Hydrological and Ecological Assessment of the Impacts of the Walsh Ditch Drainage Plugs

By
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A THESIS

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Applied Ecology

MICHIGAN TECHNOLOGICAL UNIVERSITY
2011

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This thesis, “Hydrological and Ecological Assessment of the Impacts of the Walsh Ditch Drainage Plugs”, is hereby approved in partial fulfillment of the requirements for the Degree of MASTER OF SCIENCE IN APPLIED ECOLOGY

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Abstract

The largest wetland drainage project in Michigan was initiated in 1912 near the town of Seney in the eastern Upper Peninsula. This project included the construction of a series of drainage ditches intended to prepare the land for agricultural use. The largest of these ditches was the 35 km-long Walsh Ditch. Much of the drained wetland affected by the Walsh Ditch is now managed by the U.S. Fish and Wildlife Service as part of Seney National Wildlife Refuge (Seney NWR). Starting in 2002, a series of earthen ditch plugs were installed along the length of the ditch found within Seney NWR (and adjacent to the Seney Wilderness Area) in an attempt to restore the hydrology and ecological integrity to the affected wetlands and streams. The plugs North of C-3 Pool were completed in 2002. The ditch plugs South of C-3 Pool were completed in 2005. This study explores the effect of the ditch plugs on the hydrology and vegetation structure in the adjacent landscape north of C-3 Pool at multiple scales. Plot level measurements of hydrology and vegetation, combined with an analysis of landcover change over the entire study area, indicate that some areas are converting from artificial upland communities created by wetland drainage to more natural wetland community types. Mortality of upland tree species and colonization by typical wetland species are good indications that these sites will continue to develop into wetland ecosystems over time. However, some areas have shown no response to the hydrologic restoration. This is expected, as areas of the landscape were upland (referred to as "pine islands" in the literature) before Walsh Ditch and should remain so as natural hydrology is restored to the area. Landcover change analysis showed a decrease in open water of 90.82 ha, a decrease of upland area of 67.88 ha and an increase in wetland area of 151.88 ha. The areas of change were concentrated around stream channels and in the area just east of Walsh Ditch. With time, it is possible that areas further removed from the ditch will show a shift towards more natural hydrology and vegetation composition, but for the areas furthest removed from the ditch this may require active management.

Chapter 1 - Introduction

History of Wetland Management in the United States

In the United States, greater than 45 million ha of wetlands, representing more than half the wetland present prior to European settlement, have been drained (Dahl & Johnson 1991, Dahl 2006). Wetlands have often been seen as places of little value, and drainage was historically promoted by polices such as the *Swamp Land Act* (passed in 1849) (Dahl & Allord 1997). By the 1940's, the Federal Government was providing free technical assistance for (and sharing the cost of) wetland drainage projects. These projects were even classified as conservation projects (Dahl & Allord 1997). In the mid-1970's, a shift from drainage to protection and restoration occurred. This shift was prompted by recognition of the many values of wetlands, such as flood and storm protection, nutrient and sediment filtering, and recreational and educational opportunities (Mitsch & Gosselink 2007).

In light of the observed importance of wetlands, a number of laws and policies have been passed in the past half century to halt the wide-spread destruction of wetlands in the United States. For example, in 1972 the *Clean Water Act* was passed and has since provided restrictions on the discharge of dredged or fill materials into wetlands (Votteler & Muir 2002). The subsequent "*Swampbuster Act*" of 1985 discontinued the financial incentives for farmers to convert wetlands to agriculture (Votteler & Muir 2002). The *Emergency Wetland Resource Act* of 1986 promoted wetland conservation by allowing for the purchase of wetlands with Land and Water Conservation Fund money and by requiring the establishment of a National Wetlands Priority Conservation Plan (USFWS 2010). The "no net loss" policy established in 1988 also aimed to reduce wetland loss. It required that new wetland areas be created to replace any unavoidable wetland losses (Votteler & Muir 2002).

Wetland loss in Michigan reflects the national average, with just over 50% of the original wetland area lost since European settlement (Dahl & Johnson 1991). The first statewide wetland protection legislation in Michigan was the *Geomare-Anderson Wetlands Protection Act*, passed in 1979. This act later became part 303 of the 1994 *Natural Resources and Environmental Protection Act*, which along with several other sections, regulate and protect Michigan wetlands (MDNRE 2006). Unfortunately, even with regulations to prevent wetland loss, Michigan wetland area continues to decline (MDNRE 2006). In recent years, interest and research in wetland restoration has increased more than any other area of wetland science (Mitsch & Gosselink 2007). The Michigan Department of Natural Resources and Environment (MDNRE), and several non-profit organizations, have created wetland restoration programs in an attempt to reverse the trend of wetland loss. Federal wetland restoration programs have also been established by the U.S. Fish and Wildlife Service (USFWS) and the U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS) to deal with this issue on a national scale (MDNRE 2002).

Types of Wetlands

Many wetland classification systems exist, most of which classify wetlands according to their vegetation, hydrology, chemistry, morphology, and position in the landscape (Mitsch & Gosselink 2007). The U.S. Army Corps of Engineers defines wetlands as, "those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions" (33 CFR 328.3 1986). This definition includes such areas as marshes, swamps, bogs, fens, wet meadows, and vernal pools.

Peatlands are the most widespread type of wetland, accounting for 50-70% of all wetlands (Joosten & Clarke 2002). Peatlands are wetlands that accumulate partly decomposed plant material. This is possible because a constant high water table creates an anoxic environment which significantly slows decomposition of organic matter. Most definitions of peatlands require a minimum depth of 30-50 cm of organic material. Maximum peat depths can be > 15 m. Peatlands can be further broken down into more specific classes based on vegetation, hydrology, chemistry, shape, and peat characteristics. The most common division between peatland types is that between bogs and fens. Bogs are nutrient poor, or ombrotrophic, systems that receive all their water from precipitation. Fens, on the other hand, receive a portion of their water from ground water and/or surface runoff. Fens are, therefore, more nutrient rich, or minerotrophic, and tend to have a higher pH than bogs (Charman 2002).

Within wetland science, peatlands are of special interest. Peatlands hold 20-30% of the worlds stored soil carbon and may play an important role in climate change (Mitsch & Gosselink 2007). Many peatlands have been drained for agricultural purposes and other land uses through the installation of drainage ditches. These drainage ditches have been shown to lower water tables (Coulsen 1990, USFWS 2001, Bruland et al. 2003, Simpson 2008), which can lead to peat oxidation and decomposition (Keddy & Reznicek 1986, Bruland et al. 2003) and the release of stored carbon into the atmosphere (Komulainen et al. 1999, Asada 2005). The loss of carbon from peatlands can be slowed by raising the water table. However, doing so may increase the emission of methane, a major greenhouse gas (Charman 2002). In terms of greenhouse gas emissions, peatland restoration may be negative in the short term, but beneficial over the long term (Charman 2002). In addition to altering greenhouse gas fluxes, ditches prevent the area from supplying the full array of ecosystem services provided by the original peatland, such as ground-water recharge, storm-water retention, and contaminant filtering (Smith et al. 2008).

Once drainage ditches are constructed, they can often drain wetlands on a continuous basis without further maintenance, and must therefore be actively removed or blocked to stop the drainage (Cooper et al. 1998). Consequently, wetland restoration may require active management, but guidance in the form of applied research is often lacking. Moreover, there is no single method for restoring wetlands that works for all sites (Shantz & Price 2006). In fact, some peatlands that have been intensely disturbed may be impossible to restore to their original condition (Gorham & Rochefort 2003).

The likelihood of successful restoration decreases the longer a site has been drained (Vasander et al. 2003). Fortunately, past restoration projects have allowed us to develop basic rules that increase the likelihood of success.

Wetland Restoration

The starting point for most wetland restoration projects is the restoration of the original hydrology (Vasander et al. 2003, Duranel et al. 2007, Zhang & Mitsch 2007). Hydrology is one of the driving factors behind wetland structure, function, and species composition and is the main factor contributing to restoration success or failure (Richter et al. 1996, Duranel et al. 2007, Zhang & Mitsch 2007). Different types of wetlands have different patterns of saturation and inundation throughout the year and even between years. The easiest way to understand the differences is to look at hydroperiod graphs for different wetlands. A hydroperiod shows the water table level in a wetland throughout the year (Figure 1.1).

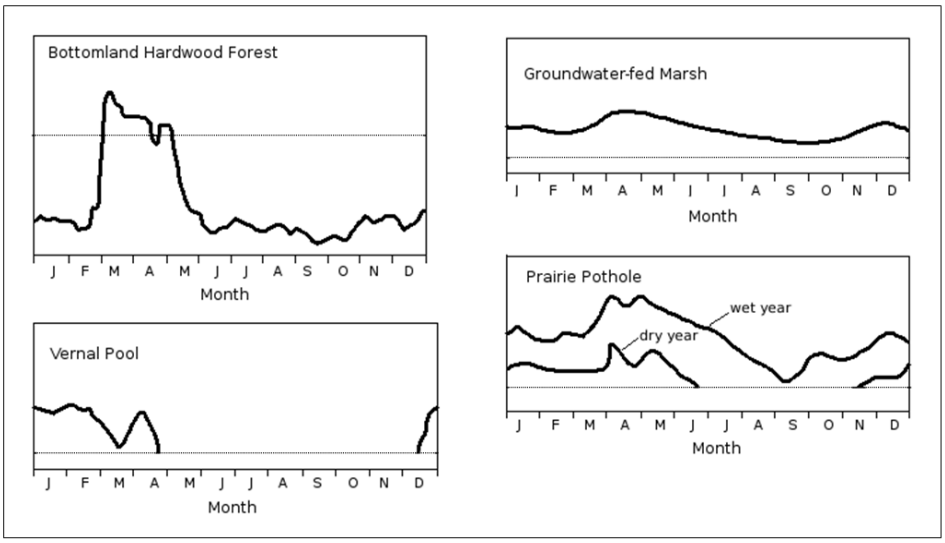

Figure 1.1. Typical hydroperiod of selected wetland types. The dashed line in each graph represents the surface of the wetland. (Modified from Mitsch & Gosselink 2007)

Bottomland forests and vernal pools are inundated for only a portion of the year. However, the timing of inundation is different for the two wetland types. Other wetland types, such as marshes, remain inundated throughout the year, though the water level may vary temporally and spatially. For example, prairie potholes have large variations in hydroperiods between years. Conversely, peatlands have relatively little variation in water table height, with a water table consistently near the surface over any given year or during any given season. Ultimately, it is important when restoring a particular wetland type that the hydroperiod of the restored area coincides with the particular wetland type of interest in restoration. This requires an understanding of the target hydroperiod and site conditions as well as hydrological monitoring.

After restoring the hydrology to an altered wetland, the next step is to encourage recolonization by appropriate native wetland flora. Where there is an appropriate seed bank, or where recruitment can occur due to the spatial connection to a seed source, wetland vegetation may develop on its own and without active management. In other cases, native plants may need to be directly introduced though transferring roots, rhizomes, or substrate containing seeds, planting seedlings or mature plants, or sowing seeds (Mitsch & Gosselink 2007). If plant material must be introduced, it is best to allow the system to develop through natural secondary succession. However, care should be taken to avoid the establishment of invasive species (Mitsch & Gosselink 2007). It usually takes 15-20 years before the success of the restoration can be judged, though this period is even longer for coastal wetlands, forested wetlands, and peatlands (Mitsch & Gosselink 2007).

Peatland Restoration

The high quantity of stored carbon make peatlands an important consideration in climate change and further supports the need for restoration. Unfortunately, the ecological uniqueness and significance to global climate change are not enough to protect many peatlands from damage or conversion. It is therefore critical to have an understanding of how to restore damaged peatlands. Scientific research has done much to advance this understanding, though there are still unanswered questions to be explored.

Peatlands form over very long time spans and can be difficult to restore after damage has occurred. As with restoration of other wetland types, the first step in restoring a peatland is to return the hydrology of the area to a natural state. If the hydroperiod of a restored peatland does not match that of a reference peatland, then native peatland plant species may not colonize the area and interact to form a peat developing system. Because blocking ditches does not necessarily keep the water table near the surface throughout the growing season (Ferland & Rochefort 1997), other measures may need to be taken to restore the original hydroperiod. These measures may include recontouring and shaping the site, sealing the edges of the site, and pumping water into the site (Charman 2002).

For many common plant species of fens, re-wetting a restoration site is sufficient to trigger plant growth (Richert et al. 2000). Species with long lived or easily dispersed seeds will often recolonize a re-wetted wetland without further restoration efforts (Budelsky & Galatowitsch 2000). A functioning peatland should accumulate peat; however, this requires the establishment of specific plants such as *Sphagnum* moss or *Carex* (sedges). Some of these plants, especially *Sphagnum* species, do not usually recolonize re-wetted wetlands without specific efforts to reintroduce them (Ferland & Rochefort 1997, Budelsky & Galatowitsch 2000, Richert et al. 2000). Studies have shown that some interventions, such as active introduction of moss diaspores, mulching, and

phosphorous fertilization can improve the establishment success of *Sphagnum* (Rochefort 2000, Rochefort et al. 2003). The presence of companion species has also been shown to increase *Sphagnum* establishment, with herbaceous plants such as *Eriophorum angustifolium* providing the best results (Ferland & Rochefort 1997).

The final step in peatland restoration is to ensure that a functioning peat forming ecosystem is present (Rochefort et al. 2003). When the water table in a peatland is initially lowered, the upper layers of peat are oxidized and enzymes in the peat that promote decomposition are activated (Wallage et al. 2006). Raising the water table may stop decomposition of the peat, but in some cases the enzymes remain active and the peat continues to decompose at a higher rate than is natural for peatlands (Wallage et al. 2006). It is important to ensure that the decomposition is slowed to a reference level and that peat is accumulating. Even in healthy peatlands, the rate of peat accumulation can be very slow and several decades may pass before this final step is achieved (Rochefort et al. 2003). This highlights the need for long term monitoring.

Research Objectives

This research focuses on a large scale hydrologic restoration in Seney National Wildlife Refuge in the Upper Peninsula of Michigan. The drained area was a large patterned peatland until the early 1900's when it was drained by a series of drainage ditches. This drainage project is the largest wetland drainage project in the history of Michigan. In 2002 Seney National Wildlife Refuge constructed a series of earthen dams, or ditch plugs, in the largest of the ditches, Walsh Ditch, in an effort to restore the "hydrology and ecological integrity of the wetlands and streams" affected by the Walsh Ditch (USFWS 2001). The goal of this study is to describe how the area affected by the installation of the Walsh Ditch drainage plugs is responding to the new hydrologic regime created by the installed ditch plugs. The objectives of this research are to 1) determine how the vegetation communities are changing, 2) determine how the hydrology of the area is responding after the installation of the ditch plugs, and 3) determine what landscape level changes are occurring. The results from this research are intended to aid Seney NWR staff in adapting future management of the area above and below C-3 Pool and establishing a basis for further research and monitoring.

Chapter 2 – Master's Research

Introduction

In recent years, interest and research in wetland restoration has increased more than any other area of wetland science (Mitsch & Gosselink 2007). Many studies focus on restoring harvested peatlands (Ferland and Rochefort 1997, Rochefort et al. 2003, Waddington et al. 2003, Cobbaert et al. 2004, Lavoie et al. 2005, Graf and Rochefort 2008, Graf et al. 2008). The results of these studies are not directly applicable to projects like this one, where land has been abandoned for long periods and no longer has a layer of peat. There are other studies that focus on restoring wetlands that have been abandoned after being drained for agriculture or forestry. Though some of these areas have been drained for a comparable time, they have not experienced as considerable of a transformation of the original vegetation as at Seney NWR, where wetlands have transitioned to upland forests in much of the area (Cooper et al. 1998, Richter et al. 2000, Mälson and Rydin 2006, Duranel et al. 2007, Thogmartin et al. 2007). The drastic change in hydrology and vegetation in the land adjacent to Walsh Ditch makes restoration of the historic conditions a unique challenge. The restoration is further complicated due to the heterogeneous nature of the original vegetation of both the peatland and upland forested areas. This research provides a relevant case study for others pursuing large-scale wetland restoration projects in the Upper Midwest.

The largest wetland drainage project in Michigan was initiated in 1912 near the town of Seney in the eastern Upper Peninsula (Wilcox et al. 2006). This project included the construction of a series of drainage ditches intended to prepare the land for agricultural use. The largest of these ditches was Walsh Ditch, which was 35 km long, 6 m wide and 2 m deep when constructed between 1912 and 1915 (USFWS 2001, Figure 2.1). Walsh Ditch runs south from M-28 to the Manistique River (Wilcox et al. 2006). When it was discovered that the drained soils and the environment were too harsh for successful agriculture, the lands drained by the Walsh Ditch and surrounding areas were abandoned, tax-reverted to the State, and then transferred to the Federal government in 1935 to make what is now referred to as the U. S. Fish and Wildlife Service's Seney National Wildlife Refuge (Seney NWR) (Sweat 2001, Wilcox et al. 2006, USFWS 2009). Most of the length of Walsh Ditch now resides on Seney NWR.

From the time of its creation, the Walsh Ditch has significantly altered the historic hydrology of the adjacent land and water channels at Seney NWR. The ditch has diverted water away from the parts of Walsh Creek and Marsh Creek east of the ditch, lowered the water table of the neighboring wetlands (including those of the Seney Wilderness Area), allowed for peat subsidence, and altered the overall vegetation structure of the general vicinity (Wilcox et al. 2006). Further altering the historic hydrology of the area is an anthropogenic pool (C-3 Pool) created for waterfowl production in 1942 (USFWS 2009). In particular, management of water outflow from C-3 Pool has historically sent more water through the lower end of Walsh Ditch than to the natural Walsh and Marsh Creek channels (Wilcox et al. 2006).

The goal of this research is to quantify the changes to the surrounding landscape since the installation of the ditch plugs. The objectives of this research are to 1) determine how the vegetation communities are changing, 2) determine how the hydrology of the area is responding after the installation of the ditch plugs, and 3) determine what landscape level changes are occurring. The results from this research are intended to aid Seney NWR staff in adapting future management of the area above and below C-3 Pool and also establish a basis for further research and monitoring.

Methods

Study Site Description

The eastern Upper Peninsula of Michigan ecoregion contains large expanses of wetlands in a diverse arrangement of landscape types (Albert 1995). This ecoregion encompasses all of Alger, Chippewa, Delta, Luce, Mackinac, and Schoolcraft counties as well as parts of Dickinson, Marquette, and Menominee counties (MDNRE 2006). The area is relatively flat and predominantly covered by forests (67%) and wetlands (20%), with less area in agriculture (4%) and urban development (2%). Peatlands are common in the sand and clay lake plain areas where the poorly drained soils are conducive to peat accumulation (MDNRE 2006).

The highest concentration of patterned peatlands in Michigan occurs in Schoolcraft County (Kost et al. 2007), itself dominated by Seney NWR. Two thirds of Seney NWR is covered by a layer of peat ranging from a few centimeters to two meters in depth (Wilcox et al. 2006). Seney NWR is relatively flat with a southeast slope of 1.89 m/km (USFWS 2009), and is part of the 3,797 km^2 Manistique Watershed (Sinclair 1959, USFWS 2009). Underlying deposits include sand over Ordovician sandstone, limestone, and dolomite (Wilcox et al. 2006). Sand was deposited by the Valders glacial outwash and later influenced by the inundation and drainage of early stages of the Great Lakes (Heinselman 1965). The climate is strongly influenced by Lake Superior and Lake Michigan with an annual precipitation of 81 cm and 312 cm of annual snowfall (USFWS 2009). Temperatures in the area range from -37°C to 36°C, with an average temperature of 5.1°C (Wilcox et al. 2006, USFWS 2009).

Seney NWR is predominantly covered by open peatlands, lowland swamps, and upland forests (USFWS 2009). The peatlands are generally dominated by sedges (*Carex* L. spp.) and shrubs (*Salix* spp. L., *Alnus* spp. Mill, and *Betula pumilla* L.), interspersed with sandy knolls on which grow primarily pines (*Pinus* spp. L) (Heinselman 1965). These peatlands are the largest of their type in Michigan (Heinselman 1965, Wilcox et al. 2006). Upland areas are generally mixed forests with varying tree species, including American beech (*Fagus grandifolia* Ehrh.), sugar maple (*Acer saccharum* Marsh.), yellow birch (*Betula alleghaniensis* Britton), red pine (*Pinus resinosa* Ait), eastern white pine (*Pinus strobus* L.), jack pine (*Pinus banksiana* Lamb.), black spruce (*Picea mariana* (Mill.) B.S.P.), and balsam fir (*Abies balsamea* (L.) Mill.) (USFWS 2009). Fire is also a major native ecological disturbance that shapes the plant communities at Seney NWR, although

human alterations to this ecological processes too has been profound (Drobyshev et al. 2008a,b).

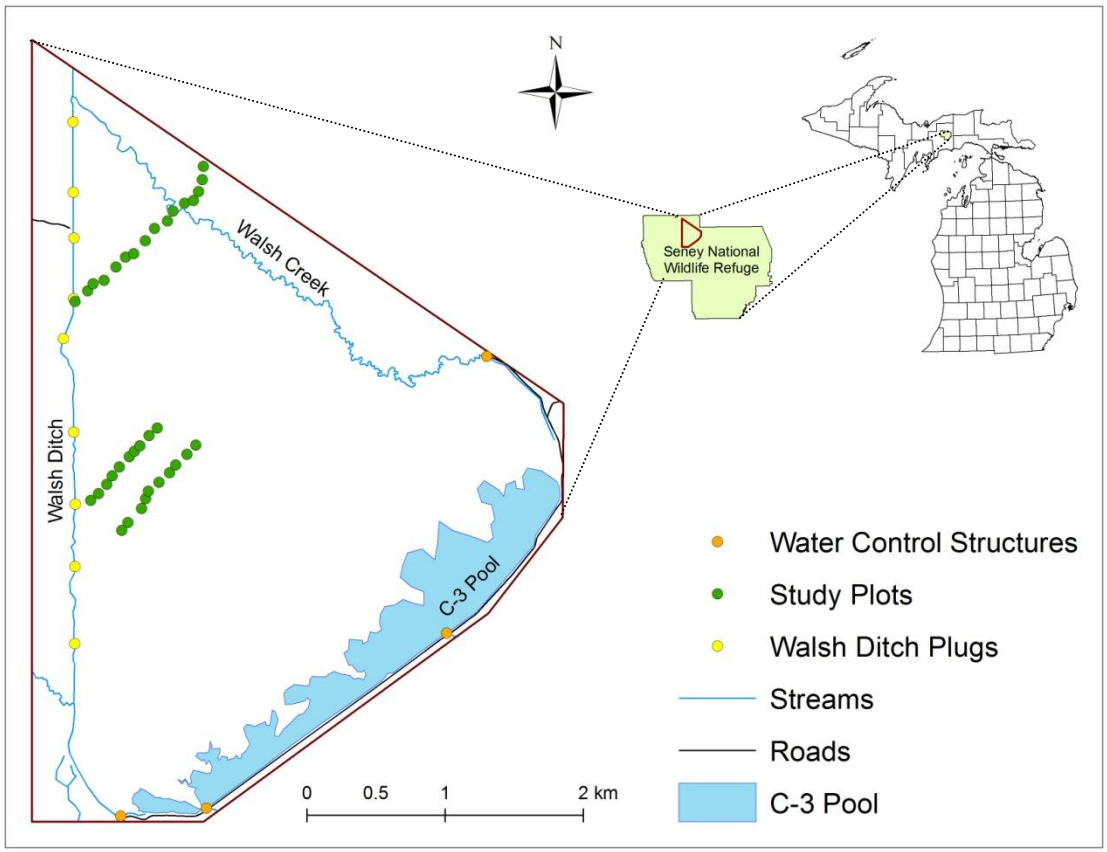

Figure 2.1. Study sites were located in Seney National Wildlife Refuge in Schoolcraft County, Michigan. The yellow dots show the location of the ditch plugs that are diverting water from the ditch to the adjacent landscape. The orange dots represent the water control structures that regulate the water level of C-3 Pool by controlling flow out of the pool. The green dots represent the study plot locations. The map was digitized using a 2005 orthophoto of the area. (Source of aerial photograph: USDA-FSA Aerial Photography Field Office. Datum/Projection: NAD_1983_UTM_Zone_16N)

Hydrologic Management of Study Site

In 1991, the main water control structure of C-3 Pool was discovered to be in need of replacement (USFWS 2001). This prompted a review of the hydrology of the watershed of the C-3 Pool area (USFWS 2001). The resulting new water management of the area reflects the policy shift of the National Wildlife Refuge System (NWRS) toward an ecosystem management approach, with a focus on ecological restoration (Kowalski & Wilcox 2003). In fact, to guide land management actions within the NWRS, the 1997 *Refuge Improvement Act* stipulated that managers should, "where appropriate, restore and enhance healthy populations of fish, wildlife, and plants…." (Public Law 105-57-October 9, 1997). Along with the subsequent *Biological Integrity Policy* (2001), land

managers were encouraged to favor ecologically-based wildlife habitat management, with restoration to historic conditions where and when possible (Schroeder et al. 2004; Meretsky et al. 2006).

The goal of the Walsh Ditch restoration project was to restore the "hydrology and ecological integrity of the wetlands and streams" affected by the Walsh Ditch (USFWS 2001). Between 2002 and 2003, nine earthen ditch plugs were installed in the portion of Walsh Ditch from M-28 south to where it is intersected by C-3 Pool (Wilcox et al. 2006, Figure 2.1). These plugs were comprised of sandy soils removed from locations adjacent to the ditch and, in some instances, the plugs were reinforced with metal sheet-piling. The northern most ditch plug redirects water to the historic Walsh Creek channel (Wilcox et al. 2006). The remainder of the ditch plugs divert water from the ditch into the adjacent landscape where it flows primarily to the southeast. Two new water control structures were also installed to the south and east of the plugs at the interface of C-3 Pool with the Walsh Creek and Marsh Creek stream channels (Wilcox et al. 2006, Figure 2.1).

Before the Walsh Ditch restoration project began and ditch plugs were installed, the majority of the discharge from C-3 Pool was sent to lower Walsh Ditch. Now the majority of springtime discharge from the pool flows to Marsh Creek (3.11 m3/s), and the remainder of the outflow goes through an old water control structure at Sweeny Creek (0.80 m3/s) (Wilcox et al. 2006). When springtime discharge exceeds the capacity of the other channels, water is diverted to the Driggs River through a new water control structure in Walsh Creek northeast of C-3 Pool. This has approximately restored springtime flow in to the Driggs River (Wilcox et al. 2006). Under normal circumstances, no water is released to the portion of Walsh Ditch south of C-3 Pool, thereby significantly reducing the linear flow of water leaving this watershed and Seney NWR in general.

Previous research in the Walsh Ditch area has focused on the water channels and the area immediately surrounding the channels (Sweat 2001, Kowalski & Wilcox 2003, Wilcox et al. 2006). This work has identified the impact of the altered hydrology on the surrounding vegetation. However, the installation of the ditch plugs has affected a much larger area and little is known about how this larger area is responding. Our initial observations of the area after the installation of the ditch plugs indicated that the water level in the ditch was elevated relative to the level of the surrounding water table and surface water discharge to the ditch was reduced (Wilcox et al. 2006). Water was also observed to overflow the channels of Walsh and Marsh Creeks, restoring surface flow to the northern portion of the study site and the area below C-3 Pool (Wilcox et al. 2006). Beaver (*Castor canadensis* L.) dams have also been observed along Walsh Ditch north and south of C-3 Pool (Wilcox et al. 2006).

Previous Study and Site Selection

This research took advantage of baseline study conducted by Walter Loope in 2002 before the first ditch plug was installed (Loope & Lucas unpublished). For this study a vegetation survey was performed along a single transect extending approximately 2.3

km northeast from Walsh Ditch. As part of this assessment 30, 50 m x 30 m (1500 m^2), vegetation plots were established (northern transect in Figure 2.1). Within each plot, all stems of tree species ≥2.54 cm diameter breast height (1.5 m, hereafter dbh) were recorded. The abundance or coverage of herbaceous species within each plot were not quantified, but notes of observed species were taken for 23 of the 30 plots. For the current study, we included the 16 southern most previously established plots, as well as an additional 20 plots along two transects south of Walsh Creek and parallel to the original transect. In the current study, plots were established as 15 m-radius circular plots (707 m^2). For plots along the northern transect, the center of the current plots were located at the coordinates of the previous plot markers. Because we wished to avoid the dry, slightly elevated portions of the landscape (referred to as "pine islands") that would not be affected by the hydrologic restoration, plots in the southern transects were concentrated in the low areas and spaced further apart in the elevated areas to best capture the effects of the ditch plugs. The center of the 20 newly established plots were also recorded using global positioning system (GPS) technology (UTM Zone16N, NAD83).

Vegetation Composition and Structure

Within the 15 m-radius circular plots (707 m^2), the dbh of all trees ≥2.54 cm dbh were measured by species. Four 3 m radius sub-plots (28 m^2) and twelve 1 m square sub-plots (1 m^2) were used for surveying the shrub layer and herbaceous layer respectively. These plots were located at random locations within the 15 m-radius plot, but evenly divided among the quadrats (Figure 2.2). Species and cover class were recorded for all shrub and herbaceous vegetation (Braun-Blanquet 1932, Table 2.1). Basal area and number of stems per hectare were compared between the pre-treatment study and the current study using two-tailed paired t-tests. For these tests data from only the 16 northern plots were analyzed, and all trees < 2.54 cm dbh were excluded from analysis in order to make the current data comparable to the pre-treatment data.

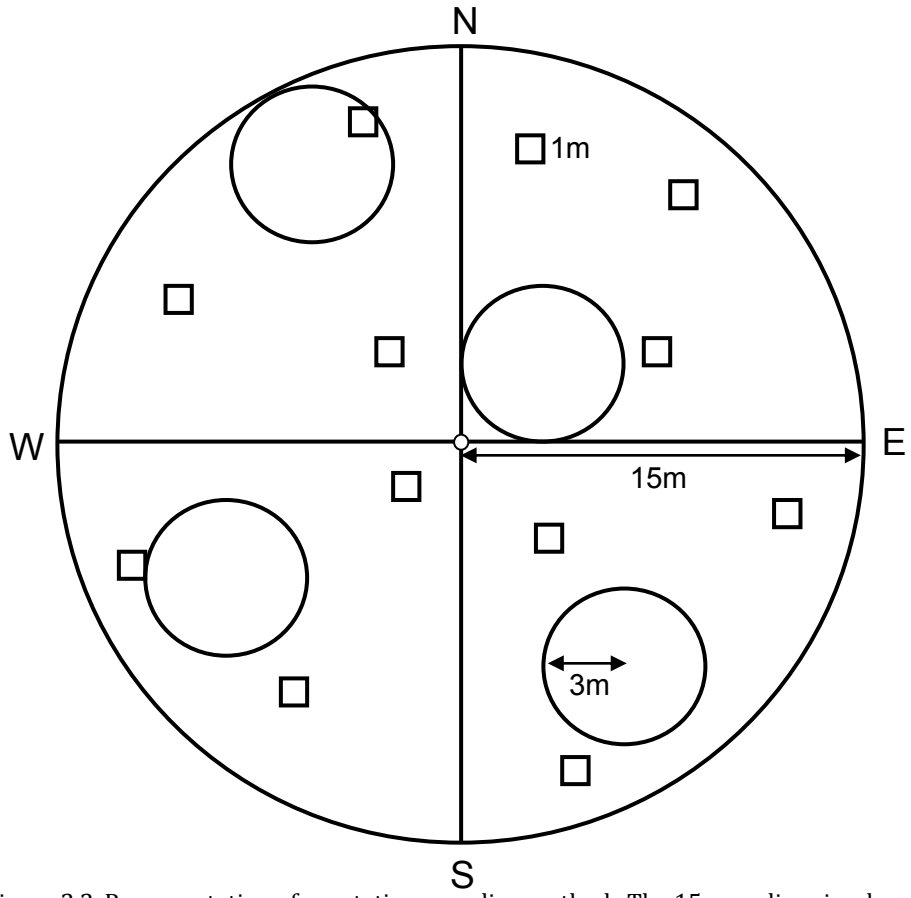

Figure 2.2. Representation of vegetation sampling method. The 15 m-radius circular plot (707 m^2) was used for tree samples, the 3 m-radius (28 m^2) sub-plots were used for shrub samples, and the 1 m^2 plots were used for herbaceous samples. One shrub plot and three herbaceous plots were located in each quarter section using randomly generated coordinates. Coarse woody debris (CWD) was measured along the N-S and E-W transects. A groundwater well was located at the center of each plot and also acts as a plot marker.

Table 2.1. Braun-Blanquet scale used for recording percent cover of shrub and herbaceous vegetation. Adapted from Braun-Blanquet 1932.

% Cover	Class
<1	0
1-5	1
5-25	2
26-50	3
51-75	4
>75	5

Table 2.2. Classification system for coarse woody debris (CWD) decay classes. All measured CWD was placed into one of the five decay classes. Only logs in classes 1 through 4 were used in analysis. (Adapted from Waddell 2002)

Decay Class	Structural Integrity	Wood Texture	Condition of branches and twigs
1	Sound	Intact, no rot; conks on stem absent	If branches present, fine twigs still attached with tight bark
2	Heartwood sound; sapwood somewhat decayed	Mostly intact; sapwood partly soft and starting to decay. Wood cannot be pulled apart by hand	If branches present, many fine twigs gone; fine twigs still present have peeling bark
3	Heartwood sound; log supports its weight	Large, hard pieces of sapwood can be pulled apart by hand	Large branch stubs will not pull out
4	Heartwood rotten; log maintains its shape but does not support its weight	Soft, small, blocky pieces; metal pin can push apart heartwood	Large branch stubs pull out easily
5	No structural integrity; does not maintain its shape	Soft, powdery when dry	Branch stubs and pitch pockets have rotted away

Coarse woody debris (CWD) was measured (Waddell 2002), but included CWD with a minimum diameter of 5 cm and used a different arrangement of transects. CWD was measured along two transects running N-S and E-W through the center of the plot (Figure 2.1). All CWD at least 1 m in length, with a minimum diameter of 5 cm, were included in the sampling. For forked trees where both branches crossed a transect, the main fork (the one with the larger diameter at the fork) was measured for the length of the log and the smaller branch was measured starting at the fork. Each section had to meet the length and diameter criteria used for individual logs as discussed above. Where logs crossed a transect multiple times, or crossed multiple transects, it was recorded separately for each intersection. Decay class for each log was also recorded (Waddell 2002) (Table 2.2). Logs with a decay class of five (i.e., no structural integrity remained) were not included in the survey. For logs with portions in different decay classes, only sections with a decay class of ≤ 4 were measured.

Hydrology

At the center of each 707 m^2 study plot, we established a ground water well for hydrologic monitoring (Figure 2.2). Wells were constructed of slotted 3.8 cm or 5 cm polyvinyl chloride (PVC) pipe with caps at both ends and were installed to a depth of about approximately 1 m using a hand soil auger. The 30 previously established plots all received new groundwater wells. The locations of the wells were recorded using GPS

technology to facilitate future monitoring. Wells were installed in early May 2009 and were monitored bi-weekly through the first week of September 2009. Water table measurements were made using a hand operated weighted measuring tape with a water sensor.

Statistical Analyses

To determine what types of vegetation communities are developing within the study site, all plots were sorted into community groups using hierarchical cluster analysis of vegetation data with Sorensen distance measure and flexible beta (β=-0.25) using PC-ORD 5.32 (McCune & Mefford 2006). Indicator species analysis was used to find the optimal number of groups. The optimal separation was determined by averaging the p-values obtained from Monte Carlo Analysis as well as totaling the number of species with significant p-values ($p <= 0.05$). Ordination of vegetation and environmental variables was carried out using Nonmetric Multidimensional Scaling (NMS) to determine what factors best explained the separation of community groups.

Landcover Change Analysis

To assess landscape scale changes in the study site, geographic information system (GIS) technology was used to map landcover for one pre-restoration year (1998) and one post-restoration year (2005). The landcover maps were created by manual interpretation of aerial photographs using ArcGIS version 9.3 (ERSI 2008). The aerial photograph used for the 1998 map was a mosaic of standard digital orthophoto quadrangles (DOQ) from the National Digital Cartographic Data Base. Images were taken on 21 April 1998 by the National Aerial Photography Program (NAPP) which is administered by the U.S. Geological Survey (USGS). Color infrared film was used and the resulting image had a scale of 1:40,000 with a pixel size of 1m x 1m. The 2005 map was created from color digital imagery collected by U.S. Department of Agriculture – Farm Service Agency (USDA-FAS) Aerial Photography Field Office using a Leica ADS40 Digital Sensor on 15 September 2005. The pixels in the resulting image were 1m x 1m. The system used for cover type classification was a simplified version of the National Vegetation Classification System (NVCS) (Table 2.3) (FGDC 1997). The minimum mapping unit was 15 m^2. The projection/datum used for both landcover maps was UTM Zone 16N, NAD 83.

Change in landcover between years was analyzed using matrix analysis in ERDAS Imagine version 10.1 (ERDAS 2010). An x/y tolerance of 2 m was used to eliminate slivers resulting from the imperfect alignment of the different maps. The spatial patterns of change as well as the total area of change were analyzed.

Table 2.3. Description of cover types used for comparing landcover change. Descriptions come from the formation level of the National Vegetation Classifciation System (NVCS), though multiple formation levels were combined to create some of the covertypes used in the classification of the landcover maps (FGDC 1997).

Cover Type	Description
Forested Wetland	Temporarily flooded, saturated or seasonally flooded forested areas
Upland Forest	Forested areas not experiencing regular saturation or inundation
Other Wetland	Seasonally flooded temperate or subpolar grassland; Semipermanently flooded temperate or subpolar grassland; Saturated temperate or subpolar grassland; AND/OR Permanently flooded temperate or subpolar hydromorphic rooted vegetation
Developed	Areas of human influence that are predominantly artificial in nature (i.e. buildings, roads, etc.)
Grass/Ferns/ Hayfields	Perennial grass crops with or without a sparse shrub layer, including transitional fallow fields; Temporarily flooded temperate or subpolar grassland; Short sod temperate or subpolar grassland; Medium-tall sod temperate or subpolar grassland; Tall sod temperate grassland; AND/OR Tall temperate or subpolar perennial forb vegetation
Open Water	All non-vegetated bodies of water
Scrub/Shrub Wetland	Seasonally flooded cold-deciduous shrubland; Saturated cold-deciduous shrubland; AND/OR Needle-leaved evergreen shrubland
Upland Scrub/Shrub	Temperate cold-deciduous shrubland

Results

Vegetation Composition and Structure

A total of 119 plant species were identified among the 36 plots, including 15 tree species, 20 shrub species, and 84 herbaceous species (Appendix A). The number of species per plot ranged from 6 to 43, with a mean (±1 SE) of 21.4 (±1.07). Based on measures of total coverage and the number of plots in which species occurred, the most common tree species overall were red pine, red maple (*Acer rubrum L. var. rubrum*), quaking aspen (*Populus tremuloides* Michx.), and eastern white pine. Serviceberry (*Amelanchier* spp. Medik.), spirea (*Spirea* spp. L.), and willow (*Salix* spp. L.) were the most common shrub species. Carex spp., bluejoint (*Calamagrostis canadensis* (Michx.) P. Beauv.), woolgrass (*Scirpus cyperinus* (L.) Kunth), bristly dewberry (*Rubus hispidus* L.), and starflower (*Trientalis borealis* Raf.) were the most common herbaceous species encountered.

Two-tailed paired t-tests found no significant difference in basal area or stems per hectare for trees in either size class between 2002 and 2009 (α=0.05). Stem density of trees in the smaller size class showed the most significant change between years (P=0.058).

Table 2.4. Results of two-tailed paired t-tests for basal area and stem density between 2002 and 2009.

	2002	2009	P(t)
Trees >= 10cm DBH			
Basal Area (m2/ha)	23.66	24.05	0.925
Stem Density (Stems/ha)	410.4	443.87	0.737
Trees < 10cm DBH			
Basal Area (m2/ha)	0.958	1.6	0.123
Stem Density (Stems/ha)	347.08	694.1	0.058

Cluster Analysis

Hierarchal cluster analysis and indicator species analysis resulted in an optimal solution of five community types (Table 2.5, Appendix B). Group 1 consists of flooded forested areas. This group has a high water table, high coarse woody debris, and high herbaceous cover. It has a relatively low living basal area and high dead standing basal area. All plots in this group occur south of Walsh Creek (Figure 2.3). Group 2 is a spruce/fir forest that has a high living basal area, high basal area of small trees (<10cm DBH), low standing dead basal area, low coarse woody debris, and a deep water table. All plots in this group occur in the northern portion of the study area but south of Walsh Creek. Group 3 is a pine forest with high living basal area and low standing dead basal area, and high coarse woody debris. The water table at these sites is generally below the surface, but not very deep. All plots in this group occur south of Walsh Creek. Group 4 is a scrub/shrub wetland. Plots in this group have a high water table, low basal area, somewhat high dead standing basal area, low coarse woody debris, and high shrub cover. All plots in this group occur south of Walsh Creek. Group 5 is a hemlock forest with a deep water table, high basal area, high coarse woody debris and high herbaceous cover. All plots in this group occur north of Walsh Creek in or near the Society of American Forester's Hemlock Research Natural Area which was established in the 1940's.

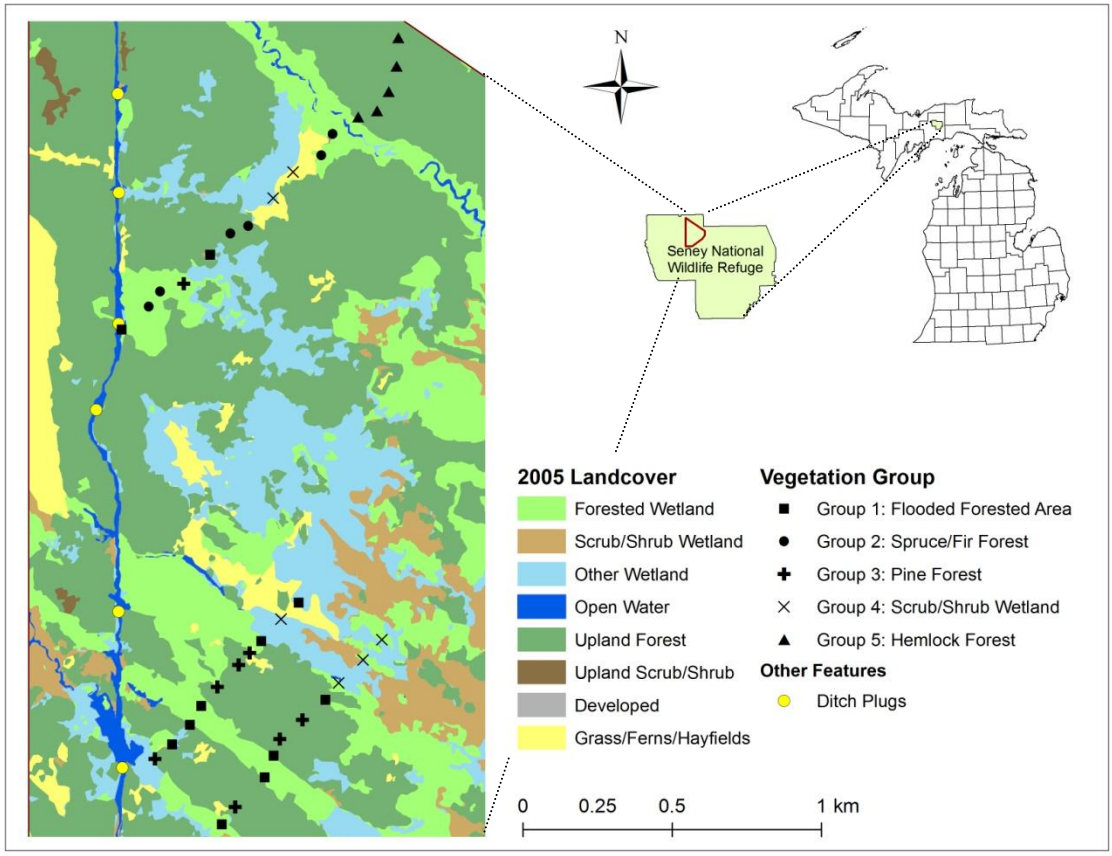

Figure 2.3. Location of study plots by vegetation group as defined by cluster analysis. Groups were defined in PC-ORD 5.32 (McCune & Mefford 2006) and plotted in ArcGIS version 9.3 (ERSI 2008).

Table 2.5. Defining species for each community type. Based on a Monte Carlo test of permutations, all defining species have a $P<0.05$ and are present in at least 70% of all plots in the group.

Group	Indicator Value Probability
Group 1: Flooded Forested Areas	
Scirpus cyperinus (L.) Kunth	0.0034
Solidago altissima L.	0.0142
Fragaria sp.	0.0198
Salix	0.0272
Group 2: Spruce/Fir Forest	
Deschampsia flexuosa (L.) Trin.	0.0002
Vaccinium angustifolium Aiton	0.0002
Vaccinium myrtilloides Michx.	0.0002
Gaultheria procumbens L.	0.0004
Abies balsamea	0.0024
Corylus americana Walter	0.0054
Picea glauca	0.0116
Cladina (Nyl.) Nyl.	0.0206
Polytricum sp.	0.026
Viburnum lentago L.	0.0342
Abies balsamea	0.0458
Group 3: Pine Forest	
Trientalis borealis Raf.	0.0002
Pinus strobus	0.0008
Amelanchier spp. Medik	0.0018
Rubus hispidus L.	0.002
Pinus resinosa	0.003
Pinus strobus	0.0124
Populus tremuloides	0.0254
Prunus virginiana L.	0.028
Group 4: Scrub/Shrub Wetland	
Spirea	0.0002
Carex sp.	0.0264
Betula pumila L.	0.0366
Group 5: Hemlock Forest	
Cornus canadensis L.	0.0002
Dryopteris sp.	0.0002

Group	Indicator Value Probability
Coptis trifolia (L.) Salisb.	0.0002
Oxalis montana Raf.	0.0002
Maianthemum canadense Desf.	0.0008
Clintonia borealis (Aiton) Raf.	0.0014
Tsuga canadensis	0.0016
Huperzia lucidula (Michx.) Trevis.	0.002
lex verticillata (L.) A. Gray	0.0024
Lonicera canadensis	0.0078
Acer rubrum	0.0078
Lycopodium obscurum L.	0.015
Osmunda regalis L.	0.0152
Ribes triste Pall.	0.0152
Betula alleghaniensis	0.0174
Rubus pubescens Raf.	0.0298
Aralia nudicaulis L.	0.0314

Multivariate Nonmetric Multidimensional Scaling

Multivariate Nonmetric Multidimensional Scaling (NMS) resulted in a 3-dimensional solution with a cumulative r^2 of 0.878 and a final stress of 10.39720 (Figure 2.4). The first axis was most correlated with percent shrub cover and percent herbaceous cover (r^2=0.133) (Table 2.6). The second axis was most correlated basal area of large trees (>=10cm DBH), the amount of coarse woody debris and percent shrub cover (r^2=0.204). The third axis was most correlated with average water table, basal area of large trees (>=10cm DBH), and percent shrub cover (r^2=0.541).

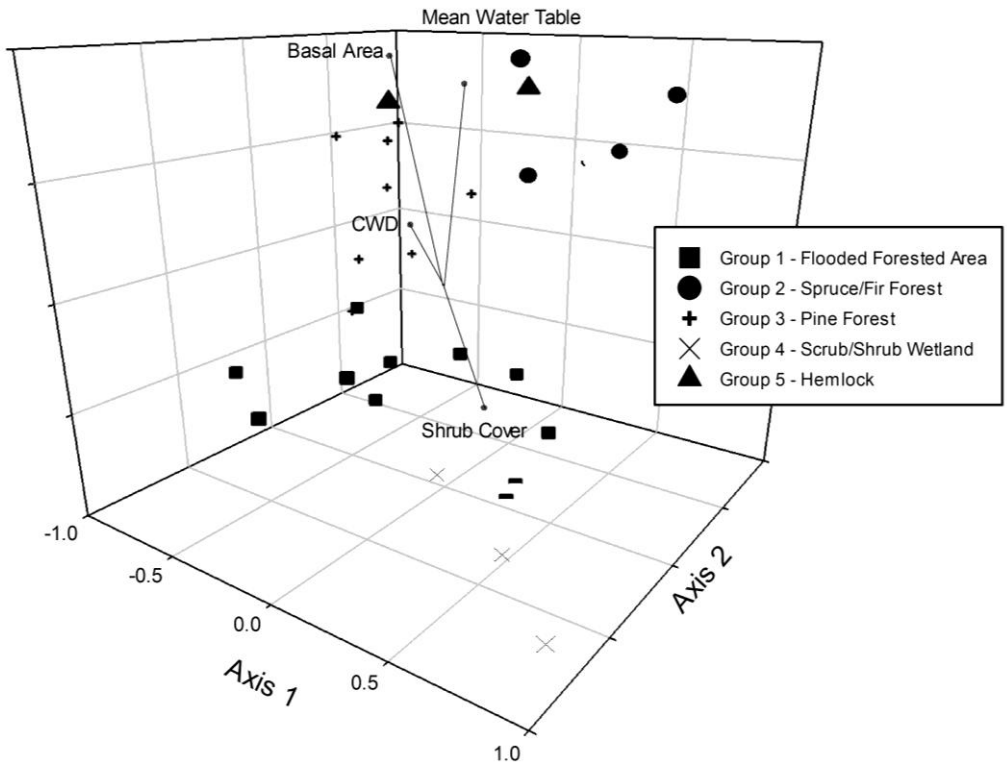

Figure 2.4. Nonmetric Multidimensional Scaling (NMS) diagram of plots grouped by community type (Groups 1 to 5). Vectors represent environmental variables: CWD-volume of coarse woody debris/ha, Basal Area-basal area of trees >10cm DBH/ha, Shrub Cover-total shrub cover for plot.

Table 2.6. Pearson (r2) and Kendall (tau) correlations of Nonmetric Multidimensional Scaling ordination axes with environmental variables.

Variable	**Axis 1**		**Axis 2**		**Axis 3**	
	r^2	**tau**	**r^2**	**tau**	**r^2**	**tau**
Mean Water Table	0.039	0.098	0.003	0.092	0.371	0.444
Basal Area/Hectare (Trees >= 10 cm DBH,	0.023	-0.088	0.097	-0.056	0.423	0.402
Basal Area/Hectare (Snags > 2.54 DBH, m2)	0.019	-0.074	0.003	-0.127	0.049	-0.074
Basal Area/Hectare (Trees < 10cm DBH,	0.022	-0.15	0.049	0.061	0.081	0.424
Coarse Woody Debris (m^3/ha)	0.009	-0.265	0.182	-0.331	0.17	0.242
Total % Cover by Shrub Species	0.195	0.231	0.163	-0.214	0.122	-0.182
Total % Cover by Herbaceous Species	0.138	-0.126	0.002	-0.018	0.066	0.155

Hydrology

Although peaks in water table height occurred around the same time for all plots, there was a difference in the magnitude of hydrologic peaks and overall water table variability across the study site and within our defined vegetation groups (Figure 2.5, Appendix C).

Group 1 of the vegetation composition ordinations (flooded forested area) was one of two groups with a mean water table above the surface. Plots in Group 1 had mean water table values ranging from 24.89 cm above the surface to 24.51 cm below the surface for individual plots, with an average of 0.84 cm above the surface for the group (SE=4.23). Moreover, water table height for plots in Group 1 had an average range of 27.84 cm throughout the study period, with a maximum range of 52.72 cm and a minimum range of 14.06 cm for individual plots, making it the group with the least variability in the water table.

The mean water table heights for Group 2 (Spruce/Fir Forest) ranged from 8.78 cm below the surface to 100.51 cm below the surface for individual plots, with an average for all plots of 37.70 cm below the surface (SE=13.75), making it the driest group. The mean range in water table height for plots in Group 2 was 51.12 cm, with a maximum of 71.50 cm and a minimum of 17.00 cm for individual plots.

The mean water table height for Group 3 (Pine Forest) plots ranged from 5.99 cm above the surface to 29.81 cm below the surface for individual plots, with a mean of 10.71 cm below the surface for the group (SE=4.19). The mean range in water table height for plots in group 3 was 29.33 cm, with individual ranges from 19.96 cm to 54.53 cm.

Group 4 (Scrub/Shrub Wetland) was the wettest overall group. The mean water table height for the group was 3.62 cm above the surface (SE=5.84), with mean water tables for individual plots ranging from 16.69 cm above the surface to 23.01 cm below the surface. The mean range in water table for plots in group 4 was 44.98 cm, with a minimum range of 24.35 cm and a maximum range of 88.95 cm for individual plots.

Group 5 (Hemlock Forest) was the second driest group, with a mean water table 33.15 cm below the surface (SE=10.84). Mean water table heights for individual plots ranged from 9.41 cm below the surface to 73.81 cm below the surface. The mean range in water table for the group was 32.86 cm, with a maximum range of 45.42 cm and a minimum range of 21.44 cm.

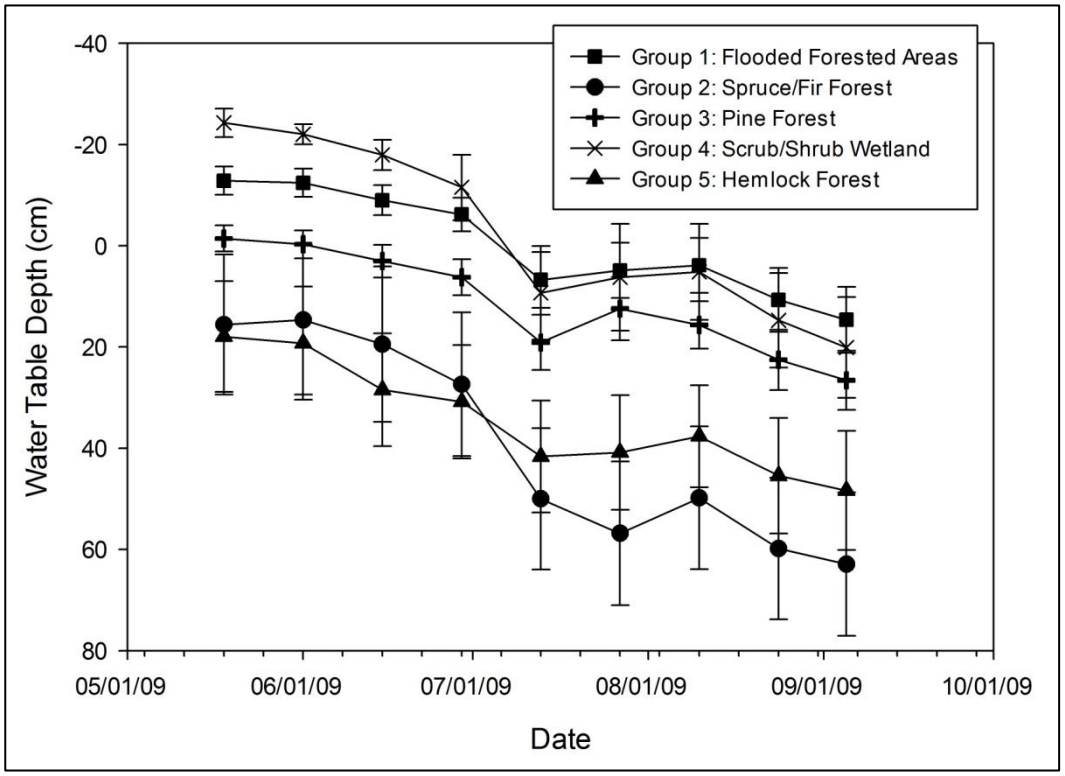

Figure 2.5. Mean water table for all plots in each group. Negative values are water table levels above the ground surface. Data are from manual water table readings. Error bars respresent standard errors.

Change in Landcover

Landcover change analysis showed an increase in other wetland area (105.36 ha in 1998 to 185.94 ha in 2005), scrub/shrub wetland area (379.87 ha in 1998 to 427.85 ha in 2005), and forested wetland area (194.11 ha in 1998 to 217.53 ha in 2005) (Table 2.7, Figures 2.6, 2.7, 2.8, 2.9). The total increase in wetland area was 151.88 ha, or 10.75% of the study area. Most of the increase in wetland area occurred where C-3 Pool receded (61.58 ha), but forested areas that were flooded also accounted for a significant portion of the change (14.34 ha). There was a slight increase in developed area (0.62 ha in 1998 to 1.56 ha in 2005, 0.07% of the study area) as well, probably as a result of the actual earthen ditch plugs. Open water decreased in area (227.66 ha in 1998 to 136.84 ha in 2005, 6.43% of the study area), most of which was a result of the open water of C-3 Pool converting to other wetland or scrub/shrub wetland (61.63 ha and 35.88 ha respectively). Upland forest also decreased in area (474.18 ha in 1998 to 409.23 ha in 2005). Most of this change was a result of flooding without a shift in vegetation leading to a classification of forested wetland (47.12 ha). Upland forest areas that were flooded and no longer supported woody vegetation were classified as other wetland (8.63 ha). Upland scrub/shrub increased slightly (3.8 ha in 1998 to 4.09 ha in 2005). The area of grass/ferns/hayfields decreased slightly (from 30.37 ha in 1998 to 27.15 ha in 2005). The total decrease of upland cover types was 67.88 ha, or 4.8% of the study area.

Table 2.7. Total cover of different cover types in 1998 and 2005. Percent change was calculated by dividing the total area of change by the total study area (1413 ha).

Cover Type	1998 area (ha)	2005 area (ha)	change (ha)	% change
Open Water	227.66	136.84	-90.82	-6.43
Upland Forest	474.18	409.23	-64.95	-4.60
Grass/Ferns/Hayfields	30.37	27.15	-3.22	-0.23
Upland Scrub/Shrub	3.80	4.09	0.28	0.02
Developed	0.62	1.56	0.94	0.07
Forested Wetland	194.11	217.53	23.43	1.66
Scrub/Shrub Wetland	379.97	427.85	47.88	3.39
Other Wetland	105.36	185.94	80.58	5.70
Sub Totals				
Upland	508.34	440.47	-67.88	-4.80
Wetland	679.44	831.32	151.88	10.75
Water	227.66	136.84	-90.82	-6.43
Developed	0.62	1.56	0.94	0.07

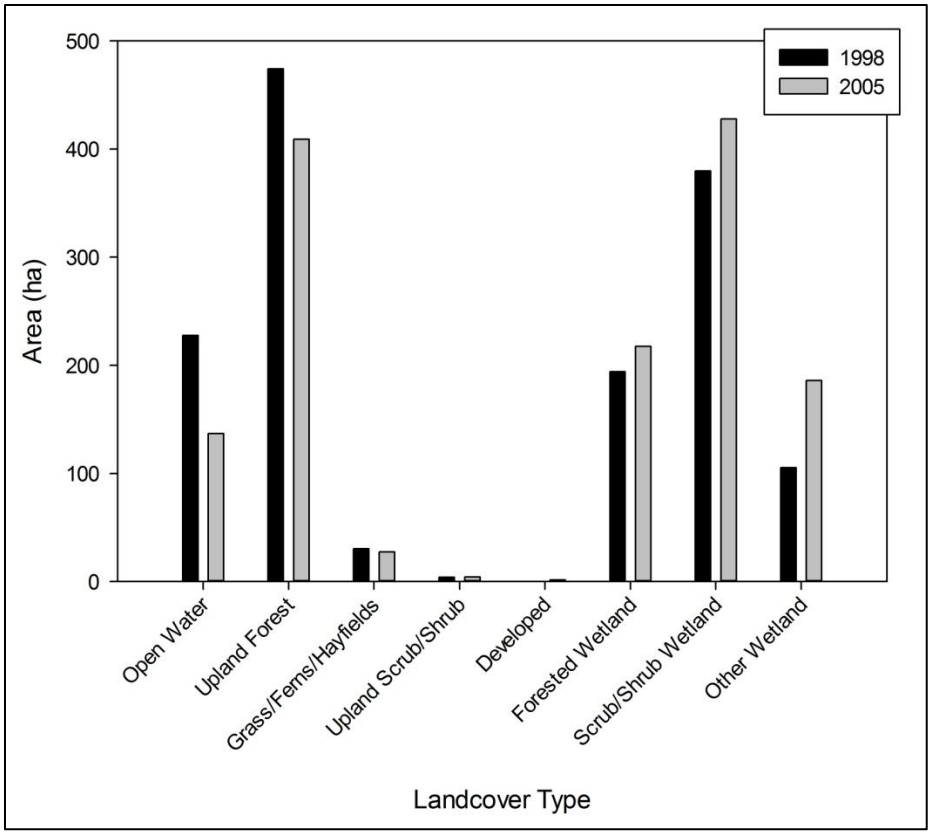

Figure 2.6. Change in total area of each cover type between 1998 and 2005. Areas were calculated from digitized landcover maps in ArcGIS version 9.3 (ERSI 2008).

There was some change in landcover throughout the study area, however, much of the change was concentrated in a few locations (Figure 2.9). The largest area of change was along the northwest shore of C-3 Pool. In this area, because of the new water management of the pool, the water has receded and has been replaced by other wetland and scrub/shrub wetland landcover types. There is also significant change immediately east of Walsh Ditch, mostly due to upland forest converting to forested wetland. These areas generally begin just north of a ditch plug and extend along the path of water flow to the southeast.

Discussion

Vegetation and Hydrologic Changes

The five vegetation community groups defined by cluster analysis have fairly distinct hydrologic characteristics, likely due to the patchy nature of flooding. Plots in groups 1 and 4 (Flooded Forested Areas and Scrub/Shrub Wetland) have the shallowest water tables. Plots in group 1 have a low basal area of living trees and the greatest

amount of standing dead wood of any of the vegetation groups, and have been colonized by wetland species such as willow, and woolgrass. Most of these plots also occur in areas directly south east of ditch plugs in areas that have been most heavily affected by flooding. Group 4 has the lowest basal area of all groups and has no trees smaller than 10 cm DBH. The group has a medium amount of standing dead wood and low coarse woody debris. The group has the highest level of shrub cover of any of the groups. Group 4 has the shallowest average water table of all groups, but group 1 varies less and is wetter than group 4 during the later part of the summer and into the autumn.

Group 3 (Pine Forest) has a shallow water table, but is generally not inundated for most of the year. This group has a high basal area and the second highest basal area of trees less than 10 cm DBH. Plots have relatively high coarse woody debris but low standing dead wood.

Groups 2 and 5 are the driest of the 5 vegetation groups. Both groups are forested. Group 2 is a spruce/fir forest. It has the deepest water table and the highest basal area of trees less than 10 cm DBH of the 5 groups. It also has low coarse woody debris and herbaceous cover. Group 5 has by far the highest basal area and coarse woody debris of the 5 groups. It also has low standing dead wood and relatively low basal area for small trees (<10 cm DBH). Group 5 has the highest coverage of herbaceous vegetation but low shrub coverage.

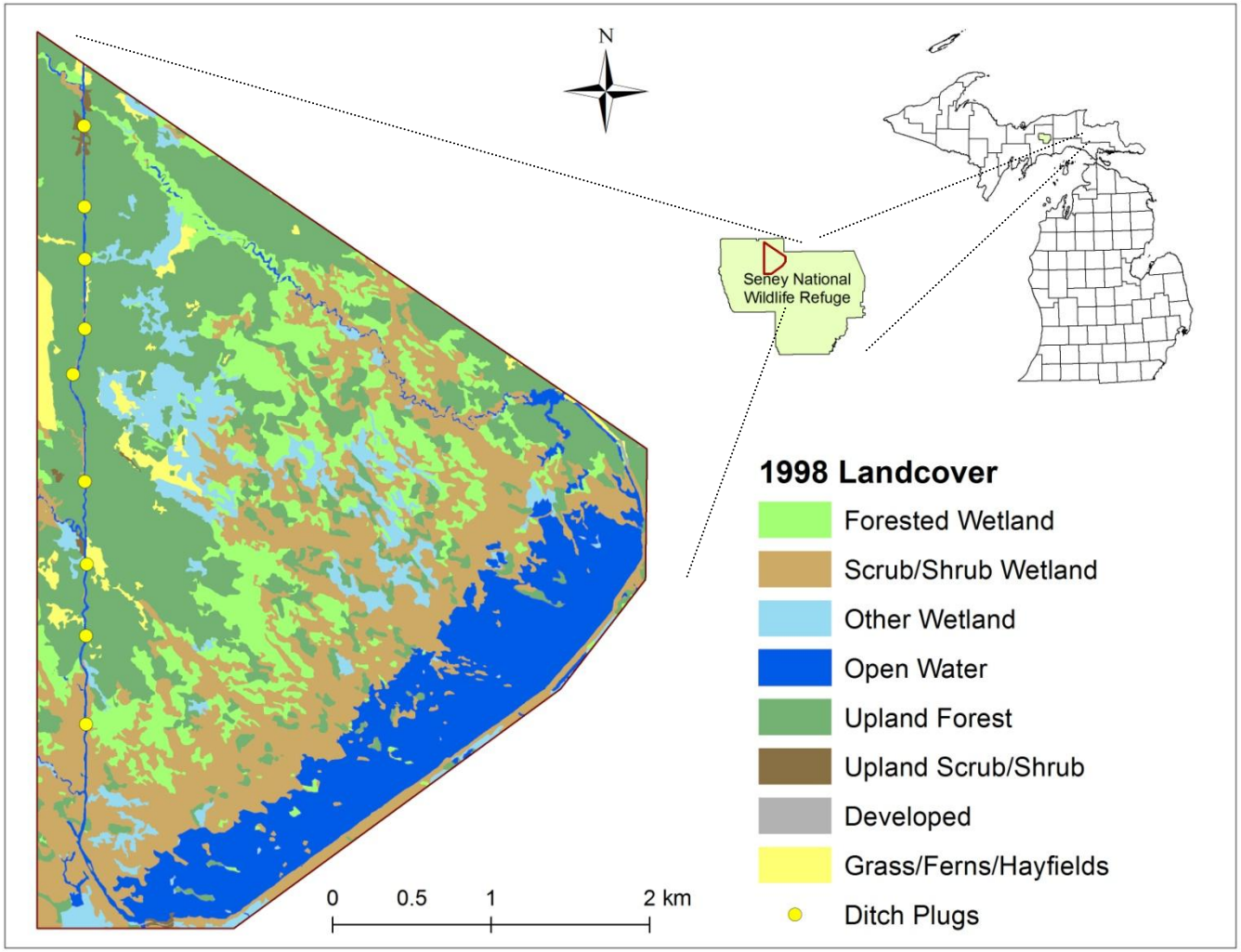

Figure 2.7. Map of 1998 landcover at study site in Seney National Wildlife Refuge. The map was digitized using a 1998 a mosaic of standard digital orthophoto quadrangles (DOQ) from the National Digital Cartographic Data Base. (Datum/Projection: NAD_1983_UTM_Zone_16N)

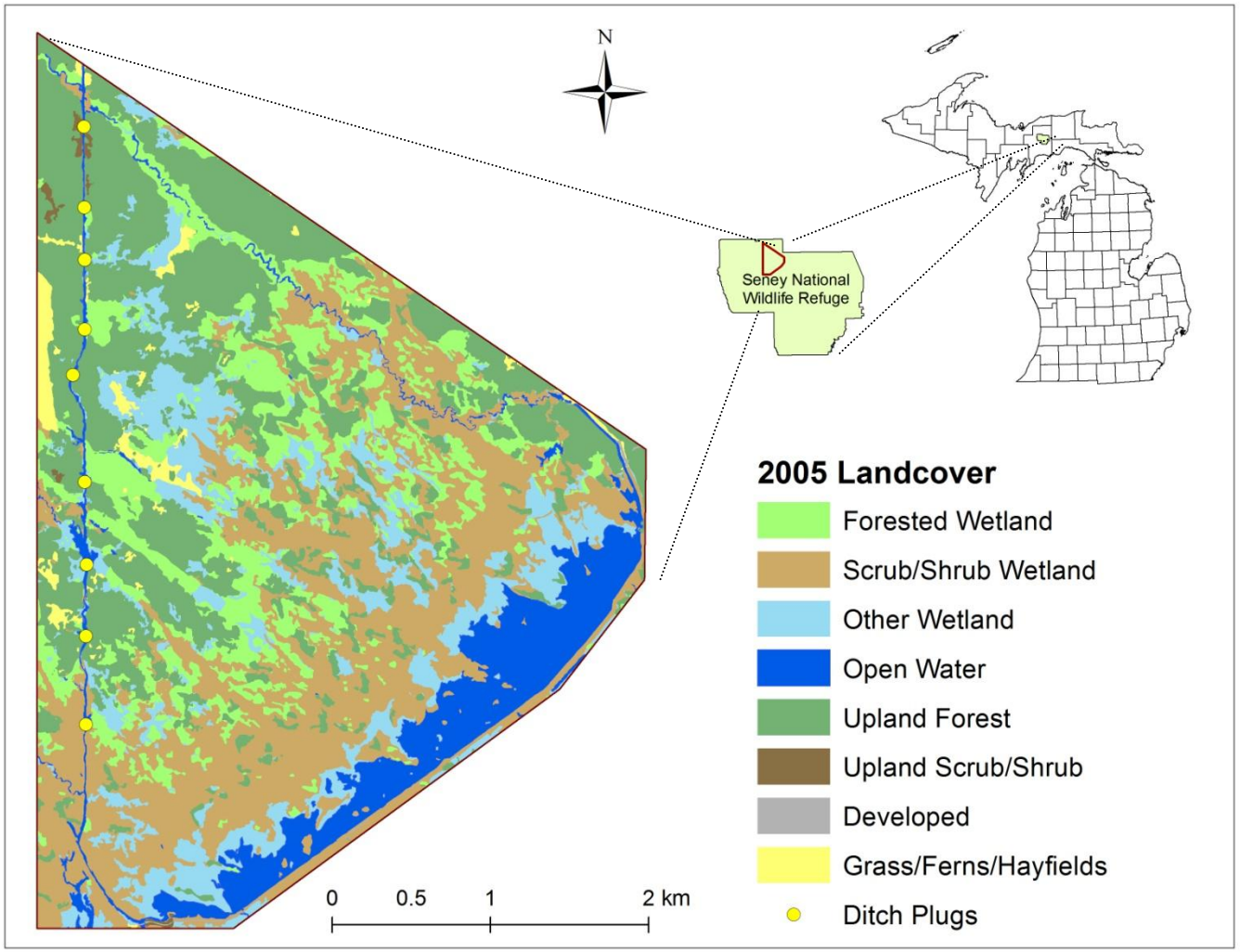

Figure 2.8. Map of 2005 landcover at study site in Seney National Wildlife Refuge. The map was digitized using color digital imagery collected by United States Department of Agriculture – Farm Service Agency (USDA-FAS) Aerial Photography Field Office. (Datum/Projection: NAD_1983_UTM_Zone_16N)

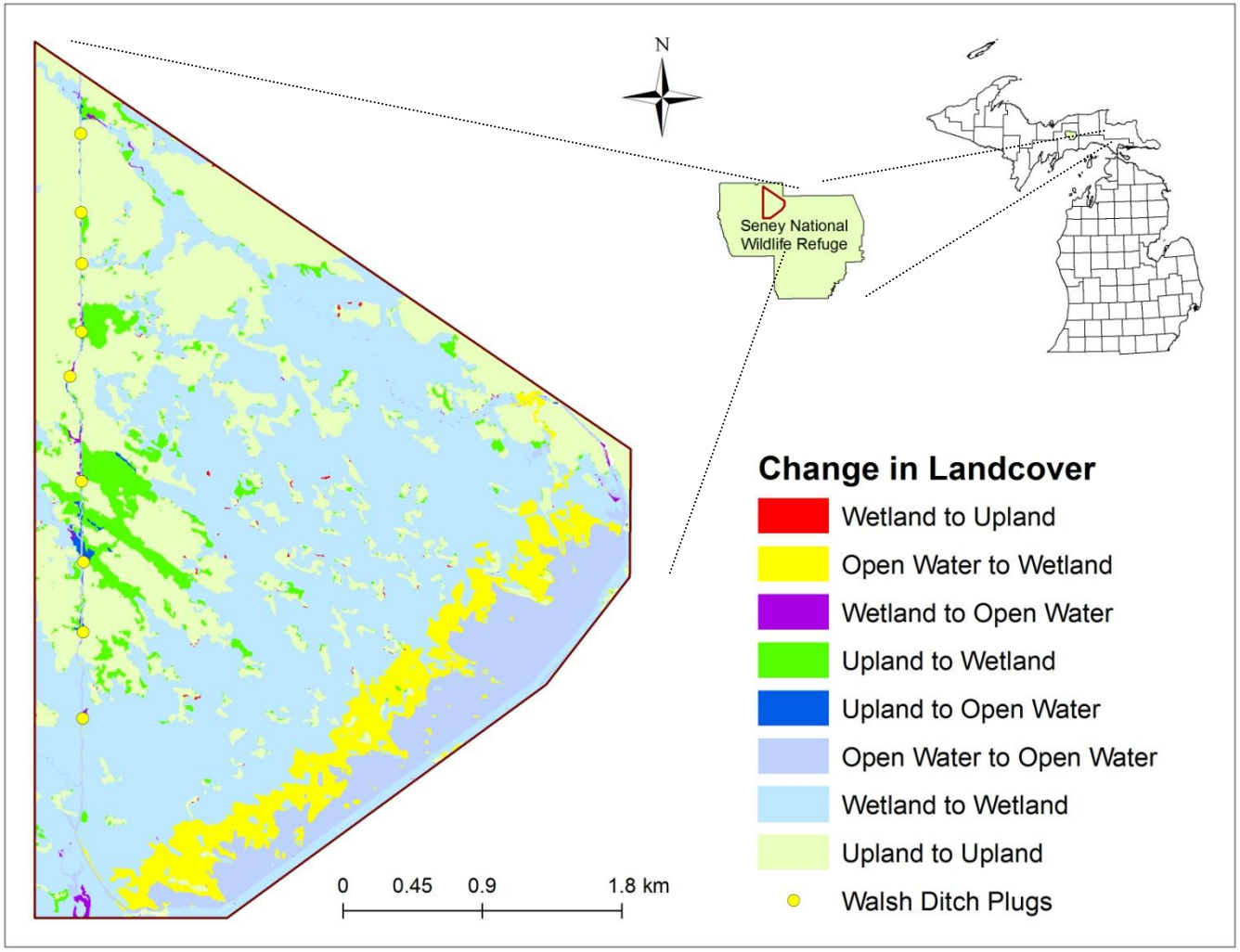

Figure 2.9. Change in landcover between 1998 and 2005. Landcover change was analyzed in ERDAS Imagine version 10.1 (ERDAS 2010)

Landcover Change

Because the pre-European landscape of Seney NWR consisted of a mosaic of uplands as well as wetlands (Heinselman 1965, USFWS 2009), it cannot be expected that the hydrologic restoration will cause the entire study area to revert to a single wetland community type. According to General Land Office (GLO) survey notes taken between 1816 and 1856, most of the study area was a heterogeneous mix of community types generally referred to as "muskeg/bog" (Comer et al. 1995).

The installation of the Walsh Ditch plugs has caused water to flood the adjacent landscape, as evidenced by aerial photographs as well as plot level measurements of water table depth. The flooding is not evenly distributed through the landscape, but is concentrated to the areas surrounding the natural water channels and areas immediately east of the ditch plugs (Figure 2.9).

The vegetation group that occurs in areas with the most change is Group 1 (Flooded Forested Areas). Many plots in this group are located in those areas that have been most affected by the ditch plugs. These are areas that prior to the hydrologic restoration were upland forests, but are shifting towards wetland community types. The success of restoration at these sites is comparable with other studies, in which blocking ditches led to flooding of the area (Cooper et al. 1998, Richert et al. 2000, Mälson and Rydin 2008), and a slow shift in vegetation towards wetland species (Richert et al. 2000, Mälson and Rydin 2008).

The other group that is a wetland community type, group 4 (Scrub/Shrub Wetland), occur in areas that have been less affected by the hydrologic restoration. These areas were lowland community types before the restoration and remain so. These areas may have experienced a raise in water table, but not a shift in vegetation.

Plots in group 5 (Hemlock Forest) occur north of Walsh Creek, in the area least affected by the hydrologic restoration. This group has not experienced a shift in vegetation due to the restoration.

Some plots in Group 2 and 3 (Spruce/Fir Forest and Pine Forest) occur in areas that have experienced a change in landcover, however, most of the plots occur in areas of no change. Those sites that have experienced a change in landcover are upland forests that have been flooded by the hydrologic restoration. It is possible that the plots in these groups that have been flooded will experience a shift in landcover in time, but so far the vegetation composition has not changed.

If restoration to a historic wetland cover is to be achieved over the entire study area additional effort may be needed to restore the wetland hydrology and vegetation to the areas not currently in the path of direct flooding. The poorly dispersed nature of the flooding is not surprising, considering how large an area of restoration is being attempted. Most similar studies cover a smaller area that has been less significantly drained (Cooper et al. 1998, Richert et al. 2000, Acreman et al. 2007, Mälson and Rydin 2008)

Future Research

Relative to the long-term mean, the year that the plot level data were collected (2009) was warmer (mean 9.1°C) and drier (66.9 cm) than average (Mesowest 2010). It is possible that the hydroperiods would be significantly different in wetter years, highlighting the importance of continued monitoring of hydrology throughout the study area. This study has shown that those areas that are elevated in comparison with the general landscape are not affected by the installation of the ditch plugs. Future studies could focus on those areas that have begun to show a change in vegetation composition and landcover, and those areas that have been flooded but so far have not shown a shift in vegetation composition. Using the plots developed for this study would benefit future research, and the detailed data for all vegetation types, as well as hydrology, will allow for a quantitative analysis of community development.

Conclusion

Raised water tables and colonization by wetland species in previously forested areas are both good indicators that natural hydrologic processes have begun to be restored at least in parts of the study area. Because of the long term nature of wetland restoration, it may be a while before the vegetation at some sites shows a response to the altered hydrologic conditions. The objectives of the hydrologic restoration project have been achieved in portions of the study area. There are other portions of the landscape that will most likely remain unchanged. What will be interesting to see in the future are those areas that have not shown a significant response yet, but with time may shift towards more natural lowland system. However, it is not likely that those areas that are furthest removed from the ditch plugs will show much change without additional efforts to distribute the water evenly throughout the area.

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Appendix A: Species List

Functional Group	Common Name	Scientific Name	Total Coverage[1]	Number of Plots Present in	Wetland Indicator Value[2]
Trees	Balsam Fir	*Abies balsamea*	4.746	10	FACW
	Red Maple	*Acer rubrum*	5.813	27	FAC
	Yellow Birch	*Betula alleghaniensis*	1.037	2	FAC
	American Beech	*Fagus grandifolia*	0.016	8	FACU
	Tamarack	*Larix laricina*	0.005	2	FACW
	White Spruce	*Picea glauca*	0.701	8	FACU
	Black Spruce	*Picea mariana*	0.906	11	FACW
	Jack Pine	*Pinus banksiana*	1.568	11	FACU
	Red Pine	*Pinus resinosa*	14.749	23	FACU
	Eastern White Pine	*Pinus strobus*	5.037	25	FACU
	Quaking Aspen	*Populus tremuloides* Michx.	6.617	26	
	Black Cherry	*Prunus serotina*	0.000	2	FACU
	Mountain Ash	*Sorbus* L.	0.006	2	
	Eastern Hemlock	*Tsuga canadensis*	6.774	4	FACU
	White Birch	*Betula papyrifera* Marsh.	1.886	13	FACU+
Shrubs	Speckled Alder	*Alnus incana* (L.) Moench ssp. *rugosa* (Du Roi) R.T. Clausen	1.500	2	OBL
	Serviceberry	*Amelanchier* spp. Medik	32.500	26	
	Spreading Dogbane	*Apocynum androsaemifolium* L.	2.500	5	

	Bog Birch	*Betula pumila L.*	4.750	6	OBL
	Redosier Dogwood	*Cornus sericea L*	0.250	1	FACW
	American Hazelnut	*Corylus americana* Walter	4.000	6	FACU-
	Beaked Hazelnut	*Corylus cornuta*	2.500	1	UPL
	Northern Bush Honeysuckle	*Diervilla lonicera* Mill.	0.500	2	
	Common Winterberry	*Ilex verticillata* (L.) A. Gray	1.500	3	FACW+
	American Fly Honeysuckle	*Lonicera canadensis*	2.250	4	FACU
	Honeysuckle	*Lonicera* spp.	0.500	2	
	Black Chokeberry	*Photinia melanocarpa*	4.250	2	FACW-
	Pin Cherry	*Prunus pensylvanica* L. f.	0.250	1	FACU-*
	Sandcherry	*Prunus pumila* L.	3.500	1	
	Prunus	*Prunus* spp.	0.250	1	
	Chokecherry	*Prunus virginiana* L.	7.250	12	FAC-
	Willow	*Salix* spp. L.	19.750	16	
	Spirea	*Spiraea* spp. L.	26.750	13	
	Steeplebush	*Spiraea tomentosa* L.	0.500	1	FACW
	Nannyberry	*Viburnum lentago L.*	5.500	11	FAC+
Herbaceous	Common Yarrow	*Achillea millefolium* L.	0.167	1	FACU
	Wood Anemone	*Anemone quinquefolia* L.	0.750	2	FAC*
	Wild Sarsaparilla	*Aralia nudicaulis* L.	2.417	4	FACU
	Bluejoint	*Calamagrostis canadensis* (Michx.) P. Beauv.	29.000	20	OBL

Sedge	*Carex* spp.	22.750	30	
Common Mouse-ear Chickweed	*Cerastium fontanum* Baumg.	0.083	1	
Fireweed	*Chamerion angustifolium (L.) Holub ssp. circumvagum (Mosquin) Hoch*	1.250	3	
Thistle	*Cirsium* spp.	0.250	1	
Reindeer Lichen	*Cladina* (Nyl.) Nyl.	6.083	7	
Wild Basil	*Clinopodium vulgare L.*	0.917	5	
Bluebead	*Clintonia borealis (Aiton) Raf.*	0.083	1	FAC+
Threeleaf Goldthread	*Coptis trifolia* (L.) Salisb.	5.750	7	FACW
Bunchberry Dogwood	*Cornus canadensis L.*	9.250	10	FAC
Wavy Hairgrass	*Deschampsia flexuosa (L.) Trin.*	3.500	5	
Wood Fern	*Dryopteris* spp.	9.000	13	
Trailing Arbutus	*Epigaea repens L.*	0.083	1	
Purpleleaf Willowherb	*Epilobium coloratum* Biehler	0.417	2	OBL
Flat-top Goldentop	*Euthamia graminifolia* (L.) Nutt. var. *graminifolia*	3.167	9	FACW-
Strawberry	*Fragaria* spp.	4.417	11	
Rough Bedstraw	*Galium asprellum* Michx.	1.000	3	OBL
Northern Bog Bedstraw	*Galium labradoricum* (Wiegand) Wiegand	0.750	3	OBL
Bedstraw	*Galium* spp.	0.167	2	
Fragrant Bedstraw	*Galium triflorum* Michx.	1.083	6	FACU+
Eastern Teaberry	*Gaultheria procumbens* L.	1.917	4	FACU

American Mannagrass	*Glyceria grandis* S. Watson	1.833	2	
Orange Hawkweed	*Hieracium aurantiacum* L.	6.000	16	
Meadow Hawkweed	*Hieracium caespitosum* Dumort.	0.250	1	
Shining Clubmoss	*Huperzia lucidula* (Michx.) Trevis.	2.667	3	FAC+
Common St. Johnswort	*Hypericum perforatum* L.	0.167	1	
Jewelweed	*Impatiens capensis* Meerb.	1.417	5	FACW
Harlequin Blueflag	*Iris versicolor* L.	0.417	2	OBL
Tall Blue Lettuce	*Lactuca biennis* (Moench) Fernald	0.167	1	FAC
Marsh Seedbox	*Ludwigia palustris* (L.) Elliot	0.667	3	OBL
Stiff Clubmoss	*Lycopodium annotinum* L.	0.250	1	FAC
Rare Clubmoss	*Lycopodium obscurum* L.	0.667	2	FACU
American Water	*Lycopus americanus* Muhl. ex W.			OBL
Horehound	Bartram	0.667	3	
Northern Bugleweed	*Lycopus uniflorus* Michx.	1.250	5	OBL
Earth Loosestrife	*Lysimachia terrestris* (L.) Britton, Sterns			OBL
	& Poggenb.	3.500	10	
Canada Mayflower	*Maianthemum canadense* Desf.	13.500	12	FAC
Indian Cucumber	*Medeola virginiana L.*	0.417	1	
Narrowleaf Cowwheat	*Melampyrum lineare* Desr.	0.917	4	FAC-
Wild Mint	*Mentha arvensis* L.	0.333	2	FACW
Sensitive Fern	*Onoclea sensibilis* L.	1.000	3	FACW
Cinnamon Fern	*Osmunda cinnamomea* L.	0.750	1	FACW
Royal Fern	*Osmunda regalis* L.	1.417	4	OBL
Mountain Woodsorrel	*Oxalis montana* Raf.	4.333	5	FACU*

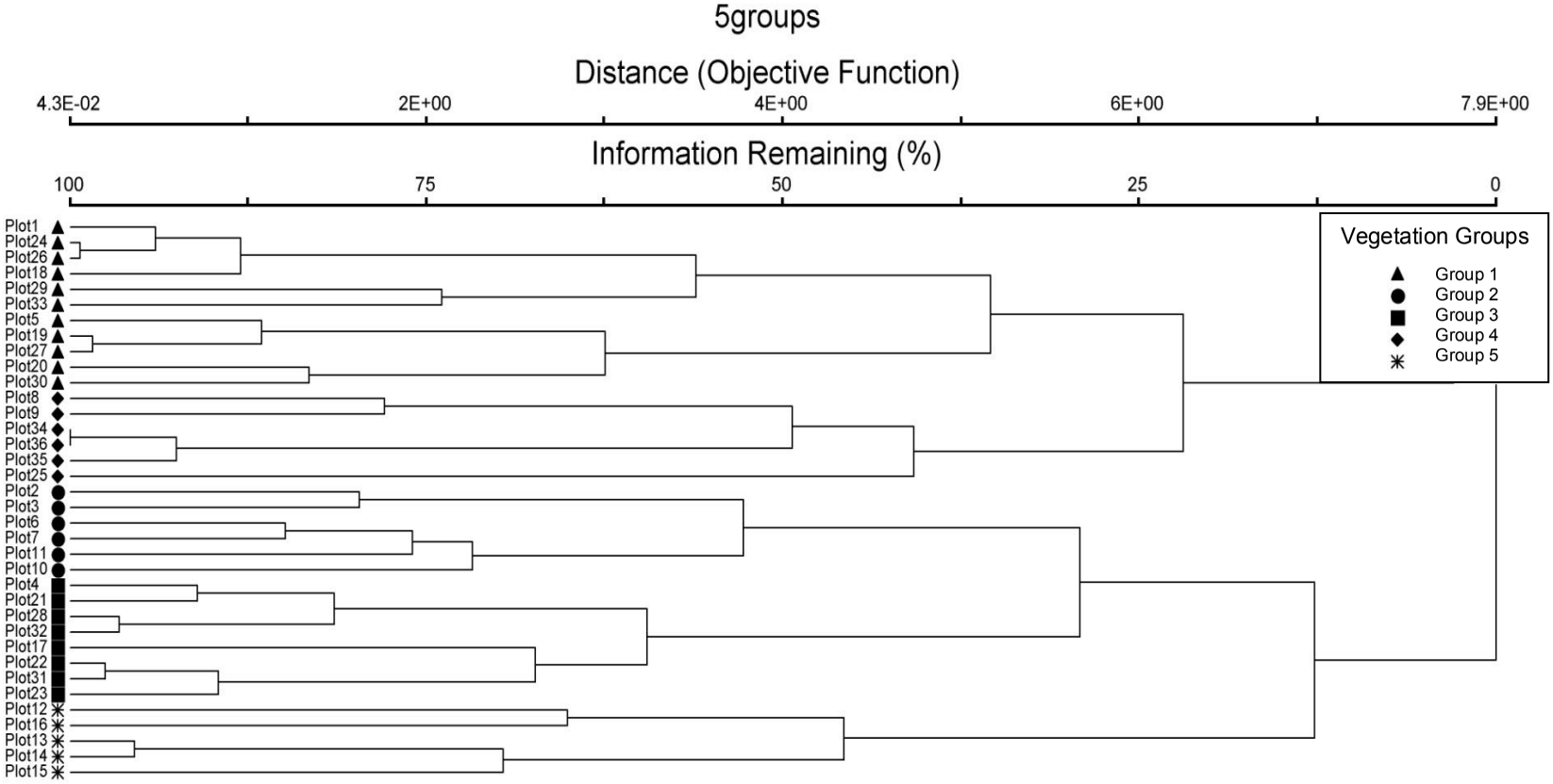
Panicgrass	*Panicum* L. spp.	3.333	10	
Timothy	*Phleum pratense* L.	2.917	6	FACU
Bluegrass	*Poa* L. spp.	5.333	12	
Polytrichum Moss	*Polytrichum* Hedw. spp.	7.500	15	
Western Brackenfern	*Pteridium aquilinum* (L.) Kuhn	11.500	15	FACU
Wintergreen	*Pyrola* L. spp.	2.917	8	
Littleleaf Buttercup	*Ranunculus abortivus* L.	0.750	2	FACW-
Pennsylvania	*Ranunculus pensylvanicus* L. f.			OBL
Buttercup		0.333	3	
Hairystem Gooseberry	*Ribes hirtellum* Michx.	0.417	2	FACW
Red Currant	*Ribes triste* Pall.	0.583	2	OBL
Brickly Rose	*Rosa acicularis* Lindl.	0.500	2	FACU
Rose	*Rosa* L. spp.	0.167	1	
Allegheny Blackberry	*Rubus allegheniensis* Porter	1.417	3	FACU+
Northern Dewberry	*Rubus flagellaris* Willd.	0.250	1	FACU-
Bristly Dewberry	*Rubus hispidus* L.	23.167	21	FACW
American Red	*Rubus idaeus* L.			FACU+
Raspberry		8.667	15	
Dwarf Red Blackberry	*Rubus pubescens* Raf.	2.167	3	FACW+
Common Sheep Sorrel	*Rumex acetosella* L.	2.583	7	FAC
Greater Water Dock	*Rumex orbiculatus* A. Gray	0.500	2	OBL
Woolgrass	*Scirpus cyperinus* (L.) Kunth	28.000	20	OBL
Marsh Skullcap	*Scutellaria galericulata* L.	0.750	2	OBL
Blue Skullcap	*Scutellaria lateriflora* L.	0.417	2	OBL

Hemlock Waterparsnip	*Sium suave* Walter	2.000	5	OBL
Canada Goldenrod	*Solidago altissima* L.	6.667	11	FACU
Giant Goldenrod	*Solidago gigantea* Aiton	2.083	5	FACW
Longleaf Starwort	*Stellaria longifolia* Muhl. ex Willd.	0.417	2	FACW+
Common Dandelion	*Taraxacum officinale* F.H. Wigg.	0.333	2	FACU
Purple Meadow-rue	*Thalictrum dasycarpum* Fisch. & Avé-Lall.	0.250	1	FACW-
Fraser's Marsh St. Johnswort	*Triadenum fraseri* (Spach) Gleason	0.750	3	OBL
Starflower	*Trientalis borealis* Raf.	11.917	19	FAC+
Field Clover	*Trifolium campestre* Schreb.	0.167	1	
Whip-poor-will Flower	*Trillium cernuum* L.	0.250	1	FAC
Broadleaf Cattail	*Typha latifolia* L.	1.667	4	OBL
Lowbush Blueberry	*Vaccinium angustifolium* Aiton	10.083	18	FACU
Velvetleaf Huckleberry	*Vaccinium myrtilloides* Michx.	7.167	12	FACW-
Common Mullein	*Verbascum thapsus* L.	0.167	1	
Common Gypsyweed	*Veronica officinalis* L.	0.583	2	UPL
Violet	*Viola* L. spp.	0.417	3	

[1] For trees, the coverage value is the total basal area for that species. For shrub and herbaceous species the coverage is the sum of all cover class values for that species. Cover class values can be found in Table 1.

[2] Wetland indicator statuses for all species are from the USDA Plants Database for the North Central Region (Region 3). [Plants Database. U.S. Department of Agriculture; Natural Resources Conservation Service, 29 Nov. 2010. <http://plants.usda.gov/index.html>.]

Appendix B: Hierarchical Cluster Analysis Dendrogram

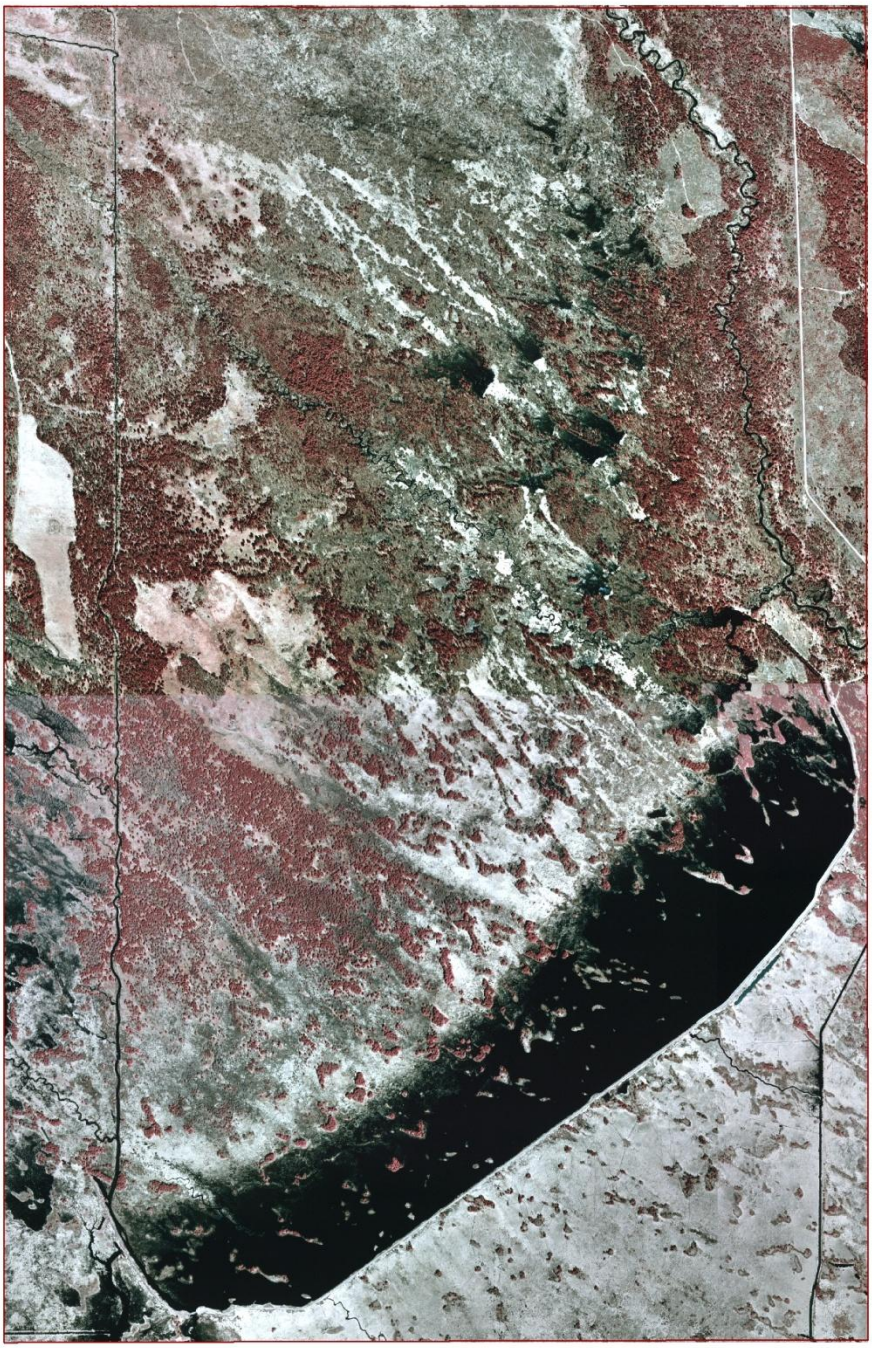
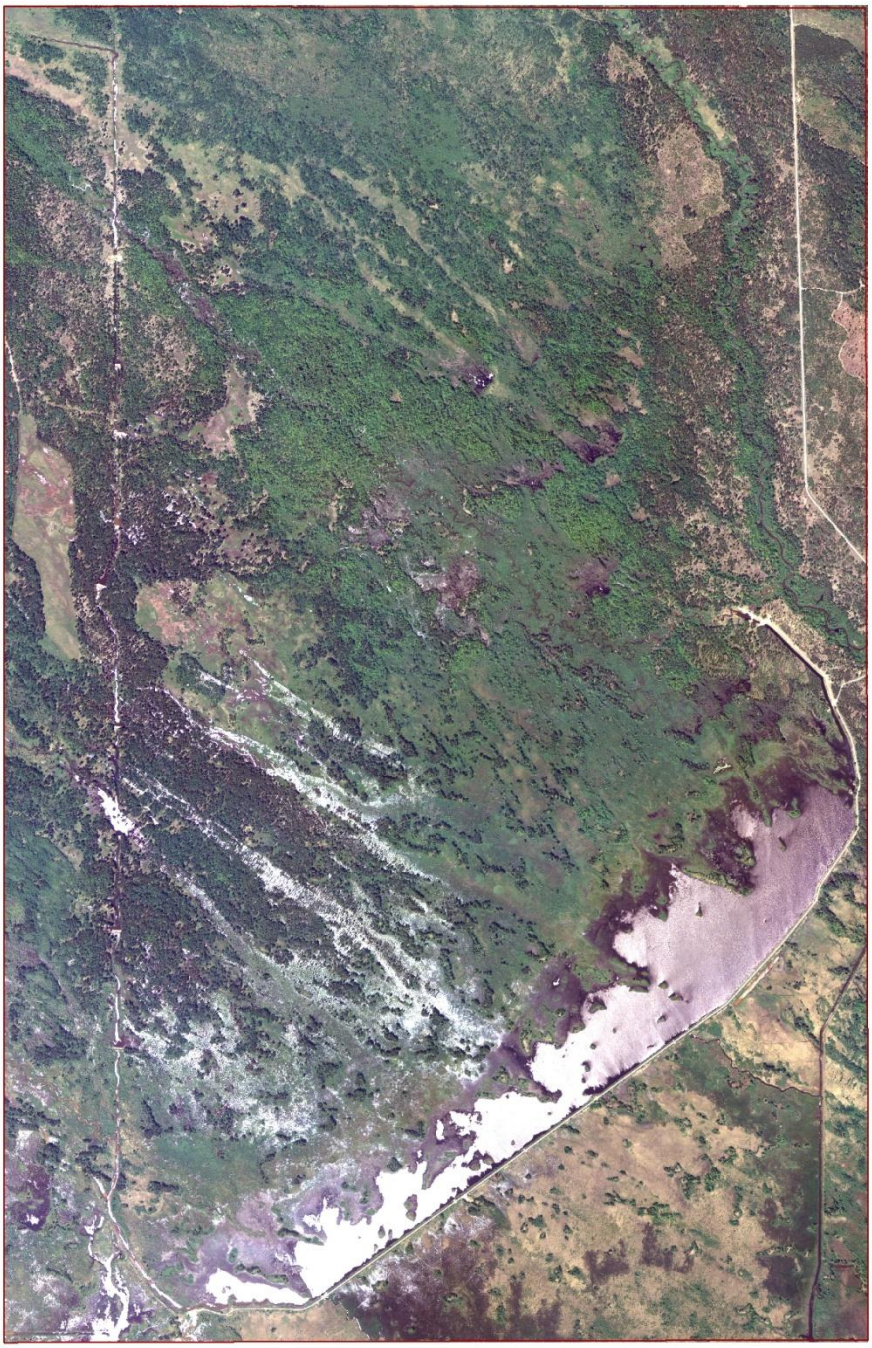


Appendix C: Plot Specific Water Table Depth

Group	Plot	Mean Water Table Depth (cm)	Range in Water Table Depth (cm)
Group 1: Flooded Forested Areas	Plot1	24.5099	52.7248
	Plot5	15.8105	57.5224
	Plot18	3.3338	17.7032
	Plot19	-15.8307	14.5248
	Plot20	-1.2328	20.0560
	Plot24	-1.2389	30.7000
	Plot26	7.2465	33.3440
	Plot27	-10.5533	14.0592
	Plot29	-8.5954	19.4840
	Plot30	-24.8919	18.9360
	Plot33	2.2184	27.1896
	Group 1 Mean	**-0.8385**	**27.8404**
Group 2: Spruce/Fir Forest	Plot2	35.3627	71.5000
	Plot3	14.2295	52.9368
	Plot6	45.9490	68.0000
	Plot7	21.3425	65.4680
	Plot10	100.5078	31.7968
	Plot11	8.7824	17.0000
	Group 2 Mean	**37.6956**	**51.1169**
Group 3: Pine Forest	Plot4	29.8082	54.5296
	Plot17	-5.9863	24.0792
	Plot21	14.1889	29.7500
	Plot22	24.8846	28.0016
	Plot23	1.7342	28.2856
	Plot28	5.36736	19.9568
	Plot31	7.1492	22.104
	Plot32	8.55328	27.9296
	Group 3 Mean	**10.7124**	**29.3296**
Group 4: Shrub/Scrub Wetland	Plot8	23.00924	88.9544
	Plot9	1.10304	69.6424
	Plot25	-16.68636	30.5184
	Plot34	-12.02888	24.3472
	Plot35	-8.7578	25.8744

	Plot36	-8.3714	30.5320
	Group 4 Mean	**-3.6220**	**44.9781**
Group 5: Hemlock Forest	Plot12	9.4149	21.4408
	Plot13	73.8075	25.4200
	Plot14	28.1833	32.5632
	Plot15	31.3981	39.4536
	Plot16	22.9472	45.4160
	Group 5 Mean	**33.1502**	**32.8587**

Appendix D: Aerial Image Used for Digitizing 1998 Landcover Map



Appendix E: Aerial Image Used for Digitizing 2005 Landcover Map