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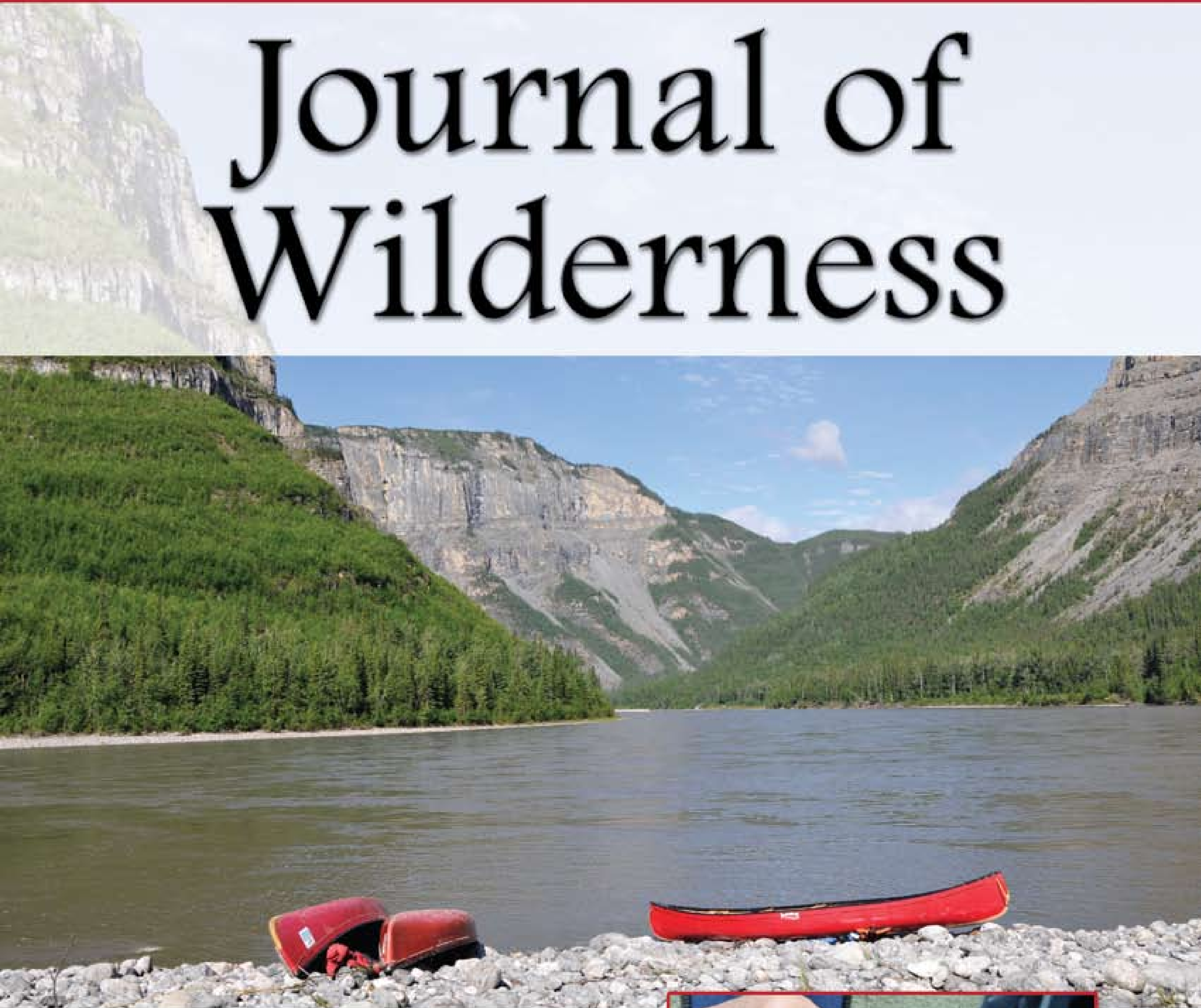

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How Do Migratory Species Add Ecosystem Service Value to Wilderness?

Calculating the Spatial Subsidies Provided by Protected Areas

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Abstract: Species that migrate through protected and wilderness areas and utilize their resources, deliver ecosystem services to people in faraway locations. The mismatch between the areas that most support a species and those areas where the species provides most benefits to society can lead to underestimation of the true value of protected areas such as wilderness. We present a method to communicate the "off-site" value of wilderness and protected areas in providing habitat to migratory species that, in turn, provide benefits to people in distant locations. Using northern pintail ducks (*Anas acuta*) as an example, the article provides a method to estimate the amount of subsidy – the value of the ecosystem services provided by a migratory species in one area versus the cost to support the species and its habitat elsewhere.

Introduction

Wilderness and protected areas generate benefits well beyond their boundaries – many species that migrate through wilderness areas and utilize their resources, deliver ecosystem services to people in faraway locations (Semmens et al. 2011; López-Hoffman et al. 2010). Migratory species – animals such as birds, mammals, fish, and insects that regularly migrate between two or more different areas – provide ecosystem services to people, such as controlling crop pests, pollinating food plants, or supporting recreational hunting, fishing, and bird-watching. For example, the migratory Mexican free-tailed bat (*Tadarida brasiliensis mexicana*) helps control cotton crop pests in the southwestern United States and northern Mexico. Female bats migrate annually from central Mexico to the U.S.-Mexico borderlands where they feed on corn earworm/cotton bollworm, providing an estimated $700,000 worth of pest control annually in one region of Texas (Cleveland et al. 2006). Throughout the yearly cycle of migration, bats and many other migratory species depend on wilderness areas for food, shelter, and breeding habitat (see Figure 1).

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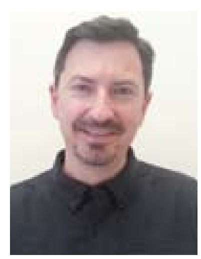

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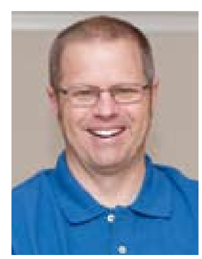

Jay Diffendorfer

This mismatch between the areas that most support a species and those where the species provides most benefits to society can lead to underestimation of the true value of protected areas such as wilderness. People, and most critically decision makers, may not realize that locally used ecosystem services may be linked to (supported by) distant protected areas. In the United States, in an era of concern about visitation rates to national parks and wilderness areas (Pergams

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Figure 1 – Mexican free-tailed bats near Bracken Cave near San Antonio, Texas. Photo by A. Russell.

and Zaradic 2008; Cordell et al. 2008), it is important to be able to understand, calculate, and communicate the full value of wilderness (Watson and Venn 2012), including the "on-site" benefits provided within or near protected areas and the "off-site" benefits provided to people far beyond area boundaries (Loomis and Richardson 2001). The purpose of this article is to present a method to communicate the "off-site" value of wilderness areas in providing habitat to migratory species that, in turn, provide benefits to people in distant locations.

What is the full ecosystem service value of protected areas? How do protected areas support the delivery of ecosystem services in distant locations by providing habitat for migratory species? Using northern pintail ducks (*Anas acuta*) as an example, we (1) outline a method to estimate the amount of subsidy – the value of the ecosystem services provided by pintails in one area versus the cost to support the species and its habitat elsewhere, (2) describe how the approach can be applied to account for individual wilderness areas, and (3) suggest how such an approach could be used to communicate the value of protected areas to people and decision makers in distant locales.

Calculating the Spatial Subsidy Provided by a Wilderness Area

Consider a wildlife refuge on a migratory flyway that is widely judged a "critical" stopover site for birds. Scientists trying to ascertain the ecosystem service "value" of this refuge would traditionally consider the number of visitors, how much the average visitor spends, and any other goods or services extracted from or provided by the refuge. If they were to consider the birds, however, they would recognize the refuge plays an important role in supporting bird migration and thus the overall ability of the species to provide ecosystem services in other locations – a service that was previously unaccounted for in the valuation of the refuge. This "migration support" is a type of supporting service (*sensu* Millennium Ecosystem Assessment 2003) provided by ecosystems. By understanding the nature of migration support as an ecosystem service, it is possible to quantify spatial subsidies one location provides to, or receives, from others.

All locations regularly used by a migratory species can both provide and receive benefits via migration support. Locations *provide* benefits by contributing to the overall viability of migratory species that in turn provide services to humans elsewhere in their range. Locations *receive* benefits in the form of services provided locally by migratory populations that are dependent on distant areas. Therefore, the net ecosystem service subsidy either provided or received by an area is a balance between the services received from a species dependent on other locations and the support the area provides to the species. The following description of how the subsidy can be calculated is excerpted from Semmens et al. (2011), which can be referenced for additional details.

For a single species, the gross migration support provided (out) by location *A* to all other locations, M_{Ao}, is simply the value of migratory services provided at all other locations multiplied by the species' proportional dependence on location *A*:

$$M_{Ao} = (V_S - V_{SA}) \times D_{SA} \quad (1)$$

Where V_S is the total value of services provided by a species *S* throughout its range, V_{SA} is the value of services provided at location *A*, and D_{SA} is the proportional dependence of the species' population on location *A*. Locations can be defined in any manner and number, provided they encompass the full migratory range of a species. Values for D_S must satisfy the following two requirements:

$$0 \le D_{SL} \le 1$$

$$\sum_{L=1}^{m} D_{SL} = 1$$

where D_{SL} represents the proportional dependence at any given location, and *L* encompasses all *m* locations used by a species. The latter requirement assumes migratory species are dependent on the persistence of favorable conditions across their entire range; they cannot be more or less than 100% dependent on their environment.

The gross migration support received (in) by a location from all other locations, M_{Ai}, is the product of a species' dependence on all other locations and the value of services provided locally:

$$M_{Ai} = V_{SA}\left(1 - D_{SA}\right) \quad (2)$$

The migration support values calculated in Equations 1 and 2 are based on the annual monetary value of services provided by the migratory species (see Semmens et al. 2011 for a discussion of how nonmonetary values could be incorporated into this approach).

The net difference between outgoing and incoming migration support is the spatial subsidy for location *A* (Y_A):

$$Y_A = M_{Ao} - M_{Ai} \quad (3)$$

Positive values indicate location *A* is subsidizing other areas. Negative values indicate location *A* is being subsidized by other areas. When applied to all locations, *L*, throughout a species' range, Equation 3 satisfies the requirement that the sum of all subsidies is zero, or

$$\sum_{L=1}^{m} Y_L = 0 \quad (4)$$

For a given location, the total annual value resulting from its use by a migratory species is the sum of the spatial subsidy and value of services provided locally:

$$V_A = Y_A + V_{SA} \quad (5)$$

Equations 3 and 5 can be rewritten to accommodate multiple species by simply summing across all *n* species of interest.

$$Y_A = \sum_{S=1}^{n}\left(V_S D_{SA} - V_{SA}\right) \quad (6)$$

$$V_A = Y_A + \sum_{S=1}^{n} V_{SA} \quad (7)$$

The migratory ranges of each species need not overlap completely. Equation 6 still satisfies the requirement of Equation 4, provided that the combined spatial extent of all ranges is considered.

Despite the conceptual framework, estimating real values for V_S and D_S presents a substantial challenge. Estimates of V_S must be location specific, yet measured across all locations. This creates considerable hurdles both in the required ecological understanding of a species and its valuation at each location. Estimates of D_S must allow comparisons of different sites in terms of their contribution to overall population growth or viability. The most difficult aspect of estimating D_S and V_S lies in developing demographic and economic data across all sites – very few studies approach migratory species from a population level, or systematically address their functional interactions with humans. As a result, data limitations will hamper the application of our approach in the short term and permit analyses for only those charismatic, endangered, or economically important species that are the best studied and monitored. In the long term, the approach demands substantial investment in, and coordination of, new data collection, monitoring, and database development to systematically address migratory species. To date, there are no published examples of spatial subsidy calculations. However, a U.S. Geological Survey Powell Center for Analysis and Synthesis working group led by the authors is attempting to calculate spatial subsidies for three species: northern pintail ducks, monarch butterflies (*Danaus plexippus*) and Mexican free-tailed bats.

Global Importance of Wilderness for Migratory Species

Around the world, many wilderness and protected areas support migratory species, often by design. For instance, the Monarch Butterfly Biosphere Reserve in Mexico supports overwintering congregations of eastern North American monarchs, and the Maasai Mara/Serengeti National Parks in Africa support massive migrations of wildebeests and other ungulates. In the United States, the U.S. Fish and Wildlife Service refuge system and other managed lands in the Prairie Pothole Region account for only 2% of the breeding habitat for all waterfowl, yet contribute to 23% of the overall waterfowl production (USFWS 2007), indicating that these managed lands play an important role in waterfowl demography. Many other reserve systems around the world support migratory birds, such as Keoladeo National Park in India, Radipole Lake nature reserve in the UK, the nature reserve system in Israel (an important geographic location for bird migration between Africa, Europe, and western Asia), and numerous World Heritage sites. Within countries or regions, reserve systems also support smaller-scale altitudinal migration, such as the migration of resplendent quetzals and other tropical forest birds in Costa Rica, and ungulates in Wyoming, United States.

Example of Northern Pintail Ducks

Northern pintail ducks are a popular species for hunting and wildlife viewing. Pintails generally overwinter in the southern United States and

Mexico and fly north each spring to breed in the northern United States and Canada (the majority of the pintail population occurs in the western part of the continent, despite a broad distribution across North America). Through their migration, pintail ducks create ecological and economic links between distant locations. The potential for a large ecosystem service subsidy exists because the vast majority of the harvested birds (80–90%, Miller and Duncan 1999) are taken in the United States, yet breeding habitats in Canada play a large role in overall pintail population dynamics. Indeed, the leading hypothesis for historic pintail declines is the intensification of agriculture in the prairie pothole region of western Canada (Miller and Duncan 1999; Podruzny et al. 2002; Miller et al. 2003) (see Figure 2).

How can we estimate the spatial subsidies in ecosystem services (harvest of pintails) between locations where birds are harvested versus places that support the pintail population? A promising approach is to combine harvest value information with a demographic model of pintails via the method described earlier. Mattson et al. (2012) developed a demographic model for pintails in North America. The model included three breeding populations (Alaska, northern Canada, and the Prairie Potholes), and two nonbreeding populations (California and the Gulf Coast). It modeled both fall and spring migratory dynamics and was parameterized using a wide array of data from nest studies, aerial waterfowl surveys, and harvest records. The model can be used to estimate *Ds* for each of the five regions, while harvest data can be used to estimate *Vs*. At this broad geographic scale of North America, the subsidy calculations can inform policy between the United States and Canada for pintail management.

Figure 2 – Northern pintail ducks in Kolkata, West Bengal, India. Photo by J. M. Garg. License held by Creative Commons.

To assess the subsidy provided by an individual protected area, we suggest adapting Mattson et al. (2012) to understand how pintail demographic processes vary across the modeled regions. The maps of protected area boundaries could be compared to maps of how the landscape contributes to a species' demography to estimate the subsidy provided by particular protected areas. For pintails in the Prairie Potholes, this is nearly possible. Podruzny et al. (2002) analyzed data from 72 transects spanning an area about 600 x 400 miles (1000 x 600 km) in the Canadian Prairie Potholes. This area represents about 60% of the Prairie Pothole breeding population in Mattson et al. (2012). The analysis determined geographic features that influenced where pintails "settled" or chose to breed after their spring migration to the prairie. The analysis also generated detailed maps of the density of breeding pintails across the region and developed an understanding of how particular vegetation types, agricultural practices, and pond density affected breeding bird density. Using these maps it would be straightforward to quantitatively partition regional subsidy or proportional dependence values among subareas, such as a wildlife refuge. These types of geographic analyses are becoming commonplace given the increasing use of species distribution modeling (Scott et al. 2002) and provide a potentially powerful method for overcoming the scale discrepancy between the regional population models with which proportional dependence is estimated and the more local scale at which subsidy values are needed.

Applications

Migratory Species and Spatial Subsidies as a Communication Tool

In a large and diverse country such as the United States, communicating the value of a given protected area can be challenging. For example, managers of parks and wilderness areas west of the Rocky Mountains need to demonstrate their value to decision makers located in the nation's capital, Washington, D.C. – more than 2,000 miles away – and to stakeholders from around the country. Previous work by natural resource economists has suggested that the value of wilderness be communicated in terms of on-site and off-site values (Loomis and Richardson 2001). On-site values are the benefits received or enjoyed locally, such as recreation, protection of fish and wildlife habitat, and increased revenues to local communities from visitor expenditures. The primary metrics of off-site values, to date, are improved downstream water quality and passive-use existence values to people who many never visit the area but derive satisfaction from knowing the area exists and is protected (e.g., Pate and Loomis 1997; Chichilnisky and Heal 1998; Bateman et al. 2006).

Downstream water-quality improvements are an effective way of demonstrating the *regional* benefits of protected areas – that is, benefits to downstream users – but may not communicate why more distant stakeholders should care about protecting wilderness. On the other hand, existence values do capture how distant stakeholders value wilderness but may be viewed by some as less convincing (Defries and Pagiola 2005). Our method of expressing the value of protected areas to distant people through *migration support* can communicate the value of protected areas, and it does so in a way that is quantitative and easily understandable. As such, it provides a valuable addition to the portfolio of tools used by managers and conservation advocates to articulate the value of wilderness.

Migratory Species and Spatial Subsidies as a Framework for Conservation Funding

As described earlier, protected areas can *subsidize* the delivery of ecosystem services in other locations. In an ideal world of abundant resources for conservation, this situation may be tenable. However, with the current reality of shrinking budgets for conservation, park managers and decision makers may want to convince the people who receive benefits from a migratory species to share in the cost of protecting the species' critical habitats in distant protected areas. Our method provides a way of identifying who is receiving benefits from migration support, quantifying the "value" of those benefits, and connecting them back to source areas via an equitable subsidy calculation. Resource managers could use the calculated subsidy values to guide how much people in a receiving location might pay to support conservation efforts in the protected area(s) supplying the subsidy.

This approach provides a quantitative means to assess the need for increased conservation for migratory species and the wilderness and protected areas that support them.

Payments to support conservation and land management efforts and protect ecosystem services have been termed "payments for ecosystem services," or PES. A wide and growing literature describes PES programs, the opportunities they present, the challenges of implementing them, and possible negative consequences of doing so (Engel et al. 2008; *The Economist* 2009; Norgaard 2010). These important issues must be addressed when considering PES. Most of these issues, however, are beyond the scope of this short communication – but we do address one particular concern that might arise in the United States when considering developing PES programs for protected areas that provide migration support services.

In the United States, wilderness and other protected areas are public lands – lands that are owned and set aside by local, state, or federal governments – and receive government funds for their management and protection. The issue of paying a management agency for protecting land that they are already charged with protecting arose in the Forest to Faucets Initiative where the Denver, Colorado, water utility is paying the U.S. Forest Service for erosion control and wildfire prevention activities in agency-owned forests above the city's water-supply reservoirs. Both the Forest Service and the city have argued that the funds are for *additional* actions specifically designed to protect and enhance the ecosystem service in question (Denver Water 2011).

Conclusion

In an era of concern over the numbers of visitors to wilderness and protected areas, park managers and other conservation advocates in the United States are examining new ways to express the value of protected areas and wilderness to decision makers and stakeholders. Here we present a new approach for accounting for the value of protected areas through migration support – the provision of habitat and resources to migratory species that in turn supply benefits to people in distant locations. We believe this approach provides an effective tool for communicating the value of protected areas, in particular to people and decision makers located far from the areas in question. In addition, this method could be used by decision makers to communicate the value of a migratory species and why protecting the species' critical habitats in distant wilderness and protected areas is important. Through a U.S. Geological Survey

Powell Center working group, the authors and colleagues are implementing this approach for three North American migratory species, as we refine and make the techniques more accessible. This approach provides a quantitative means to assess the need for increased conservation for migratory species and the wilderness and protected areas that support them.

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