University of Nebraska - Lincoln

DigitalCommons@University of Nebraska - Lincoln

2013

Cost-Effectiveness Analysis of Sandhill Crane Habitat Management

Andrew C. Kessler
University of Minnesota, kessl127@umn.edu

James W. Merchant
University of Nebraska-Lincoln

Steven D. Shultz
University of Nebraska at Omaha

Craig R. Allen
University of Nebraska-Lincoln, callen3@unl.edu

Follow this and additional works at: http://digitalcommons.unl.edu/ncfwrustaff

Human Dimensions

Cost-Effectiveness Analysis of Sandhill Crane Habitat Management

ANDREW C. KESSLER,[1] *Department of Soil, Water, and Climate, University of Minnesota, 1991 Upper Buford Circle, St. Paul, MN 55108, USA*

JAMES W. MERCHANT, *Center for Advanced Land Management Information Technologies, School of Natural Resources, University of Nebraska-Lincoln, 3310 Holdrege Street, Lincoln, NE 68583, USA*

STEVEN D. SHULTZ, *College of Business Administration, University of Nebraska-Omaha, Mammel Hall 332Z, 6708 Pine Street, Omaha, NE 68182, USA*

CRAIG R. ALLEN, *U.S. Geological Survey, Nebraska Cooperative Fish and Wildlife Research Unit, University of Nebraska-Lincoln, 3310 Holdrege Street, Lincoln, NE 68583, USA*

ABSTRACT Invasive species often threaten native wildlife populations and strain the budgets of agencies charged with wildlife management. We demonstrate the potential of cost-effectiveness analysis to improve the efficiency and value of efforts to enhance sandhill crane (*Grus canadensis*) roosting habitat. We focus on the central Platte River in Nebraska (USA), a region of international ecological importance for migrating avian species including sandhill cranes. Cost-effectiveness analysis is a valuation process designed to compare alternative actions based on the cost of achieving a pre-determined objective. We estimated costs for removal of invasive vegetation using geographic information system simulations and calculated benefits as the increase in area of sandhill crane roosting habitat. We generated cost effectiveness values for removing invasive vegetation on 7 land parcels and for the entire central Platte River to compare the cost-effectiveness of management at specific sites and for the central Platte River landscape. Median cost effectiveness values for the 7 land parcels evaluated suggest that costs for creating 1 additional hectare of sandhill crane roosting habitat totaled US $1,595. By contrast, we found that creating an additional hectare of sandhill crane roosting habitat could cost as much as US $12,010 for some areas in the central Platte River, indicating substantial cost savings can be achieved by using a cost effectiveness analysis to target specific land parcels for management. Cost-effectiveness analysis, used in conjunction with geographic information systems, can provide decision-makers with a new tool for identifying the most economically efficient allocation of resources to achieve habitat management goals. © 2013 The Wildlife Society.

KEY WORDS central Platte river, cost-effectiveness analysis, geographic information system analysis, *Grus canadensis*, habitat management, invasive vegetation, sandhill cranes.

Assessing and managing the establishment, spread, and impacts of non-indigenous flora and fauna, commonly called invasive species, is gaining substantial attention. The National Invasive Species Council defines an invasive species as one that is 1) non-native to the area under consideration and 2) capable of causing or likely to cause economic harm, environmental harm, or harm to human health (Clinton 1999). Such species are a primary threat to rare and endangered species in many areas as they can alter native species composition (Gordon 1998, Henderson et al. 2006). Moreover, the costs associated with monitoring, managing, and mitigating the impacts of invasive species are large and increasing (Pimentel et al. 2000, 2005). Research is needed to identify and evaluate new techniques that reduce costs and increase the efficiency of invasive species management.

Riparian ecosystems often serve as corridors for biological invasions (Dodds et al. 2004). The consequences of invasion can be dramatic and costly. A case in point is the central Platte River in Nebraska, a region recognized as a threatened ecosystem of international ecological importance (National Research Council 2004). During the past century, a combination of variation in climate and anthropogenic factors, such as land use changes and dams, have affected flows in the Platte resulting in reduced scouring and shifting of alluvium within the channel (Frith 1974, Williams 1978) and significant tree encroachment (Johnson 1994). In many areas, anthropogenic disturbances have contributed to the spread of invasive plants, including common reed (*Phragmites australis*; Hudon et al. 2005), salt cedar (*Tamarix ramosissima*; Stromberg 1998), and purple loosestrife (*Lythrum salicaria*; Stanley et al. 2005), all of which are found along the Platte River.

In previous research, we demonstrated that discrete choice modeling can be used to evaluate effects of invasive species on sandhill cranes (*Grus canadensis*; Kessler et al. 2011). We showed that expansion of common reed will substantially

reduce the availability of sandhill crane roost sites on the central Platte (Kessler et al. 2011). Resource managers must continually make decisions about what to manage (e.g., which invasive plant species), which management techniques to use, and where to focus management efforts, all within the constraints of finite budgets. During the past decade, many management initiatives have been taken to address invasive species issues along the central Platte River, including the restoration of sandbars and adjacent wet meadow habitats (Sidle and Faanes 2006). Increasing biological invasions, competition for scarce resources such as land and water, and limited budgets require that new and/or improved methods for assessing the costs and benefits of alternative management actions be identified. However, management is complicated by the large size of the area being managed, which spans many political, administrative, and land ownership entities. Organizations such as the United States Fish and Wildlife Service, the Audubon Society, and the Platte River Recovery Implementation Program have entered into cooperative agreements that have served to help implement and monitor the management of invasive vegetation. Nevertheless, the economic efficiency of implementing invasive species management at specific locations to enhance sandhill crane roost sites has not been investigated.

Cost-effectiveness analysis (CEA) is a valuation process designed to compare alternative actions based on the cost of achieving a pre-determined objective (Gittinger 1982). Recently, a number of studies have demonstrated that CEA can be advantageous in comparing the suitability of conservation management alternatives (Horskins and Wilson 1999, Buhle et al. 2005, Busch and Cullen 2009, Crossman and Bryan 2009, Balana et al. 2011). For example, Busch and Cullen (2009) used CEA to compare the cost-effectiveness of 3 recovery treatments for yellow-eyed penguins (*Megadyptes antipodes*): intensive management, trapping of introduced predators, and revegetation. The authors found intensive management, which included antibiotics, medical care, and food supplements for individual penguins, to be the most cost-effective alternative. Crossman and Bryan (2009) showed that using CEA in a spatially explicit framework was useful for identifying sites that generated the highest return on ecosystem services while minimizing the loss of agricultural income. Their analysis was based on an evaluation of each site's area, fragmentation, and its proximity and connectivity to remnant native vegetation, rather than requirements for a specific wildlife species. The authors concluded that CEA was useful for identifying the best areas on which to restore ecosystem services but noted that the CEA approach could be improved if species-specific habitat requirements were incorporated in modeling.

Our principal objective was to evaluate the feasibility of using cost-effectiveness analysis, applied within a geographic information system (GIS) framework, to assess alternatives for managing invasive vegetation in order to enhance wildlife habitat and identify possible cost savings. In this effort, we focused on roosting habitat for sandhill cranes along the central Platte River in Nebraska. Our research tested an approach to accounting for spatially explicit variations in the effectiveness of managing invasive vegetation to improve habitat for sandhill cranes.

Over the past several decades, wildlife managers working in the central Platte River region have generally employed a 2-stage process to manage invasive vegetation to improve sandhill crane roosting. First, a voluntary land conservation and management agreement is signed between a private landowner and a management organization, granting the management organization access to the property to conduct management. Then, invasive vegetation management is conducted within the privately owned land parcels where access has been granted. We evaluated the potential use of CEA for prioritizing efforts on individual land parcels where management access has been granted, and for targeting areas to obtain land conservation and management agreements.

Targeting areas to obtain signed management agreements across the central Platte River landscape could be hampered by local spatial autocorrelation. For instance, Bastos et al. (2012) found that management on lands surrounding Azores bullfinch (*Pyrrhula murina*) habitat could increase breeding success within the preferred habitat area. In the same way, management conducted on an individual land parcel in the central Platte River could enhance sandhill crane roosting habitat quality on surrounding land parcels. We therefore adapted a spatial autocorrelation test statistic that provides a means to identify if observations at different locations are correlated (Getis and Ord 1992, Anselin 1995, Ord and Getis 1995) to account for this possibility when targeting areas across the central Platte River landscape to obtain land conservation and management agreements.

STUDY AREA

The study area for this investigation was the central Platte River in Nebraska. The north and south Platte Rivers form the headwaters of the central Platte and originate in Wyoming and Colorado, respectively. The Platte River begins at the confluence of its north and south branches near North Platte, Nebraska. The Platte, including its north and south branches, drains some 230,000 km^2 before reaching its confluence with the Missouri River in eastern Nebraska. The average annual discharge for the Platte River at Kearney, Nebraska is 39 m^3/s. Precipitation for the area usually varies from 330 mm/yr to 430 mm/yr. Most of the central Platte River watershed is under row crop agriculture, much of which is irrigated.

This central Platte River serves as a unique and critical staging area for over 500,000 migratory sandhill cranes each spring. Successful sandhill crane reproduction and migration is in large part dependent upon roosting habitat found at migration staging areas (Krapu et al. 1985). Sandhill crane roosting habitat is generally composed of wide unvegetated sections of the river channel, away from roads and rural developments (Kessler et al. 2011). In addition to serving as a vital staging area for migratory water birds, the central Platte River also provides habitat for the whooping crane (*Grus americana*), piping plover (*Chardrius melodus*), least tern (*Sterna antillarum*), and pallid sturgeon (*Scaphirhynchus*

albus), all protected under the Endangered Species Act (National Research Council 2004). At the time of this study, invasive vegetation removal projects had been undertaken on the central Platte River for over 10 years.

METHODS

We calculated the CEA using the ratio, CEA = $\sum$costs/$\sum$hectares of enhanced habitat. The management costs are reported in 2009 United States dollars per hectare of sandhill crane roosting habitat created. Recurring maintenance costs are likely associated with maintaining sandhill crane roosting habitat after vegetation has been removed; however, data related to maintenance costs were unavailable at the time of this study. Consequently, the only cost we considered in this research was the removal of vegetation. We describe our methods in 2 parts. First, we describe the CEA procedures used to prioritize the management of invasive vegetation on specific land parcels (hereafter CEA-parcel specific). Subsequently, we outline our approach of using CEA to identify areas where managers should attempt to obtain signed management agreements (hereafter CEA-landscape analysis).

Data

We based our research primarily on a 2005 land cover dataset developed by the Great Plains GIS Partnership (Brei and Bishop 2008, U.S. Fish and Wildlife Service, unpublished report). The dataset portrays land cover classified from aerial digital imagery (1-m resolution) using the National Vegetation Classification System at the alliance-association level, with the addition of several classes (e.g., common reed and purple loosestrife) to enhance the results (Brei and Bishop 2008, unpublished report). The reported accuracy of the map was 82.7% (Brei and Bishop 2008 U.S. Fish and Wildlife Service, unpublished report). We resampled the land cover data to a 10-m grid, which was identified by Kessler et al. (2011) as appropriate for modeling sandhill crane habitat. To supplement the land cover data, we obtained from the United States Fish and Wildlife Service (USFWS) a vector data file of land parcel boundaries, designating specific tracts owned by individuals. Cost estimates for the mechanical removal of vegetation on the central Platte River were also provided by the USFWS (Table 1). We co-registered the resampled land cover data; the land parcels data, and a user-developed 1 km sampling grid using ArcGIS 9.3 software (Environmental Systems Research Institute, Inc., Redlands, CA).

Table 1. United States Fish and Wildlife Service cost estimates for vegetation removal of invasive and nuisance trees and herbaceous vegetation from the central Platte River, Nebraska (K. Dinan, U.S. Fish and Wildlife Service, personal communication).

Vegetation type	Min. ($/ha)	Max. ($/ha)	Average ($/ha)
Riparian woodland	1,976	2,964	2,470
Riparian shrubland	618	1,235	865
Common reed	124	494	494
Purple loosestrife	124	309	185

Modeling Habitat Change

In a previous article, we applied a discrete choice model to identify changes in the area of available sandhill crane roosting habitat (Kessler et al. 2011). Studies have demonstrated that discrete choice models can be used to forecast changes in species habitat that may result from alternative management actions (Cooper and Millspaugh 1999, Kessler et al. 2011). In this study, we followed the approach described by Kessler et al. (2011). We assumed an individual sandhill crane achieved satisfaction by selecting an optimal roosting site based on an assessment of a set of physical features characterized by land cover, proximity, and patch size metrics (Table 2). Kessler et al. (2011) measured proximity as the distance between potential roosting habitat and a physical feature, such as common reed. The model was implemented using the binary logit linear form:

$$U_b = b_1 v_1 + b_2 v_2 + \cdots + b_p v_p + e_r \qquad (1)$$

where U_b is the utility of roost site b, b_p is an estimable parameter, v_p is the value of the variable at a location, and e_r is an error term.

CEA-Parcel Specific Analysis

We used CEA to identify the optimal parcels on which to target invasive vegetation management to gain the largest return in sandhill crane roosting (Fig. 1). We randomly selected 7 USFWS land parcels that ranged in size from 31 ha to 177 ha and used an iterative vegetation removal simulation program. We simulated changes in land cover within each parcel to establish a cost-effectiveness value based on the vegetation removed (costs) and sandhill crane roosting habitat created (effectiveness), indicating the cost of establishing 1 additional hectare of roosting habitat (Fig. 2). We viewed 7 land parcels as adequate for testing the proposed technique; however, managers are likely faced with instances where fewer or far more land parcels need to be considered. We started the process using areas predicted by the discrete choice model to have a sandhill crane roosting habitat utility greater than 0 and simulated the removal of vegetation within a 10-m buffer around each area. We assumed that even an area with a low initial utility could be

Table 2. Variables and coefficients used in a discrete choice model (Kessler et al. 2011) predicting sandhill crane roosting site selection near the central Platte River, Nebraska.

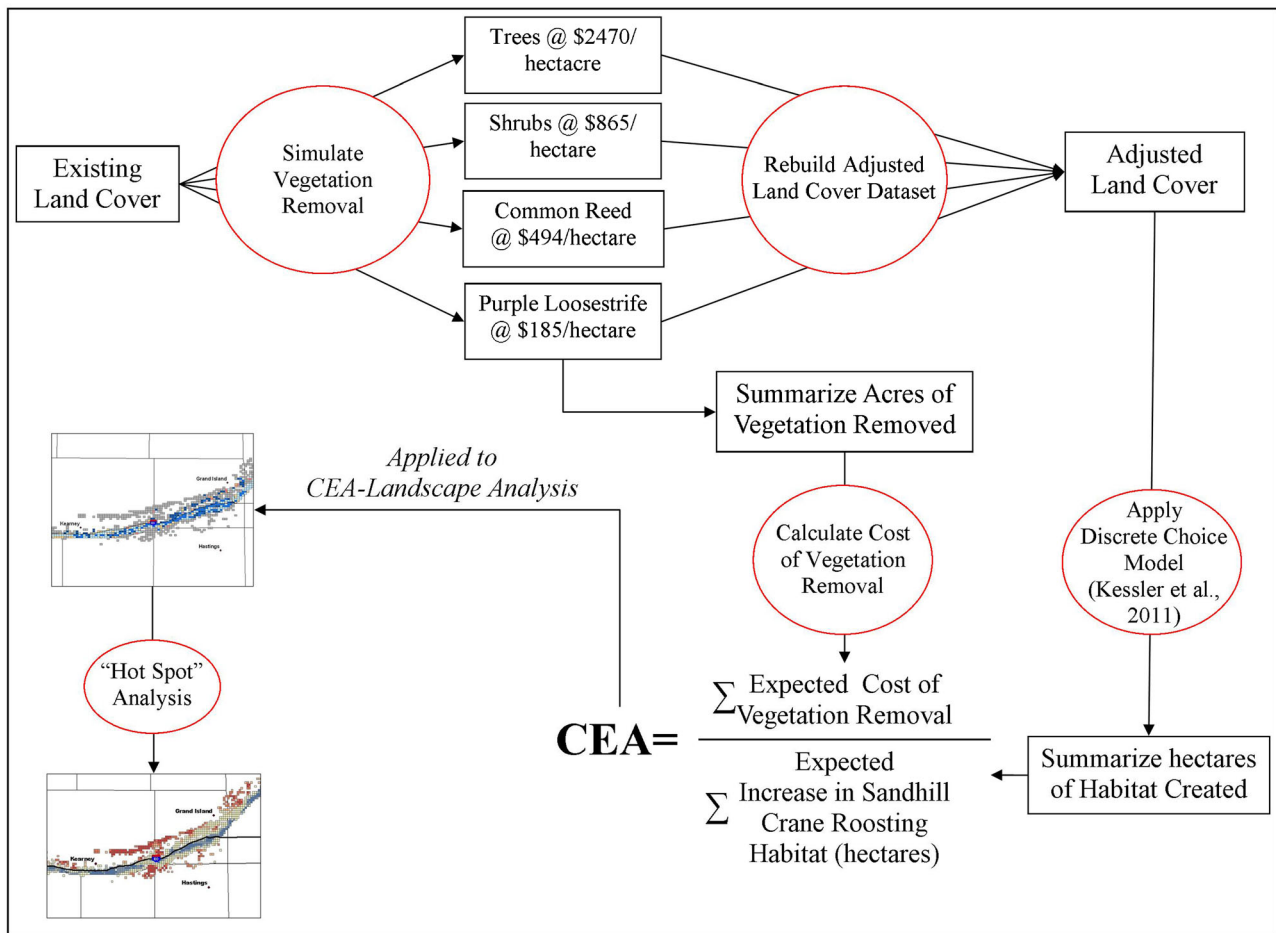| Variables	Coefficient
Proximity to	
Major roads	0.0005
Minor roads	0.0012
Rural developments	0.0013
Purple loosestrife	0.002
Riparian woodland	0.006
Riparian shrubland	0.008
River channel	−0.008
Early successional river	−0.004
Unvegetated sandbars	−0.004
Patch size	
Unvegetated sandbar	0.0002
River channel	0.0007
Wet meadow	0.00001

Figure 1. Flow chart depicting the data processing steps of a cost-effectiveness analysis (CEA) used to prioritize the management of invasive vegetation to enhance sandhill crane roosting habitat near the central Platte River, Nebraska.

improved to a preferred roost site. Greater utility values indicate higher suitability for sandhill crane roosting, and in turn a greater likelihood of sandhill crane occurrence (Kessler et al. 2011). We then simulated vegetation removal by expanding the original buffer by 10-m increments to 400 m from each site. We considered a 400-m buffer to be an area large enough for us to establish viable estimates of cost-effectiveness.

Following each iteration of the simulation process, we calculated the area of vegetation removed for each land parcel grouped by vegetation type: 1) riparian woodland (hereafter trees; eastern cottonwood [*Populus deltoids*], American elm [*Ulmus americana*], and eastern red cedar [*Juniperus virginiana*]); 2) riparian shrubland (hereafter shrubs; willow [*Salix* spp.], dogwood [*Cornus* spp.], desert false indigo [*Amorpha frutiosa*], and salt cedar); 3) common reed; and 4) purple loosestrife). Although some of the species found within the riparian shrubland and riparian woodland classifications are native to the central Platte, research has shown that anthropogenic disturbances have contributed to a significant expansion of woody species within the river channel (Johnson 1994); as such, they are often viewed as nuisance species, especially for sandhill crane roosting habitat. Therefore, for the purposes of this study, we considered riparian shrubland and woodland to be equivalent to invasive

vegetation. We multiplied the average expected cost for removing each type of vegetation (Table 1) by the area of vegetation removed.

After each iteration, we reclassified all grid cells from which vegetation had been removed as unvegetated sandbar, and applied the discrete choice model to the new adjusted land cover data set to calculate the total area of sandhill crane habitat within each parcel. We assumed that all grid cells with a utility greater than 70 were sandhill crane roosting habitat (Fig. 2).

We calculated the CEA ratio (i.e., cost per hectare) for each parcel after each iteration of the simulation and tabulated summary statistics to establish an average, median, minimum, maximum, and standard error estimate of the dollar investment required to create an additional hectare of sandhill crane roosting habitat. Additionally, we summarized the total potential management cost and total potential area of sandhill crane roosting habitat created for each parcel.

CEA-Landscape Analysis
The second phase of our research focused on the identification of areas that would provide the most-cost-effective sandhill crane roosting habitat enhancement through invasive vegetation management (see Fig. 1). As
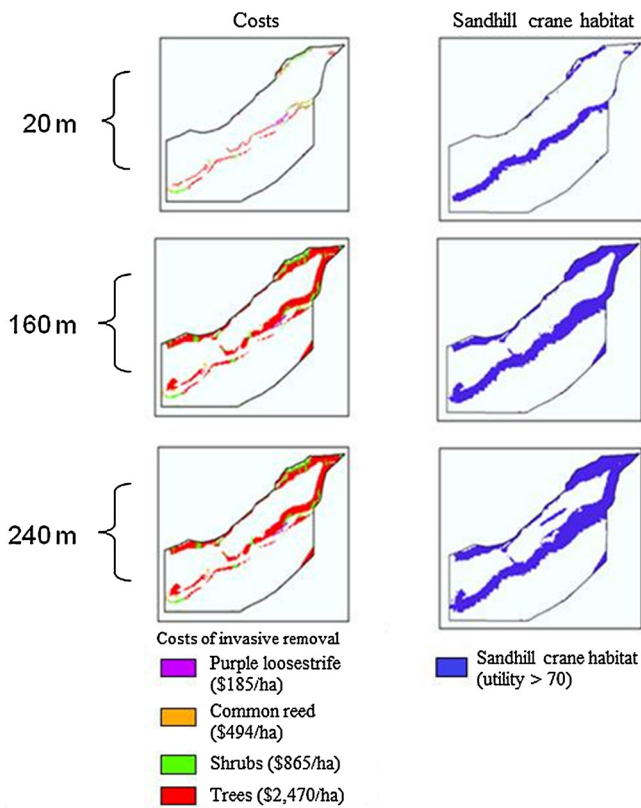
Figure 2. An example of the vegetation removal simulation process for parcel-specific cost-effectiveness analysis used to identify optimal locations for invasive vegetation removal to enhance sandhill crane roosting habitat near the central Platte River, Nebraska. The numbers (20, 160, and 240) represent the simulated removal distances for the example calculation.

described above, this analysis was similar to CEA-parcel specific analysis except that we conducted it for the entire study area and summarized it using a 1-km sampling grid rather than specific land parcels (see Fig. 1). We assumed sites having low CEA values were optimal for obtaining signed management agreements, voluntary contracts between a land owner and the USFWS that allow agency access to the property to enhance habitat. These contracts are entered into voluntarily, thus we did not consider land values in this study. Early in this analysis, we found that a low CEA value for a specific 1-km cell could simply be an artifact of the invasive vegetation removed within a neighboring 1-km cell. For example, if we modeled removal of 20 ha of vegetation from an area (cell A), but its adjacent neighbor (cell B) had 0 ha of vegetation removed, then cell B could show an increase in sandhill crane roosting habitat as an artifact of the vegetation removed from cell A. Corresponding costs for cell B would be US $0. Therefore, we adapted tests of spatial autocorrelation to our analysis to identify areas where invasive vegetation management would be the most cost-effective in enhancing sandhill crane roosting habitat.

We used spatial autocorrelation test statistics (hot spot analysis) to evaluate CEA values generated for each grid cell to identify clusters of low values. Such clusters are optimal areas to obtain signed management agreements for invasive vegetation management. We began data analysis by

simulating the removal of vegetation falling within a 10-m buffer of areas having a roost site utility greater than 0, as indicated by the discrete choice model. We continued this process by incrementally increasing the buffer around the original area at 10-m intervals out to a distance of 400 m. As with the simulations in the CEA-parcel specific analysis, we viewed 400 m as sufficient for estimating the CEA ratio. After each iteration of the simulation process, we calculated the area where the 4 types of vegetation were removed (common reed, purple loosestrife, shrubs, trees) for each 1-km sample polygon. We multiplied the average expected cost for removing each type of vegetation by the area of vegetation removed.

We created an adjusted land cover grid for each iteration of the simulation. We reclassified areas where the removal of vegetation was simulated as unvegetated sandbar. Next, we calculated the sandhill crane roosting habitat utility for the entire study area by applying the discrete choice model (Kessler et al. 2011). We classified all areas with a utility greater than 70 as sandhill crane roosting habitat. We calculated the area of roosting habitat, with the 1-km grid serving as the analysis frame rather than specific land parcels, for each iteration of the simulation and tabulated summary statistics to establish an average, median, minimum, maximum, and standard error estimate of the dollar investment required to create 1 additional hectare of sandhill crane roosting habitat for each sample polygon.

We used the Gi* test (Getis and Ord 1992) to identify areas where CEA ratio results occur in clusters (i.e., exhibit high spatial autocorrelation). As noted above, these areas area likely to be the sites on which conducting invasive vegetation management would be the most cost-effective strategy to enhance sandhill crane roost sites (i.e., optimal areas to obtain signed management agreements for invasive vegetation management). We used hot spot analysis, calculated as a Gi* test statistic, to identify local clusters of high and/or low CEA ratio values.

We applied the Getis-Ord Gi* statistic as

$$Gi^* = \frac{\sum_{j=1}^{n} w_{i,j} x_j - \bar{x} \sum_{j=1}^{n} w_{i,j}}{S \sqrt{\frac{n \sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j}\right)^2}{n-1}}} \qquad (2)$$

where x_j is the cost-effectiveness ratio for a 1-km sample polygon j, $w_{i,j}$ is the spatial weight between sample polygon i and j, n is equal to the total sample polygon,

$$\bar{x} = \frac{\sum_{j=1}^{n} x_j}{n} \quad \text{and} \qquad (3)$$

$$S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - (\bar{x})^2} \qquad (4)$$

We calculated the spatial weight for the Gi* test statistics using the zone of indifference spatial relationship, with a 2-km zone band threshold. The Gi* test statistic is calculated

as a Z score. A sample polygon with a Z score greater than 2.58 indicates strong clustering among high values, whereas a sample polygon with a Z score less than -2.58 indicates strong clustering of low values. The zone of indifference is similar to inverse distance, as distance increases the weight contributed by a sample polygon's CEA ratio value decreases. However, all sample polygon values found within the 2-km zone are weighted equally.

RESULTS

We found a wide range in the mean, median, total potential cost, and area of habitat created for the CEA-parcel specific analysis (Fig. 3). Parcel 6 had the lowest average cost per hectare for establishing sandhill crane roosting habitat ($1,264/ha), but had the greatest standard error ($67.26). Parcel 4 had the lowest median ($1,340/ha), standard error ($17.16), and total potential cost, but it also had the smallest total potential area of sandhill crane roosting habitat that could be created (10 ha). Parcel 3 had the greatest potential area of sandhill crane roosting habitat (93 ha), but also had the highest potential total cost ($104,203). Parcel 5 had the greatest mean ($1,580/ha) and median ($1,772/ha) dollars per hectare of sandhill crane roosting habitat.

The mean cost, based on the CEA-landscape analysis was $1,770/ha, the median cost was $1,778/ha, and the standard error was $32.46, with a range of $26–$29,665/ha (Fig. 4). The extreme variation in the range of CEA values supports testing for spatial autocorrelation between cells. For example, the minimum expected CEA value ($26 per ha of sandhill crane roosting habitat) could be a result of the removal of vegetation in neighboring cells, which reduced the expected CEA value. Therefore, if tests for spatial autocorrelation indicate a significant number of lower CEA values are expected to occur in neighboring locations, natural resources managers should solicit signed management agreements for these areas.

The hot spot analysis test statistics indicated that several areas exhibited local spatial autocorrelation with clusters of high and low CEA values (Fig. 5). Z scores ranged from 3.48 to -3.57. In the hot spot analysis, 8% of sample polygons had a Z score greater than 2.58, whereas 14% of sample polygons

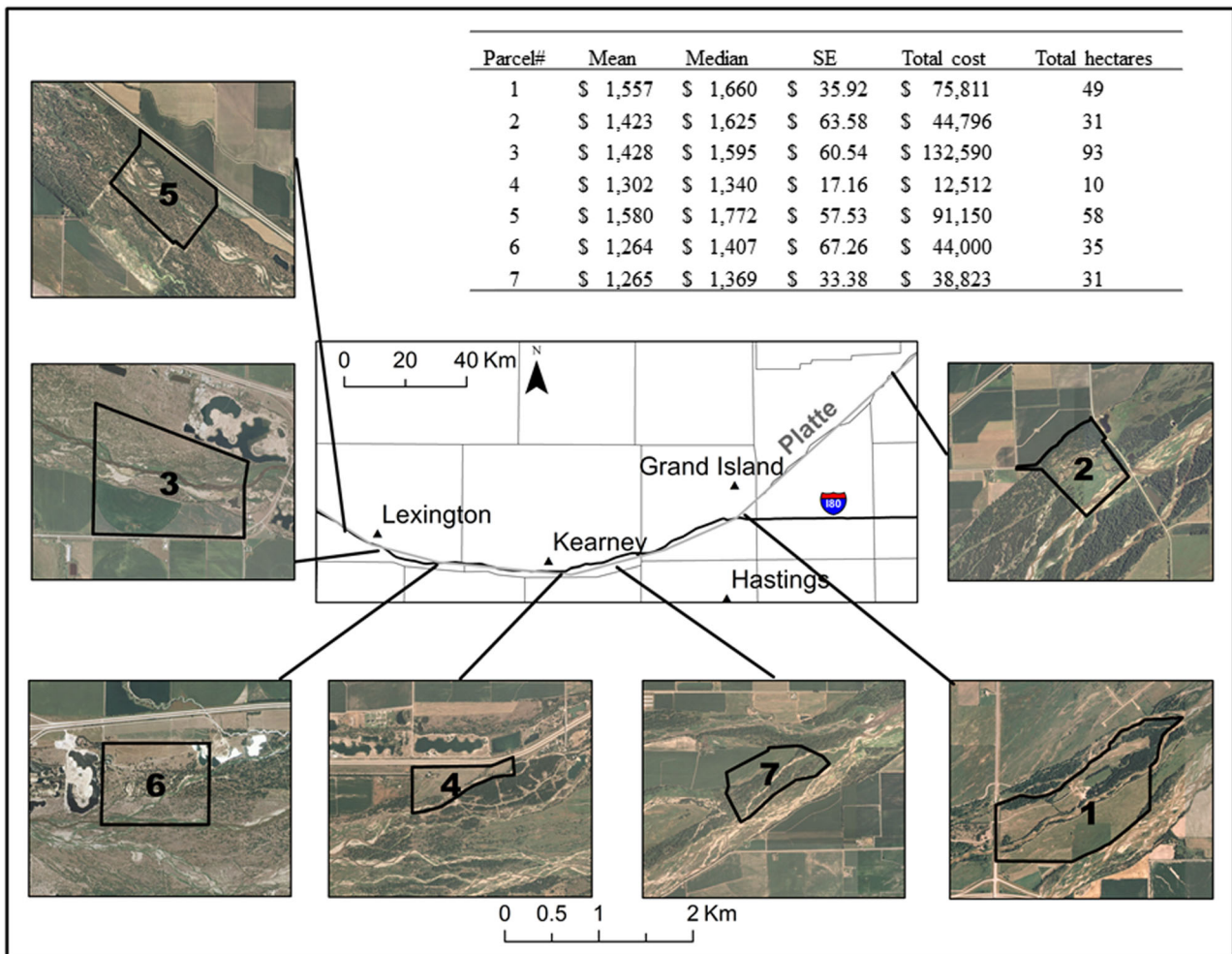| Parcel#	Mean	Median	SE	Total cost	Total hectares
1	$ 1,557	$ 1,660	$ 35.92	$ 75,811	49
2	$ 1,423	$ 1,625	$ 63.58	$ 44,796	31
3	$ 1,428	$ 1,595	$ 60.54	$ 132,590	93
4	$ 1,302	$ 1,340	$ 17.16	$ 12,512	10
5	$ 1,580	$ 1,772	$ 57.53	$ 91,150	58
6	$ 1,264	$ 1,407	$ 67.26	$ 44,000	35
7	$ 1,265	$ 1,369	$ 33.38	$ 38,823	31

Figure 3. The location of the parcels analyzed in our parcel-specific cost-effectiveness analysis. The table in the figure shows the summary statistics for the dollars needed to generate 1 additional hectare of sandhill crane roosting habitat on the central Platte River, Nebraska, along with the total potential cost that could accrue and total potential hectares of sandhill crane roosting habitat that could be created for each parcel.
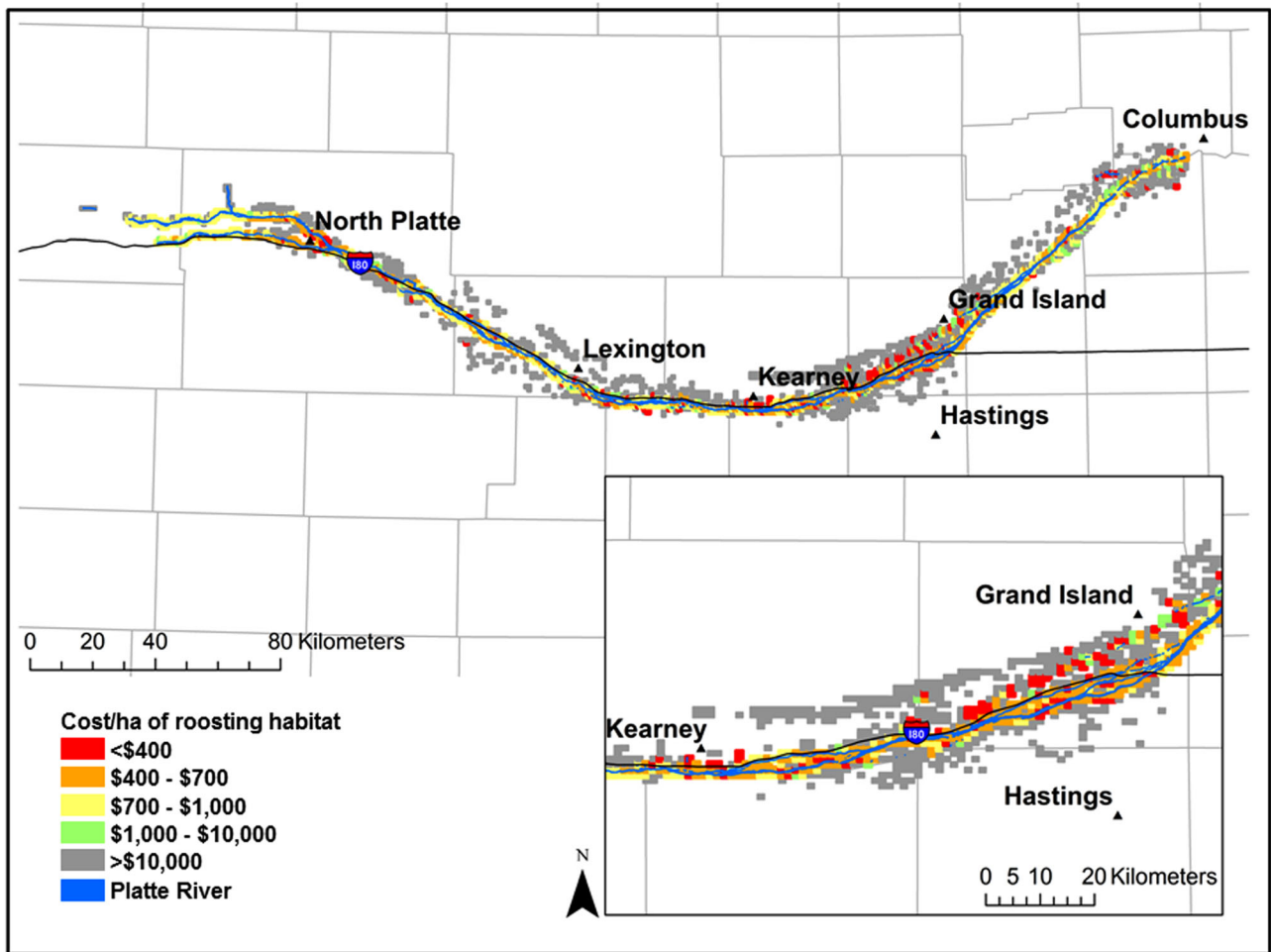
Figure 4. The results of the landscape cost-effectiveness analysis showing the average dollars needed to create 1 additional hectare of sandhill crane roosting habitat for each 1-km sample polygon along the central Platte River, Nebraska.

had a Z score less than -2.58 (sample polygons with $Z > 2.58$ or < -2.58 were significant at $\alpha < 0.05$).

DISCUSSION

Although CEA has been used to evaluate conservation strategies (Horskins and Wilson 1999, Buhle et al. 2005, Busch and Cullen 2009, Crossman and Bryan 2009, Balana et al. 2011), it has yet to be widely adopted to compare management alternatives on a species-specific basis. We employed CEA to estimate the costs that would likely incur to enhance sandhill crane roosting habitat on specific parcels. Such estimates can help decision-makers target land parcels on which to conduct invasive plant management based on the likelihood of producing a cost-effective return in sandhill crane roosting habitat. Thus, our results indicate that parcels 6 and 7 would be good candidates for invasive vegetation management because of their low mean, median, and total cost CEA estimates, and high potential for creating sandhill crane roosting habitat, whereas parcel 5 would be a low priority candidate for invasive vegetation management (Fig. 3). Although parcel 5 has potential for a large area of sandhill crane roosting habitat, its high mean, median, and

total cost CEA estimates indicate that it would not be as cost-effective as the other parcels studied. The higher cost-effectiveness for management on parcels 6 and 7 is driven by less initial vegetation within the parcel, particularly a smaller area of riparian woodlands which carry the highest management cost. Parcel 5, on the other hand, has a low cost-effectiveness driven by a large initial area of riparian woodland.

Future work should attempt to incorporate recurring management costs, as some areas could be more prone than others to reoccupation by invasive vegetation. In addition, we did not account for potential diminishing utility at alternative roost sites as the utility at managed sites increased. Accounting for these costs before the initial management decision and evaluating potential diminishing utility at alternative roost sites could further increase the effectiveness of habitat enhancement efforts and aid in selecting land parcels to manage. Crossman and Bryan (2009) demonstrated that CEA is useful in optimizing the restoration of ecosystems services. We have demonstrated that spatially explicit CEA can also be a useful tool for making species-specific habitat management decisions. This type of analysis could be advantageous in areas like the
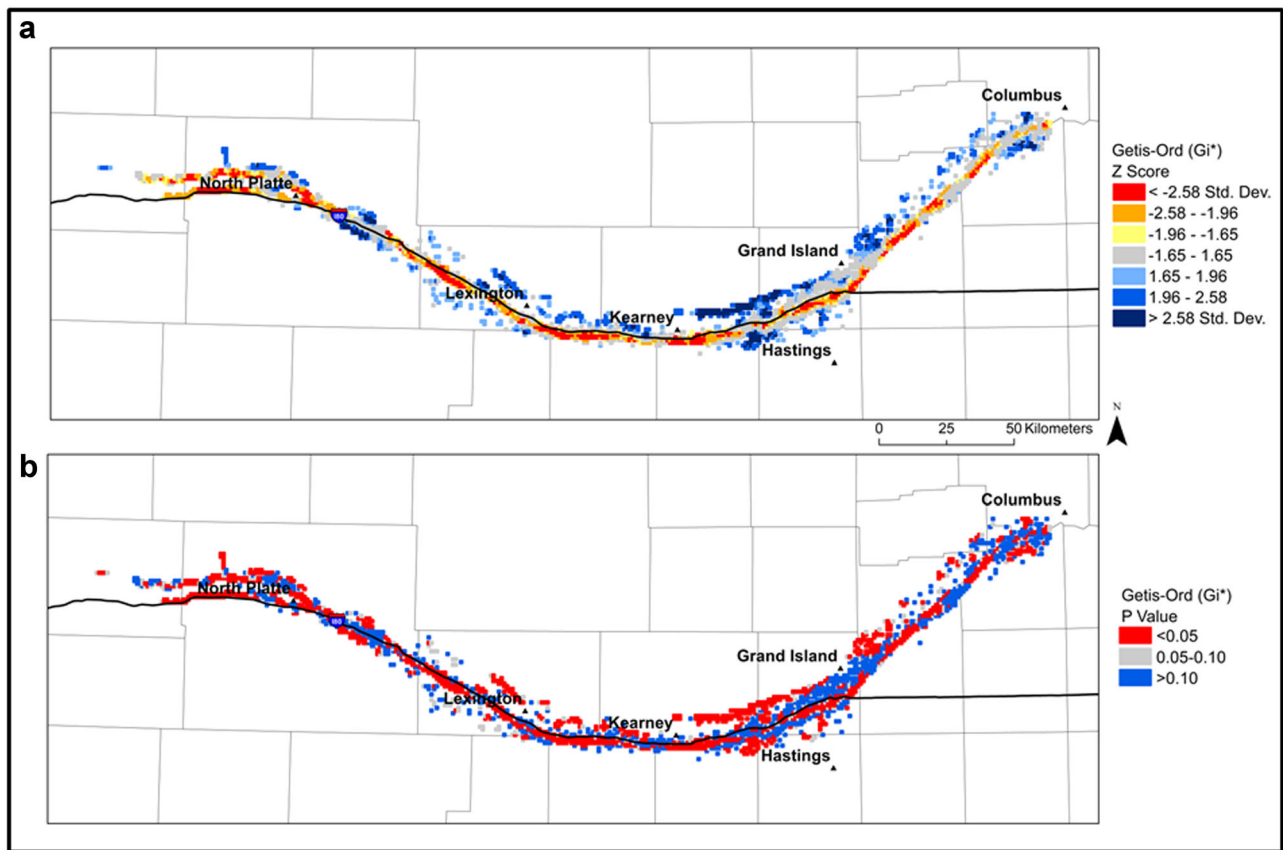
Figure 5. Results from the hot spot analysis used to identify optimal locations for invasive vegetation removal to create sandhill crane roosting habitat near the central Platte River, Nebraska. We present Z scores resulting from the Getis-Ord (Gi*) test (a) and P values corresponding to the Z score test statistic (b). Sample polygons with negative Z scores and P values <0.05 indicate significant clustering of cost-effective areas to manage invasive vegetation for the enhancement of sandhill crane roost sites.

central Platte River where wildlife managers are tasked with improving habitat.

Tools such as GIS, combined with techniques for assessing spatial relationships, such as spatial autocorrelation, have become increasingly common in applied economics research (Anselin 1998, Can 1998). We found that hot spot analysis can aid in identification of areas where management should be most cost-effective (i.e., where the cost-benefit ratio is maximized) in enhancing sandhill crane roosting habitat across a landscape. We identified several areas across the central Platte River landscape where sandhill crane roost site enhancement would likely be cost-effective and many areas where it would not. Z scores <-2.58 (Fig. 5a) and $P < 0.05$ (Fig. 5b), indicate areas where signed management agreements should be pursued, whereas Z scores >2.58 (Fig. 5a) and $P < 0.05$ (Fig. 5b) indicate areas where management is much less likely to be cost-effective relative to the other areas. Pairing the hot-spot analysis from CEA-landscape analysis with CEA-parcel specific analysis would allow practitioners to first identify areas to pursue land management agreements, then prioritize among specific parcels based on the locations most likely to provide cost-effective habitat management. The CEA-landscape analysis could be further refined by removing non-effective 1-km grid cells (i.e., cells

with extremely high CEA values) and rerunning the analysis for just those areas with lower CEA values.

Sidle and Faanes (2006) described the complexities involved in conducting management on the central Platte River, a region that encompasses many governmental jurisdictions and in which land managers must deal with private land owners, multiple public agencies, and non-governmental organizations. Previous research has shown that an expansion of invasive vegetation along the central Platte River would likely significantly reduce the availability of sandhill crane roosting (Kessler et al. 2011). We have shown that a landscape-level approach to CEA can be useful in identifying cost-effective areas to conduct management, and could provide stakeholders (both individuals and organizations) with a means to objectively assess alternatives and reach consensus. We have also demonstrated that CEA could be used to aid managers in allocating resources to areas with a high potential for management success.

The USFWS, the Audubon Society, and the Platte River Recovery Implementation Program are currently working to protect habitat for several species on the central Platte River. The methods we have presented here should be tested with other species of concern such as interior least terns, piping plovers, and whooping cranes. In addition, we recognize that

areas prone to reinvasion by invasive vegetation would likely pose additional costs to managers and these were not captured in this analysis. Further work is needed to account for such limitations.

Globally, funding for species conservation has been shown to be far lower than needed (McCarthy et al. 2012, Polasky 2012). Furthermore, budget shortfalls have pushed wildlife management agencies to seek alternative strategies to fund management programs (Jacobson et al. 2007). In the face of limited and sometimes dwindling budgets, field practitioners need tools that evaluate the economic efficacy of wildlife management decisions. The CEA framework we present could readily be applied in any area where wildlife management decisions must be made under conditions where constrained budgets dictate that resources be allocated to maximize the return on investment.

MANAGEMENT IMPLICATIONS

Natural resource managers working in the central Platte River ecosystem are confronted with complex decisions regarding the best use of funds for enhancing threatened habitats. New and improved methods for comparing the economic efficiency of management alternatives are needed (Eisel and Aiken 1997). Cost-effectiveness analysis used in conjunction with GIS technology, can provide decision-makers with an objective and site-specific means by which to identify the most economically efficient allocation of resources to achieve habitat management goals. Spatial targeting, based on economic and ecological goals, combined with active adaptive management, offers hope in the control of difficult invasive species management challenges. We established that CEA provides a framework that can be employed to support decisions regarding selection of optimal management locations on specific land parcels. In addition, we showed that CEA could provide a means of economic accounting for management decisions by serving as a tool to quantify the return on investment in managing invasive vegetation in the form of increased area of sandhill crane roosting habitat.

ACKNOWLEDGMENTS

LITERATURE CITED

Anselin, L. 1995. Local indicators of spatial association—LISA. Geographical Analysis 27:93–115.

Anselin, L. 1998. GIS research infrastructure for spatial analysis of real estate markets. Journal of Housing Research 9:113–133.

Balana, B. B., A. Vinten, and B. Slee. 2011. A review on cost-effectiveness analysis of agri- environmental measures related to the EU WFD: key issues, methods and applications. Ecological Economics 70:1021–1031.

Bastos, R., M. Santos, J. A. Ramos, J. Vicente, C. Guerra, J. Alonso, J. Honrado, R. S. Ceia, S. Timóteo, and J. A. Cabral. 2012. Testing a novel spatially-explicit dynamic modeling approach in the scope of the laurel forest management for the endangered Azores bullfinch (Pyrrhula murina) conservation. Biological Conservation 147:243–254.

Brei, J., and A. A. Bishop. 2008. Platte River vegetation mapping project 2005 land cover methods summary. Great Plains GIS Partnership, Grand Island, Nebraska, USA.

Buhle, E. R., M. Margolis, and J. L. Ruesink. 2005. Bang for buck: cost-effective control of invasive species with different life histories. Ecological Economics 52:355–366.

Busch, J., and R. Cullen. 2009. Effectiveness and cost-effectiveness of yellow-eyed penguin recovery. Ecological Economics 68:762–776.

Can, A. 1998. GIS and spatial analysis of housing and mortgage markets. Journal of Housing Research 9:61–86.

Clinton, W. J. 1999. Executive order 13112 of February 3, 1999 Invasive species. Federal Register 64:6183–6186.

Cooper, A. B., and J. J. Millspaugh. 1999. The application of discrete choice models to wildlife resource selection studies. Ecology 80:566–575.

Crossman, N. D., and B. A. Bryan. 2009. Identifying cost-effective hotspots for restoring natural capital and enhancing landscape multifunctionality. Ecological Economics 68:654–668.

Dodds, W. K., K. Gido, M. R. Whiles, K. M. Fritz, and W. J. Matthews. 2004. Life on the edge: the ecology of Great Plains prairie streams. BioScience 54:205–216.

Eisel, L. J., and D. Aiken. 1997. Platte River basin study. National Technical Information Service, Springfield, Virginia, USA.

Frith, C. R. 1974. The ecology of the Platte River as related to sandhill cranes and other waterfowl in south central Nebraska. Thesis, Kearney State College, Kearney, Nebraska, USA.

Getis, A., and J. K. Ord. 1992. The analysis of spatial association by the use of distance statistics. Geographical Analysis 24:189–206.

Gittinger, J. P. 1982. Economic analysis of agricultural projects, second edition. John Hopkins University Press, Baltimore, Maryland, USA.

Gordon, D. R. 1998. Effects of invasive, non-indigenous plant species on ecosystem process: lesson from Florida. Ecological Applications 8:975–989.

Henderson, S., T. P. Dawson, and R. J. Whittaker. 2006. Progress in invasive plants research. Progress in Physical Geography 30:25–46.

Horskins, K., and J. Wilson. 1999. Cost-effectiveness of habitat manipulation as a method of rodent control in Australian macadamia orchards. Crop Protection 18:379–387.

Hudon, C., P. Gagnon, and M. Jean. 2005. Hydrological factors controlling the spread of common reed (Phragmites australis) in the St. Lawrence River (Quebec, Canada). Ecoscience 12:347–357.

Jacobson, C. A., D. J. Decker, and L. Carpenter. 2007. Securing alternative funding for wildlife management: insights from agency leaders. Journal of Wildlife Management 71:2106–2113.

Johnson, W. C. 1994. Woodland expansion in the Platte River, Nebraska: patterns and causes. Ecological Monographs 64:45–84.

Kessler, A. C., J. W. Merchant, C. R. Allen, and S. D. Shultz. 2011. Impacts of invasive plants on sandhill crane (Grus canadenisis) roosting habitat. Invasive Plant Science and Management 4:369–377.

Krapu, G. L., G. C. Iverson, K. J. Reinecke, and C. M. Boise. 1985. Fat deposition and usage by arctic-nesting sandhill cranes during spring. Auk 102:362–368.

McCarthy, D. P., P. F. Donald, J. P. W. Scharlemann, G. M. Buchanan, A. Balmford, J. M. H. Green, L. A. Bennun, N. D. Burgess, L. D. C. Fishpool, S. T. Garnett, D. L. Leonard, R. F. Maloney, P. Morling, H. M. Schaefer, A. Symes, D. A. Wiedenfeld, and S. H. M. Butchart. 2012. Financial costs of meeting global biodiversity conservation targets: current spending and unmet needs. Science 338:946–949.

National Research Council. 2004. Endangered and threatened species of the Platte River. National Academies Press, Washington, D.C., USA.

Ord, J. K., and A. Getis. 1995. Local spatial autocorrelation statistics: distributional issues and an application. Geographical Analysis 27:286–306.

Pimentel, D., L. Lach, R. Zuniga, and D. Morrison. 2000. Environmental and economic costs of nonindigenous species in the United States. BioScience 50:53–65.

Pimentel, D., R. Zuniga, and D. Morrison. 2005. Update on the environmental and economic costs associated with alien invasive species in the United States. Ecological Economics 52:273–288.

Polasky, P. 2012, Economics: conservation in the red. Nature 492:193–194.

Sidle, J. G., and C. A. Faanes. 2006. Platte River ecosystem resources and management, with emphasis on the Big Bend reach in Nebraska. U.S. Fish and Wildlife Service, Grand Island, Nebraska, USA.

Stanley, K. E., P. G. Murphy, H. H. Prince, and T. M. Burton. 2005. Long-term consequences of anthropogenic disturbance on Saginaw Bay coastal wet meadow vegetation. Journal of Great Lakes Research 31:147–159.

Stromberg, J. 1998. Dynamics of Fremont cottonwood (*Populous fremontii*) and saltcedar (*Tamarix chinensis*) populations along the Sand Pedro River, Arizona. Journal of Arid Environments 40:133–155.

Williams, G. P. 1978. The case of the shrinking channels—the north Platte and Platte Rivers in Nebraska. U.S. Geological Survey Circular Number 781, Arlington, Virginia, USA.

Associate Editor: Miranda Mockrin.