Assessing Ecological Integrity of Wetlands From National to Local Scales: Exploring the Predictive Power, and Limitations, of Spatial Models

Providing decisionmakers with good information on wetland health across spatial scales is a challenging endeavor. The authors discuss a multi-leveled model that provides remote, rapid, and intensive site assessment data as a complementary element to ongoing probability-based sampling efforts nationally.

By Patrick Comer and Don Faber-Langendoen

Wetland conservation demands approaches to inventory, assessment, and monitoring that span a range of spatial scales, from national to watershed to local sites. At national scales, we need to document trends in wetland extent, ecosystem services (e.g., floodplain storage capacities), and ecological integrity, or condition (Scozzafava 2009) to measure progress of regulatory regimes and inform national conservation investments. Watershed planners utilize information on the type and condition of wetlands in order to prioritize sites for protection, contribute to wildlife habitat goals, and direct development to minimize conflict. At local scales, decisions regarding on-site actions (e.g., dredge/fill permitting, water quality management), and preservation or restoration require detailed information on particular wetlands. Across these scales, information on wetland type, location, function, and ecological integrity is needed for decisionmaking. Our task is to ensure that the right information is available across these scales to support good decisions. Here, we focus on providing information on the ecological integrity of wetlands, and explore the relative utility of a new national map of landscape integrity for wetland assessments.

Ecological Integrity Assessment Framework

"Integrity" is the quality of being unimpaired, sound, or complete. Many land use decisions affect wetland integrity, such as through altered hydrology or the introduction of invasive species. When we classify, describe, and map wetlands, we build the foundation for conceptual ecological models that state assumptions about ecosystem composition, structure, and functions and its response to human stressors.

Ecological Integrity Assessment frameworks (Young & Sanzone 2002; Parrish et al. 2003) translate these conceptual models into a set of cost-effective indicators of "very high" to "very low" wetland integrity. This follows the same logic of indices of biotic integrity that have been developed for lakes and streams (Karr & Chu 1999; Hawkins 2006). When choosing indicators, preference is given to *condition indicators*, that is, measures of inherent ecosystem characteristics, and which are sensitive to levels of stress. However, it is often more feasible to measure a *stressor indicator*. For example, where native species composition is difficult to measure directly, stressor indicators may be relied upon, such as evidence of hydrologic alteration or relative naturalness of the buffer (Trombulak & Frissel 1999; Mack 2006).

Increasingly, a multi-leveled structure is used to assess ecological integrity within and across multiple wetland sites. Under NatureServe's framework, Level 1 (Remote Assessment) relies primarily on remote sensing and indicators of landscape integrity affecting wetlands. Map inputs include land cover or land use. Level 2 (Rapid Assessment) involves relatively simple indicators easily observed in the field; sometimes these occur in the form of checklists. Indicators may address both stressors (e.g., ditching, road crossings, and pollutant inputs) and condition (e.g., hydrologic connectivity, relative cover of native plant species). Level 3 (Intensive Assessment) requires detailed field measurements and a statistically rigorous sample design. For example, a rapid, field-based metric of composition may be "Relative Total Cover of Native Plant Species" and measured by estimating cover of native species versus exotics in a systematic walk-through of the wetland. An intensive, field-based indicator for this might require a series of vegetation sample plots in which cover of each species is individually measured. Intensive sampling is costly, so this level of measurement is limited to a relative few "reference sites."

National Map of Landscape Integrity

Landscape integrity assessments apply principles of landscape ecology with mapped information to characterize ecological integrity (U.S. EPA 2001; Sanderson et al. 2002). Information on human land use and land cover is increasingly available in detailed mapped form, and they can be used to spatially model inferences about ecological integrity.

The NatureServe Landscape Integrity Model provides a Level 1 index of integrity. It builds on the growing body of published methods for spatially based ecological effects assessment across landscapes (Theobald 2001; Seiler 2001; Sanderson et al. 2002; Riitters & Wickham 2003; Brown & Vivas 2005; Hansen 2005; Leu et al. 2008; Falcone et al. 2010). The model uses nationally available spatial data to transparently express user knowledge regarding the relative effects of land uses on natural habitats (Figure 1). The authors' expert knowledge informed stressor selection and weightings, and was combined with numerous examples from the published literature to parameterize the model for application across the conterminous United States

(Table 1). This approach to spatial modeling enables users to express assumptions at the site (pixel) level about the relative ecological effect that each land use type has (Site Impact Score) and the potential effect as it diminishes with distance from the site (Decay Score). The resulting index combines the scores of all input layers and their per-pixel values. A variety of independent data sets, including field observations, existing maps, and expert evaluation of high-resolution imagery, were then used to validate the national model.

Evaluating the National Landscape Integrity Model

A recent effort to establish reference sites for wetland trends assessment (Faber-Langendoen et al. 2012) provides an opportunity to illustrate the strengths and limitations of the national landscape integrity map. A set of Levels 1-3 indicators for wetland assessment is provided in Table 2. Local-scale remote imagery and field visits provided ratings for the indicators at 277 sites in southern Michigan and northern Indiana. The landscape integrity map was overlain on site maps to generate L1 ratings and compare with L2 ratings (example site in Figure 2).

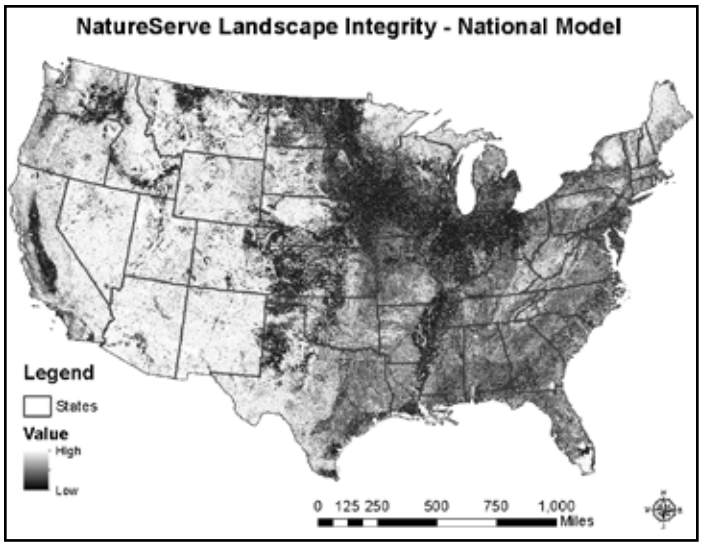

Figure 1 (above): NatureServe national landscape integrity map, which is a 90-meter-pixel resolution continuous surface with values between 0.0 (very low integrity) and 1.0 (very high integrity).
Table 1 (below): Inputs and parameters used for the NatureServe Landscape Integrity Model.

Discussion

The national landscape integrity model provides a useful complement to the probability-based sample approach being implemented by the U.S. Environmental Protection Agency for reporting on national wetland condition (Scozzafava 2009). Through map overlays, the model provides a rapid, census-based approach to indicate patterns of integrity across all wetlands. Results may also be reported by wetland type, watershed, or other geographic units. Since it uses widely available spatial data on land use/land cover, it will be periodically updated at minimal cost. Ideally, a national system of intensively sampled reference locations is complemented by many sites with rapid field assessments. Knowledge from this network would support advancement of robust spatial models, such as this landscape integrity model, to facilitate reporting on the integrity of all of the nation's wetlands. ■

Theme	Site Impact Score	Presumed Relative Stress	Decay Score	Impact Approaches Negligible
Transportation				
Dirt roads, 4-wheel drive	0.7	Low	0.5	200m
Local and connecting roads	0.5	Medium	0.5	200m
Secondary and connecting roads	0.2	High	0.2	500m
Primary highways with limited access	0.05	Very High	0.1	1,000m
Primary highways without limited access	0.05	Very High	0.05	2,000m
Urban and Industrial Development				
Low-Density Development	0.6	Medium	0.5	200m
Medium-Density Development	0.5	Medium	0.5	200m
Powerline/Transmission lines	0.5	Medium	0.9	100m
Oil/Gas Wells	0.5	Medium	0.2	500m
High-Density Development	0.05	Very High	0.05	2,000m
Mines	0.05	Very High	0.2	500m
Managed and Modified Land Cover				
Ruderal Forest & Old Field	0.9	Very Low	1	0m
Native Vegetation w/Introduced Species	0.9	Very Low	1	0m
Recently Logged	0.9	Very Low	0.5	200m
Managed Tree Plantations	0.8	Low	0.5	200m
Introduced Tree & Shrub	0.5	Medium	0.5	200m
Introduced Upland Grass & Forb	0.5	Medium	0.5	200m
Introduced Wetland	0.3	High	0.8	125m
Cultivated Agriculture	0.3	High	0.5	200m

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Major Ecological Factor	Indicator	Condition (C) vs. Stressor (S) Indicator	Indicator Level 1 – remote 2 – rapid field 3 – intensive field
Landscape	Landscape Connectivity	C	1
	Buffer Index	C	1, 2
	Surrounding Land Use Index	S	1
	Relative Patch Size	C	1
	Landscape Stressor Checklist	S	1, 2
Vegetation	Vegetation Structure	C	1, 2, 3
	Woody Regeneration	C	2, 3
	Vegetation Composition	C	2, 3
	Native Plant Species Cover	C	2, 3
	Invasive Plant Species Cover	S	2, 3
	Vegetation Stressor Checklist	S	2, 3
Hydrology	Water Source	C	1, 2
	Hydroperiod	C	2
	Hydrologic Connectivity	C	1, 2
	Hydrology Stressor Checklist	S	1, 2
Soils (Physico-Chemical)	Physical Patch Types	C	1, 2
	Soil Condition	C	2, 3
	Physicochemistry Stressor Checklist	S	3

Table 2: Wetland indicators used in reference sites (Faber-Langendoen et al. 2012).

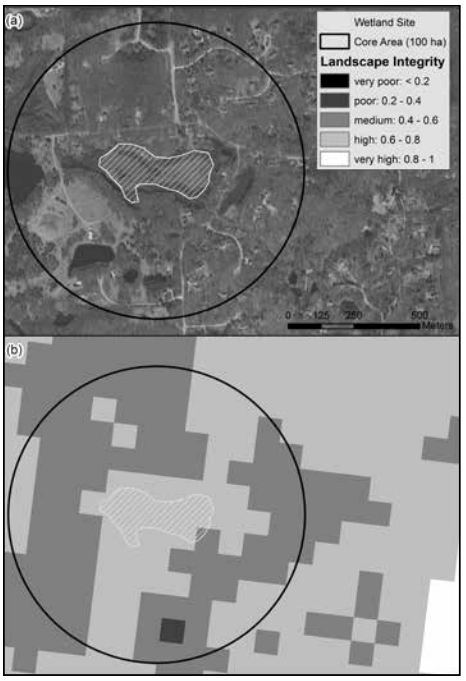

Figure 2: (a) Example reference wetland location with a circular one-kilometer-square core area used for Level 1 indicator measurement, along with (b) the national landscape integrity model for the same area, and generalized to five categories for display only. The Landscape Integrity score for the Core Area = 0.58 (medium). On-site rapid assessment rating (vegetation, hydrology, soils) = B (medium).

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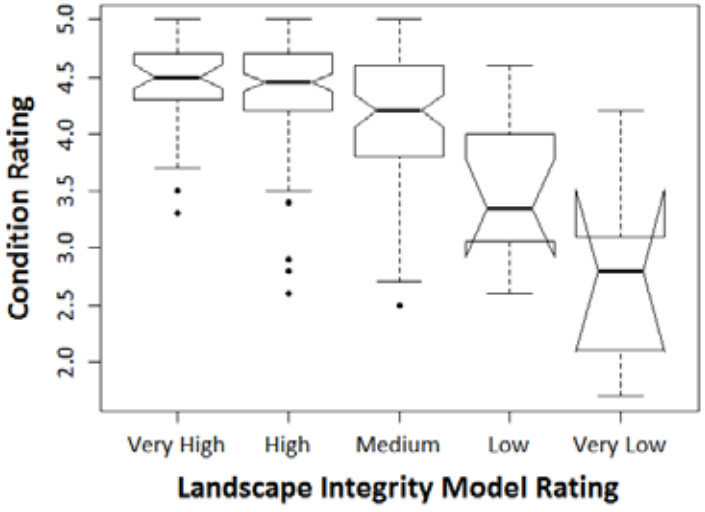

Figure 3: Statistical comparison of scores for the landscape integrity model with results from the Level 2 rapid field assessment indicators across 277 sites. From these samples, the national landscape integrity map distinguishes three levels of ecological integrity (Very High and High (4-5 points versus Medium 3-4 points versus Low and Very Low 0-3 points) as compared to the four levels (2-5) distinguished by field visits. The "box-and-whisker" diagram indicates median values (horizontal line), upper and lower quartiles (box), maximum and minimum values ("whisker" horizontals) and outliers (circles) for all 277 samples. Where angled portions of adjacent boxes overlap, no statistically significant difference exists. Kruskal-Wallis F = 32.6, p < 0.001. VL= L< M< H =VH.