Development of Environmental Indicators for the U.S. Great Lakes Basin Using Remote Sensing Technology

Gerald J. Niemi[1], Carol A. Johnston[2], and Peter T. Wolter[1]

[1]Natural Resources Research Institute
University of Minnesota
5013 Miller Trunk Highway
Duluth, Minnesota, USA 55811-1442
218.720.4270

[2]Department of Biology and Microbiology
South Dakota State University
Box 2207B
Brookings, SD 57007
605.688.6464

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Abstract

In 2001 we initiated a study of remote sensing technology to complement our development of environmental indicators for the U.S. Great Lakes coastal region. Our objectives were to: 1) quantify land use/land cover (LULC) and change for the U.S. portion of the Great Lakes basin between 1992 and 2001; 2) identify salient LULC change categories that are most likely to affect near-shore ecosystems; 3) recommend landscape indicators to guide managers toward long-term sustainable development; 4) develop methodologies to quantify SAV within near-shore areas of the Great Lakes; and 5) use historically low water levels in Lakes Michigan and Huron to produce a digital elevation model of recently exposed lake bed using radar interferometry to better model coastal wetland inundation events as lake water levels returns to normal. In addition, we completed four focused studies in the Great Lakes basin: 1) two studies to determine the degree of accuracy of Quickbird satellite imagery to identify specific vegetation types within a wetland; 2) an examination of 63 years (1940 to 2003) of land use change in a 100 km^2 area in western Lake Erie; and 3) a study to test the use of Hyperion hyperspectral satellite imagery for mapping *Phragmites*, an invasive plant species in the Great Lakes. All of the objectives were successfully completed, except objective 5 in which we had technical difficulties with the use of radar interferometry because of changes in ice and snow in the region. A total of six peer-reviewed publications have been completed and three additional publications are either in review or in preparation. The land use/land cover map produced for 1992 and 2001 will serve an extremely important baseline for future monitoring of change in the U.S. Great Lakes basin. A special issue of the *Journal of Great Lakes Research* is in preparation that summarizes additional work on this project. It is scheduled for publication in 2007.

Introduction

This project was closely associated with another project funded by US EPA on the development of environmental indicators for the US Great Lakes coastal region and its watershed (Niemi et al. 2006). LULC is one of the critical science issues of the 21st century, and quantifying LULC change is a major goal of government agencies in the U.S. (Climate Change Science Program 2003, McMahon *et al.* 2005) and the world (e.g., International Geosphere Biosphere Program 1999). LULC change is an indicator of changing human demographics, natural resource uses, agricultural technologies, economic priorities, and land tenure systems. Different land uses impose different environmental stresses on natural plant and animal communities, with consequent implications to water quality, climate, ecosystem goods and services, economic welfare, and human health (Gutman *et al.* 2004).

Water level fluctuations, shoreline erosion, and increased runoff due to LULC changes (e.g., deforestation and urban expansion) can have profound effects on plant communities in coastal wetlands and other sensitive near-shore environments through inundation, siltation, and erosion. For example, submergent aquatic vegetation (SAV) has often been referred to as the 'canary' for early signs of estuary degradation, and has been studied widely in marine environments because of its potential as an indicator of estuary health (Bjorndal 1980, Orth and Moore 1983, Zieman *et al.* 1989, Orth *et al.* 1991, Dennison *et al.* 1993, Ferguson *et al.* 1993, Carter and Rybicki 1994, Neckles 1994, Small *et al.* 1996, Gallegos 2003). Our objectives were to:

1) Quantify LULC and change for the U.S. portion of the Great Lakes basin between 1992 and 2001;
2) Identify salient LULC change categories that are most likely to affect near-shore ecosystems;
3) Recommend landscape indicators to guide managers toward long-term sustainable development;
4) Develop methodologies to quantify SAV within near-shore areas of the Great Lakes; and
5) Use the historically low water levels in Lakes Michigan and Huron to produce a digital elevation model of recently exposed lake bed using radar interferometry to better model coastal wetland inundation events as lake water levels returns to normal.

Approach

Three major tasks to achieve these objectives included: 1) assemblage of consistent LULC data for the U.S. portion of the Great Lakes basin for 1992 and 2001, 2) perform LULC change detection for the whole watershed and within specified distance inland from the shoreline and report salient LULC change categories; 3) use high spatial resolution satellite data (QuickBird, 2.44 m) to classify wetland vegetation including submergent aquatic vegetation (SAV); and 4) use radar interferometry to produce a digital elevation model (DEM) of recently exposed lake bed in lakes Michigan and Huron, where water levels are near record lows, to more accurately model potential coastal wetland inundation.

Land Use Land Cover

Heavy use of existing, Landsat-derived, 30-meter, LULC data layers from various state and federal sources was the most efficient use of time and effort for developing thematically and spatially consistent LULC data for the U.S. side of the Great Lakes watershed for both 1992 and 2001. These existing data sources were used to 1) augment the 1992 National Land Cover Data (NLCD) woody wetlands class, 2) reconcile errors in the NOAA Coastal Change and Analysis Program (C-CAP) wetlands data, 3) classify LULC change between 1992 and 2001 in areas devoid of pre-existing thematic data, 4) fix 2001 wetland classes outside the map-extent of the C-CAP data, and 5) resolve disparities between the NLCD and C-CAP "developed" classes (see: Wolter *et al.* 2006). TIGER data from 1992 and 2001 were used to augment development classes because both original C-CAP datasets (1996 and 2001) had TIGER roads data incorporated into them (pers. comm., Raber and Herold, NOAA Coastal Services Center, 2004), while NLCD 1992 data did not. Once compatible LULC layers for 1992 and 2001 were assembled, change analysis was performed on the full area and within buffer zones (e.g., 0-1, 1-5, 5-10 km) inland from the shoreline.

SAV Classification

Three areas were randomly selected throughout the U.S. portion of the Great Lakes watershed for testing the potential of using Quickbird (QB) satellite sensor data for mapping SAV. Two approaches were explored: (1) using QB data from a period of maximum SAV development (QB_{max}) and (2) using QB_{max} data along with QB data collected during a period where SAV was in a dormant state. The second method was designed to take advantage of phenological differences in SAV and minimize the confounding effects of varying substrate brightness on SAV classification. For each site, SAV beds were located and Secchi depths recorded.

Coastal DEM

Because of historically low water levels in Lakes Michigan and Huron during 2002-2003, an attempt was undertaken to use radar interferometry to map relatively fine-scale relief of the exposed lakebed. This resulted in the shoreline moving lakeward greater than 500 m in some areas during this period without appreciable colonization by terrestrial vegetation. Radarsat-1 sensor data triplicates (i.e., three successive image acquisition dates 24 days apart for each area of interest) were acquired for areas covering nearly the entire shoreline of Lake Michigan and for Saginaw Bay on Lake Huron in late winter of 2002. The Alaskan SAR Facility completed preprocessing of these Radarsat data in winter 2003-2004 and Level-1 products were received the following summer. Interferometric processing of these Radarsat-1 images began in summer 2005. Unfortunately, changes in ice and snow cover within the imaged areas prevented successful phase unwrapping for each of the three possible combinations of image pairs. Thus, this component of the project was abandoned.

Results

Land Use Land Cover

Of the total change that occurred between 1992 and 2001 (2.5 % of watershed area), salient transition categories included a 33.5 % increase in area of low-intensity development, a 7.5% increase in road area, and a decrease of mature forest area by over 2.3 % – the largest LULC category and area of change within the watershed (Wolter *et al.* 2006). More than half of the forest change observed involved transitions into early successional vegetation, and hence, will likely remain in forest production of some sort. However, nearly as much forest area was, for all practical purposes, permanently converted to developed land. Likewise, agriculture land area lost over 50,000 more ha to development than forestland, much of which involved transitions into urban/suburban sprawl (Fig. 1). Interesting, but not surprising, was the concentration of new developments near coastal areas of the Great Lakes (Fig. 2). For instance, over one third of wetland losses to development between 1992 and 2001 occurred within 10 km of a coastal area, and most of that area was within the nearest one kilometer. This is a concern because Great

Lakes coastal wetlands provide habitat for a wide variety of fauna, support plant communities adapted to water level extremes, and buffer land-lake exchanges of nutrients and other materials. High rates of LULC conversion impose stress on watersheds and near-shore ecosystems of the Great Lakes and are generally associated with inefficient land use driven by displacement of agricultural and forest lands by population growth. Salient indicators produced by this effort include proportion and connectivity of forest cover, proportion and connectivity of natural areas including wetlands, rates of agricultural conversion to permanently developed lands, and loss of wetland area through filling/draining or development on a sub-watershed basis. These indicators represent a modification of the Great Lakes - State of the Lakes Ecosystem Conference (SOLEC) indicator 7002 (land cover – land conversion) that was originally proposed in 1996, but not realized. With completion of consistent classifications for the Great Lakes watershed for two time periods, and methodologies for future years, these indicators have now been realized and quantified.

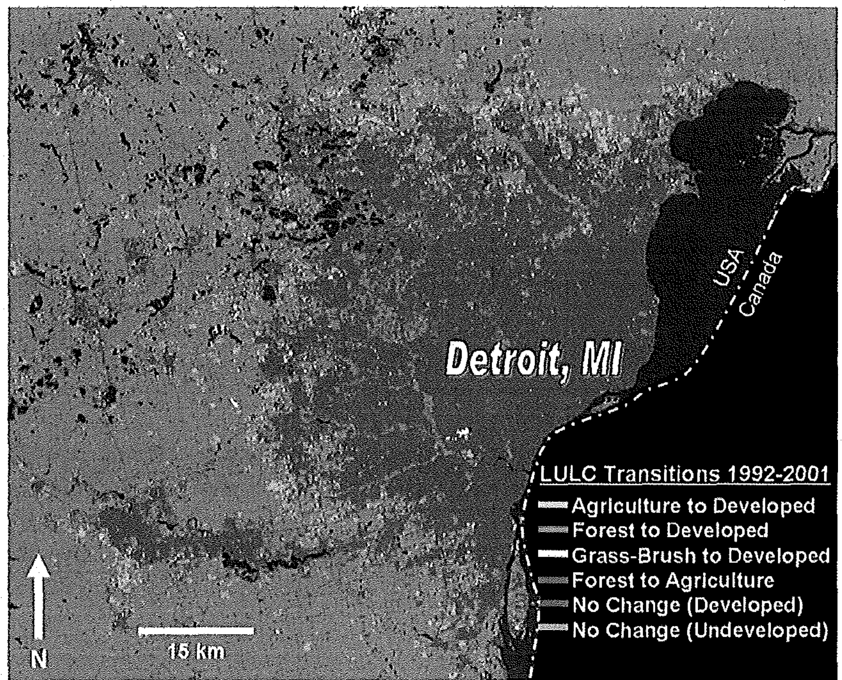

Figure 1. Land cover conversion (sprawl) around Detroit, MI 1992 to 2001.

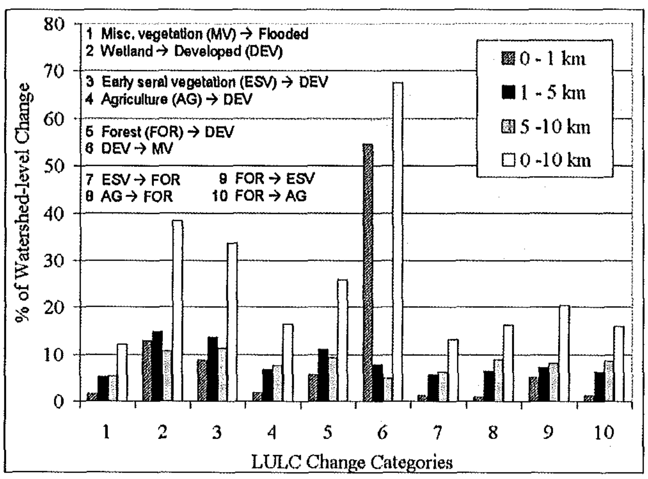

Figure 2. Percent of the overall LULC change between 1992 and 2001 that occured in near-shore areas.

SAV Classification

It was clear that Quickbird imagery was a useful tool for classifying SAV in the nearshore areas of the U.S. Great Lakes basin (Wolter *et al.* 2005). Single-date classifications of SAV produced good results in water conditions that were less than ideal. In near-ideal conditions, as was the case at Portage Bay, MI, combination of a visible red difference image (May–August) with August visible red and green bands resulted in a more accurate mapping of SAV than was possible with one date of Quickbird imagery (Fig. 3), with SAV user and producer errors improving from 52% and 84% (single date) to 82% and 84 (two dates), respectively.

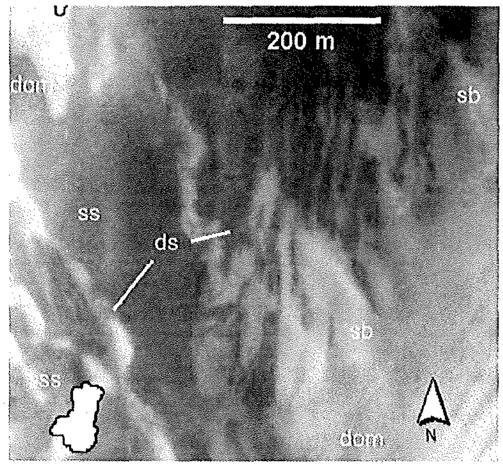

Figure 3. False color composite of Portage Bay showing dense SAV (ds), sparse SAV(ss), sand bottom without SAV (sb) and dissolved organic matter in the water column (dom). The red–red difference image (May–August) is in the red color plane, August red in the green color plane and August green in the blue color plane.

Seasonal differences in SAV phenology, exclusion of August visible blue data, and mitigation of sub-surface topographical effects, via visible red image differencing, are all suspected of contributing to superior SAV classification results. Seasonal image differencing mitigated some of the confusion related to water depth, but incorporation of detailed, continuous, bathymetry data would have been invaluable for bottom type classification. Future work should also investigate the effect of plant shading on classifying SAV presence and density, as it appeared to be an important factor between prostrate and more upright growth forms (Wolter *et al.* 2005). Furthermore, a more comprehensive field campaign looking at SAV density and substrate reflectance may permit more accurate mapping of SAV under Great Lakes conditions.

In terms of regional SAV mapping efforts, we are skeptical about the operational and economic feasibility of using Quickbird sensor data as a wall-to-wall SAV monitoring tool for the Great Lakes basin. Rigid satellite tasking constraints and high data cost, coupled with unpredictable water clarity and surface conditions in coastal areas of the Great Lakes, may preclude reliable data flow and quality for regional SAV mapping efforts. However, sub-sampling portions of the Great Lakes basin with Qucibird imagery remains a viable option for detecting changes in SAV or other more detailed land and aquatic changes.

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Niemi, G.J., Axler, R., Brady, V., Brazner, J., Brown, T., Ciborowski, J.H., Danz, N., Hanowski, J.M., Hollenhorst, T., Howe, R., Johnson, L.B., Johnston, C.A., Reavie, E., Simcik, M., Swackhamer, D. 2006. Environmental indicators of the U.S. Great Lakes coastal region. Report NRRI/TR-2006/11 to the U.S. Environmental Protection Agency STAR Program, ver.1. Agreement R82-8675, Washington DC. Prepared by Great Lakes Environmental Indicators Collaboration, Natu*ral Resources Research Institute, University of Minnesota Duluth, 121 pp + attachments (CD).*

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Wolter, P.T., Johnston, C.A. and Niemi, G. J. 2006. Land use change in the U.S. Great Lakes basin 1992 to 2001, J. Great Lakes Res. 32: 607-628.

Wolter, P.T., Niemi, G.J. and Johnston, C.A. 2005. Mapping SAV in the U.S. Great Lakes Using Quickbird Satellite Data. International Journal of Remote Sensing 26(23): 5255-5274.

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Appendix 1

SUMMARY OF PEER-REVIEWED PUBLICATIONS AS A RESULT OF THIS EFFORT (PDFs or Word files included on attached disk)

Brazner, J.C., N.P. Danz, G.J. Niemi, R.R. Regal, Trebitz, A.S., R.W. Howe, J.M. Hanowski, L.B. Johnson, J.J.H. Ciborowski, C.A. Johnston, E.D. Reavie, V.J. Brady, G.V. Sgro. 2006. Evaluation of geographic, geomorphic, and human influences on Great Lakes wetland indicators: a multi-assemblage approach. Ecological Indicators: in press.

Brazner, J.C., N.P. Danz, G.J. Niemi, R.R.Regal, T. Hollenhorst, G. Host, T. Brown, A.S. Trebitz, R.W. Howe, J.M. Hanowski, L.B. Johnson, J.J.H. Ciborowski, C. Johnston, E. Reavie, G. Sgro. 2007. Responsiveness of Great Lakes wetland indicators to human disturbances at multiple spatial scales: a multi-assemblage assessment. Journal of Great Lakes Research: in press.

Johnston, C.A., T. Brown, T. Hollenhorst, P. Wolter, N. Danz, G. Niemi. In press. GIS in Support of Ecological Indicator Development. Manual of Geographic Information Systems. American Society for Photogrammetry and Remote Sensing, Bethesda, MD.

Pengra, B.W., C.A. Johnston, and T.R. Loveland. Mapping an Invasive Plant, *Phragmites australis*, in Coastal Wetlands Using the EO-1 Hyperion Hyperspectral Sensor. Remote Sensing of Environment: in press.

Wolter, P.T., G.J. Niemi and C.A. Johnston. 2005. Mapping SAV in the U.S. Great Lakes Using Quickbird Satellite Data. International Journal of Remote Sensing 26(23): 5255-5274.

Wolter, P.T., C.A. Johnston, and G. J. Niemi. 2006. Land use change in the U.S. Great Lakes basin 1992 to 2001, J. Great Lakes Res. 32: 607-628.

SUBMITTED

Johnston, C.A., T. Watson, and P. Wolter. Sixty-three Years of Land Alteration in Erie Township. Submitted to *Journal of Great Lakes Research.*

IN PREPARATION

Ghioca, D.A., C.A. Johnston, and M.G. Tulbure. Assessing the Use of Multitemporal QuickBird Imagery for Mapping Coastal Marsh Vegetation.

Thanapura, P. and C.A. Johnston. QuickBird Imagery for Mapping Wetlands in a Great Lakes Freshwater Estuary.

PRESENTATIONS (Note – these are examples – many of the presentations listed in the Great Lakes Environmental Indicators final report to us EPA incorporated aspects of this NASA-funded project)

Johnston, C.A., 2006, GIS in ecology: history of useful analytical tools and new approaches. 91st Annual Meeting of the Ecological Society of America. Memphis, TN. 6-11 August. http://abstracts.co.allenpress.com/pweb/esa2006/document/?ID=60835

Johnston, C.A., and B. Pengra, 2006, Phragmites mapping using Hyperion imagery. Remote Sensing Across the Great Lakes: Observations, Monitoring and Action. Great Lakes Regional Data Exchange, Rochester, NY. 4-6 April.

Pengra, Bruce, 2005, Remote sensing of *Phragmites australis* with Hyperion imagery. PECORA 16, Sioux Falls, SD. 23-27 October.

Chang, Jiyul, Carol Johnston, Gerald Niemi, and Peter Wolter, 2005, Object-oriented Classification of High-resolution Coastal Wetland Imagery (poster). PECORA 16, Sioux Falls, SD. 23-27 October.

Pengra, Bruce, Jiyul Chang, and Carol Johnston, 2005, Influence of Coastal Geology on Wetland Abundance in the Great Lakes (poster). South Dakota/North Dakota EPSCoR 5th Biennial Joint Conference, Brookings, SD. 8-9 September.

Chang, Jiyul, Carol Johnston, Gerald Niemi, and Peter Wolter, 2005, Classification of High-resolution Coastal Wetland Imagery using object-oriented segmentation method (poster). So. Dak./No. Dak. EPSCoR 5th Biennial Joint Conf., Brookings, SD. 8-9 Sept.

Niemi, G.J. Overview of Great Lakes environmental indicators project. Great Lakes Area Management Plan (Lamp), Chicago IL. 13-Dec-01.

Niemi, G.J. Great Lakes environmental indicators project. Great Lakes Fisheries Commission, Duluth MN. 25-Feb-02.

Niemi, G.J. Overview of Great Lakes environmental indicators project. Cornell University Faculty Seminar, Ithaca NY. 25-Apr-02.

Niemi, G.J. Overview of Great Lakes environmental indicators project. NY Department of Conservation, U.S. EPA, Region 2, Albany NY. 26-Apr-02.

Niemi, G.J. Overview of Great Lakes environmental indicators project. State of the Lakes Ecosystem Conference, Cleveland OH. 16-Oct-02.

Niemi, G.J. The quest for indicators of the U.S. Great Lakes freshwater coast. Invited: Dept of Biology Seminar, Duluth MN. 13-Dec-02.

Niemi, G.J Development of environmental indicators for the U.S. Great Lakes coastal region. Keynote speaker: Midwest Society of Toxicology and Chemistry, Rhinelander WI.. 29-30 Jan 03.

Niemi, G.J. Development of environmental indicators for the U.S. Great Lakes coastal region. Region 5 STAR Environmental Research Seminar, Chicago IL. 17-Jun-03.

Niemi, G.J., R.P. Axler, V.J. Brady, N.P. Danz, J.M. Hanowski, T.P. Hollenhorst (speaker), G.E. Host, L.B. Johnson, C.A. Johnston, J.C. Kingston, R.R. Regal, C. Richards, D.L. Swackhamer, R.W. Howe, J.J.H. Ciborowski, S. Bradbury. Development of environmental indicators for the U.S. Great Lakes coastal region. Western Great Lakes Research Conference, Marquette MI.. 2-3 Apr 02.

Niemi, G.J., R.P. Axler, V.J. Brady, J.M. Hanowski, T.P. Hollenhorst, G.E. Host, L.B. Johnson, C.A. Johnston, J.C. Kingston, R.R. Regal, C. Richards, D.L. Swackhamer, R.W. Howe, J.J.H. Ciborowski, S. Bradbury. Development of environmental indicators for the U.S. Great Lakes coastal region. International Association of Great Lakes Research, Winnipeg MB. 5-Jun-02.

Niemi, G.J., R.P. Axler, V.J. Brady, N.P. Danz, J.M. Hanowski, T.P. Hollenhorst (speaker), G.E. Host, L.B. Johnson, C.A. Johnston, J.C. Kingston, R.R. Regal, C. Richards, D.L. Swackhamer, R.W. Howe, J.J.H. Ciborowski, S. Bradbury. Development of environmental indicators for the U.S. Great Lakes Coastal Region. Northern Minnesota Geographic Information System User Group, Duluth MN. 30 Feb 03.

Niemi, G.J, R.P. Axler, V.J. Brady, J.M. Hanowski, G.E. Host, L.B. Johnson, CA. Johnston, J.C. Kingston, R.R. Regal, C. Richards, D.L. Swackhamer, R.W. Howe, J.J.H. Ciborowski, S. Bradbury. Development of environmental indicators for the U.S. Great Lakes coastal region. EPA All-EaGLes Meeting, Bodega Bay CA. 3-6 Dec 03.

Niemi, G.J., N.P. Danz, R.R. Regal, T.P. Hollenhorst, V.J. Brady, T.N. Brown, L.B. Johnson, J.M. Hanowski. Experimental design for linking stress with response in the Great Lakes coastal ecosystem. Ecological Society of America, Savannah GA. 7-Aug-03.

Niemi, G.J., L.B. Johnson, V.J. Brady. Environmental indicators of the US Great Lakes coastal region. International Conference on Environmental Bioindicators and International Society for Environmental Bioindicators, Linthicum Heights MD. 24-26 Apr-06.

Niemi, G.J., L.B. Johnson, N.P. Danz, J.C. Brazner, V.J. Brady, J.R. Kelly. Local, landscape, and regional influences on biotic indicators in Great Lakes coastal zones. Ecological Society of America, Montréal QC. 9-Aug-05.

Niemi, G.J. H. Paerl, B. Levinson Organized Oral Session 17: Coastal indicators of ecological condition: integration of spatial scales. Ecological Society of America, Montréal QC. 9-Aug-05.

Abstracts for Additional Papers in Preparation and Review

We pursued a variety of additional questions using much of the data gathered during this project and the associated EPA-supported project (http://www.glei.nrri.umn.edu). Note – a CD of the final report for the EPA-supported project is also attached)

Ghioca, D.A., C.A. Johnston, and M.G. Tulbure. In preparation. Assessing the Use of Multitemporal QuickBird Imagery for Mapping Coastal Marsh Vegetation.

QuickBird multispectral satellite images acquired during early September 2002 (peak biomass) and early April 2003 (pre-growing season) were evaluated for mapping vegetation communities and species within Erie Marsh, a diked coastal wetland at the western end of Lake Erie. An unsupervised classification was performed on a nine-layer image stack consisting of all four spectral bands from both dates plus a September Normalized Difference Vegetation Index (NDVI) image. The resulting 100 classes were reduced to eighht cover classes that distinguished three monodominant genera (*Phragmites australis, Typha* spp., *Nelumbo lutea*), three multi-genera plant communities (wet meadow, non-persistent emergents, woody vegetation), and two unvegetated cover types (water, bare soil). Field validation of the classified image at 201 data points yielded an overall accuracy of 60%, with Producer's Accuracy values ranging from 38 to 91% for the eight individual classes. Three-fourths of areas designated as *Phragmites* were correctly mapped, but 13.5% of areas designated as *Phragmites* were found to be cattail (*Typha*) during field validation. The use of multi-temporal imagery greatly aided the detection of lotus (*Nelumbo lutea*) beds (Producer's Accuracy = 91%), which were fully developed in September but had not yet emerged above water in early April. Other types of non-persistent vegetation were confused with managed areas in which vegetation had been cut and burned to control invasive *Phragmites*. Both situations, the natural senescence of non-persistent emergent vegetation and the anthropogenic removal of aboveground biomass, involved changes from high biomass in September 2002 to shallow water in April 2003 that were causally distinct but spectrally indistinguishable. Multi-temporal QuickBird imagery was judged suitable for distinguishing emergent wetland species having pronounced phenological differences.

Johnston, C.A., T. Watson, and P. Wolter. Sixty-three Years of Land Alteration in Erie Township. Submitted to *Journal of Great Lakes Research.*

Land use/land cover (LULC) was mapped using historical aerial photos (1940) and contemporary QuickBird satellite imagery (2003) for a 100 km^2 area covering portions of Erie Township, Michigan and Toledo, Ohio on the western end of Lake Erie. GIS analysis was used to measure LULCr change within the study area based on the 1940 and 2003 maps, and to illustrate the use of historical aerial photos and data to quantify changes in anthropogenic pressures to coastal ecosystems. Agriculture was and is the main land use in the study site, constituting 78% and 55% of upland area in 1940 and 2003, respectively. Most conversions to other land uses originated as agricultural lands. Transportation changes over the time period included the loss of two major railroad yards and the gain of an interstate highway. The area of commercial and industrial development increased 12-fold, from 20 ha in 1940 to 246 ha by 2003. Major industries built after 1940 included an electrical power plant and a sanitary landfill. Residential development approximately doubled from 353 ha in 1940 to 717 ha in 2003, consistent with an 80% increase in population. Coastal ecosystems within the study area included a coastal spit (Woodtick Peninsula) and a large, partially-diked wetland behind it (Erie Marsh), both of which changed extensively over the time period due to lake level changes and anthropogenic alteration. This approach offers a means of incorporating long-term observations into the evaluation of environmental condition in coastal wetlands.

Pengra, B.W., C.A. Johnston, and T.R. Loveland. Mapping an Invasive Plant, *Phragmites australis*, in Coastal Wetlands Using the EO-1 Hyperion Hyperspectral Sensor. Revised and resubmitted to *Remote Sensing of Environment.*

Mapping tools are needed to document the location and extent of *Phragmites australis*, a tall grass that invades coastal marshes throughout North America, displacing native plant species and degrading wetland habitat. Mapping *Phragmites* is particularly challenging in the freshwater Great Lakes coastal wetlands due to dynamic lake levels and vegetation diversity. We tested *the applicability of Hyperion hyperspectral satellite imagery for mapping* Phragmites in wetlands of the west coast of Green Bay in Wisconsin, U.S.A. A reference spectrum created using Hyperion data from several pure *Phragmites* stands within the image was used with a Spectral Correlation Mapper (SCM) algorithm to create a raster map with values ranging from 0 to 1, where 0 represented the greatest similarity between the reference spectrum and the image spectrum and 1 the least similarity. The final two-class thematic classification predicted monodominant *Phragmites* covering 3.4% of the study area. Most of this was concentrated in long linear features parallel to the Green Bay shoreline, particularly in areas that had been under water only six years earlier when lake levels were 66 cm higher. An error matrix using spring 2005 field validation points (n=129) showed good overall accuracy-81.4%. The small size and linear arrangement of *Phragmites* stands was less than optimal relative to the sensor resolution, and Hyperion's 30 meter resolution captured few if any pure pixels. Contemporary *Phragmites* maps prepared with Hyperion imagery would provide wetland managers with a tool that they currently lack, which could aid attempts to stem the spread of this invasive species.

Thanapura, P. and C.A. Johnston. In preparation. QuickBird Imagery for Mapping Wetlands in a Great Lakes Freshwater Estuary.

The utility of high resolution (2.4 m pixel) multispectral satellite imagery for mapping wetland vegetation in freshwater estuaries was evaluated using a QuickBird image of the St. Louis River estuary, a tributary of Lake Superior. The image was masked to exclude areas above an elevation of 185.9 m, the maximum elevation of estuarine wetlands in the St. Louis River. An initial wetland classification consisted of seven classes: open water, aquatic bed, lacustrine non-persistent emergent, palustrine persistent emergent, palustrine scrub/shrub, palustrine forest, and "other." A supervised classification with a parametric classifier (maximum likelihood) was performed, and validated at 690 random points throughout the 983 ha study area using human interpretation of rectified color infrared aerial photos of the Minnesota side of the estuary. Overall accuracy using the initial six classes was only 55.4%, which was unacceptably low. A simplified classification was created by merging "open water" and "aquatic bed" into a single "water" class, and "palustrine shrub/scrub" and "palustrine forest" into a single "palustrine woody" class. Results using the simplified classification were much improved, with an overall accuracy of 75.4%. The two classes that had been merged based on the initial classification, water and palustrine woody, were well distinguished from other classes in the final classification, with User's and Producer's Accuracies > 79%. The wetland vegetation classes were also well distinguished from the non-wetland "other" land use class, which included shipping docks and marinas. Because the QuickBird image acquisition was timed to coincide with peak wetland vegetation biomass in August, the supervised classification was able to detect lacustrine non-persistent emergents that had not been detected by existing National Wetland Inventory maps prepared from 1:80,000 aerial photos taken in November. Non-persistent emergents, such as wild rice beds, have important ecological and cultural significance, and should not be overlooked.