of CRP and WRP, we assume that any retired lands that might be re-cultivated in the future have been in a conservation program for the minimum of 10 years. In turn, we take the mean estimates for cropland and apply the well-cited sequestration rate of 0.5 Mg/ha/year (Follett et al., 2001). We estimate CRP/WRP lands to have, on average, 5 more Mg/ha of SOC (i.e. 0.5 Mg/ha/year × 10 years) than cropland.[4] Mean estimates for cropland were used as the starting point for estimating CRP/WRP SOC because conservation program lands are essentially cropland at the beginning time period. Furthermore, it is assumed that this difference in SOC will emit out in the first five years, as was the case when native prairie was converted. This logic results in a transferable emission rate of 1.0 Mg/ha/year.

VOC in standing crops (live and dead) was also calculated for each land use across physiographic regions and catchment zones by Gleason et al. (2008). Unlike with SOC, the biomass (and relative carbon) is often higher on CRP/WRP lands than native prairie because of differing plant communities (Gleason et al., 2008). Due to the relatively fast establishment (and cultivation) of crops and planted CRP/WRP vegetation, a static VOC gain/loss is calculated for each land-use scenario from each land uses' mean VOC estimates (Table 1-d).

Once total carbon fluxes (SOC plus VOC) have been determined, they are then converted into units of carbon dioxide equivalents (CO_2e) by multiplying by the conversion factor of 3.67. Converting the carbon sequestration values into units of CO_2e provides the currency for which they are monetized.

2.3.2. Reduction of Sedimentation

Gleason et al. (2008) quantified the potential of conservation program lands to reduce upland soil losses and sedimentation of wetland basins in the PPR. They used the Revised Universal Soil Loss Equation (RUSLE) to estimate the change in soil erosion rates on uplands when tillage was replaced with perennial cover as part of the CRP and WRP. Their study provides mean annual soil-loss estimates (Mg/ha/year) for cropland and CRP/WRP lands within each MLRA in North and South Dakota. Mean soil loss estimates for respective land uses are used in the ecosystem service analysis, with estimates for CRP/WRP lands conservatively assigned to native prairie hectares. The multiple estimates within each physiographic region are averaged to provide a single multiplier. Because the study is focused on the changes to ecosystem services occurring under land-use scenarios, net differences are calculated from the mean estimates. These values are then used in the accounting model to track changes in soil-loss tonnage as one land use changes to another.

2.3.3. Waterfowl Habitat Suitability

We relied on a waterfowl production model produced by Reynolds et al. (2007) to assess the potential waterfowl habitat suitability of different land covers within the study region. In producing their original model, these authors utilized duck population and wetland habitat data collected on 335 10.4-km^2 sample blocks in the PPR of North and South Dakota during 1987–1998. They also used models presented by Cowardin et al. (1995; Eqs. (3)–(7)) and Krapu et al. (2000) to estimate production parameters for 5 upland nesting duck species [mallard (*Anas platyrhynchos*), gadwall (*Anas strepera*), blue-winged teal (*Ana discors*), northern shoveler (*Anas clypeata*) and northern pintail (*Anas acuta*)] for years 1992–2004. The principal production parameters include (1) overall nest success, (2) recruitment rate (number of females fledged/adult females in the breeding populations), and (3) recruits (total males and females fledged). Reynolds et al.'s (2007) waterfowl production model also relies on Northern Prairie Wildlife Research Center's Waterfowl Nest file – a repository of waterfowl nest records submitted yearly by numerous researchers and land managers within the study area – to determine duck preference (probability that a female will select a particular habitat for nesting, given all habitats are equally available) and daily survival rate of nests. These additional inputs within the production model are ultimately computed for various nesting habitats using methods outlined in Klett et al. (1988).

With the necessary parameters in place, Reynolds et al.'s (2007) model is able to estimate duck production under current and potential land configurations. Using 2007 breeding pair densities, wetland conditions, and available upland habitat as the baseline, we altered percentages of native prairie, CRP/WRP, and cropland (i.e. the available nesting habitat) congruent to the percent changes in this study's land-use scenarios. In this way we estimated the additional number of fall fledgling recruits from the PPR of North and South Dakota. Wetland habitat conditions in 2007 in the U.S. prairies were highly variable throughout the region, generally ranging from good to poor. The overall pond[5] estimate (2.0 ± 0.1 million) was 29% above the long-term average (1.5 ± 0.02 million from 1955 to 2005), coupled with favorable conditions in the Canadian prairies (USFWS, 2007), meaning that our initial estimate of duck breeding population size may have been slightly above average but certainly not atypical.

In addition to using 2007 wetland and habitat conditions as the baseline in the model, these standard additional assumptions apply (Cowardin and Johnson, 1979; Reynolds et al., 2001, 2007): (1) spatial distribution of breeding pairs in 2007 is representative of the 20-year period, (2) brood survival rates are constant (0.74), (3) female annual survival rates are constant (0.67) and are the same for adults and juveniles, (4) nest survival in all habitats is positively related to percent perennial cover in the landscape, (5) population growth rate is density-independent, (6) wetlands loss due to conversion of grasslands to croplands is minimal, and (7) the ND and SD duck breeding populations are closed (immigration and emigration offset one another).

Wetlands containing water in Spring attract breeding duck pairs that establish and defend territories during the breeding season. Small, shallow, temporary and seasonal wetlands (Cowardin and Johnson, 1979) provide invertebrate-rich environments upon which breeding females rely as a source of protein and other nutrients critical to egg-development. Some of these wetlands experience altered hydro-periods as a result of grasslands being converted to croplands, which can impact the wetlands' capacity to attract breeding duck pairs and can lead to a reduction in local breeding population. For purposes here, we assumed that reductions in breeding population size resulting from conversion of grassland to cropland would be minimal (assumption 6). In doing so, we likely underestimate reductions in duck productivity resulting from conversion of grassland to cropland.

Assumption 7, in its strictest sense, says that ducks produced in North Dakota or South Dakota will return to North Dakota or South Dakota each year thereafter to breed. That assumption is questionable as some species of breeding ducks, especially northern pintail and blue-winged teal, are opportunistic in terms of where they settle. Fortunately, the assumption can be relaxed in our modeling without great loss in accuracy by requiring only that ducks not returning are offset by ducks produced elsewhere that choose to breed in North Dakota or South Dakota.

[4] This assumes that SOC does not reach an equilibrium prior to the end of the 10-year time period.

[5] The number of ponds in the region is estimated by aerial observation, coupled with a multiplier that is the ratio of the number of ponds seen by a ground crew on a subsample of transects to the number seen by the aerial observer. A 'pond' is classified as being at least 6 in. deep, being greater than 3 m^2, and is expected to retain water without additional precipitation for at least 3 weeks.

2.4. Monetizing Ecosystem Services

2.4.1. Carbon Sequestration

In 2009, under Executive Order 12866, a U.S. government interagency working group was established and assigned the responsibility of calculating social cost of carbon (SCC) estimates to be used in regulatory impact analysis. This was the first U.S federal government effort that was aimed at improving the accuracy and consistency of how federal agencies value reductions in carbon dioxide (CO_2) emissions. Relying primarily on existing peer-reviewed models, the group worked to develop improved estimates by accounting for key uncertainties, model differences, and defensible input assumptions. The four SCC estimates ultimately chosen by the group were $5, $21 (central value), $35, and $65 (2007 U.S. dollars). We apply the central value of $21/tCO_2e within our accounting model. This marginal price embodies the present value of the stream of future economic damages associated with an incremental increase (of an additional metric ton) in carbon dioxide emissions in a particular year. Total carbon fluxes are tracked for each land use in each scenario for a 20-year horizon. The amount of CO_2 sequestered/emitted is multiplied by the SCC price for each year. The monetary values are discounted back to the present with a 3% real discount rate, as this was the central rate presented by the SCC working group in their assessment.

2.4.2. Reduction in Sedimentation

Per-ton benefit values for reduced soil erosion are derived from Hansen and Ribaudo, 2008 USDA-Economic Research Service (ERS) study and referenced database. Their study is a progression of work done by the ERS since the 1980s, and is believed to be the best available data for larger analyses on soil conservation benefits with respect to farmland erosion. Hansen and Ribaudo (2008) rely on reduced-form models, incorporating complex physical processes that ultimately link soil erosion to environmental quality, and the economic values that both the public and private sectors place on fluctuations in that quality. Soil erosion values are summed from twelve applicable categories pertaining to soil quality, sediment in reservoirs, damage to navigation passages, irrigation channels, and road drainages, water-based recreation, freshwater fisheries, flood mitigation, municipal water treatment and use, and effects to steam-powered power plants. The applied values can be viewed as prices that people, businesses, and government agencies would be willing to pay for a 1-ton reduction in soil erosion. These marginal values are provided for each county within the study region, and are noted to increase in accuracy when aggregated up to regional scales. Total benefits ($) equate to the economic soil-loss values multiplied by the changes in erosion (summed across all changes). Specifically, we multiply the changes to dry-land hectares of specific land uses by the net difference in soil-loss estimates of cropland, CRP/WRP lands, and native prairie. Calculated values are then summed over the 20-year period and simplified down to NPV using a 3% real discount rate.

2.4.3. Waterfowl Habitat Suitability

Within our analysis, we chose to value waterfowl as an input to satisfying recreation hunting demand. Because the PPR serves as the essential breeding habitat to North American waterfowl, the valuation is done at the margin of additional ducks added to the fall (autumn) flight. Greater population numbers can result in additional waterfowl hunter days (a quantity effect) as well as increased harvest rates for hunters (a quality effect) (Murray et al., 2009). After a review of the recreation economics literature, it was decided to value the quality effects of an additional waterfowl 'kill' beyond people's current harvest. In this light, we conclude that harvest figures are part of a hunter's individual utility function and add to the net economic value they derive from the hunting experience (Laughland, 2005). For this type of benefit transfer estimate, we relied on a previous study done by Hammack and Brown (1974). Results from their contingent valuation survey indicate the marginal value of an additional duck bagged to be between $14.18 and $31.04 (2007 prices), for a mean value of $22.61 (U.S. Department of Labor–Bureau of Labor Statistics (BLS), 2009).

An additional duck bred in the PPR and added to the fall flight does not unequivocally result in an additional duck harvested. In turn, we calculated the average take of waterfowl as a percentage of the total population and annual harvest figures. This resulted in a U.S. harvest percentage of nearly 35% (in 2007) (Flyways.us, 2007; Raftovich et al., 2009). The marginal value of a bagged duck revealed in Hammack and Brown (1974) is multiplied by the estimated harvest rate, resulting in a range of $4.99 to $10.97, and a mean of $7.96. This mean value is used as the price for an additional duck produced in the study region and added to the fall flight. As is the case with the other two ecosystem services, the NPV of additional ducks is calculated over the twenty-year study horizon using a 3% real discount rate.

2.5. Valuing Economic Services (Agriculture Production and Government-related Payments)

While the ecosystem services produced on different land covers provide societal benefits, one must also look into the production of marketed commodities in considering the land's true economic contribution. Cash rent values ($/ha) for general cropland (individualized by county) are taken from USDA National Agricultural Statistics Service 2008 data and are assigned to the deemed hectares. Cash rents were chosen for the study because they are relatively unbiased towards crop type. Additional government payments/subsidies related to cropland were not considered as we assume they are intuitively built in to the cash rent values.

Average annual CRP/WRP county-level payments are derived by dividing 2007 USDA Census data for total government payments made for CRP/WRP by the estimated CRP/WRP lands in each county. These figures are converted into per hectare values and are assigned to the associated land uses within the model. Revenues generated by managed or emergency grazing and haying on CRP/WRP lands were initially considered, however coinciding reductions in rental payments for these practices counter the potential gains.[6] Grasslands deemed as native prairie, are assigned no additional market value. These are likely conservative estimates, as some managed grazing and/or recreational activities (e.g. hunting, fishing, and wildlife viewing) often co-exist with these lands (Allen and Witter, 2008).

2.6. Land-use Scenarios

Four land-use change scenarios were developed for the ecosystem and economic service tradeoff analysis. The hypothetical scenarios were engineered to represent broad changes is social agendas. These changes represent foreseeable trends in social and/or private thinking and management that could occur within the next 20 years, such as increased vigilance to preserve remaining native prairie or economic circumstances that lead to continued conversion of these native lands. Some of these structural changes were purposefully designed to go beyond what might be considered in the current policy arena, which is limited to a shorter time horizon. The 20-year period was chosen to allow for the dynamics of the ecological impacts of land-use change to play out and be captured (ex. carbon sequestration). The scenarios are carried out by varying the percentages of native prairie, CRP/WRP lands, and cropland across counties within the study region in relation to 2007 baselines. Their formulation was aided by existing literature, along with consultation with USDA economists and USFWS habitat

[6] Managed haying and grazing are authorized no more frequently than one out of every three years after the CRP cover is fully established. CRP participants requesting managed haying and grazing are assessed a 25% payment reduction. Emergency haying and grazing are only authorized in areas that have experienced a severe drought or natural disaster (USDA-FSA).

Table 2
Land-use change scenarios.

Land-use change scenario	Native Prairie		CRP/WRP		Cropland	
	Change in ha (acres)	% gained or (−) lost	Change in ha (acres)	% gained or (−) lost	Change in ha (acres)	% gained or (−) lost
Scenario 1 ("Aggr. Conservation")	0	0	738,685 (1,825,291)	+50	−738,685 (−1,825,291)	−8.21
Scenario 2 ("CRP Mitigation")	−399,491 (−987,131)	−10	399,491 (987,131)	+27.04	0	0
Scenario 3 ("Market Forces")	−399,491 (−987,131)	−10	0	0	399,491 (987,131)	+4.4
Scenario 4 ("Exten. Conversion")	−399,491 (−987,131)	−10	−369,342 (−912,633)	−25	768,834 (1,899,790)	+8.54

"CRP/WRP" accounts for lands enrolled in the Conservation Reserve Program and Wetlands Reserve Program. Percentages gained or lost are relative to 2007 baseline figures.

specialists. The four scenarios are described below as well as in Table 2.

The first scenario, dubbed "Aggressive Conservation," forecasts the land-use makeup following the ultimate investment in conservation/preservation. Based on conversations with the USDA (i.e. Hyberg, 2009), it is not politically feasible to go much beyond a 10% increase in program lands in the near future. While this judgment is upheld in all of the other scenarios, the Aggressive Conservation scenario was designed to look at the long run by expanding beyond the limits of current politics. We assume all remaining native prairie in the PPR (1,477,371 ha) is preserved along with a 50% increase in CRP/WRP lands in the region that are substituted away from overall cropland (a decrease of roughly 8.2%). The land-use changes within this scenario are plausible in the long run if studies like this one continue to show that there is value in doing so and if policy makers continue to seek greater market structure for the allocation of ecosystem services.

The other three scenarios included in the study all look into the effects (environmental and economic) of projected native prairie loss, coupled with varying degrees of conservation investment. Since 1984, the overall average rate of native prairie conversion to cropland has been 0.5% a year (Stephens, 2008). While many note that this conversion rate has been increasing in recent years, especially in the Dakotas, we conservatively maintain the 0.5% average over the time span of the analysis, resulting in a 10 % reduction in existing native prairie in 20 years that is assumingly transferred into cropland.

The second scenario, titled "CRP Mitigation," estimates the effects of mitigating projected native prairie conversion to cropland by enrolling additional lands into the CRP/WRP; resulting in no net change in cropland hectares. Given current estimates, nullifying a 10% reduction in native prairie would require roughly a 27% increase in conservation program lands within the region. The third land-use change scenario, "Market Forces," examines the environmental and economic consequences of projected native prairie loss with CRP/WRP lands remaining at current levels. The fourth and final scenario in the analysis, titled "Extensive Conversion," investigates the effects of projected native prairie loss with a compounded 25% reduction in conservation program lands. This group of scenarios is certainly relevant if high commodity prices are maintained, demand for biofuels continues to increase, and additional funds for conservation programs such as the CRP/WRP are not granted due to constraining federal and state budgets.

3. Results

Table 3 provides the biophysical results for ecosystem services accounting for land-use changes in the scenarios. Corresponding economic results are presented later. Scenario 1, Aggressive Conservation, increases all ecological measures over current baseline conditions. SOC is increased by 12 million Mg, and VOC increases by 1.2 million Mg, or just over 11%. Soil loss is reduced by 80 million Mg, and over 75 million new fledglings are produced within the study region. Recall that the Aggressive Conservation scenario explores a 50% increase in enrolled CRP/WRP lands, a corresponding reduction of over 8% of cropland, and no additional loss of native prairie grasslands. The increase in biophysical values is provided by the substitution of CRP/WRP lands for cropland within the PPR.

All other scenarios reduced all ecological measures modeled in the study, with the exception of no impact on soil loss in Scenario 2, CRP Mitigation. Each of these other scenarios is allowing native prairie to be reduced by 10%. The CRP Mitigation scenario counters this conversion with a 27% increase in CRP/WRP lands, nullifying changes to overall cropland hectares. While soil erosion is unaffected, large losses in both waterfowl and carbon sequestration services indicate that CRP/WRP lands are not suitable substitutes for these services, although CRP/WRP lands did mitigate more than cropland would have. In Scenario 3, Market Forces, cropland is increased at the expense of native prairie and ecological services are at an even greater loss. SOC increased by over 40% compared to Scenario 2, where conservation was attempted, and VOC increased nearly tenfold in similar comparison. Soil loss is estimated at nearly 45 million Mg, and the reduction in number of fledged waterfowl is virtually doubled that predicted under the CRP Mitigation scenario. These losses are only augmented under Scenario 4, Extensive Conservation, where cropping is increased and both CRP/WRP and native prairie lands experience reductions. Interestingly, the increase in lost SOC between Scenario 2 to 3 and 3 to 4 is only about a third as big as the jump from the baseline to Scenario 2. This result emphasizes the large decreases in SOC stocks when native lands are initially converted, and demonstrates the importance of maintaining native prairie preservation for greenhouse gas mitigation.

Table 3
Total biophysical values of each ecosystem service and scenario for 20-year time period.

Change in biophysical values over 20-year period by scenario	Scenario 1 "Aggressive Conservation"	Scenario 2 "CRP Mitigation"	Scenario 3 "Market Forces"	Scenario 4 "Extensive Conversion"
Change in soil organic carbon (Mg)	12,551,454	−34,525,992	−49,299,699	−56,686,552
Change in vegetation organic carbon (Mg)	1,242,467	−68,642	−630,013	−1,251,247
Soil lost (−) or retained (Mg)	80,595,677	0.00	−44,971,047	−85,268,886
Waterfowl (additional/lost fledglings)	76,284,125	−48,670,082	−92,165,626	−113,876,648

Table 4
Net present value ($) of annual flow and total stock by ecosystem service and land-use scenario (see Table 2).

Values from land-use change		Scenario 1 "Agg. Conservation"	Scenario 2 "CRP Mitigation"	Scenario 3 "Market Forces"	Scenario 4 "Exten. Conversion"
		Millions of $	Millions of $	Millions of $	Millions of $
Annual flow value	Carbon (SOC + VOC)	57.80	−181.94	−244.20	−283.52
	Soil loss	11.49	0.00	−6.39	−12.14
	Waterfowl	25.90	−16.24	−30.99	−38.36
	CRP/WRP market value	66.29	35.39	0.00	−33.14
	Cropland market value	−91.98	0.00	49.87	95.86
	Net ecosystem service value	95.22	−198.18	−281.49	−334.02
	Net commodity value	−25.69	35.39	49.87	62.71
	Overall (Net) value of scenario	69.52	−162.79	−231.63	−271.31
	Overall value/ha ($)	3.63	−8.50	−12.09	−14.17
Total stock value (over 20-year period)	Carbon (SOC + VOC)	859.91	−2706.87	−3633.10	−4218.08
	Soil loss	170.94	0.00	−95.10	−180.57
	waterfowl	385.71	−241.56	−459.68	−570.75
	CRP/WRP market value	986.16	526.56	0.00	−493.08
	Cropland market value	−1368.43	0.00	741.87	1426.09
	Net ecosystem service value	1416.56	−2948.43	−4187.89	−4969.39
	Net commodity value	−382.27	526.56	741.87	933.00
	Overall (net) value of scenario	1034.29	−2421.87	−3446.02	−4036.39
	Overall value/ha ($)	54.00	−126.50	−179.90	−210.75

"SOC" stands for soil organic carbon; "VOC" stands for vegetation organic carbon; "CRP/WRP" refers to lands enrolled in the Conservation Reserve Program and the Wetland Reserve Program.

The monetary impact of each of these scenarios is presented in Table 4. Total stock values for the 20-year period were calculated, as well as amortized annual flows. Stock values are expressions of total value, like the price tag of a $300,000 home. Flows are annual values, accounting for the opportunity cost of money — the payment per year required to pay off a $300,000 home in twenty years. In the Aggressive Conservation scenario, the increase in CRP/WRP lands in the PPR would generate overall ecosystem services equal to $1.4 billion over the 20-year policy period, or an annual flow value of $95.2 million. Large reductions in commodity production valued at nearly $92 million per year are offset by conservation program payments of over $66 million and the increased supply of ecosystem services. Overall, land-use changes in the region lead to gains of $69 million annually and roughly $1 billion over twenty years.

Under the CRP Mitigation scenario, we estimate there to be an annual ecosystem service loss of nearly $200 million. This estimate is largely influenced by the decreases in SOC stocks when native lands are converted to cropland, supplemented by the moderate sequestration of SOC when cropland is retired into the CRP/WRP. Decreases in waterfowl fledglings valued at just over $16 million annually make up the additional loss. The modest increase in CRP/WRP land rental payments does little to negate the overall decline in ecosystem services value; however it does more than counter the valued decrease in waterfowl. The overall net loss modeled in the CRP Mitigation scenario over the 20-year period is estimated at just under $2.5 billion. Our model indicates CRP/WRP lands cannot mitigate native prairie lands in their entirety when considering the three ecosystem services evaluated and potential rental payment gains.

The Market Forces scenario estimates the effects of converting the projected 10% of overall native prairie to cropland in the next 20 years. Our model estimates net annual losses to ecosystem services valued at just over $281 million under this land use scenario, which again is dominated by decreases in carbon stocks. Additional cropping income was estimated at only around $50 million, which could not offset a $244 million loss in carbon alone. However, crop income is enough to offset waterfowl and soil erosion if carbon losses are ignored. These negative trends are furthered in the fourth and final scenario, Extensive Conversion. Enormous losses of carbon, soil, and waterfowl

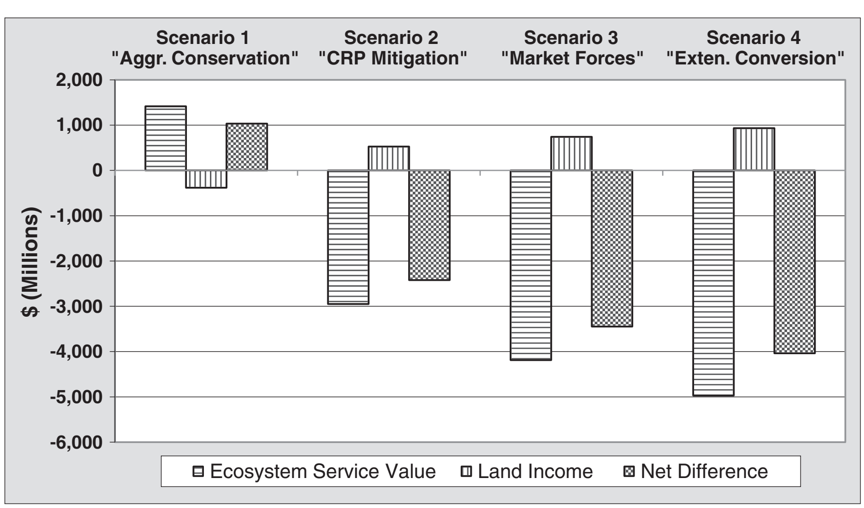

Fig. 2. Comparison of ecosystem service values, land incomes, and net economic differences for all scenarios.

Table 5
Net present value of each scenario with varying carbon price.

CO_2 price	Scenario 1 "Aggr. Conservation"	Scenario 2 "CRP Mitigation"	Scenario 3 "Market Forces"	Scenario 4 "Exten. Conversion"
\$21.00	1034.29	−2421.87	−3446.02	−4036.39
\$5.00	379.12	−359.49	−677.94	−822.62
\$2.20	264.47	1.42	−193.53	−260.21

Carbon prices displayed are in metric tons of CO_2 equivalent.

due to conversion come at an estimated cost to society of over \$271 million per year, or \$4 billion over the 20-year policy period. Increases in cropland revenue do little to counteract these losses.

A comparison of ecosystem to economic contributions as each relates toward the net outcome for each scenario is presented in Fig. 2. This figure helps show how tangible economic market gains (land income) compare to less observable non-market ecosystem service values. The results show that production income is positive for scenarios 2–4 and ecosystem services are positive for scenario 1. Only scenario 1 has a net positive value compared to the baseline. Yet, what is observable without full ecosystem markets is the positive income associated with scenarios 2–4.

The loss of carbon services dominates Scenarios 2–4. Scenarios 2–4 would have all been positive if we had chosen not to include carbon. Similar influence has been observed in other economic studies [see Kremen et al. (2000) and Naidoo et al. (2009)], and highlights the importance of accurate carbon valuation. The SCC used in this study (\$21/tCO_2e) was chosen as the central value from a U.S. government interagency working group recently charged with establishing its value. Given its considerable dominance in our study and general debate among disciplines, we chose to look at the working group's low estimate and to find the breakeven price where Scenario 2 would become positive. The results are displayed in Table 5.

While there are decreases in the overall net benefit/cost to society, we still observe the same trends (or rankings) across land-use change scenarios when the carbon price is reduced to \$5/tCO_2e. We observe that the Aggressive Conservation scenario would still be a positive policy shift if carbon were valued at only \$5/tCO_2e, but the NPV would be reduced by about two thirds. The net cost under the CRP Mitigation scenario would be reduced from over \$2 billion down to about \$359 million. Estimated costs in Scenarios 3 and 4 are between half a billion and a billion dollars with the lower bound SCC price in the accounting model. The last row of Table 5 reveals that the carbon price would have to drop to about \$2.20/tCO_2e for the overall net value of the CRP Mitigation scenario to break even.[7] This certainly has implications when considering native prairie preservation and potential ecosystem service payments. While \$2.20/tCO_2e is surely in the lower bounds of debated SCC values, it is higher than current market values for carbon within the U.S., which could arguably leave room for debate on the carbon dominance in our modeling.

Our results are not as sensitive to other variables as they are to carbon. For example, the cost of waterfowl is only one-tenth of the total annual loss in the CRP Mitigation scenario and therefore would not impact the rankings with any realistic change in the values we investigated. CRP/WRP payments would have to increase by fivefold to offset carbon losses. Likewise, net revenue for crops would need to increase almost as much to offset SOC losses in the Market Forces scenario.

4. Conclusion

Ecosystem services have been traditionally obscured by the modern way of life and lack of value in the marketplace. However, in recent decades we have begun to realize the essential links to human welfare and have relied on the government to invest in conservation programs such as the CRP and WRP and attempt to provide market structure for greater allocation. There is even a growing cadre of funds paying for ecosystem services (e.g. Chicago Climate Exchange, Conservation Marketplace of Minnesota, Maryland Nutrient Trading Program). With a foreseeable future of tightening fiscal budgets, it is imperative to have good information on the return of these investments. Subsequently, policy makers and natural resource managers need to know how their actions might affect the flow of these goods and services and the overall value they provide to society. It is the goal of this study to help address these issues.

The PPR of the Dakotas is a unique and rich area with a constantly changing landscape. It is important to measure how competing land uses, like agriculture and native-like conditions, work for and against each other. We chose to model the economic values of ecosystem services, commodity production/land income, and net differences across policy-relevant land-use change scenarios. Our findings suggest that a large investment in conservation programs, and more importantly, native prairie preservation, would provide a net benefit to society of over \$1 billion over the 20-year policy time-period. The largest benefits arise from increases in carbon sequestration, followed by additional waterfowl fledged to the fall flight. Coincidently, we observe significant losses when we employ land-use scenarios modeling native prairie conversion in the PPR. A projected 10% conversion of native prairie grasslands to cropland over the next 20 years is estimated to come at a net cost of roughly \$3.4 billion NPV. These estimates are largely dictated by the SCC values employed; however the ranking of scenarios in terms of economic returns remain unchanged across the entire range of SCC values considered in the valuation study we used. Finally, the data shows that the CRP/WRP cannot mitigate the loss of native prairie lands (hectare for hectare) when considering the three ecosystem services we evaluated and potential payment gains.

While the three ecosystem services included in the analysis are perceived to be top priorities, there are myriad services not included in this study that have real and significant relations to human welfare, both directly and indirectly. It is difficult to pass judgment on how the inclusion of other ecosystem services in the region would affect our results, given the diversity of services across the three land uses. Presumably, but not necessarily, identification of additional services would make a stronger case for converting cropland to more native-like uses. Therefore, it is important for future researchers to endeavor to expand valuations to include all ecosystem and economic services reliable data will allow.

This analysis reveals how economic valuation can be matched with site-specific biological data to evaluate trade-offs in ecosystem services under varying land-use change scenarios. Moreover, this type of work increases efficiency at a more macro level, where various organizations and/or governing bodies can see where to focus their limited resources or to consider policy adjustments. Ultimately, this research contributes to an emerging literature that attempts to quantify the value of multiple ecosystem services at a regional scale by way of linking sound ecological field data, an accounting metric, and economic valuation. This type of data is a necessary input into the decision making process for policies affecting land use and the management of organizations such as the USDA's Office of

[7] Results for \$2.20/tCO_2e are displayed in Table 5 for display purposes; there would be zeros across the rows at the breaking-point price of \$2.21/tCO_2e.

Environmental Markets. The results from this study provide initial insight for ecosystem service valuation in the PPR, and a foundation to build upon.

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