5.7 Remote Sensing- and GIS-Facilitated Biological Monitoring of DRIWR Wetlands

Introduction

Applications of remote sensing and geographic information systems (GIS) for environmental monitoring and decision support systems to assist environmental managers are increasingly expanding. Mapping habitat characteristics at the landscape level can provide managers with a useful tool for monitoring environmental change, such as the spread and control of invasive plant species, especially over large regions or in difficult to access areas. In addition to directly detecting changes in plant communities, remote sensing can be used to quantify and map ecosystem services that are linked with specific plant communities. Here we describe an ongoing study using hyperspectral remote sensing and biological monitoring of coastal wetland ecosystems in the Detroit River International Wildlife Refuge (DRIWR) to assess the spread and control of invasive species and the impacts of these changes in plant communities on wetland ecosystem services. First, we describe temporal and spatial biological monitoring of wetland communities. We then provide an example of how these data can be integrated with remotely-sensed imagery to quantify effects of an invasive plant, *Phragmites australis*, on ecosystem services and discuss future applications of this approach.

Linking biological monitoring and remote sensing is potentially a powerful tool for scaling up measurements of ecosystem services and assessing impacts of invasive species. Ecosystem services refer to various components of ecosystem structure and function that support, provide, or regulate ecological processes and biota considered valuable to humans or the maintenance of intact natural systems. For example, common ecosystem services attributed to coastal wetlands include biodiversity support, regulation of flooding and erosion, sediment and nutrient uptake, water purification, and nutrient cycling. Wetlands may also play an important role in carbon storage, because of high plant productivity and low rates of decomposition in saturated soils. However, these saturated soils can result in carbon (C) release to the atmosphere in the form of methane gas, a greenhouse gas that is 21 times more potent than CO₂. The specific services provided by a given wetland and the balance of C storage and release depend on a number of factors, including anthropogenic impacts. Ecologists typically measure ecosystem services at the plot level. While this approach is useful for comparing services among different treatments or vegetation types, determining the degree to which a given wetland provides specific services requires scaling up to the landscape level.

Biological Monitoring

In an ongoing project at the DRIWR, we are combining biological monitoring with GIS and remote sensing to better understand how the spread of *Phragmites australis* and its management are impacting ecosystem services. Monitoring occurred at two spatial scales: transect studies covered large spatial scales and a wide range of plant communities, and intensive monitoring was carried out at the plot-level to compare sites with and without *Phragmites*. 
Transect monitoring
Vegetation/soil transects were established in thirteen DRIWR management units. Data were collected for 22 transects, including the start and end of wetland plant communities, basic soil diagnostics at selected points, digital photography, and GPS ground control. Each transect was plotted to bisect plant communities of interest, particularly wetlands infested to varying degrees with *Phragmites*, but also included non-invaded landscapes for comparison. Certain transects were located in the vicinity of the intensively sampled plots, though care was taken not to trample or otherwise interfere with these experiments. Our intent was to use the transects as a means of linking intensive sample plot data to a more spatially-extensive scale via assumptions of similarity between plant community and soil type. Also, the transects allow us to monitor changes in plant community boundaries over time, including the documentation of the effects of treatment and control of invasive species. Finally, each transect serves as a source of ground truth for the calibration of remote sensing image analyses. Future research will demonstrate the results and use of transect data. This presentation focuses on the integration of hyperspectral remote sensing imagery with the intensive sample plots.

Intensively-sampled plots
Many of the measurements required to monitor ecosystem services are time consuming and/or require repeated sampling throughout the year. We therefore conducted plot-level studies in areas with and without *Phragmites* to quantify ecosystem services related to biodiversity support, nutrient cycling, and carbon storage. We used a before-after, control-impact (BACI) design, taking measurements for one year before one set of plots was treated with herbicide (and later burned). We measured a number of water, plant, and soil characteristics to allow us to assess shifts in ecosystem services with changes in plant community, either through invasion or removal. Water quality measurements were taken throughout the ice-free season to capture seasonal changes and inter-annual variability. These measurements included pH, conductivity, dissolved nutrients (nitrogen in ammonium and nitrate and soluble reactive phosphorus), organic carbon, CO$_2$ and methane. Other measurements, such as water depth and soil moisture, were also regularly monitored. Once each year we identified all plant species in our plots and measured annual biomass production. We also analyzed above ground vegetation to determine the quantity of carbon, nitrogen, and phosphorus sequestered in plant material each year. Soils provide a number of critical ecosystem services, and while direct sensing of soils remotely is difficult, soil processes are closely linked with plant communities. We measured several soil characteristics, including pools of carbon and nutrients, microbial communities, and microbial processes, such as CO$_2$ and CH$_4$ release.

Our results indicate that invasion by *Phragmites* has significant effects on plant diversity and carbon and nutrient cycling. Compared to *Typha* stands, plant diversity was reduced by *Phragmites* invasion (Figure 1). Biomass production and nutrient uptake were greater in *Phragmites* stands (Figure 2), while soil CO$_2$ and methane release were lower (Figure 3). These results suggest that wetlands become more of a sink for carbon and nutrients following *Phragmites* invasion.

Remote Sensing
This project is primarily utilizing remote sensing imaging devices that measure electromagnetic energy in the reflected-optical range, typically sub-divided into the visible (400nm to 700nm), the near-infrared (700nm to 1100nm), and the short-wave or middle-infrared (1100nm to 2500nm) wavelength regions. From the standpoint of green vegetation, each of the above wavelength regions has a special significance. Within the visible wavelengths, sunlight falling on plants is selectively absorbed by leaf pigments, including chlorophyll, to be used during photosynthesis. Reddish (600nm to 700nm) and bluish (400nm to 500nm) wavelength regions are considered the chlorophyll absorption bands, with the greenish region (500nm to 600nm) being more reflected relative to the other two. Hence, healthy, growing vegetation appears to us in shades of green, and the visible wavelength region contains information about the vigor and condition of plants. If something occurs that affects photosynthesis,
such as drought or senescence, the spectral pattern of reflected visible energy changes. Within the near-infrared region, the structure of the plant leaf (spongy mesophyll) acts to scatter the incident electromagnetic radiation. Hence, this wavelength region contains information about type of vegetation as expressed by leaf structure, such as discrimination between deciduous versus evergreen trees. Finally, reflection and absorption by plants of solar energy within the middle-infrared wavelength region is controlled by leaf water content (turgidity), and as such can provide information about drought stress, for example.

By analyzing the spectral signatures, remotely sensed imagery can be used to distinguish between different types of vegetation, and under the right conditions, to determine some of their biophysical properties. A spectral signature can be defined quantitatively as: \( SS = [(x_1, y_1), (x_2, y_2), \ldots (x_n, y_n)] \), where: \( x \) is the wavelength region, \( y \) is the percent reflectivity, and it is assumed \( x_1 < x_2 < \ldots x_n \). Understanding that different types of plants and other land cover have varying and oftentimes distinct spectral signatures is essential to grasping the importance of remote sensing for invasive plant species research and monitoring.
Optical remote sensing systems are designed to measure the spectral reflectance patterns within the instantaneous field of view (IFOV) of the device. Basically, the IFOV is analogous to the ground sample area of the intensively sampled plots discussed above, and determines the source pixel dimension. The detector collects reflected electromagnetic energy within the IFOV within a certain continuous wavelength region (e.g. 400nm to 1100nm), then the energy is subdivided into smaller regions (often referred to as spectral bands), and undergoes an analog-to-digital conversion. The result is a digital image comprised of n-by-m arrays of pixels stacked into sequential spectral bands. In *multispectral* remote sensing, there are typically only a few bands of relatively wide regions of the electromagnetic spectrum that comprise a given image. National Agricultural Imagery Project (NAIP) imagery has four bands (blue, green, red, and near-infrared), for example. Hence, a NAIP pixel has four measurements of reflected electromagnetic energy corresponding to one (pure) or more (mixed) types of land cover that were within the IFOV. The spectral signature for the pixel, if graphed, would only have four data points.

Thus, a limitation of multispectral remote sensing for the study of vegetation is the coarse spectral resolution of the imagery. For example, *Phragmites* and *Typha* are spectrally similar, even though we can easily tell them apart when viewed in the field or on a photograph. To address this limitation, we are employing *hyperspectral imagery* (HSI), which has many more bands and much narrower wavelength regions than multispectral remote sensing devices. To this end, we contracted with NASA-Glenn in Cleveland, Ohio, to conduct primary data acquisition over much of the DRIWR between August 15 and September 15, 2010. Scientists at NASA have designed and built a hyperspectral imaging device with 179 bands, 3nm wide, ranging from 400nm to 930nm. The NASA HSI device was mounted on a single-engine plane and flown at a height that resulted in approximately 1.2meter pixel size. The HSI data provides much more detailed spectral signature for the various vegetation and land cover types found within our study area. We are now processing and experimenting with this recently-acquired imagery as a means of integrating intensive plot scale biological variables and scaling up the variables based on their (assumed) relationship to vegetation and soil spectral properties.

Our research design involves selecting the HSI pixels that correspond to the ground locations of each of the eight intensive-sampling plots and their adjacent replicates (i.e., a total of five points per plot, times eight plots, totaling 40 points/pixels). Next, we select the adjacent pixels to each of the 40 plots within a 3x3 pixel neighborhood, then repeat for a 5x5 pixel area, and so on, until the pixel neighborhoods around each of the plots coalesces into a single region. A spectral signature will be collected from the HSI for each pixel associated with the eight sampling plots. Individual signatures will be compared using the Transformed Divergence (TD) and Jeffries-Matusita (JM) indices of spectral similarity. Our intent is to determine how far from the intensive-sampling plot the spectral signature, and hence the assumed determinant vegetation properties, remain constant. Ultimately, we hope to be able to infer plot-scale properties and associated ecosystem services to the entire landscape as a function of hyperspectral image signatures and GIS modeling.

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5.8 A GIS for Remediation of Fish Spawning Habitat in the Huron-Erie Corridor

Introduction

Habitat-related Beneficial Use Impairments (BUIs) within designated Areas of Concern are system-level issues that require macro scale spatial modeling to address. Petts et al. (1989) noted that "It is now clear that river management should address problems at a scale larger than that of a short reach of main channel" and it was the intention of this study to look at potential fish spawning habitat on a system-wide spatial scale. Historically, the Huron-Erie Corridor (HEC) supported large commercial fisheries for lake whitefish and lake sturgeon (Roseman et al. 2007, 2011). Construction of shipping channels greatly altered the hydraulic structure within the HEC and disturbed large areas of river bottom through dredging and spoil disposal (Bennion and Manny 2011). A U.S. Fish Commission report (Smith 1917) directly attributed the loss of the lake whitefish fishery near Grassy Island in the Detroit River to shipping channel construction. In addition to the loss of mid-channel fish habitats, other major fish habitat alterations within the HEC have been extensive shoreline armoring and a loss of coastal wetlands (Manny et al. 1988).

In recent years, man-made fish spawning habitat in the Detroit River has been used as a spawning ground by walleye lake whitefish, lake sturgeon and white sucker (Caswell et. al. 2004; Roseman et al. 2007; Manny et al. 2010; Roseman et al. 2011). Past evaluation of fish spawning habitat construction projects have demonstrated that native species of fish spawn concurrently or sequentially on spawning habitat constructed for lake sturgeon by adding suitable spawning substrates to the Detroit River (Lyttle 2008; Manny 2010).

The goal of this study was to locate areas of acceptable water depth and velocity as possible sites for remediation of lost fish spawning habitat for a particular guild of large bodied, migratory, lithophilic, benthic, broadcast spawning fishes represented by walleye, lake whitefish, and lake sturgeon. The focus of our study was on the mid-channel spawning habitat lost or altered by past shipping channel construction projects and changes to hydraulic function from the construction of water level compensating structures. The assumptions of this approach are that lack of spawning habitat is a limiting factor for these fish populations, and lack of suitable bottom substrate in areas that the fish are naturally drawn to is a limiting habitat component. Threader (1998) concluded that for lake sturgeon “the spawning variables were more important in determining the overall Habitat Suitability Index for a particular study area than variables associated with the food life requisite”. Four main physical habitat parameters, (i.e. water depth, flow velocity, substrate, and water temperature) were identified as important to spawning walleye, lake whitefish, and lake sturgeon (Threader 1998, Lyttle 2008). From these habitat parameters, water depth and flow velocity were singled out to form the basis of our analysis because fish respond to both of these variables in seeking places to spawn in the HEC (Roseman et al. 2011) and data sets for these two variables were available with complete coverage of the HEC. We assumed that river bottom, rock-rubble substrate was the limiting factor to be remediated and that changing the temperature regime in a large unregulated river system is largely outside the scope of remediation.
efforts. This summary outlines a spatial modeling investigation designed to integrate data on two variables (water flow velocity and water depth) that many riverine fish respond to in selecting where to spawn in these waters.

**Methods**

Our study area was the entire 117 kilometer (73 mile) channel connecting lakes Huron and Erie, between Michigan and Ontario, Canada, including the St. Clair River, Lake St. Clair, and the Detroit River. Bathymetric data and three discrete sources of modeled water flow velocity were obtained and interpolated to create continuous raster surfaces. To facilitate the assignment of relative habitat rankings, the created raster surfaces representing water depth and flow velocity were reclassified. Our selection of reclassified values placed a premium on the highest available water flow velocities, while also acknowledging that lake sturgeon spawning has been documented in areas exhibiting a wide range of water velocity values. The reclassified depth and flow velocity rasters were combined and the presence of maintained dredged shipping channels was accounted for to produce ranking surfaces that contained relative scoring values with higher values considered acceptable fish spawning habitat. To account for variation in the rankings produced by each individual hydraulic model input, a further step of combining each output surface by adding all results together was performed. This process created a final ranking surface for each river. Model validation was achieved by comparing areas identified by the model with the locations in this connecting channel where fish spawning habitat is either known, or has been remediated and fish are spawning there. All known and postulated lake whitefish and lake sturgeon spawning areas in the HEC were selected as acceptable fish spawning habitat by our model. Our analysis revealed areas in each river, in addition to the known and postulated sites, that possessed suitable water velocity and depth, and therefore theoretically could be remediated by the addition of rock-rubble spawning substrate.

**Results**

The final ranking surface for the Detroit River contained a total area of potential habitat of roughly 15,000,000 m². The final ranking surface for the St. Clair River, including the delta, indicated a total potential habitat area of roughly 19,000,000 m². These areas predicted by the model comprise less than 5% of the total area of the HEC. This calculation is the result of comparing all acceptable habitat areas to the total area of the Huron-Erie Corridor, including Lake St. Clair. Considering sites already selected for remediation, those that should not be altered due to current use as spawning habitat and those which have a lower remediation potential, a subset of sites was selected as good candidates for further assessment.

**Discussion**

The indicated sites should not be considered the only possible areas for habitat remediation, but represent the most likely areas for spawning habitat remediation for our target species, when considering the HEC on such a large spatial scale. Because of the selection of depth and velocity as our model parameters, the model favors the riverine environments over Lake St. Clair. It is not unreasonable that some spawning by our target species may occur in Lake St. Clair on wave-washed rocky shorelines and rocky shoals, but it is expected that the bulk of suitable spawning habitat for these species is located within the Detroit and St. Clair Rivers.

The known spawning areas represent a small portion of the overall indicated potential habitat in the HEC, suggesting that larger populations of our guild of fish should be possible, if lack of suitable spawning grounds is the limiting factor. This assumption is supported by historic reports and modern scientific studies. Bowers (1897) related the success of the Detroit River lake whitefish population to the high quality spawning habitat that was found in the river and notes the destruction of a fishery at Fort Wayne by land fill.

This study was designed to address the overall fish spawning habitat remediation potential for native fish species on a large spatial scale and was meant to provide a guide for further meso and micro scale habitat analysis on a site by
site basis. Next steps would include assessment of these indicated areas and to determine whether or not they are currently being utilized by spawning fish. If coarse substrate is not the limiting factor in these areas, other issues, such as substrate contamination, local thermal disturbances or water quality issues could be considered. The influence of freighter traffic on fish is largely unstudied in the HEC. Propeller hits on the fish themselves and regular short term alterations to hydraulic function created by prop wash could play a role in the ultimate productivity of some of these indicated fish spawning habitat areas.

References


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