Applications of GIS & Remote Sensing in Wetland Restoration

It’s only recently that humanity has stopped actively destroying wetlands and that progress often seems tenuous. Objectively, the scientific community has recognized the importance of wetlands and the ecosystem services that they provide and have made moves to protect them with the Ramsar Convention and similar arrangements, but individual states and persons may consider them a nuisance when managing their land. Unfortunately, legislation is still being considered to roll back wetland protections within the United States under the guise of land management (Rott, 2018) demonstrating that wetland protection importance is far from settled. Even with conventions and other protections in place, the state of global wetlands remains bleak: “Wetlands are particularly degraded, with 87 per cent lost globally in the last 300 years, and 54 per cent since 1900.” (IPBES, 2018) Given the realities of limited funding, labor and a variety of wetland conversion pressures, scientist need techniques to maximize their output. GIS and Remote Sensing tools and methodologies are integral to the successful prioritizing and monitoring of wetland restoration projects and perhaps more importantly to the mitigation of wetland conversion risk.

The first phase of any wetland restoration plan is to identify which wetlands to restore. Holistic methods in which large scale planning and prioritization is done allow government bodies and NGOs to consider the state of wetlands across multiple countries. (Schleupner & Schneider, 2013) Schleupner & Schneider describe a GIS-based systematic planning technique which considers the economic benefits and costs, both direct and indirect, in their resource allocation planning, enabling financial implications to be weighed. While this technique is useful for determining a large-scale plan, it is somewhat limited when discussing restoration options for a particular wetland. Such things often require expert knowledge and higher resolution data. Multi-criteria spatial decision support systems (MCSDSS) are often employed to evaluate how best to restore or enhance a particular wetland. (Darwiche-Criado, Sorando, Eismann, & Comín, 2017) (Malekmohammadi & Rahimi Blouchi, 2014) These methodologies can be employed to establish a course of action which will maximize the overall restored ecosystem services even when the wetland in question is faced with extreme drought and degradation. (Maleki, Soffianian, Koupaei, Pourmanafi, & Saatchi, 2018) The specific techniques usually involve the creation of priority indices with expert knowledge and RS data to feed into a MCSDSS, and the appropriate weighting of indices to determine an overall best-case scenario.

It’s not enough to simply restore the wetlands; we must also monitor them to evaluate the success of the techniques employed and to prevent any further degradation.
To employ RS / GIS techniques in monitoring, appropriate indicators must be established which can be observed in multispectral or MODIS data. (Taddeo & Dronova, 2018) Long wavelength SAR techniques (Davidson & Finlayson, 2007) are useful for these monitoring efforts and encouraged by the Ramsar convention. Data and analysis costs remain high and so it’s important to develop techniques where monitoring can be performed in a semi-automated fashion. Image differencing provides a targeted approach to area that are changing (Nielsen, Prince, & Koeln, 2008) but requires human analysis to determine if the changed area are positive or negative. More interesting is the use of machine learning algorithms for object based image analysis (OBIA) on a mixture of input data. (Whyte, Ferentinos, & Petropoulos, 2018) This technique can be used to rapidly create LULC data with granular wetland categorizations and could be compared to previous data output to detect changes with less manual intervention. Combining both OBIA and change analysis allows for monitoring of dynamic situations. (Chapple & Dronova, 2017) When the time window over which change is being examined is long, analysis of vegetation indices derived from Landsat data can be employed. (Lopes, Mendes, Caçador, & Dias, 2019).

While GIS and RS clearly serve vital functions within all aspects of the restoration planning and prioritizing, they may ultimately be more valuable in risk assessment and loss prevention. A meta-analysis suggests “that recovery of wetlands following restoration as currently practiced is often slow and incomplete” with biological structure and biogeochemical functioning 26% and 23% lower respectively on average. (Moreno-Mateos, Power, Comín, & Yockteng, 2012) It is thus important to accurately evaluate the pressures on wetlands and identify high risk areas. Fuzzy Risk Assessment Models are a powerful tool which allow users to take a variety of input risk indicators and generate a priority assessment even if data is not on the same resolution. (Sarkar, Parihar, & Dutta, 2016) In the referenced paper, the authors are able to consider a variety of anthropogenic wetland conversion pressures and generate a priority map of the areas at greatest risk. This technique or similar can and should be employed in all scenarios where wetlands are at risk from human action, allowing scientist and activists to target the truly tenuous

Through the goals described above it’s clear that certain techniques and datasets are integral to the wetland restoration. High resolution, multi-spectral orthorectified images are the cornerstone of the field. They allow ready assessment of change, detection of both vegetative and risk indicators and allow ex situ data collection in large swaths at varying resolutions. Wetland inventories like NWI and SWEDI are useful but lag behind satellite data and require guided delineation and human effort to build. The type of project will ultimately dictate the data used – high risk projects needing active monitoring will employ the latest satellite data and monitoring methods, whereas lower risk planning and monitoring / assessment projects may employ established LULC / NWI datasets and look at change over long periods.

As techniques are refined, all aspects of wetland restoration will improve but there’s a lot of room for growth in using these tools for risk mitigation. Due to the slow recovery time of wetlands, humanity needs to expend more effort towards preventing their damage to begin with. Not discussed in any surveyed papers was the use of UAV or drones in
monitoring. These technologies represent a relatively low-cost data acquisition method that can provide current high spatial, time and even spectral resolution data as needed. Additionally, few active remote sensing techniques were mentioned, though this may be a bias from the papers selected. The field has room to develop in both data collection and analysis techniques and that even without employing the full extent of available option that targeted, well executed wetland restoration is fundamentally tied to remote sensing and GIS.
References


https://doi.org/10.1016/j.envsoft.2018.01.023
Annotated Bibliography


Maleki et al. discuss using geospatial data as input to a multi-criteria spatial decision support system. The study area, Iran’s Hamoun Wetlands, is severely degraded and prone to droughts. As data they use a DEM, Landsat 7 imagery, an LULC from a previous work, priority maps from a previous work and expert knowledge. They generate three priority maps for distinct restoration scenarios and calculate a weighted linear combination as an MC-SDSS tool. This serves as a useful practical example of a method to choose between competing restoration priorities. The method is readily translated to other sites insofar that WLC is a straightforward technique.


While not explicitly a GIS / RS paper, Moreno-Mateos et al. inadvertently make a strong argument for using GIS / RS in risk mitigation and loss prevention over restoration planning. The authors perform a meta-analysis of 621 wetland sites with a focus on plant biodiversity and carbon sequestration in wetland soils. The results suggest that restored degraded / damaged wetlands recover poorly and never achieve the same ecosystem service level that they previously held. This suggests that the bulk of efforts should be placed not on wetland restoration but on preventing the wetlands from being damaged at all, which require a computational model that can examine the various conversion pressures faced by wetlands.


In this paper, Sarkar et al. present a powerful technique for wetland risk management. The East Kolkata Wetland Area (EKWA) faces numerous conversion pressures that are difficult to assess holistically and identify the true risk areas of the wetlands. The identified risks were predominantly anthropogenic and related to population and infrastructure. As such, the authors generate maps for each index using LULC data, census data, topographic data. Numeric maps are then converted to ‘fuzzy’ linguistic terms that describe the risk in natural language and used as the basis of a fuzzy risk assessment model (FRAM). The resulting risk priority map is suggestive of the power of this tool in all types of risk mitigation scenarios.


Schleupner et al. conduct a broad analysis of the EU-25 countries and corresponding geospatial data to plan a variety of scenarios with existing wetlands. Scenarios discussed include preserving existing wetlands, restoring degraded or destroyed native wetlands and creating non-native managed habitat areas. They use as data a GIS-based wetland distribution estimation of Europe (SWEDI) which has a distinction between existing wetlands and suitable sites for wetland
restoration. A second data set is EUFASOM, a forestry and agricultural optimization model. Interestingly, EUFASOM includes environmental impact accounting equations and as such the resulting scenario planning has a cost analysis, a useful addition when you need to present the findings in a meaningful way to a government organization. The actual technique employed is GIS-based numerical optimization.


Taddeo et al. performed a meta-analysis of literature to identify the value of using different indicators in restoration monitoring. They analyze 99 papers determined four groups of post-restoration indicators: structural, compositional, functional and spatial. Within each group, they evaluate the distinct metric types and their efficacy and how they may be applied. They call to attention that remote sensing was not heavily used among the papers they reviewed but that it may provide a cost-effective alternative to in situ indicator measurement depending on the spatial, spectral and time resolutions that the monitoring effort requires.


Whyte et al. discuss an interesting monitoring application quick LULC generation. The study area is the iSimangaliso Wetland Park, a Ramsar site that technically has ‘good’ status but faces planation and invasive species pressures. LULC data is typically slow to be generated from satellite data and the author sought to use multispectral Sentinel data to quickly generate LULC for a higher monitoring frequency. They combined Sentinel 1 and 2 images on a day with 0% cloud cover with SRTM data and the SAGA wetness index and developed algorithms to accomplish object based image analysis to quickly generate high accuracy wetland LULC maps with a greater deal of wetland differentiation. This type of technique is very important because monitoring for large, high pressure wetlands needs to happen frequently and in a semi- or fully automated fashion given funding limitations.