Wetlands
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ECOSYSTEM SERVICES OF WETLANDS

Modeling the Supporting Ecosystem Services of Depressional Wetlands in Agricultural Landscapes

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Abstract
We explored how a geographic information system modeling approach could be used to quantify supporting ecosystem services related to the type, abundance, and distribution of landscape components. Specifically, we use the Integrated Valuation of Ecosystem Services and Tradeoffs model to quantify habitats that support amphibians and birds, floral resources that support pollinators, native-plant communities that support regional biodiversity, and above- and below-ground carbon stores in the Des Moines Lobe ecoregion of the U.S. We quantified services under two scenarios, one that represented the 2012 Des Moines Lobe landscape, and one that simulated the conversion to crop production of wetlands and surrounding uplands conserved under the USDA Agricultural Conservation Easement Program (ACEP). While ACEP easements only covered 0.35% of the ecoregion, preserved wetlands and grasslands provided for 19,020 ha of amphibian habitat, 21,462 ha of grassland-bird habitat, 18,798 ha of high-quality native wetland plants, and 27,882 ha of floral resources for pollinators. Additionally, ACEP protected lands stored 257,722 t of carbon that, if released, would result in costs in excess of 45-million USD. An integrated approach using results from a GIS-based model in combination with process-based model quantifications will facilitate more informed decisions related to ecosystem service tradeoffs.

Keywords Conservation effects assessment project - Des Moines lobe ecoregion - ecosystem services · InVEST - pothole wetlands - prairie pothole region

Introduction

Through their natural functioning, ecosystems perform a variety of services that provide benefits to society (Daily 1997; Euliss et al. 2013). The societal services provided by ecosystems have been termed "ecosystem services" and come in four types: provisioning, regulating, cultural, and supporting (Millennium Ecosystem Assessment 2005). Ecosystem provisioning services include commodities that are provided by the ecosystem for use by society. The food, fiber, and biofuel feed-stocks provided by ecosystems are examples of provisioning services. Regulating services are the functions of ecosystems that can have a regulating or damping influence on negative, societal impacts. A wetland ecosystem retaining water during a flood event and thus playing a role in reducing downstream flooding is an example of an ecosystem providing a regulating service. Cultural services are the spiritual, recreational, aesthetic, and educational benefits that societies gain from natural ecosystems. Lastly, supporting services are the features and processes of ecosystems that support the ability of an ecosystem to provide the other ecosystem service types, i.e., regulating, provisioning, and cultural, to society.

Due to the inherent value of the unique ecosystem services performed and provided by wetland ecosystems, there has been great effort to quantify, conserve, and restore the natural functioning of these ecosystems and the services they provide (Euliss et al. 2010; Brinson and Eckles 2011). Multiple federal agencies have established programs that benefit wetland ecosystems and contribute to their functioning, with the U.S. Department of Agriculture (USDA) administering some of the farthest-reaching conservation programs because of the extent of privately-owned agricultural lands across the United States (Eckles 2011). Foremost among these USDA

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programs in terms of area affected are the Conservation Reserve Program (CRP) administered by the USDA's Farm Service Agency and the Agricultural Conservation Easement Program (ACEP), which includes what was formerly the Wetlands Reserve Program, administered by the USDA's Natural Resources Conservation Service (Fig. 1).

Given the need to better understand the conservation benefits derived from programs such as CRP and ACEP, USDA implemented the Conservation Effects Assessment Project (CEAP) in 2003. Within CEAP, the Wetlands National Assessment (CEAP—Wetlands) is focused primarily on evaluating conservation effects on wetland ecosystems (Eckles 2011). Specifically, the goal of CEAP—Wetlands is "to develop a broad collaborative foundation that facilitates the production and delivery of scientific data, results, and information" (Natural Resources Conservation Service 2019). This collaborative foundation is designed to better inform conservation decisions through evaluations of the effects and effectiveness of USDA conservation programs, and specific practices within programs, on the ecosystem services provided by wetlands in agricultural landscapes.

The approach taken by CEAP—Wetlands to quantify effects of conservation programs and practices is broad and diverse to reflect the similar scope of ecosystem services performed by wetlands in agricultural landscapes. The Agricultural Policy / Environmental eXtender (APEX) model (Williams and Izaurralde 2006) is the primary process-based model being used in CEAP—Wetlands to provide information on several of the regulating services (e.g., regulation of floodwaters, nutrients, and sediments) performed by wetlands in agricultural settings. We contributed to CEAP—Wetlands by developing a method for quantifying the conservation impacts of programs such as ACEP on several supporting services. Since the supporting services we modeled were primarily related to the type, abundance, and distribution of specific landscape components, we used a geographic information system (GIS) modeling approach.

Fig. 1 Restored wetlands and uplands in the Des Moines Lobe ecoregion of Iowa (photo by DMM)

As an example of the utility of using a GIS-based approach to quantify the influence of conservation programs and practices on supporting services that are related to the type, abundance, and distribution landscape components, we use the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) model (Natural Capital Project 2013). The InVEST model consists of a suite of spatially-explicit modules designed to quantify various ecosystem services within a variety of systems. As part of the CEAP—Wetlands effort, we previously parameterized several of the InVEST modules to provide quantifications of habitats that support amphibian (Mushet et al. 2014) and bird (Shaffer et al. 2019) populations, the floral resources that support pollinators (Lonsdorf and Davis 2017), and native-plant communities that support regional biodiversity (Mushet and Scherff 2017). We also showed how an estimate of above- and below-ground carbon stores, an ecosystem service supporting greenhouse gas regulation, can be obtained (Mushet and Scherff 2017).

In this paper, we used information gained from the CEAP—Wetlands efforts to demonstrate how, when combined into a single assessment, the InVEST modules allow for the quantification of multiple services provided by wetland ecosystems, thereby allowing for a more complete accounting of value, and for tradeoffs to be identified and quantified. For all InVEST model runs, we used a series of GIS-derived, landcover-change scenarios in which we explored the influence of ACEP conserved wetlands and associated uplands on multiple, supporting, ecosystem services. While we use actual landcover and easement-location information in our scenarios, the results provided here are primarily intended for the purposes of demonstrating these methodologies, and their utility, that can be transferred to other regions, programs, and conservation practices. We also discuss how to obtain an even more complete and better-integrated picture of the effects of conservation programs and practice on ecosystem services by considering the results from both process-based models such as APEX and GIS-based models such as InVEST.

Study Area

In order to demonstrate the utility of the InVEST model for quantifying multiple ecosystem services provided by wetlands and associated grasslands, we performed a series of InVEST model runs focused on the Des Moines Lobe, Level IV, ecoregion (Omernik 1987). The Des Moines Lobe ecoregion makes up the most southeasterly portion of the North American Prairie Pothole Region (Fig. 2). The Prairie Pothole Region is a 770,000 km^2, glacially formed, landscape that contains an exceptionally high density of depressional

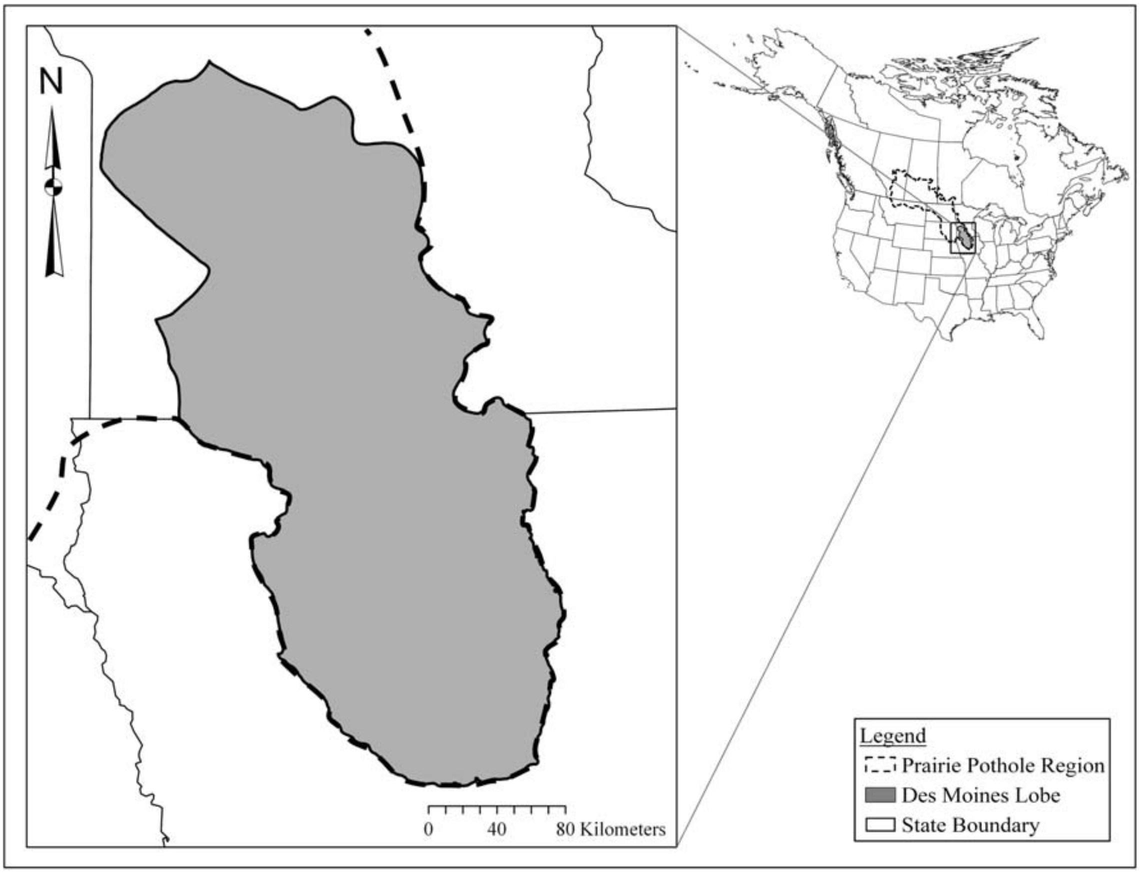

Fig. 2 The Des Moines Lobe, Level IV, ecoregion (Omernik 1987) within the Prairie Pothole Region of North America

wetlands, known as prairie potholes. The multitude of small depressions dotting the landscape after the glaciers receded and the relatively impermeable nature of the deposited glacial till work in concert to facilitate the ponding of surface waters and formation of the region's abundant wetlands. However, wetland losses have been especially great throughout the Prairie Pothole Region, primarily through changes resulting from conversion of the landscape for crop production.

In the Prairie Pothole Region, wetland and grassland losses have been greatest in the Des Moines Lobe ecoregion, due to the fertile soils, warmer summers and greater annual precipitation compared to other portions of the Prairie Pothole Region. Thus, the Des Moines Lobe ecoregion is now a predominately agricultural landscape where over 99% of the tall-grass prairies that once dominated the ecoregion has been converted (Smith 1998), and 90% of the wetlands have been lost to filling and drainage (Dahl 2014). In the ecoregion, wetlands and associated grasslands conserved through ACEP easements account for only 0.35% (21,616 ha) of the ecoregion's total area (6,247,762 ha), while croplands (4,778,359 ha) account for 76.5%. However, due to the highly altered condition of the region, the relatively small footprint of ACEP easements on the Des Moines Lobe landscape can misrepresent the importance of the program in terms of the supporting ecosystem services conserved in this agriculturally dominated landscape.

Methods

InVEST Modeling

We used the InVEST modeling suite to quantify the contribution of ACEP easements on ecosystem services in the Des Moines Lobe ecoregion. The various modules of the InVEST model use land-cover maps of an area of interest as their primary inputs. This GIS-based approach then uses other GIS layers, equations and look-up tables specific to each module to translate the land-cover maps into spatial depictions of the ecoservices generated by the area. We made land-cover maps of the ecoregion representing two scenarios. Our first scenario represented the land-cover configuration with ACEP easement lands intact. For this base land-cover map, we used the 2012 National Agricultural Statistic Service (NASS) Cropland Data Layer (NASS 2012). We used the 2012 Cropland Data Layer to match the year of the ACEP easement-location data that was available for our use. We then merged the NASS Cropland Data Layer with National Wetlands Inventory (NWI) wetlands maps (U.S. Fish and

Wildlife Service 2019); NWI mapping better accounts for small wetlands that can be missed if the Cropland Data Layer alone were used (Mushet et al. 2014). For the base land-cover map of our second scenario, we used the merged, Cropland/NWI land-cover layer created for our first scenario, but converted to croplands all areas, both wetlands and their surrounding uplands, conserved under ACEP easements. This second scenario represented the Des Moines Lobe ecoregion without the influence of ACEP conservation on the landscape. By comparing the landscape with ACEP wetlands and grasslands intact to the same landscape with the influence of these easements removed, we obtained a quantification of the effects of maintaining these easements. Quantifying conservation effects by comparing model results of landscapes both with and without the influence of a particular program or practice is the same methodology used in other CEAP components (e.g., CEAP Croplands) to explore conservation effects of programs and practices (CEAP Cropland Modeling Team 2012). Note that in our scenarios, we assume that if an ACEP easement is removed, the wetlands and grasslands that were previously protected by the easement would be converted to crop production, even though in some cases a landowner may decide to retain the wetland or grassland cover types even if an easement were not present.

In our InVEST model runs, we quantified five different supporting ecosystem services. The first was a quantification of amphibian habitat. Our measure of amphibian habitat not only provides a measure of how frog, toad, and salamander populations are supported by habitat available under a particular landscape scenario, but also indirectly quantifies benefits to other wildlife species that are similarly supported by intact wetland and grassland habitat associations, e.g., waterfowl. Since ACEP wetland-conservation easements include upland areas in addition to the actual wetland basins in a land tract, the second supporting service we quantified was the benefits of these surrounding uplands in terms of providing habitat that supports grassland birds. Humans derive numerous benefits from maintaining natural biodiversity (National Research Council 1999), so the third ecosystem service we quantified under both scenarios was a measure of intactness of the native-plant communities occurring in the ACEP-protected wetlands. Flowering plants support honey-bee (*Apis mellifera*) colonies, which in turn support food production across the Nation, so our fourth quantification was of the floral resources present to support healthy honey-bee colonies. Lastly, we included a quantification of carbon stores under each scenario given the negative climate influences of this element if released into the atmosphere as a greenhouse gas.

Amphibian Habitat

We used the merged Cropland/NWI base maps to identify potential amphibian habitat. Potential amphibian habitat included all palustrine wetlands identified in the base map, plus grassland areas surrounding wetlands out to a 160-m buffer distance. This definition was based on previous amphibian habitat-suitability work conducted under in the Prairie Pothole Region as part of CEAP—Wetlands (Mushet et al. 2014). In our scenarios depicting the loss of lands enrolled in ACEP, we modified our habitat layer by converting to croplands wetlands and surrounding grasslands protected by ACEP easements. Once potential habitat is identified, the InVEST model uses GIS layers identifying specific habitat threats. These threats then degrade the quality of the areas identified as habitat across a defined distance. We identified four specific threats to amphibian habitats in the Des Moines Lobe ecoregion and developed spatially explicit land-cover layers for each. The first threat layer we created identified croplands due to the marked influence of this land-cover type on chemical and sediment inputs to wetlands; disturbance of surrounding soils; plants and insect communities; and potential to negatively alter wetland hydrology. The second threat layer we created identified all wetlands and lakes with potential to support fish, which we determined from the NWI permanency class of a wetland or lake. Those with a permanent-pond classification were deemed to be suitable for fish and thus a threat to amphibian populations, thereby degrading habitat quality. The third threat layer we created was also related to pond-permanence, but at the other end of the inundation gradient. We identified wetlands with temporary ponds as a threat due to the likelihood that those ponds would dry before larval amphibians metamorphed into adults, which were then safe from the effects of pond drying. The last threat layer we identified was isolation. If a pond was a great distance from any other available amphibian habitat (i.e., > 0.5 km), it was treated as a threat to itself which lowered its quality rating due to its isolation from other wetlands.

Once threats to habitats are identified, the InVEST model is parameterized by weighting each threat by their impact to habitat quality and specifying the distance over which each threat acts. The cropland threat layer was set to influence amphibian-habitat quality up to a maximum distance of 1 km. The permanent-pond, temporary-pond, and isolation threats were internal to the wetlands themselves, but also influenced surrounding habitat within a 0.1-km distance. The strength of all threats was set to decay linearly across the 1-km or 0.1-km distance specific to the threat type. In all InVEST runs, the half-saturation constant was set to 0.5. Completed threat (includes weight of each threat type and influencing distance) and threat-susceptibility tables used in our runs match those provided in the supplementary online material for Mushet et al. (2014) at: https://ars.els-cdn.com/content/image/1-s2.0-S0006320714001347-mmc2.pdf. A more in-depth description of our CEAP—Wetlands work developing and validating threat weights, influencing distances, and habitat susceptibility values used in the InVEST model for quantifying amphibian-habitat quality in the PPR can be found in Mushet et al. (2014). We quantified suitable amphibian habitat as the total area in the region with a final habitat quality score $\geq$ 0.8 on a 0 to 1 scale (Mushet et al. 2014).

Grassland-Bird Habitat

For our InVEST modeling of grassland-bird habitat under the two scenarios, i.e., with and without ACEP protected areas converted to croplands, we used the base land-cover maps used for amphibian habitat, but with the addition of roads delineated from Tiger/Line city census data. Land-cover types that were identified as either habitat or habitat threats also differed. In our amphibian-habitat runs, we considered wetlands and a limited (160-m) area of surrounding grasslands surrounding wetlands to be habitat. However, for grassland birds, habitat was identified as all areas of grass (including intact grasslands surrounding wetlands that were enrolled in conservation programs) plus specific types of small grains. Small-grain habitats received a reduced habitat value relative to grasslands. The threats to the quality of these habitats included surrounding croplands that restrict the size of grassland patches and disturb birds through activities associated with crop production, woodlands that can harbor predators and reduce patch size of grasslands, urban areas, and roads. Shaffer et al. (2019) also included energy-development infrastructure such as well pads and wind turbines as a threat, but publicly available GIS layers providing location information for this threat type is not available of the Des Moines Lobe ecoregion. Thus, we did not consider the potential influence of energy development on habitats in our InVEST runs of the Des Moines Lobe ecoregion. We used the same threat weights, influencing distances, and habitat susceptibility values as used and validated by Shaffer et al. (2019). The Shaffer et al. (2019) validations were based on comparisons of model output to grassland-bird abundances from North American Breeding Bird Survey (Bystrak 1981; Sauer et al. 2013) data. We quantified suitable grassland-bird habitat as the total area in the region with a final habitat quality score $\geq$ 0.3 on a 0 to 1 scale (Shaffer et al. 2019).

Wetland Floristic Quality

We quantified the integrity of native-plant communities in our two scenarios by using the same base land-cover maps used for amphibian-habitat runs, and a measure of floristic quality (Swink and Wilhelm 1994) provided in Gleason et al. (2008). The floristic-quality values identified by Gleason et al. (2008) were specific to the native-plant communities of wetlands within differing land-use treatments, including native, restored, and cropland treatments. Thus, we considered all palustrine wetlands in our base land-cover map identified by NWI as temporarily, seasonally, or semi-permanently ponded to be the land-cover types of interest. The plant communities of these wetland areas were assigned a starting floristic-quality value of 1. Threats to the native-plant species in these wetlands were croplands and nonnative grasslands immediately surrounding the wetland, and isolation due to its influence on seed dispersal. All threats impacted wetland plant communities across a 0.5 km distance, and the impact of cropland threats (1.0) were weighted twice that of the nonnative-grass and isolation threats (0.5). The threat weights, influencing distances, and habitat susceptibility values we used were the same as those used by (Mushet and Scherff 2017). Resultant floristic-quality values greater than 0.5 (on a scale of 0 to 1) indicated native-plant communities that retained species typically absent from disturbed or invaded plant communities. Lower values indicated a greater presence of nonnative species and a loss of "conservative" native species. Conservative species are defined as species that primarily occur only in undisturbed, native settings. We quantified area of quality native plant communities as the total of wetland areas in the region with a final floristic-quality score $\geq$ 0.5 (Mushet and Scherff 2017).

Floral Resources

While the InVEST Version 3.5.0 model contains a module for pollinators, the module is specific to native pollinators due to its incorporation of nesting substrate into quantifications of habitat suitability. As opposed to native pollinators, honey bees do not require nesting habitat since they are purposefully located in apiaries and nest within hives that are supplied by bee keepers. Therefore, a model specific to managed honey bees was developed (Lonsdorf and Davis 2017). The managed-bee model developed by Lonsdorf and Davis is similar to the native-bee model of InVEST, but focuses solely on quantifying floral resources across three distinct periods when honey bees are present in the region's apiaries, i.e., spring, summer, and fall. The model then sums the weighted floral resources across these three seasons to obtain an overall rating of the floral resource quality. The initial floral-resource values we used for each land-cover type in our modeled region were derived by expert opinion of multiple bee managers in the area (Lonsdorf and Davis 2017) and validated by Mushet and Scherff (2017). For our land-cover maps, we used the same base-maps used in our amphibian habitat assessments. By quantifying the floral resources available to honey bees in the Des Moines Lobe ecoregion under scenarios that both include and exclude the influences of ACEP easement lands, we obtained firstly a measure of that area's ability to support honey bee and secondly, a quantification of the influence of those lands on floral resources. We quantified area of quality floral resources for pollinators as the total of area in the region with a final floral-resource score $\geq$ 0.25 on a 0 to 1 scale (Mushet and Scherff 2017).

Carbon Stores

The InVEST model quantifies carbon stores in both above-ground (e.g., standing vegetation, litter) and below-ground (i.e., organic, inorganic) pools. Sampling of the above- and below-ground carbon stores in 422 prairie-pothole wetlands and their surrounding catchments was conducted in 1997 and 2004 (Gleason et al. 2008a). From this data, estimates of carbon stores under various land-cover types were calculated (Gleason et al. 2008b). The InVEST model uses these values to calculate carbon pools under various land-use scenarios. Land-cover maps for each scenario were again the same as those in our amphibian habitat modeling except that wetlands embedded in grassland were uniquely identified since carbon-pool estimates differed between wetlands surrounded by grasslands versus those embedded in croplands (Gleason et al. 2008b). Separating these wetland types in our land-cover maps allowed for carbon pool estimates specific to those wetlands to be assigned. The above- and below-ground carbon pools estimates for each land-cover type in our modeled region are provided in Appendix 3 of Mushet and Scherff (2017). We used the values for the Northern Glaciated Plains ecoregion (Omernik 1987) as being the most similar ecoregion to the Des Moines Lobe. The outputs from our InVEST carbon module runs were spatially explicit maps of carbon stores across the region in g per m^2; we converted this to tonnes per ha.

Results and Discussion

We quantified the influence of ACEP wetland conservation easements on multiple ecosystem services in the Des Moines Lobe ecoregion of the northern Great Plains (Table 1, Fig. 3) to demonstrate how GIS-based ecosystem-service models such as the InVEST model can facilitate quantifications of the effects of conservation programs and practices. We focused on ACEP effects, as easements obtained under this USDA program influence both wetlands and the surrounding upland habitats. We focused on the Des Moines Lobe ecoregion due to the extreme nature of agricultural development in this region, its effect of both wetlands and grasslands, and the correspondingly large role of conservation programs in maintaining environmental quality in this highly agricultural landscape.

We found that in the Des Moines Lobe ecoregion, amphibian habitat would be reduced by approximately 19,020 ha if ACEP-protected wetlands and associated uplands were not protected by the program and were instead developed for crop production. While 19,020 ha may seem small in a region with a total area of >6.2 million ha, it is considerable when one considers that less than 3.4% (211,453 ha) of this area remains as suitable amphibian habitat. Since Iowa alone historically contained approximately 4-million ha of wetlands (Dahl 1990), it is clear that all remaining suitable habitat is of great importance to sustaining amphibian populations, and populations of other species in the region that require wetland/grassland habitat mixes (e.g., waterfowl).

Similarly, we found that grassland-bird habitat would decrease by approximately 21,462 ha if ACEP protected grasslands associated with protected wetlands were converted for crop production. This result shows that while the primary focus of ACEP easements was historically on wetland conservation, a significant benefit is realized in terms of conserved grassland habitats supporting grassland-bird populations. This grassland-bird benefit is easily underappreciated given the programs past identification as the Wetlands Reserve Program. As with amphibians, unquantified benefits related to the conservation of other species dependent upon grassland habitats are undoubtedly realized from these easement-preserved lands.

We found that if ACEP easements were not in place, 18,798 ha of high-quality native wetland-plant communities would be lost from the landscape of the Des Moines ecoregion. These native plant communities support great biodiversity. Biodiversity supports the integrity of ecosystem and their ability to resist or adapt to change (National Research Council 1999). It also can provide benefits to humans in terms of preserving species whose benefits to humans have not yet been identified or fully realized.

Honey bees that over-summer in the northern Great Plains provide pollination services throughout the nation (Smart et al. 2016). The floral resources in the immediate area surrounding

Table 1 InVEST model output for five ecosystem-service measures under two scenarios, one with land-cover from the NASS 2012 Cropland Data Layer and a second in areas protected under ACEP wetland easements are converted to crop production. The overall effect is calculated as the measures with ACEP conserved lands on the landscape minus values for the same measures when ACEP lands are converted to crops

	Amphibian Habitat (ha)	Grassland Bird Habitat (ha)	Native Plant Communities (ha)	Floral Resources (ha)	Carbon Stores (M)
With ACEP conserved lands	211,453	111,266	101,889	219,708	283,120,798
Without ACEP conserved lands	192,433	89,804	83,091	191,825	282,863,076
With ACEP – Without ACEP = Effect	+19,020	+21,462	+18,798	+27,882	+257,722

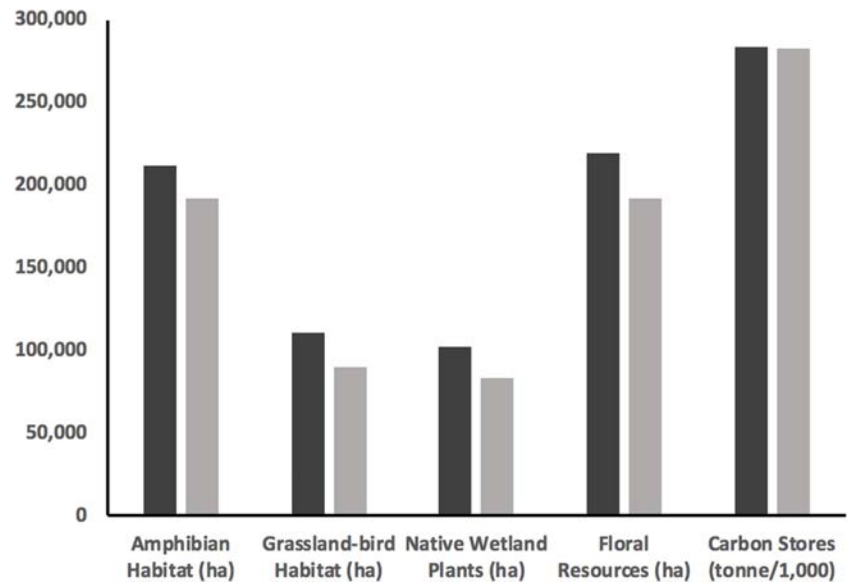

Fig. 3 Area (ha) of amphibian habitat, grassland-bird habitat, quality native wetland-plant communities, and floral resources for pollinators; and above- and below-ground carbon stores (tonnes/1000) in the Des Moines Lobe Ecoregion of the northern Great Plains under two scenarios, 1) 2012 land cover (black bars) and 2) 2012 land cover with wetlands and surrounding uplands conserved under the USDA Agricultural Conservation Easement Program converted to a cropland cover type (gray bars)

apiaries contribute not just to the production of honey (a valued commodity) but also influences the health and strength of honey-bee colonies (Otto et al. 2016, 2018). Strong, healthy, colonies are needed to survive transportation from apiaries in the northern Great Plains to other areas across the nation where their pollination services are needed, e.g., the almond orchards of California. Colony strength, usually measured as the number of worker bees in a colony, contributes to the ability of a colony to pollinate crops as well as the income that the bee keeper receives for providing that colony for its services (Smart et al. 2018). Our results showed that 27,882 additional ha of land with quality floral resources is available to support honey-bee colonies in the Des Moines Lobe ecoregion due to the conservation of wetlands and grasslands by ACEP easements. While the value of grasslands and their associated forbs to pollinators, including honey bees, have long been known, the role that wetlands play in providing floral resources that support pollinators has only recently been realized (Otto et al. 2017). Thus, through the program's focus on wetlands in addition to upland habitats, ACEP easements provide great benefits in terms of supporting pollinators and, in turn, the myriad crops that would not be produced but for these pollinators.

Lastly, our modeling results show that an additional 257,722 t of carbon would be added to the global, atmospheric, carbon pool if ACEP easement lands were to be converted for crop production. With the addition of two oxygen atoms, this carbon would exist in the atmosphere as 944,981 t of CO_2, an important greenhouse gas. Using a country-specific (U.S.) social cost of carbon estimate of 48 U.S. dollars per tonne (Ricke et al. 2018), release of the above- and below-ground carbon stores currently sequestered as a result of ACEP easements would result in societal costs of in excess of $45 million.

The similarity in area (range = 18,798 to 27,882 ha) for the four habitat associated measures, i.e., amphibian habitat, grassland-bird habitat, wetland floristic quality, and floral resources for pollinators shows the overlap in use of the wetland and upland resources provided by ACEP easement. Our wetland floristic quality measure was restricted to influences directly in the wetland portions of easements. Amphibian habitat consisted of a larger are due to the use of uplands surrounding wetlands by juvenile and adult amphibians. Uplands generally formed a large portion of the easement and these areas were used by grassland birds. Pollinator floral resources occurred throughout both wetland and upland areas and therefore had the greatest area estimates. This finding highlights the added value of including upland areas within easements focused on wetlands.

Conclusions

The two scenarios we ran quantified the significant influence that ACEP wetland conservation easements have had on maintaining the ability of easement-protected areas to support local (amphibians) to international (migratory grassland birds) wildlife populations, regional biodiversity, national pollination services, and global atmospheric conditions. While we focused on supporting services, several other types of ecosystem services are provided by wetland and upland habitats in the Des Moines Lobe ecoregion. An obvious example is the provisioning of food for humans. Under a scenario in which ACEP-protected wetlands and uplands are utilized for crop production, there would undoubtedly be a direct, positive effect on the provisioning of human foods from these lands. However, by considering a fuller range of services that also includes regulating, supporting, and cultural services, tradeoffs in ecosystem services are identified. In addition, when pollination services are considered, the human-food provisioning benefit may not be as large as expected if crops elsewhere in the nation are negatively affected by reduced strength and health of the honey-bee colonies needed for their pollination services.

Quantifications of the effects of programs and practices on multiple ecoservices is especially needed in the face of changes in climate that are influencing species distributions. If a species is unable to adapt to changing conditions, it must either move to a location where conditions are favorable or perish. Having habitat on the landscape, whether it is currently supporting a particular species or not, is key to enabling those species to move in response to shifts in underlying environmental factors influencing species distributions. Similarly, habitat measures that target broad groups (e.g., amphibians, grass-land birds) provide a better measure then species-specific measures in uncertain conditions when species distributions are shifting, and the ultimate species composition of communities are yet to be determined. As with habitat measures, floral resource and plant community quality measures provide a broad-based measure of the influence of conservation programs and practices. Similarly, the amount of carbon on both above-ground and below-ground reserves provides a broad measure of how conservation programs and practices support soil health and regulating services influencing CO_2 and other greenhouse gas concentrations in the atmosphere.

We have shown how GIS-based models can play a role in accounting for ecosystem services related to the distribution and quality of habitats on a landscape, services that are not typically accounted for in process-based models. By integrating results from both GIS and process-based landscape models, a more complete picture of the influence of conservation programs and practices is attainable. We have shown how the InVEST model can be used to quantify those services best suited to a GIS modeling approach. These results can be provided as spatially-explicit maps of ecosystem services, which can inform on-the-ground management efforts. When combined with results from process-based models, a more complete picture of the influence of conservation programs and practices is obtained. Only when one has such a picture can the true tradeoffs of competing management and policy decisions be determined.

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