

# WETLAND SCIENCE AND PRACTICE

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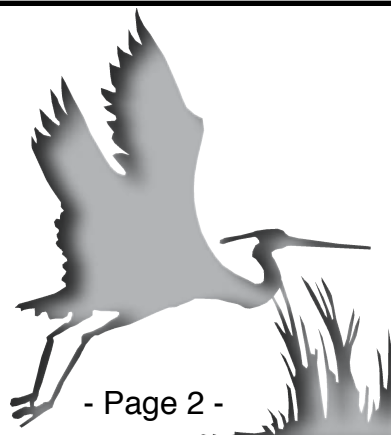
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# Perspectives on European Wetland Restoration

Robert McInnes<sup>1</sup>, Christopher Joyce<sup>2</sup>, Francisco A. Comin<sup>3</sup> and Kim Andersson<sup>4</sup>

<sup>1</sup> RM Wetlands & Environment Ltd, Ladman Villas, Littleworth, Oxfordshire, SN7 8EQ, UK\*

<sup>2</sup> School of Environment and Technology, University of Brighton, Cockcroft Building, Lewes Road, Brighton, East Sussex, BN2 4GL, UK

<sup>3</sup> Instituto Pirenaico de Ecología, CSIC, Zaragoza, Spain

<sup>4</sup> Stockholm Environment Institute, Kräftriket 2B, SE-106 91, Stockholm, Sweden

\* Corresponding author. E-mail: rob@rmwe.co.uk

## Restoring Europe's Wetlands

Estimates suggest that wetlands account for 7% of the European land area (excluding Russia and marine areas) (Nivet & Frazier, 2004). From the Scandinavian peatlands to the Mediterranean salt fields; from the Atlantic fringe raised bogs to the floodplain meadows of the great continental rivers, Europe's wetlands provide a vast and important biological and societal resource (Silva et al. 2007). However, as long ago as the 1970s, the Council of Europe recognised the importance of wetlands and raised concerns that they were in danger of becoming severely degraded and ultimately disappearing (Hoekstra, 1976). These fears were not misplaced and estimates suggest that wetland losses in the 21st century will continue at around 8% per annum (Nicholls, 2004).

Many European countries, both within and beyond the European Union (EU), are signatories to a variety of international conventions, such as the Ramsar Convention on the Wetlands, the Bonn Convention on Migratory Species and the Convention on Biological Diversity, all of which commit the signatories to protect and restore of wetland ecosystems. This commitment is further enforced within the EU through legislation, such as the Birds Directive (79/409/EEC) and the Habitats Directive (92/43/EEC), which seeks to rectify or reduce damage to European natural habitats and associated species. Through the Water Framework Directive (2000/60/EC) which aims to improve and protect surface and groundwater and to deliver good ecological status; and Directive (2007/60/EC) on the assessment and management of flood risks which provides opportunities to restore wetlands as essential components of water management infrastructure, especially as Europe struggles to adapt to a changing climate with a greater prevalence of meteorological extremes and rising sea levels.



In addition to legislative and political drivers, wetland science has a relatively long and high quality tradition in Europe (Cizkova et al. 2013). Therefore, the science base exists, even if the application and transferability of understanding sometimes needs to be approached with caution, especially when considering knowledge transfer across European climatic zones and cultural systems (Acreman et al. 2007). Increasingly, the social sciences and the economic importance of the ecosystem services provided by wetlands are being advocated to promote wetland restoration in Europe (Meyerhoff & Dehnhardt, 2007) and this situation will improve as the scientific community develops further information on the ecosystem services and socio-economic values of wetlands (Cizkova et al. 2013).

Protecting the existing wetlands in Europe should be the imperative (Gardner et al. 2012). However, the necessity to restore wetlands and mitigate centuries of wetland loss and degradation remains if the benefits wetlands provide to nature and, particularly, to human society are to be delivered (Alexander & McInnes, 2012). This is an urgent task as it has been argued that the recovery of wetlands following restoration can take considerable time and may ultimately be incomplete in terms of structure and function (Moreno-Mateos et al. 2012). However, wetland restoration should be based on sound scientific understanding and practices (Acreman, et al., 2007) and seek to deliver multiple benefits (Zak et al. 2011). To further this aim, the European Chapter of the Society of Wetland Scientists met at Aarhus University, Denmark, in June 2012, to discuss *Wetland restoration – challenges and opportunities*. Attended by over 80 wetland experts from 15 countries the meeting addressed a range of wetland restoration dimensions and included field visits to several restored wetlands including the iconic River Skjern (Pedersen et al. 2007) (Figure 1). The following examples are provided describing the drivers and approaches to wetland restoration in Europe from which lessons can be learned and more universally applied to other wetland restoration projects.

## **Tools for wetland restoration**

Different protocols have been proposed for wetland restoration in relation to the unique characteristics of the target sites (Almendinger, 1999; Eades et al. 2003; Davies et al. 2004; Lesta et al. 2007). Conventionally the process starts with an evaluation of the hydrogeomorphic characteristics of the site, to ascertain whether the desired restoration outcomes are achievable, and an assessment of the degraded hydro-ecological characteristics that must be addressed as drivers of the wetland restoration. A further step is defining the

actions required to restore, or launch the recovery of, the biological community, with special emphasis on the vegetation as support for the rest of the ecosystem. Sometimes, as expanded below, livestock grazing is essential to control plant community development and invasive plant species (Reeves & Chiampon, 2004). Water quality improvement can be a major driver of wetland restoration, and this aspect should be integrated in any restoration plan. Specific tools must be used for understanding the appropriate wetland size and design according to selected objectives, for example restoring wetlands for water quality improvement (Kadlec & Wallace, 2008) or facilitating the recovery of aquatic bird populations (Huang & Isobe, 2012).



**Figure 1:** Restored floodplain and river channel, River Skjern, Denmark.

Restoration protocols can either comprise successive, incremental steps in selecting the characteristics of the wetland site, or sites, to be restored or multipurpose protocols where a simultaneous assessment of combinations of characteristics or sites is undertaken. The first approach is useful where a hierarchical order of objectives is established (e.g., firstly improving water quality; secondly recovering plant populations; thirdly delivering recreation objectives, etc.) (Newbold, 2005). The second approach is more appropriate to define the optimum combination of restoration actions to deliver multiple objectives while restoring a single wetland or to select the wetland restoration sites that contribute to one or several combined objectives (Zhou et al. 2008; Moreno-Mateos & Comin, 2010). In either case, integrating the social and economic aspects which are most relevant to the acceptance and participation of



local people and the availability of funding are key aspects that require specific tools for consideration in wetland restoration projects (Comin et al. 2005).

## Restoring Abandoned Wetlands

The nature conservation value of many European wetlands is a result of historical human management. Certain wetlands have developed and subsequently been maintained for centuries by human intervention, and are used for agricultural production by livestock grazing and mowing for hay, or reed swamps cut for building material. This is particularly the case for wet grassland. Their regular management is perceived in Europe as being essential for nature conservation because it removes the aboveground biomass to allow a diversity of less robust plants to coexist, and to maintain an open landscape suitable for large numbers of wading birds and wildfowl (Joyce and Wade, 1998). Agricultural changes during the 20th century have resulted in enormous losses of wet grasslands, with a decline in the European resource of at least 80% and up to 99% in some regions (e.g., Luoto et al. 2003). The main driver has been agricultural intensification to increase productivity, usually in the form of drainage, inorganic fertilizers, and ultimately ploughing. The relatively few wet grasslands that have escaped intensification practices are now threatened by a less well-known but potentially critical phenomenon: abandonment, which is the cessation of farming practices often due to marginal economic viability or policy changes.

Wetland abandonment is widespread in Europe, especially in the central European and Baltic countries, and results in losses of characteristic and rare plant and animal species, and overall species diversity, as succession proceeds and the more robust plants eventually dominate the habitat. Abandonment can be seen as a positive opportunity to return to a more self-sustaining system or to steer management towards other, more utilitarian ecosystem services. However, managed European wet grasslands often represent biodiversity hotspots in wider, impoverished landscapes. Consequently, initiatives to restore abandoned wet grasslands in Europe by reinstating management have begun, although the success of these schemes appears to be variable. There is evidence that indicates abandoned wet grasslands can be rehabilitated by reinstating cutting or grazing, with beneficial changes being observed in two years in some cases (e.g., Straškrabová & Prach, 1998; Billeter et al. 2007), but that complete restoration to a previous condition is elusive. Long-abandoned grasslands, or those where shrubs or reeds have invaded, may need a more interventionist approach to initiate or accelerate vegetation recovery, such as additional disturbance to the vegetation or soil surface (Berg et al. 2012). Moreover, the viability of wet grassland restoration can be constrained by a lack of diaspores (e.g., in the seed bank) and dispersal vectors (e.g. flooding). However, even if the environmental constraints can be overcome, the restoration of abandoned wet grasslands needs to demonstrate a societal relevance and a benefit to stakeholders.

## Stakeholder Engagement in Wetland Restoration

The restoration of wetlands is often associated with potentially conflicting issues such as the demands of food production against the requirement to enhance biodiversity. Embedded in these issues is the limiting factor of how wetland restoration will be financed. In some EU member states the restoration of wetlands or actions for their conservation are considered agri-environmental measures which are eligible for financial support within rural development plans (DG AGRI, 2005). The criteria to access state financing for wetland restoration in the agricultural landscape are mainly based on the delivery of positive impacts on biodiversity or nutrient retention. However, in most cases agricultural landowners have to prioritise production to ensure economic viability, and often it is incumbent on the landowner to take the final decision regarding initiating a restoration project (Hansson et al. 2010). Consequently, there is a strong need to find new ways of engaging landowners and other key stakeholders in wetland restoration. In this respect, the promotion of multi-functional wetlands may be a promising way forward (Andersson, 2012). From a farming perspective, the appealing wetland services include the provision of irrigation water and hunting and fishing opportunities, offering recreational benefits with an economic return. From a societal perspective, the flood buffering capacity of wetlands may be valuable (Jenkins et al. 2010). To achieve flood risk protection, it is necessary to consider the implementation of a broad range of wetland systems such as wet grasslands and larger wetlands with permanent water, preferably developed at a catchment level (Mitsch & Gosselink, 2000). Applying a catchment approach supports more coordinated actions and facilitates large-scale impact modelling and monitoring. Schemes that deliver payments for ecosystem services (PES) represent potential instruments to create new financial arrangements to support wetland restoration and conservation (Wendland et al. 2010). For instance, landowners who convert drained cropland into wet grasslands facilitating seasonal flooding can be financially rewarded for providing a flood risk reduction service. Under such initiatives the role of farmers is rebalanced from primarily producing food to delivering a broader suite of ecosystem services. This has the potential for new actors to be engaged in wetland restoration.

### Conclusions

Wetland science has a long history in Europe, which encompasses social sciences, economics and the understanding of local knowledge and culture. The embracing of stakeholders from multiple sectors to optimise the benefits delivered by wetlands is both increasingly necessary and apparent in Europe, and none more so than in the field of wetland restoration. Similarly, the use of tools and protocols that integrate environmental and socio-economic components within wetland restoration projects are increasingly relevant. From local projects seeking to restore small abandoned meadows to pan-European





initiatives seeking to disseminate information, the importance of demonstrating the benefits that flow from wetland restoration is now widely recognised. While much work still needs to be done, novel and exciting perspectives on wetland restoration continue to be exchanged through a range of fora, including meetings such as those hosted by the Society of Wetland Scientists, and the message that restoring wetlands delivers positive benefits to multiple stakeholders is slowly permeating a wider consciousness.

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# The Sharper Image: Hyperspatial Remote Sensing of Wetlands

Meghan Halabisky<sup>1</sup>, Michael Hannam<sup>1</sup>, A. Lexine Long<sup>2</sup>, Chris Vondrasek<sup>1</sup>, and L. Monika Moskal<sup>1</sup>

<sup>1</sup> 1. School of Environmental and Forest Sciences, University of Washington, Seattle, WA 98195

<sup>2</sup> 2. Quinney College of Natural Resources, Utah State University, Logan, UT 84321

## Abstract

Recent advances in remote sensing such as increased availability of high-spatial-resolution data and new processing techniques promise to broaden the applicability of remote sensing to wetland scientists and managers. We aim to introduce wetland practitioners to several cutting-edge remote sensing imagery analysis techniques now available; illustrate new innovative uses of these techniques by highlighting four case studies where high spatial techniques were employed; and finally to identify the unique abilities, challenges, and limitations of these remote sensing tools. We present four case studies of high spatial resolution remote sensing data used in wetland research applications, each using different data sources and processing techniques. These case studies illustrate the use of multispectral and historical aerial photography, aerial LiDAR, and Terrestrial Laser Scanning, to investigate invasive species, land use change, and mapping in wetland systems. We demonstrate how emergent remote sensing technologies offer both unique abilities and unique challenges.

**Keywords:** Wetlands, Remote Sensing, Hyperspatial, OBIA, LiDAR, TLS

## Introduction

Since the early 1970s, scientists have mapped, monitored, and studied wetland ecosystems using remote sensing techniques, which continue to facilitate understanding of wetland ecosystems at multiple spatial scales (Ozesmi and Bauer 2002). Unfortunately, the spatial resolution of many remotely sensed data is too coarse to resolve individual wetlands and is not often useful in wetland science. For example, 88 % of wetlands in the prairie pothole region of North Dakota are smaller than 0.4 hectares (Gilmer et al. 1980), thus, satellite imagery with a 30 meter pixel size (e.g., Landsat) cannot map these wetlands. Recent advancements in computer processing, sensor capability, and analytical techniques, coupled with wider availability of remotely sensed data of finer spatial, temporal, and spectral resolutions promise to broaden the applicability of remote sensing to wetland scientists and managers.



The trend towards hyper-resolution of remote sensing has always been part of the discipline; however, the aforementioned factors have recently accelerated this trend. Thus, Chambers et al. (2007) defined the term 'hyper' in remote sensing, where the spatial dimension is referred to as hyperspatial, spectral dimension as hyperspectral and temporal dimension as hypertemporal. Data that resolve differences in scene properties at a location separated by 1 meter or less, such as: aerial photography, aerial, terrestrial and mobile light detection and ranging (LiDAR), and multispectral satellite imagery (e.g., IKONOS and Quickbird) have been referred to as hyperspatial (Chambers et al. 2007; Greenberg et al. 2005; Turner et al. 2003).

Hyperspatial data can include historical black and white aerial photography, a temporally rich resource allowing for studies of change detection in wetlands. Although the historical frequency of hyperspatial data is not in the hypertemporal realm, the ability to look at landscapes as early as the 1930s is appealing and the data frequency can facilitate multitemporal analysis such as decadal change detection studies. Much of the historical hyperspatial aerial photography data are in the public domain making it an attractive choice to research projects struggling with funding limitations (Moskal et al. 2011). With the advent of hyperspatial data availability, new tools and methodologies for working with these types of data are necessary; moreover, it is important to understand how traditional per-pixel based techniques developed for coarse spatial resolution imagery (e.g., Landsat) can be applied to hyperspatial data. Therefore, we focus on hyperspatial resolution remote sensing application in wetland sciences.

We aim to introduce wetland practitioners to several cutting-edge remote sensing techniques now available; illustrate new innovative uses of these techniques by highlighting four case studies where hyperspatial techniques were employed; and finally to identify the unique abilities, challenges, and limitations of these remote sensing methods.

Specifically we present the following case studies:

- Mapping of an invasive wetland plant using pixel-based classification of hyperspatial-resolution aerial photography.
- Investigating historical changes to wetlands using Object-Based Image Analysis of hyperspatial-resolution aerial photographs with low spectral resolution.
- Mapping montane wetlands using Object-Based Image Analysis and aerial LiDAR.
- Mapping and monitoring intertidal microtopography using Terrestrial Laser Scanning.

## Case Study 1: Using remote sensing to map *Phragmites australis* in Great Salt Lake wetlands

In this case study we used pixel-based classification (PBC) of hyperspatial multispectral aerial imagery to map the distribution of the invasive strain of the wetland grass *Phragmites australis* (herein *Phragmites*). *Phragmites* is a widespread invasive wetland plant across North America, with large populations in the northeast, great lakes region and areas in the west (Bourgeau-Chavez et al. 2012; Kettenring et al. 2012; Kulmatiski et al. 2011; Saltonstall 2002). It is a tall, clonal, perennial grass that creates dense monocultures, displaces beneficial native wetland vegetation, fragments marshes, and can reduce the quality of the habitat and ecosystem services provided by wetlands (Chambers et al. 2008; Silliman and Bertness 2004). *Phragmites* has become a major problem in the wetlands of the Great Salt Lake (GSL), Utah. Despite significant resources spent controlling this plant on public and private lands in Utah, the full extent of *Phragmites* around the GSL wetlands remains unknown (Kettenring 2012). Previous mapping efforts using field surveys and low-resolution air photos were outdated (2006), limited in extent and at a coarse resolution. *Phragmites*-dominated marshes are dense and difficult to walk through, making field surveys of *Phragmites* challenging. Additionally, these marshes are often hard to access due to deep water, water control structures, and land ownership issues. These reasons underscore the value of using remote sensing techniques to determine current extent of *Phragmites* around the lake.

### *Pixel Based Classification*

Pixel based classification (PBC) of remote sensing imagery is one of the simplest, best understood, and most commonly used classification techniques for aerial imagery (Jones and Vaughn 2010), and has been used for a variety of wetland research applications. PBC classifies landscape features using their spectral signatures, the intensity of reflected and emitted radiation of different wavelengths. With coarser-resolution imagery, such as satellite imagery, PBC can often only classify vegetation types into broad categories. However, as finer-resolution multispectral aerial imagery becomes more available, PBC can be used to differentiate between wetland plant species.

With PBC, each pixel is assigned a class based on its spectral signature. We used supervised classification techniques, in which the user selects 'training pixels' of a known class type (e.g., *Phragmites* marshes). The computer then assigns each remaining pixel to the class of the training pixel of greatest spectral similarity.



In May and June 2011, we acquired hyperspatial multispectral aerial imagery for all major wetland areas around the GSL. We used the Utah State University Remote Sensing Services lab Cessna TP206 aircraft, which is set up for remote sensing data collection, and collected imagery specifically for this project.

Images are one-meter pixel resolution, with imagery in four spectral bands- red, green, blue, and near-infrared. We acquired data in late spring, an ideal time to identify *Phragmites* using remote sensing, because of the differences in growth stages between *Phragmites* and other wetland plants (Maheu-Giroux and Blois 2005; Neale et al. 2007).

Following image acquisition, we pre-processed the aerial images using ERDAS Imagine 2010 software ("Intergraph, Geospatial Operations, Norcross, GA). We identified training pixels from ground-truthed data by visiting major wetland units in the summer and fall of 2011, and again in the spring of 2012. We used PBC to classify vegetation into nine groups based on the dominant species and/or communities to determine the distribution of wetland plant species of interest: *Phragmites australis* (common reed), *Typha* spp. (cattail), *Distichlis spicata* (saltgrass), *Salicornia europaea* (pickleweed), *Schoenoplectus acutus* (hardstem bulrush), playa wetlands, native emergent wetland, upland, and open water. We used ground-truthed points that we had set aside and not used as training pixels to evaluate the accuracy of the classification.

Our vegetation map represents the most extensive and detailed mapping of *Phragmites* around the GSL to date. Our results indicate a substantial *Phragmites* invasion of key federal, state, and private wetland areas around GSL. Management of these wetlands for waterfowl habitat should benefit from our documentation of *Phragmites* distribution. We created an interactive online website that displays the imagery, and allows users to draw an area of interest and return the amount of *Phragmites* or other wetland vegetation in that area (<http://maps.gis.usu.edu/gslw/index.html>). The resulting vegetation data will also be used for future work to determine correlations between environmental and anthropogenic variables and the presence of *Phragmites*.

### Considerations

Pixel-based classification and hyperspatial imagery offered a time and cost effective method for determining the extent of an invasive wetland plant that would have been difficult to survey in the field due to dense vegetation, varying water level and access issues from a patchwork of land ownership around the GSL. However, in our study there were several areas where management actions such as early season mowing, breached dikes, or previous herbicide applications caused classification errors. These areas were generally easily identifiable because of their large size, and were manually recoded based on verification

from field visits, land manager information and aerial imagery. Despite these complications, using hyperspatial remote sensing to map wetland vegetation around the GSL proved to be a better solution for determining the current extent of *Phragmites* distribution as opposed to labor intensive comprehensive wetland field surveys. PBC was successful because we were able to acquire multispectral imagery at a high resolution. Hyperspatial multispectral imagery can be somewhat expensive to acquire, but is relatively efficient to process using PBC methods. While our aerial imagery was acquired specifically for this project, there are often publically available hyperspatial image datasets. For example, the state of Utah collects hyperspatial 4-band multispectral imagery every two to three years (Utah AGRC), and other states may have similar programs. More readily available, true-color aerial photographs do not allow for as much spectral differentiation, and would not work as well for differentiating between wetland species.

## **Case Study 2: Understanding historical ecology using aerial photographs and Object Based Image Analysis**

In this study we sought to quantify long-term decadal changes in wetlands in a region of semi-arid sage shrub-steppe in eastern Washington State, and to understand how trends in the surrounding land uses influenced these wetlands. In the study area, conversions of the sage shrub to livestock grazing lands and agricultural uses over the past century have affected water resources, native plant species and wildlife habitats, generally leading to a decline in species populations (Foster Creek Conservation District 2013; Mitsch and Gosselink 2007). We hoped to identify areas where wetlands persisted and to identify the long-term factors that influenced them. However, understanding historical wetland conditions and identifying the drivers of wetland change across a large landscape can be challenging. Evidence of past conditions is often ephemeral, as when a wetland has been plowed over, or non-existent, because field data on wetland conditions were never collected.

Historical aerial photographs offer the unique opportunity to see and measure temporal changes in wetlands and the surrounding land uses. These photographs allow investigations into past wetland conditions before satellite imagery became available. They are available to the public from archives in governmental agencies and university libraries, at hyperspatial resolutions and at modest, if any, cost.

The limited spectral information contained in black and white historical aerial photographs and lack of near-infrared coverage, has limited their use to projects where manual photo interpretation and hand delineations were appropriate, for example, the National Wetland Inventory (NWI). In this case study we used Object-Based Image Analysis (OBIA) methods to develop a new way to use these historical images to quantify changes in wetlands. We combined our





OBIA classifications of wetland ponds and agricultural activities with County precipitation records and WA State Geographic Information System (GIS) geology layers to develop a more complete picture of the historic ecology of these wetlands.

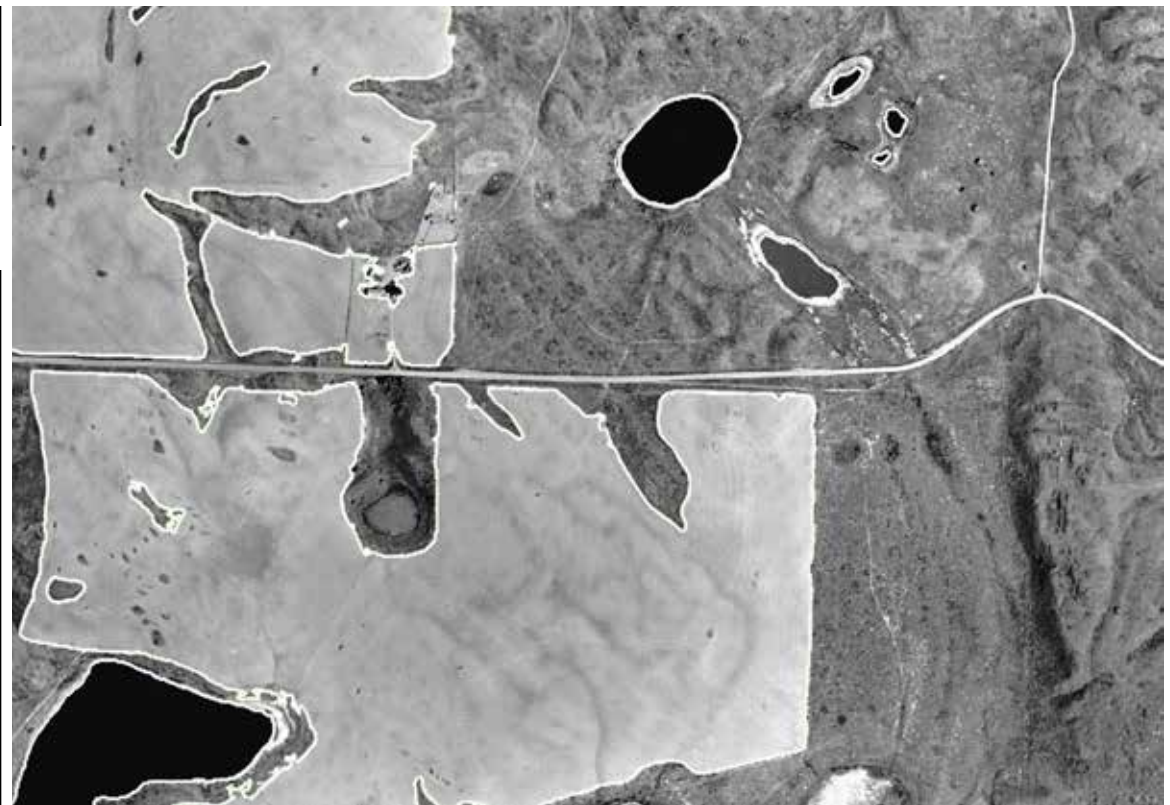
### *Object-Based Image Analysis*

Object-Based Image Analysis (OBIA) is a technique to derive “meaningful objects” from a raster dataset by delineating or classifying areas with similar characteristics (Blaschke 2010). These “objects” can range from features of interest in the landscape to critical medical anomalies in a tissue biopsy. OBIA differs from the traditional PBC technique in that it mimics human pattern recognition. The first step in an OBIA process is image segmentation, which aggregates pixels into objects based on their spectral similarities. After the initial segmentation by the computer, the human analyst begins an iterative and heuristic process to select spectral characteristics such as color as well as spatial characteristics such as shape and texture that will best classify the objects of interest. The analyst builds a unique computer algorithm, called a ruleset, using the characteristics that best separate the classes of interest. The primary differences between OBIA and PBC are the initial segmentation, and OBIA classification of multi-pixel objects as opposed to individual pixels.

### *Process*

In this study, we classified the open water ponds and plowed agricultural fields in a 20,200 hectare study area, known as the channeled scablands. We used five sets of images: historic, black and white aerial photographs from 1955, 1965, 1978, and 1991, and true color National Agriculture Imagery Program (NAIP) imagery (red, green blue) from 2006 obtained through the USDA Farm Service Agency. This study focused on changes to wetland ponds during this time span. The ponds were classified as a central feature anchoring the seasonal wetlands surrounding them. The “plowed fields” classification defined a land use where the native sage and shrub-steppe vegetation had been completely destroyed, and land cover no longer had the surface hydrology and water infiltration characteristics of the native plant coverage (Figure 1).

Our approach mapped and quantified changing water resources and related wetland habitats across the landscape. It indicated influences on the variability of surface and ground water flows around the ponds from the nearby land uses and vegetation conditions. We also spatially correlated locations of ponds and wetlands that persisted and varied less through the decades with areas of intact native sage shrub-steppe vegetation. These persistent ponds and sage shrub habitats were underlain with thin basaltic soils, which are both less porous for ground water penetration, and historically have limited plowed agriculture.



**Figure 1:** Black and white aerial photograph from 1955 showing high resolution of historical imagery with ponds and agricultural fields classifications.

### *Considerations*

Although the classifications were limited to ponds and plowed fields in part due to the limits of the black and white imagery for this analysis, OBIA allowed historical aerial images to be used in a new way and to quantify wetland changes over a much longer period of time than previous work. Although the historical imagery provides only one band of image information with which to discern critical classification characteristics such as size, shape, texture and pattern, it often offers wetland researchers several additional dates of hyperspatial images for analysis. In contrast, though a full color infrared image will offer the analyst and the software red, green, blue, and infrared bands as well as the ratios between them with which to develop a classification algorithm; it may lack either the resolution or the historical reach needed to answer all research questions.

Challenges with using historical imagery include repurposing imagery that was originally taken for other goals, as well as finding archived imagery. These individual photographs required extensive preprocessing to standardize the gray-scale variability between images and then to mosaic the image tiles into a single raster for the complete study area.



## Case Study 3: Mapping montane wetlands using Object-Based Image Analysis and aerial LiDAR.

Comprehensive wetland inventories are a necessary first step in protecting and preserving wetlands. The National Wetland Inventory (NWI), the most comprehensive wetland inventory in the U.S., was created by manual interpretation of hyperspatial aerial photos. In some areas the NWI can be used as a reliable source, while in other areas it is either out-of-date or inaccurate (Morrissey and Sweeney 2006; Tiner 1990). The accuracy of the NWI varies across the U.S., with omitted wetlands being particularly common in forested areas where the forested canopy obstructs the aerial view of the wetlands beneath (Morrissey and Sweeney 2006). This problem is exacerbated in areas that contain high densities of evergreens, as the persistent forest canopy never allows an unobstructed view of the ground. Additionally, tree canopy and complex topography create shadows that can impede the photograph interpreter's view of wetlands.

Previous research mapping wetlands in eastern Washington proved OBIA to be an accurate (overall accuracy was 89 %), yet affordable technique to automate mapping of semi-arid wetlands (Halabisky et al. 2011); however, this project focused on non-forested areas. To adapt this method to map wetlands in forested and mountainous areas with steep topography and tree canopy, we used data products derived from aerial LiDAR and combined them with aerial imagery and thematic data to map wetlands in Mt. Rainier National Park.

### *Aerial LiDAR*

LiDAR is an active remote sensor that emits laser light toward a target and measures its return time to the sensor. Using this information the sensor is able to record a three-dimensional coordinate of the objects that the laser light hits. Scanning a surface with LiDAR produces a cloud of such coordinates, known as a point cloud. LiDAR allows the analyst to identify wetlands that would otherwise be obscured by trees or shadows.

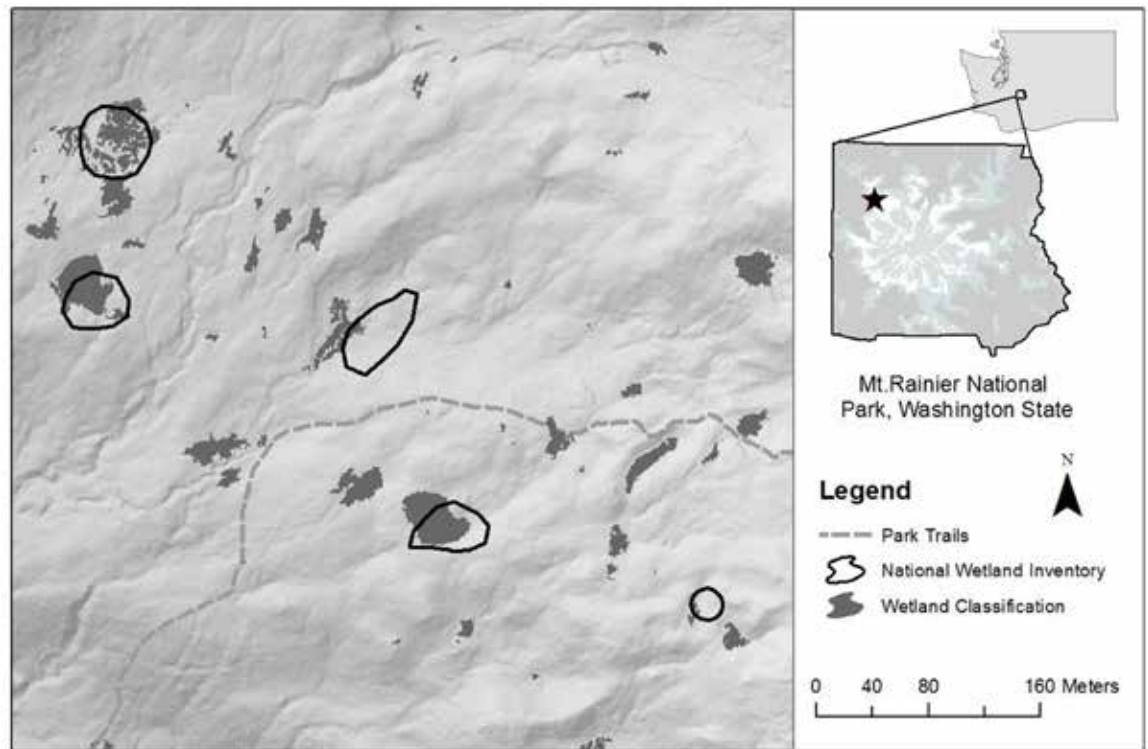
Typically LiDAR is delivered to a researcher as three unique data products; a ground model, a canopy surface model, and an intensity image. Raw data are also delivered, and should be archived as future processing and algorithms can improve the applicability of the data. The ground model provides hyperspatial detail of the topography. In our instance, we were able to detect even the decimeter-scale changes in elevation surrounding small ponds within our study area. A canopy surface model provides a surface of the highest objects in the scene (e.g., tree canopy). Finally, an intensity image provides the intensity of the reflected laser energy, which is typically an infrared wavelength. This intensity varies across a landscape as the laser pulses come in contact with different materials. The patterns evident within intensity images can be used to

identify wetlands. Because water absorbs light energy it often has low intensity values or will even contain “no data” if the light is fully absorbed by water. On the other hand, wetlands that do not have standing water during the time of LiDAR acquisition may highly reflect infrared light due to the presence of photosynthetic wetland vegetation.

### *Process*

In addition to the LiDAR data products available to us, we created several data layers to assist with the classification. We used the LiDAR ground model to create a slope index to help us highlight areas of low or no slope and a canopy height model, by subtracting the LiDAR ground model from the canopy surface model, which helped us to detect wetlands with low or no vegetation.

To map wetlands within our study area we analyzed the ground model, canopy surface model, canopy height model, intensity image, aerial imagery, and GIS layers of park roads and trails. We used OBIA to segment an image composed of the aforementioned data, and then created and applied an object classification rule set to delineate and classify wetlands in the study area. Not only could we detect substantially more wetlands than the NWI, we could also produce a finer, more accurate delineation (Figure 2).



**Figure 2:** Comparison of the National Wetland Inventory to semi-automated classification of montane wetlands using LiDAR and OBIA.



OBIA software programs, such as eCognition (Trimble Navigation, Ltd, Sunnyvale, CA), allow the user to detect patterns within multiple data inputs. This can improve upon photo interpretation because it allows identification of patterns that might otherwise be hard to detect manually from so many different data layers. This was helpful for our project which incorporated many data input layers describing wetland characteristics such as slope and canopy height.

Some challenges inherent in LiDAR analyses result from the technology's relative youth. LiDAR intensity data commonly fluctuates across a scene due to internal sensor errors, rather than actual target properties. Recent advances allow normalization of LiDAR intensity across a LiDAR acquisition (Vain and Kaasalainen 2011), but such data are not yet commonly available. Intensity values cannot be easily used to detect more subtle patterns such as specific vegetation communities or individual plant species because few datasets are normalized.

When studying forested areas, LiDAR data must be acquired at a high enough density to penetrate the forest canopy. Low-density LiDAR, typically acquired for topographic applications, will be unable to detect forested wetlands as the laser will be unlikely to reach the ground below the canopy. Thus, as with the decadal aerial photography change analysis, one can find challenges using data collected for a different application.

An additional challenge is that the output dataset from an OBIA process delineates the pixel edges, creating highly detailed wetland polygons with many vertices. This differs from manual delineation, which simplifies the wetland border, using significantly fewer vertices. Although the increased detail provided by OBIA is usually more accurate, it creates a large and unwieldy dataset that can be difficult to display in GIS. Finally, although this technique can be more cost effective than manual photo interpretation, the high cost of both LiDAR data acquisition and OBIA software programs, and the computational hardware requirements, limit their availability to many users.

#### **Case Study 4: Terrestrial Laser Scanning of Intertidal Habitats**

Intertidal estuarine topography, even at centimeter to decimeter scales, can profoundly affect biological communities by affecting local tidal inundation patterns and temperature (eg., Garrity 1984), but it is particularly difficult to measure. Soft, unconsolidated sediment hinders direct measurement both by limiting travel, and by making it difficult to measure elevations without disturbing or compacting sediments. Unfortunately, remote measurements are also problematic. Conventional aerial LiDAR data must be obtained during

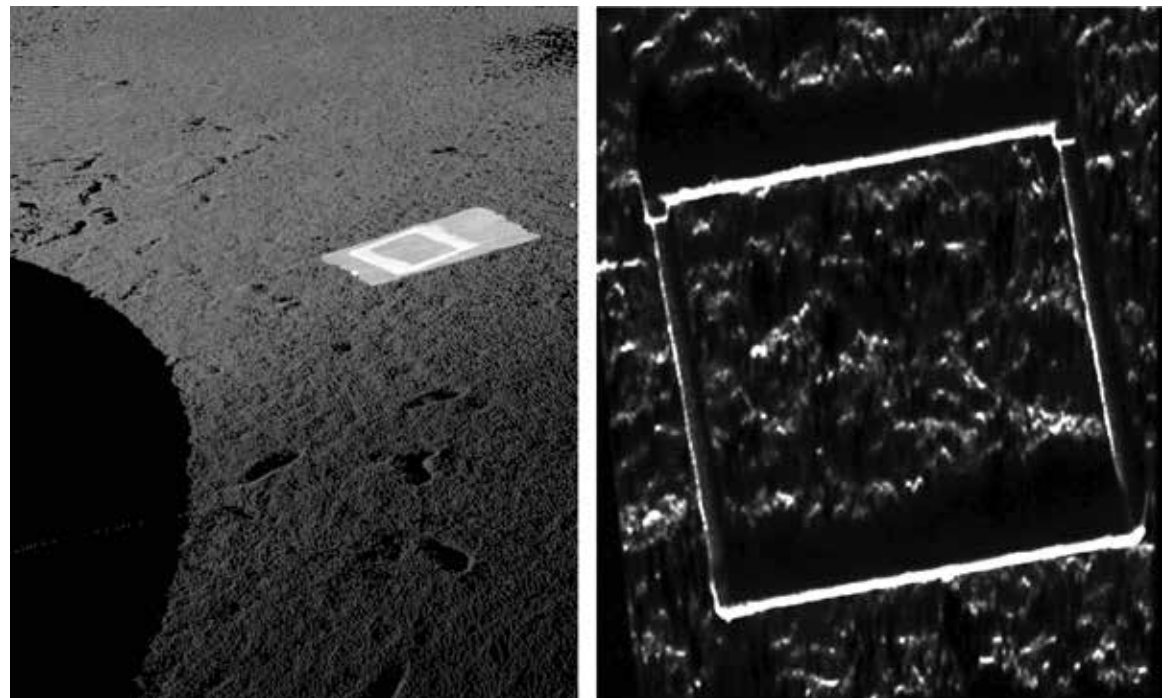
a low tide (e.g., Chust et al. 2008), which precludes the use of much readily-available LiDAR data. Even during a low tide exposure, standing water and saturated soils reduce the efficacy of the infrared lasers used in most aerial LiDAR applications. The shallow water depth at such locations inhibits sonar surveys.

Terrestrial Laser Scanning (TLS), also known as ground-based LiDAR, may potentially overcome some of the aforementioned challenges to topographic measurement in estuarine wetlands. These tripod-mounted instruments are capable of mapping surfaces with sub-centimeter precision (Vierling et al. 2008). Just as aerial LiDAR, TLS measures the time of flight of emitted laser pulses to create three dimensional point clouds of a surface (Figure 3). With this technique, sediment disturbance can be limited to the scanner location while remotely measuring undisturbed areas.

### *Process*

An invasive, intertidal seagrass, *Zostera japonica*, appears to be influenced by centimeter-scale topography when growing alongside its native congener, *Zostera marina* (Shafer 2007). To elucidate this relationship, we first sought to quantify the relationship between local microtopographic relief and cover of these two species. Second, we sought to quantify spatiotemporal variability in the patterns of intertidal microtopographic relief at the study site.

We created fine scale topographic maps, digital elevation models (DEMs), of the study site from TLS surveys over three years. From these DEMs, we calculated a Bathymetric Position Index (BPI), a scalable index of topographic



**Figure 3:** Example of TLS scan data. Note that the scan resolves footprints in left panel. The right panel shows a close up intensity image of a 0.5 meter X 0.5 meter PVC quadrat.

position (Lunblad 2004). With the DEMs and BPI maps, we examined the relationships between microtopographic setting and species cover, and investigated temporal changes in site topography.

During each mapping visit at our study site, we conducted multiple TLS scans from different vantage points to extend the spatial extent of our study area. Multiple stationary, reflective targets placed in the study site provided common spatial landmarks for subsequently combining scan data. We georeferenced scans by taking kinematic Global Positioning System (GPS) measurements at each reflective target during each survey.

### *Considerations*

Despite the logistical challenges of managing the equipment required for TLS surveys in soft sediment intertidal environments, we could relate species cover to centimeter scale topographic relief at the site.

TLS data acquisition may be limited by characteristics of the landscape, and by characteristics of the instrument. Intertidal mudflats are characteristically wet, and periodically submerged. Although saturated sediments did not inhibit data acquisition in this study, standing water did. Pools of standing water greatly reduced TLS return density, and introduced occasional reflection artifacts.

A common instrument-specific limitation of TLS is its stationary tripod mount. Scanner height limits data acquisition because of its fixed vantage point. Data-point spacing increases as target range increases because the vertical and horizontal angle between successive scan lines is fixed within a scan. This limited our useful scan radius to approximately 50 meters. Some researchers have extended the useful range of scans by elevating the scanner to considerable heights above the sediment surface (e.g., Anderson et al. 2009).

Another challenge presented by the TLS vantage point is shadowing created by topography, or erect vegetation. Although shadowing was nonexistent in our application because of the gentle nature of site topography and the lack of erect vegetation, it could pose a serious challenge in densely vegetated sites (Anderson et al. 2009). To overcome this challenge, the researcher may increase the point density of scans to penetrate more vegetation gaps, and scan from multiple vantage points.

Quantification of temporal change in microtopography proved more difficult than relating species to topography. Quantification of temporal change requires the spatial alignment of scans from different dates. This may be done by creating persistent, stable landmarks in the study area that can be referenced at different survey dates, or by georeferencing scans from different dates with GPS, as we did. The dynamic nature of an intertidal environment makes the

former approach challenging, although permanent monuments can be created in tidelands (Boumans 1993). GPS was our greatest source of positional error in our workflow. Longer GPS observations should yield some improvement in GPS, error, but the tidal regime and security of a study site will determine the feasibility of this approach.

Perhaps the greatest challenge of many TLS-based studies is determining how to use the acquired data. A “shoot first and ask questions later” approach will likely cause frustration. TLS data are dense and detailed (Figure 3), and a researcher must first plan on how to extract useful summaries or measurements from the data. This can be both a conceptually and practically difficult problem.

## Discussion

Hyperspatial remote sensing promises to provide wetland scientists and managers with data at spatial scales that are relevant to wetland issues. Like traditional satellite based remote sensing, hyperspatial remote sensing allows for non-destructive sampling, measurements of great spatial extent, and investigation of locations that are difficult to access in person. Hyperspatial remote sensing and the new analysis techniques that accompany it additionally provide unique opportunities and unique challenges to those who employ them.

By virtue of the finer spatial detail afforded by hyperspatial remote sensing, the size of objects that can be detected and mapped has decreased, sometimes enough to resolve individual study organisms. Improved resolution allows the study of smaller wetlands, which are both numerous, and perhaps more vulnerable than larger wetlands (Tiner 2003). Although the spatial resolution of data has grown finer, the spatial extent remains broad. This wealth of data allows for multi-scale investigations of ecological phenomena.

The fine spatial resolution of hyperspatial remote sensing data is a double-edged sword. Increased information density yields novel insight, but requires greater storage capacity and processing power, and often more complex analyses. For example, an aerial image with a 1 meter pixel resolution is more than 300 times larger than one with the 30 meter per pixel resolution typical of most Landsat satellite imagery (Table 1). These large file sizes result in time-consuming computationally expensive processing. While continuing improvements in computational ability and data storage will ameliorate one aspect of the problem, file size is not the only challenge of too much information

The great detail in hyperspatial data includes information irrelevant to the investigator. Hyperspatial aerial photography resolves shadows that would be averaged in a 30 meter pixel. This kind of detail often necessitates more complex analytical procedures such as OBIA. TLS data may map every limb of





Data Type	File Size/ Hectare	Spatial Resolution/ Spatial Extent	Strengths	Weaknesses
<i>Hyperspatial Data</i>				
Black and white aerial photography	~140 kb	0.25m/varies based on camera type and flight parameters	Inexpensive to acquire, historical coverage as early as the 1930's	Spectrally limited, rarely acquired after year 2000
True color aerial photography	~38 kb	1m or finer	Publicly available imagery	Radial distortion, not radiometrically standardized
Multispectral aerial imagery	~250 kb	1 m/ based on camera and flight parameters; example: 50 km <sup>2</sup> at 1:30,000 scale	More spectral bands than true color photographs	Sometimes expensive to acquire
Aerial LiDAR	~5 MB	Variable, but mostly 1 m to sub m, flight swaths cover up to 500 m	Provides 3-D data. Not impacted by shadows	File size, not always available
TLS	~ 200 MB	Variable, can be sub-centimeter and cover areas as large as 20 m radius	Fine spatial resolution	File size, acquisition logistics, issues with occlusion
<i>Multispectral Satellite Imagery</i>				
Example: Landsat	~114 b	30 m/~185 km <sup>2</sup>	Widely available, free to download, global coverage, historical coverage	Low spatial resolution
Example: IKONOS	~300 kb	1m to 4m/11 km <sup>2</sup>	Widely available, free to download, global coverage, historical coverage	Availability varies

**Table 1:** Comparison of file size, spatial resolution and potential value of hyperspatial remotely sensed data. Landsat and IKONOS are included for comparison.

a tree (Moskal and Zheng 2011) or individual blades of a sedge (Moskal and Zheng 2012). Such detail requires data summary, just as plot-based surveys summarize vegetation for a site. It is imperative for a researcher to have a hypothesis and an analytical plan before beginning to collect these data.

PBC can be a time and cost-effective option for classification of high resolution remote sensing imagery. PBC is one of the most well-known and straightforward ways of classification of hyperspatial imagery. PBC can be an especially good option for institutions and agencies that focus most of their analysis in GIS software, as the method can be implemented in GIS such as ArcGIS 10.0 (ESRI, Redlands, CA) without requiring a separate software package or more expensive programs such as ERDAS Imagine. Furthermore, spatial features implemented in OBIA analysis can, to some extent, be utilized in PBC with the

implementation of texture (Franklin et al. 2000). Additionally, there are open source software options for PBC such as GRASS (GRASS Development Team 2012) and MultiSpec (Purdue Research Foundation 2011).

Hyperspatial resolution tends to come at a penalty to the other resolution dimensions applicable in remote sensing: the spectral and temporal. Although many hyperspatial sensors are also multispectral (collecting four or more wide spectral bands), there are only a few hyperspatial sensors capable of collecting hyperspectral data (data collected at 10 nanometer or finer spectral increments). Such data availability is only a recent development and very costly, especially for repetitive (temporal) observations. Although hyperspectral data are often utilized to determine vegetation species composition, and could be a useful indicator related to ecological condition of wetlands; few studies have employed this technology to study wetlands (but see Adam et al. 2009; Hestir et al. 2008).

Finally, some satellite hyperspatial data does not easily allow for repeat coverage at 'hyper' frequencies, such as the daily or better coverage defined by Chambers et al. (2007), or long term bi-weekly satellite imagery such as Advanced Very High Resolution Radiometer (AVHRR) or Moderate-Resolution Imaging Spectroradiometer (MODIS ) satellites, due to the orbit characteristics of the sensors. However, aerial platforms, including non-traditional platforms such as: kites, blimps, balloons and drones, can provide for such frequencies, at costs much lower to the traditional aerial platforms such as a fixed-wing aircraft and helicopter. For example, open technology and science initiatives such as "The Public Laboratory" (cite: <http://publiclaboratory.org>) are leading the incorporation of the public remote sensing community by collecting near-infrared remote sensing data with alternative aerial platforms. Although the data collected have pixel sizes of much less than 1 meter, and can be deployed by the user at any time, the technical aspects of processing such data and acquiring it at large spatial extents are a technological challenge, but this is also being tackled by the community.

The temporal resolution of these data make them suitable for understanding wetland function, unfortunately, the coarse spectral and spatial resolution of these data has limited such research. As new remote sensing platforms such as unmanned aircrafts and webcams become cheaper and more common, these could revolutionize wetland observations the way wireless sensor networks and iButtons have changed *in-situ* field data collection.

## Conclusion

The advances in high-resolution, and specifically hyperspatial remote sensing, computational power, and analytical techniques promise great improvements in the inventory, monitoring, and study of wetlands and wetland-related species. The applications of these technologies, only a few of which we have outlined



here, could be useful to wetland research and management in a variety of ways. However, wetland researchers and managers should be aware of the benefits and limitations of each method. Using hyperspatial remote sensing can be extremely useful in wetland management, given the capacity to monitor large spatial extents with often incredible detail, and ability to monitor areas that are difficult to access, which is commonly an issue with wetlands. However, cost of data acquisition and processing may limit the practicality of these techniques in some cases. Presently, mapping and studying of wetlands through the use of hyperspatial data is typically a secondary use and not the primary reason for hyperspatial data acquisition. Researchers and managers should take into account the spatial extent of the study area, project budget, and resolution needed on a case-by-case basis.

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## **Author Contributions**

Michael Hannam helped conceive of the paper and orchestrate the collaborative effort. Meghan Halabisky, Michael Hannam, and A. Lexine Long contributed to the introduction and conclusion. Meghan Halabisky wrote the case study mapping montane wetlands using LiDAR and OBIA, Michael Hannam wrote the terrestrial laser scanning case study, A. Lexine Long wrote the pixel based classification case, and Chris Vondrasek wrote the historical aerial photography case study. L. Monika Moskal assisted in the writing of the introduction and conclusions as well as advised and supported the authors on three of the four case studies.

## Glossary

**Classification:** To arrange into classes according to shared characteristics; an analyst-defined system or order for describing distinct features (such as wetland types, land uses, location of patches of similar vegetation).

**Hyperspatial:** Data that resolves differences in scene properties at a location separated by 1 meter or less.

**Multispectral:** Imagery capturing data at frequencies across the electromagnetic spectrum, including light from frequencies beyond the visible range (red, green, blue).

**Pixel based classification:** A remote sensing method which classifies objects using their spectral signatures, the intensity of reflected and emitted radiation of different wavelengths. Each pixel is assigned a class by matching the spectral signature that mostly closely matches each class.

**Object-based image analysis (OBIA):** A technique to classify objects based on shared spectral, spatial, and contextual properties. OBIA differs from the traditional PBC technique in that it mimics human pattern recognition and allows for additional object features, not just spectral information.

**LIDAR:** “Light Detection and Ranging” or “Laser Imaging Detection and Ranging” is an optical remote sensing technology. It is an active remote sensor that emits laser light toward a target and measures its return time to the sensor. Using this information the sensor is able to record a three-dimensional coordinate of the objects that the laser light hits. As an active remote sensor LIDAR differs from a passive remote sensor (such as aerial photography) because it measures light that is provided directly from the sensor rather than reflected sunlight.

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## Society of Wetland Scientists Professional Certification Program - 2013-2014 President-Elect Announcement

May 8, 2013

Dear Professional Wetland Scientist:

Your votes have been cast and tallied for the SWS Professional Certification Program (SWSPCP) 2013-2014 President-Elect, so please join us in welcoming Rob Shannon as the newly-elected SWSPCP President-Elect. Rob is no stranger to our organization, having been certified as a Professional Wetland Scientist in 1998 and soon after joining the Certification Review Panel until he was appointed as Chair of the Review Panel in 2009. He is currently serving a second three-year term as Chair of the Review Panel and, in that capacity, also serves as a member of the SWSPCP Board of Directors as well as the SWSPCP Certification Standards and Ethics Committees.

Rob has been involved in wetland science for over 25 years, and is currently the faculty coordinator of the Environmental Resource Management program at the Pennsylvania State University. His wetland research coming to Penn State has focused on the biogeochemistry of trace gas emissions from natural and constructed wetlands, as well as on the effectiveness of nutrient removal in natural and constructed wetlands. As an experienced member of the SWSPCP Board of Directors, Rob is uniquely qualified in contributing to the mission of SWSPCP by serving wetland scientists across the world.

We look forward to working with Rob on many of the emerging issues for a young professional organization and to make sure the certification program continues to be accessible to aspiring wetland scientists in the private, non-profit, and public sectors, as well as to international applicants.

Congratulations and welcome aboard, Rob!

Sincerely,

Ingeborg Hegemann, PWS  
President, SWSPCP





# Environmental Law Institute Recognizes Seven National Wetlands Award Winners

Washington, DC — The Environmental Law Institute announced today the recipients of the prestigious National Wetland Awards—individual stewards from across the country who have been recognized for their exceptional and innovative contributions to wetlands conservation. “I congratulate the extraordinary individuals selected for the National Wetlands Awards for demonstrating how citizens and communities can—and do—make a difference,” stated ELI President John Cruden. “With our partners from the five leading federal agencies, we look forward to an awards ceremony that showcases the remarkable contributions they have made to a healthy and productive environment.”

The 2013 National Wetlands Awards recipients were honored at a ceremony on May 9, 2013 at the U.S. Botanic Garden starting at 6 pm. This year’s recipients were:

## Conservation & Restoration

Thomas Ries has played an instrumental role in wetland restoration in southwest Florida for over 25 years. Tom, executive vice president at Scheda Ecological Associates, has been involved in over 80 habitat restoration and stormwater retrofit projects. His work has won numerous environmental awards, and resulted in the restoration of more than 2,400 acres of wetlands.

## Education & Outreach

Ohio landowners, brothers Steve and Jerry Panzner, have transformed their restored wetlands into a living laboratory that have been used by hundreds of elementary, undergraduate, and graduate students. In 2012, Steve and Jerry donated their land to the University of Akron to be used for wetlands education, research, and outreach.

## Landowner Stewardship

Landowner Robert Zorb has worked with federal, state, and local partners to restore his land in Washington and Idaho. Since the late 1980s, over 150,000 plants and scrubs have been planted on Bob’s land, and many acres of upland and riparian wetlands have been improved. At the age of 83, Bob continues to plant trees on his land.

## Science Research

Pennsylvania State University Professor of Geography and Ecology Dr. Robert P. Brooks is a preeminent wetlands researcher. Rob’s work has resulted in more than 100 peer-reviewed articles, numerous book chapters, and more than 140 presentations. Rob has also trained 42 graduate students, furthering his contribution to wetlands conservation.

## State, Tribal, and Local Program Development

Doug Norris has been at the forefront of wetlands protection and conservation in Minnesota for over 20 years. As Wetlands Program Coordinator for the Minnesota Department of Natural Resources, Doug has been a tireless advocate for wetlands in Minnesota, championing their protection through regulation, monitoring, mapping, and restoration.

### Wetland Community Leader

As the director of the Elkhorn Slough Foundation for 30 years, Mark Silberstein has worked tirelessly to protect, restore, and share the Elkhorn Slough. Under Mark's guidance, the Foundation has brokered 48 land transactions, protecting nearly 4000 acres of land, and has restored more than 2000 acres of coastal and estuarine habitats.

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The National Wetlands Awards program is administered by the Environmental Law Institute and supported by the U.S. Environmental Protection Agency, U.S. Fish and Wildlife Service, Natural Resources Conservation Service, Federal Highway Administration, and USDA Forest Service.

“Wetlands are part of the foundation of our nation's water resources and are vital to the health of waterways and communities that are downstream,” said EPA acting Assistant Administrator for Water Nancy Stoner. “The extraordinary actions of National Wetlands Awards winners past and present provide continued inspiration in our efforts to protect and restore our nation's wetlands. EPA commends the winners for their incredible work.”

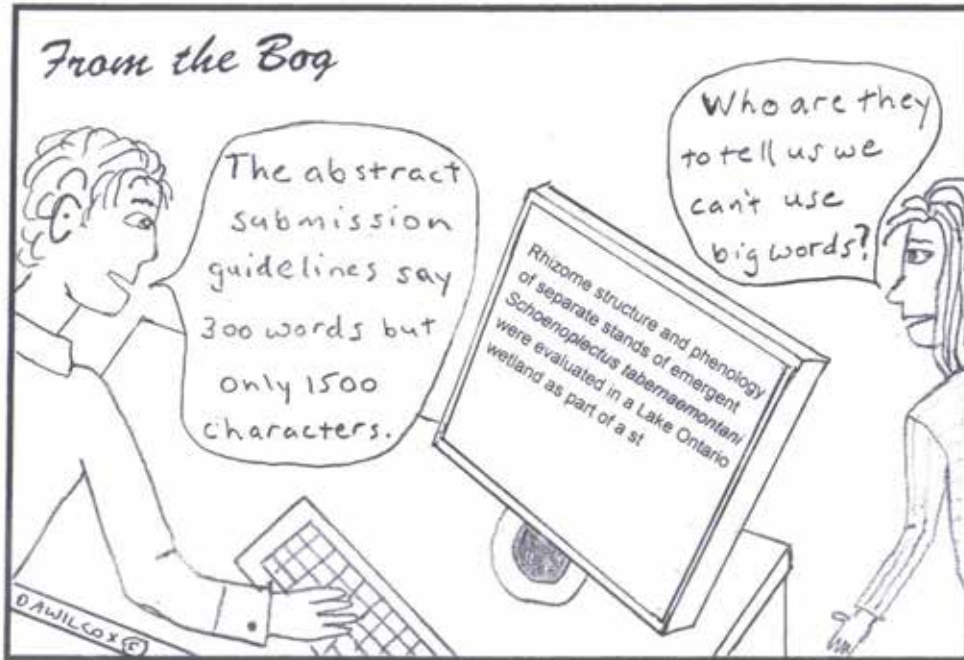
“In addition to providing vital habitat for fish and wildlife, wetlands help protect the health, safety and economies of communities across the nation. We are proud to help recognize and celebrate the outstanding people who have contributed so much to wetlands conservation for the benefit of all Americans,” said U.S. Fish and Wildlife Service Director Dan Ashe.

For more information about the National Wetlands Awards, visit [www.nationalwetlandsawards.org](http://www.nationalwetlandsawards.org) or e-mail [wetlandsawards@eli.org](mailto:wetlandsawards@eli.org).

Environmental Law Institute  
2000 L Street NW, Suite 620  
Washington, DC 20036

The Environmental Law Institute makes law work for people, places, and the planet. With its non-partisan, independent approach, ELI promotes solutions to tough environmental problems. The Institute's unparalleled research and highly respected publications inform the public debate and build the institutions needed to advance sustainable development.





A reason not to study softstem bulrush.



WETLAND SCIENCE AND PRACTICE



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