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The ecological condition of geographically isolated wetlands in the southeastern United States: The relationship between landscape level assessments and macrophyte assemblages

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ABSTRACT

Geographically isolated wetlands (GIWs) are common features of the Dougherty Plain physiographic region in southwestern Georgia. Due to lack of protection at the state and federal levels, these wetlands are threatened by intensive agricultural and silvicultural land uses common in the region. Recently, the ecological condition of such GIWs was assessed for the southeastern United States using the Landscape Development Intensity Index (LDI), a practical assessment tool that relies on remotely sensed land use and land cover (LULC) data surrounding isolated wetlands to rapidly predict wetland condition. However, no assessments have been attempted for GIWs in the Dougherty Plain specifically. Our goal was to develop a framework to guide and refine remote assessment of wetland condition within this agriculturally intense region of the southeastern USA. In this study, we characterized human disturbances associated with isolated wetlands in the Dougherty Plain, and paired the rapid assessment of GIWs using LDI with an intensive assessment of wetland plant communities. Specifically, we: (1) examined how macrophyte assemblages and vegetation metrics vary across a human disturbance gradient in the Dougherty Plain; (2) compared multiple condition assessment outcomes using variations of the LDI method that differed in spatial extent and resolution of LULC categories; and (3) determined the predicted condition of GIWs in the Dougherty Plain as indexed by LDI and compared with region-wide assessments of GIWs of the southeastern USA. Generally, the relationship between wetland plant communities and surrounding land use supported the assumptions of the LDI index in that wetlands surrounded by agricultural land use classes featured distinct plant communities relative to those surrounded by forested land use classes. Our results indicated that finer spatial resolution of LULC data improved the predictive ability of LDI. However, based on incongruence between wetland vegetation composition and LDI scores in some forested landscapes, this study identified limitations of the LDI assessment method, particularly when applied in regions in which prescribed fire is an important ecological driver of vegetation and habitat. Thus, we conclude that LDI may be biased toward an overestimation of reference condition GIWs, even though the habitat may be functionally degraded by the absence of natural processes such as fire. Regardless, relative to the assessment of the entire southeastern US, a greater proportion of total GIWs of the Dougherty Plain were identified as impaired due to the intensity of irrigated agricultural land use.

1. Introduction

Anthropogenic activities have direct, secondary or cumulative impacts on biological, chemical and physical processes of adjacent communities. The linkages between upland disturbances and altered ecological processes are of particular interest in wetlands, given the landscape position of wetlands relative to adjacent terrestrial environments (Ehrenfeld, 1983; Findlay and Houlahan,

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1997; Houlahan et al., 2006). A growing body of evidence indicates that geographically isolated wetlands (GIWs), those wetlands completely surrounded by uplands (Tiner, 2003b), often have distinctive ecological functions relative to the functional roles of riparian wetlands in terms of unique habitat provision (Golladay et al., 1997; Kirkman et al., 1999; Smith et al., 2006; Sutter and Kral, 1994), water storage and flood reduction (De Steven and Lowrance, 2011; Lane and D'Amico, 2010; Leibowitz, 2003), and nutrient processing (Cohen et al., 2008; Neely and Baker, 1989; Whigham and Jordan, 2003), in addition to effects on downstream conditions through episodic surface flow connections similar to headwater streams (Cohen and Brown, 2007; Leibowitz, 2003; Nadeau and Rains, 2007). Coupled with their landscape position, the smaller size and seasonal patterns of dry down are characteristics of GIWs that render them particularly vulnerable to land use perturbations. While few studies have examined linkages between human disturbances and ecological functions of GIWs by direct quantification of changes in rates of processes (Cohen et al., 2007; McLaughlin and Cohen, 2013), various metrics derived from land use/land cover (LULC) have been developed to represent human disturbance gradients that are correlated with field-based measures of biota and physical attributes. In turn, these metrics have been used to infer the degree or capacity to which certain functions are being performed (Abbruzzese and Leibowitz, 1997; Brown and Vivas, 2005; Hychka et al., 2007).

Correlative relationships between the percentage of disturbed land cover classes and community structure have been used to estimate the degree of disruption of biological integrity of community complexes (DeKeyser et al., 2009; Houlahan et al., 2006; Lopez and Fennessy, 2002; Reiss and Brown, 2007). One such widely applied index, used to estimate the expected condition of isolated wetlands based on the LULC surrounding a wetland, is the Landscape Development Intensity Index (LDI). This metric is based on the amount of nonrenewable energies (e.g., electricity, fuels, pesticides, or irrigation) required to maintain each land use, weighted by the proportional area of each land use class within an annulus (a buffer area surrounding a wetland, but excluding the wetland itself; Brown and Vivas, 2005). This metric does not directly measure specific drivers of change in wetland integrity; rather it indexes the cumulative anthropogenic impacts. Application of this measure in numerous case studies has demonstrated correlation with pollutant loads, field-based biotic assessments, and elevated nutrient levels (Chen and Lin, 2011; Cohen et al., 2008; Lane and Brown, 2007; Mack, 2006; Reiss et al., 2009; Reiss and Brown, 2005). Such quantifiable human disturbance gradients also permit cross-regional comparisons of ecological condition. Because these assessments can be made with readily available LULC data (e.g., National Land Cover Database for the USA), they are considered a potentially viable rapid assessment tool.

The efficacy of such remote assessment tools depends on the type of wetland as well as topography, physiography, and spatial extent of the site under investigation (Cohen et al., 2004; Lane et al., 2003; Mack, 2006; Stein et al., 2009). The degree to which a LULC-based metric can represent a local or regional human disturbance gradient is also partially dependent on the spatial resolution of the available data and the coarseness of the defined land use classes. Furthermore, some classification schemes may group together land uses that have differing effects on wetlands, thereby masking differences. For example, irrigated agriculture often leads to complete clearing of the wetland interior to permit free movement of center pivot irrigation equipment whereas dryland agriculture may result in cultivation around GIWs without direct alterations to the soil and vegetation within the wetlands (Martin et al., 2013). Finally, other major drivers of wetland community composition, such as fire in the southeast (Kirkman et al., 2000), are not incorporated into these LULC-based assessments. Interpreting such LULC-based metrics as an assessment of biotic integrity of isolated wetlands requires an understanding of the wetland community response to a gradient of disturbance as well as knowledge of the extent and impact of land cover (e.g., within wetland, surrounding buffer land cover, wetland complexes within a broader land use context), and other regionally important drivers of wetland communities (Boughton et al., 2010; De Steven and Toner, 2004; Galatowitsch et al., 2000; Lopez and Fennessy, 2002; Stapanian et al., 2013). In some instances, observed relationships between LULC-based estimates of anthropogenic impact and direct measures of wetland biological integrity demonstrate a wide range of variability or overlap (Lane et al., 2003; Reiss and Brown, 2005). Thus, LULC-based assessments such as LDI, though a consistently reliable tool for identifying impaired wetlands, may not be an appropriate tool for making finer-scale predictions about biological integrity (e.g., identifying reference wetlands, or determining degree of biological impairment).

Our goal is to develop a framework to guide and refine remote assessment of wetland condition within an agriculturally intense region of the southeastern USA. As an initial step toward this goal, we characterized human disturbances and associated shifts in macrophyte communities of isolated wetlands in the Dougherty Plain, a karst physiographic region of Georgia. We focused on macrophytes as biological indicators of disturbance because within GIWs they have been shown to be correlated with other biological indicators (e.g., diatom assemblages; Reiss and Brown, 2005) as well as some wetland functions (secondary productivity; Entrekin et al., 2001), and they reflect changes along physical (Kirkman et al., 2000), chemical (Lane et al., 2003), and hydrologic gradients (Kirkman et al., 2000). Specifically, in this study we: (1) examined how macrophyte assemblages and vegetation metrics vary across a human disturbance gradient in the Dougherty Plain; (2) compared multiple condition assessment outcomes using variations of the LDI method that differed in spatial extent and resolution of LULC categories; and (3) determined the predicted condition of GIWs in the Dougherty Plain as indexed by LDI and compared this with a region-wide assessment of GIWs of the southeastern USA.

2. Methods

2.1. Study area

The study was conducted in the Dougherty Plain, a physiogeographic subregion of the Coastal Plain characterized by karst topography (Beck and Arden, 1983), which covers approximately 6690 km^2 in southwestern Georgia (Fig. 1). Geographically isolated limesink wetlands are common in the landscape with an average density of 1.7 per km^2 (Hendricks and Goodwin, 1952; Martin et al., 2012; Tiner, 2003a). Historically, the Dougherty Plain was dominated by fire-maintained longleaf pine-wiregrass (*Pinus palustris* Mill.-*Aristida beyrichiana* Trin. & Rupr.) savannas with a highly diverse ground cover in both the upland and wetlands (Drew et al., 1998; Engstrom et al., 2001; Walker, 1993). Today, intensive agriculture, both in the form of commercial pine plantations and irrigated row-crops, exerts a strong influence on the landscape of the region (Couch et al., 1996; Martin et al., 2013; Turner and Rushcer, 1988). However, natural forested lands are also a common land cover type (Martin et al., 2013; Turner and Rushcer, 1988).

2.2. Wetland selection and delineation

A subsample of individual wetlands was identified across the study area using recent (2010) aerial photography from the National Agriculture Imagery Program (NAIP) and a map developed by Martin et al. (2012) that predicts the location and extent of isolated wetlands throughout the Dougherty Plain. We selected