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Short communication

Quantifying the relative contribution of an ecological reserve to conservation objectives

Kevin Aagaard[a,*], James E. Lyons[b], Wayne E. Thogmartin[a]

[a] U.S. Geological Survey, Upper Midwest Environmental Sciences Center, La Crosse, WI 54603, USA
[b] U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, MD 20708, USA

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ABSTRACT

Evaluating the role public lands play in meeting conservation goals is an essential step in good governance. We present a tool for comparing the regional contribution of each of a suite of wildlife management units to conservation goals. We use weighted summation (*simple additive weighting*) to compute a Unit Contribution Index (*UCI*) based on species richness, population abundance, and a conservation score based on IUCN Red List classified threat levels. We evaluate *UCI* for a subset of the 729 participating wetlands of the Integrated Waterbird Management and Monitoring (IWMM) Program across U.S. Fish and Wildlife Service Regions 3 (Midwest USA), 4 (Southeast USA), and 5 (Northeast USA). We found that the median across-Region *UCI* for Region 5 was greater than Regions 3 and 4, while Region 4 had the greatest within-Region *UCI* median. This index is a powerful tool for wildlife managers to evaluate the performance of units within the conservation estate.

1. Introduction

If one area of ecological conservation or preservation (e.g., a reserve) covers a large expanse and supports a wide variety of unique species, is it inherently more valuable than another reserve of smaller area that supports a fraction of the number of unique species? In terms of abundance of individuals and biodiversity provided, the larger reserve would likely be considered more valuable. Imagine, however, that the species supported at the larger reserve are all of low conservation concern and make use of many different habitats across the landscape. If the few species at the smaller reserve are each endangered and endemic to that reserve, then perhaps this smaller reserve is contributing a greater value than the large reserve in terms of helping to accomplish conservation objectives.

Valuation questions like these pervade ecological investigations (e.g., Pressey and Nicholls, 1989; Margules et al., 2002; Nicol et al., 2016) and are difficult to answer because of inherent subjectivity (Smith and Theberge, 1987). This subjectivity is critical, however (Millsap et al., 1990; Hunter et al., 1993). As long as the specific objectives and metrics of a study are clearly outlined, then other researchers and managers can replicate and change them as they deem necessary. This makes the subjectivity itself testable (Smith and Theberge, 1987; Hunter et al., 1993). Approaches to test subjectivity and quantify the value of landscape units to the networks they comprise have proliferated; for instance, using heterogeneity of habitat types offered by a unit (e.g., Willis et al., 2012), the biodiversity a unit supports (e.g., Humphries et al., 1995; Margules et al., 2002), ecosystem functionality (e.g., nutrient cycling, population dynamics) (e.g., Egoh et al., 2007; Nelson et al., 2009), or a monetary estimate of the services provided by a unit (e.g., ecosystem services, recreation/hunting, materials and

* Correspondence to: 2630 Fanta Reed Road, La Crosse, WI 54603, USA.
E-mail addresses: kaagaard@usgs.gov (K. Aagaard), jelyons@usgs.gov (J.E. Lyons), wthogmartin@usgs.gov (W.E. Thogmartin).

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resources) (Ricketts et al., 2004; Bottrill and Pressey, 2012). The approach selected can vary depending on the focus of the entity conducting the study, data availability, or conservation needs of an area (Nicol et al., 2016).

There are two principal objectives in conservation valuation. The first is to optimize reserve design, usually with the aim of conserving a given species (Pressey and Nicholls, 1989; Csuti et al., 1997; Thogmartin et al., 2014) or maximizing biodiversity (Humphries et al., 1995; Margules et al., 2002). Optimizing reserve design means valuing an area intrinsically using criteria like regional/global rarity of local habitat types, habitat diversity, size and extent of the area, vulnerability to human modification, and other criteria such as "naturalness" (Margules and Usher, 1981). This objective seeks to measure the properties of the area and extrapolate an expected conservation contribution from these properties, ultimately selecting the best areas to serve as a reserve network. In this case, the condition of an area (in terms of the criteria mentioned above) acts as a baseline against which expectations are measured. The second principal objective takes the inverse perspective; what is the value of a given area *relative to all other areas in the relevant conservation region*. This objective preserves some intrinsic properties (size, extent), but trades others (rarity, vulnerability) for emergent ecological properties (biodiversity supported, total abundance of individuals; Turpie, 1995). In this case, the individual contribution by a given area to the larger region is compared to the contribution to the larger region by all other areas. Rather than creating an optimal reserve design, this perspective seeks to identify how to optimize resource allocation to an already existing reserve network to improve performance of flagging areas while maintaining performance of high-quality areas (Smith and Theberge, 1987). In essence, the first perspective is a forecast and the second perspective offers a snapshot in time.

Our goal matches the second perspective, to take a snapshot in time of an actively surveyed reserve network of wetlands used by migratory waterbirds (waterfowl, shorebirds, wading birds). Migratory waterbird habitat has received significant management focus, largely attributable to the role of waterbirds in recreational harvest (Raftovich and Wilkins, 2013). The scope of waterbird migration across North America highlights the importance of establishing a framework to identify areas that most positively contribute to waterbird conservation to inform management decisions aimed at allocating scarce resources. Of course, waterbird migration is not bounded by political borders, so while we demonstrate the functionality of the valuation framework we describe below by using data from a North American monitoring program, our framework is easily applied to any area included in the global movement of waterbird populations with sufficient data.

We formulate a metric to quantify the contribution of each unit participating in the Integrated Waterbird Management and Monitoring (IWMM) Program to the migratory waterbird conservation efforts of the US Fish and Wildlife Service's (USFWS) Midwest, Southeast, and Northeast Regions (Regions 3, 4, and 5, respectively; see Fig. 1). Because our focus is on conservation, we will adopt a framework in which "value" and "contributions" are in terms of biodiversity and species status (e.g., threatened, endangered, not listed, etc.). Additionally, given the data available, we are interested in formulating a metric that relates unit contributions to waterbird conservation for use by unit managers. This focus is germane to the conservation needs of the IWMM, wetland managers, and the USFWS in general—which has identified waterbirds as a focal guild in part because of their large economic and ecological influence in the area of interest (Eastern USA). The method we employ is known as *weighted summation* or *simple additive weighting* in the multi-criteria evaluation literature and is becoming increasingly used in conservation decision making (Margules and Usher, 1981; Smith and Theberge, 1987; Ananda and Herath, 2009; Nelson et al., 2009).

2. Methods

The IWMM is collaborative, involving multiple government and non-government agencies seeking to identify optimal conservation and management actions across a large spatial scale to provide sufficient habitat for migratory waterbirds during the non-breeding period of their annual cycles. The IWMM provides tools to aid with decision support for management officials. The core of the program is its large-scale monitoring program which includes bird and vegetation surveys with a rigorous protocol aimed at standardizing the observation process across regions. Additionally, there are now well-vetted and robust techniques for IWMM data-handling (Link et al., 2008; Aagaard et al., 2015, submitted for publication). This has provided us with a quality dataset and a rigorous methodology for accounting for variable effort and multiple sources of error that no amount of protocol standardization can eliminate.

The IWMM has established 165 survey sites comprised of 729 wetlands (henceforth, "units") in USFWS Regions 3, 4, and 5, each under a unique management authority participating in frequent and recurring waterbird management actions. The 694 units included in this study (inclusion criteria explained below) have a mean area ($\pm$s.d.) of 101.17 ha ($\pm$310.72), with a range of 0.26–5015.71 ha. Over 166,000 observations were collected during the pilot phase of the IWMM between 25 January 2010 and 11 July 2014.

We evaluated USFWS focal guilds (waterfowl, shorebirds, wading birds) during the non-breeding period (i.e., excluding June) in USFWS Regions 3, 4, and 5. We removed observations with start times before 05:00 and after 19:00, as these were assumed to be data entry errors. We also excluded units with only one observation or only one species recorded, as these units either precluded bird-use-day calculations (which require multiple samples, see below), or produced superfluous biodiversity metrics. This resulted in a dataset with 131,412 observations. In total, we used data from 21,309 bird surveys and 3747 vegetation surveys.

Because units differ in size, and surveys differ in the date and location in which they occurred, we corrected the data for various sources of potential error. The corrected-counts were converted to a more meaningful management value, bird-use-days. For the error correction we employed the modeling framework proposed by Link et al. (2008) in which variation in observations is partitioned into spatial, temporal, and observational effects, and an effort-effect parameter is used to yield an effort-corrected abundance count via a hierarchical mixed-effects linear model. The original model was applied to Audubon Christmas Bird Count and Breeding Bird Survey data, and included effects for strata, circles/routes, observers, year, and an effort effect (which includes survey length) (Link et al., 2008). The analogous categories for the IWMM are region, unit, observers, year, and effort, respectively. Effort is estimated by assuming that the traditional effort correction (length of a survey divided by the average length of all surveys) is a normally distributed parameter. This model was formulated in Stan (v. 2.10.0, Stan Development Team, 2015; Carpenter et al., 2016) through R (v. 3.3.1, R Core Team, 2016) via 'rstan'. Details of the model, including model structure and parameter distributions, can be found in Aagaard et al. (submitted for publication).

Next, we calculated bird-use-day (BUD) estimates for each unit. This calculation is based on the area-under-the-curve method (Millar et al., 2012). For each pair of successive surveys, the average count from two surveys is calculated and multiplied by the difference in days between the surveys. The final values for the unit are summed to produce the bird-use-day estimate for the season. We also computed bird-use-days per hectare and bird-use-days per hectare of open water, for equivalence across units.

The contribution of each unit to the Region within which it resides was calculated to quantify the value of a unit relative to all other units within each Region (henceforth, unit contribution index, *UCI*). *UCI* was defined as the sum of the total *BUDs*, species richness (*R*), and species-conservation score (*SCS*) for each unit, *i*, divided by the maxima of all units within a Region. In this way all three components are on the same scale (0–1). Setting the weights (w_i) such that they sum to 1, the maximum possible *UCI* is therefore also 1:

$$UCI_{Reg} = w_1\left(\frac{BUDs_i}{\max(BUDs_{Reg})}\right) + w_2\left(\frac{R_i}{\max(R_{Reg})}\right) + w_3\left(\frac{SCS_i}{\max(SCS_{Reg})}\right).$$

The indexed value of each unique species' IUCN threat level was assigned on a scale from 0 (not listed) to 5 (Critically Endangered). Scores of 1 through 4 correspond to Least Concern, Near Threatened, Vulnerable, and Endangered, respectively (see Appendix I). The *SCS* represents the sum of the indexed IUCN Red List (IUCN 2001) threat level for all species represented in a unit, divided by the maximum possible IUCN Red List threat level sum for a unit with that many species. For example, a unit that supports 32 species could have a maximum IUCN Red List threat level sum of 46 (the 32 most threatened species represented in the data have an indexed threat level status sum of 46). If that unit's realized sum is 35, it has a $SCS = \frac{35}{46} = \sim 0.76$.

This process was repeated for all units *across* Regions, such that

$$UCI_{Tot} = w_1\left(\frac{BUDs_i}{\max(BUDs_{Tot})}\right) + w_2\left(\frac{R_i}{\max(R_{Tot})}\right) + w_3\left(\frac{SCS_i}{\max(SCS_{Tot})}\right).$$

After applying this equation to the data we performed *post hoc* diagnostic analyses to evaluate the output. First, we assessed the correlation of the final *UCI* score with each of the components to identify the strength of the relationships. Second, we performed a sensitivity analysis on the weighting scheme for the formulation to identify the effect each component's weight on the overall *UCI* score produced. Details of these analyses are presented in Appendices II and III of the Supporting Information.

3. Results

The unit-specific contribution to migratory waterbirds across Regions ranged from 0.02 to 0.67, with a mean of 0.36 (sd = 0.12) (Fig. 2). When scaled to identify the relative contribution of each unit compared to all units $\left(\frac{UCI_i}{\sum UCI}\right)$, the mean was 0.0015 (sd = 0.0005), indicating that the average unit contributes 0.15% to the total value for migratory waterbird conservation (in terms of species diversity, abundance, and conservation status).

The mean (±sd) across-Region *UCI*s were 0.32 (±0.12, Region 3), 0.36 (±0.09, Region 4), and 0.40 (±0.12, Region 5) (Fig. 2). These mean (±sd) values increased when calculating the *within*-Region *UCI*s for Regions 3 and 4: 0.37 (±0.14, Region 3), 0.41 (±0.13, Region 4), but decreased for Region 5: 0.34 (±0.14).

Despite the equal weighting and additive nature of our equation, some components were more highly correlated with *UCI* than others. The correlation coefficients among across-Regions *UCI*, and Richness, ln(*BUD* s), and *SCS* were 0.87, 0.69, and 0.87, respectively (see Appendix II).

$\overline{UCI}$ was relatively robust to changes in the weighting schemes for *BUDs* and SCS, with both components demonstrating slight increases in $\overline{UCI}$ with increasing weight (see Appendix III, Figure S1). Changing the weight for species Richness, however, resulted in a more substantial (and negative) modification of $\overline{UCI}$ (Figure S1). This is explained by the density plots of the normalized values for each of the components (Figure S2). There was only marginal difference in these results between the within-Regions and across-Regions settings (Figure S1).

4. Discussion

We have demonstrated a tool to identify the value that a given area contributes to the larger landscape matrix for a particular conservation objective, in this case migratory waterbird management. Coupled with the broad-scale IWMM

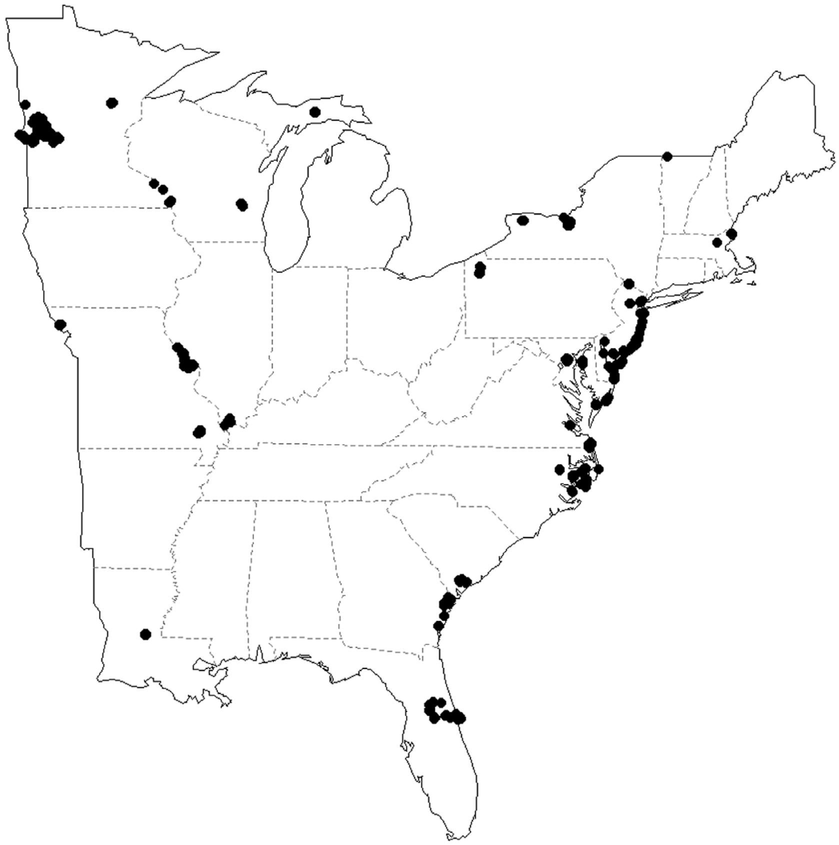

Fig. 1. Map of the Integrated Waterbird Management and Monitoring Program participating units.

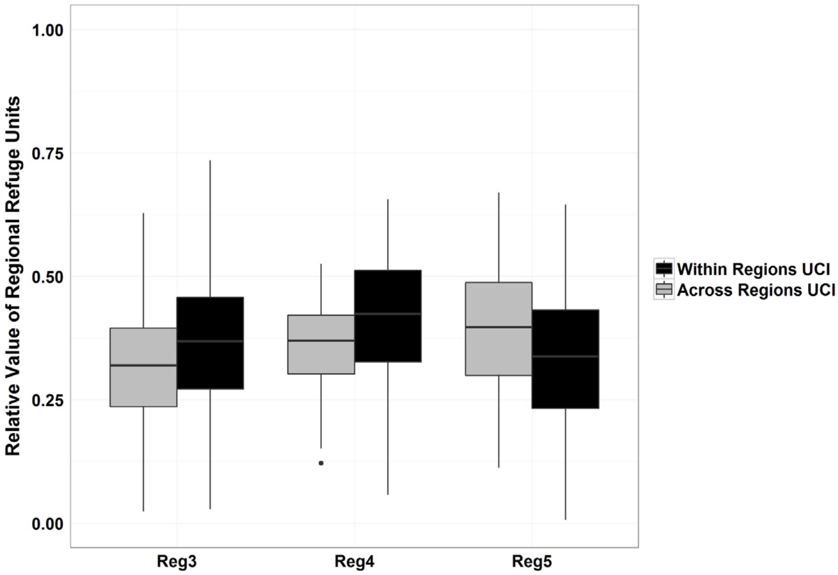

Fig. 2. Relative contribution to waterbird conservation, in terms of species diversity, abundance, and conservation status of each participating unit within the Integrated Waterbird Management and Monitoring program, *within* (black boxes) and *across* (gray boxes) Regions.

Program, we hope that this tool will prove to be of great value to wildlife management officials. The utilities of this tool are to simplify the comparison of the conservation efficiency of disparate units, and to identify the effectiveness of management actions and conservation interventions by comparing the before-and-after *UCI* of the unit of interest, a critical need in wildlife conservation (Bottrill and Pressey, 2012).

We include weights (w_i) for each component of *UCI* for flexibility, allowing managers to set their own weighting schemes dependent upon specific priorities at units or within Regions. The results of our sensitivity analysis suggest that our formulation is robust to changes in the weighting scheme using this dataset, but this result may not hold for other datasets. Therefore, we suggest that practitioners replicate the sensitivity analysis we applied to consider multiple weighting schemes that would accomplish a variety of conservation goals (e.g., optimize biodiversity, or maximize productivity in terms of *BUDs*).

Across weighting schemes we identified unequal relationships between *UCI* and its three constituent components, both within- and across-Regions. Species richness and *SCS* were highly correlated with *UCI* scores in both settings, while the correlation with *BUDs* was also strong, but less so than with the other two components.

A final comment on the criteria applied in our formulation: we used the IUCN Red List to quantify the *SCS* metric because of its status as a globally recognized framework for establishing the degree of conservation concern associated with a species. This global perspective is appealing in that it allows for rapid implementation of our approach in systems across the world. However, if the majority of the species in the record have an IUCN Red List value of 1 (Least Concern; as is the case with the IWMM data), then units supporting any of the few species with values of 2 or above are going to receive (perhaps disproportionately) higher *SCS* scores. For this reason, it might be prudent for managers to use a more locally relevant source for establishing *SCS*. Any such source will need to capture the full breadth of species recorded in the dataset to be useful, however. Possible sources include prioritized lists of species of conservation concern compiled by Joint Ventures, or the Birds of Conservation Concern compiled by the USFWS. Alternatively, a quantification of species conservation status tailored to a target system could be achieved via a structured decision making framework (e.g., Gregory et al., 2012), in which expert opinion informs the relative conservation importance of species recorded in surveys. We suggest that the IUCN Red List serves as a useful surrogate in the absence of such a complete source or SDM framework.

It is critical to note that the framework we have presented here is strictly focused on the contribution of a given unit to the conservation efforts *for migratory waterbirds only*. We are not suggesting that the scores associated with units represents the comprehensive conservation contribution of that unit. Instead, we view this as one of a number of criteria that can be used to determine this comprehensive measure, as in Smith and Theberge (1987), who advocate for logical collections of criteria used in concert in a set of evaluations that can encapsulate objectives relating to "ecological, cultural, or human use and management criteria", and can aid in clarifying the ramifications of available decisions (Smith and Theberge, 1987). Combining the *UCI* score with criteria relating to, for example, habitat connectivity, energetic productivity, or resilience to climate change would ultimately lead to a robust quantification of the total value of a unit to broader conservation goals.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at http://dx.doi.org/10.1016/j.gecco.2017.01.002.

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