A STUDY OF BEAVER POND MORPHOLOGY AND SITE CHARACTERISTICS AFTER DISTURBANCE IN EASTERN GLACIER NATIONAL PARK, MONTANA

THESIS

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By

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A STUDY OF BEAVER POND MORPHOLOGY AND SITE CHARACTERISTICS

AFTER DISTURBANCE IN EASTERN GLACIER

NATIONAL PARK, MONTANA

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ABSTRACT

A STUDY OF BEAVER POND MORPHOLOGY AND SITE CHARACTERISTICS AFTER DISTURBANCE IN EASTERN GLACIER NATIONAL PARK, MONTANA.

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Little research has been conducted on alterations or disturbances to beaver ponds, which is important to understanding beavers' interactions with the environment. Three sites with beaver-pond sequences in Glacier National Park in northwest Montana were chosen for study, including sites near Saint Mary Lake, Lake Sherburne, and Lower Two Medicine Lake. The Saint Mary Lake site was subjected to an extensive forest fire in the watershed in 2006. The latter two sites are adjacent to human-constructed reservoirs. Aerial photos were used to create maps in a Geography Information System for all three site locations over a twenty year span from 1991-2011. Statistical analysis compared average pond areas of beaver-pond sequences between

sites, as well as a comparison of average area of pond sequences between years and site locations. Analysis proved that the Lower Two Medicine is statistically different in average area of pond sequences when compared to the other sites, but no statistical difference in beaver-pond area existed between the Saint Mary and Lake Sherburne sites. There was also no statistical difference between area of ponds when compared to different years. Varying lake levels because of irrigation draw-down at Lake Sherburne and Lower Two Medicine created a dynamic base level, whereas the local base level for the Saint Mary ponds remains relatively constant year round. The fluctuating base levels of Lower Two Medicine and Lake Sherburne ensure dynamic environments for the creek systems, and the ponds along it. The Saint Mary Ponds appear to be undergoing rapid siltation following the 2006 forest fire within the drainage basin.

CHAPTER I

INTRODUCTION

The ability of animals to alter landscapes through geomorphic means has been described as zoogeomorphology (Butler 1995). Animals influence ecosystems by their foraging strategies and physical habitat alterations. Beavers have the unique ability to alter their habitat through both mechanisms, more so than any other animal except humans. The alteration of the landscape is caused through their capacity to build and maintain dams on streams that impound water. For this reason the beaver is referred to as a keystone species, to which their ecological impact is out of proportion with their populations (Naiman 1988, Naiman et al. 1988). Little research has been conducted on alterations or disturbances to beaver ponds, so it is therefore the aim of this research to understand how beaver ponds change in response to disturbances such as fire and anthropogenic constructed impoundments within glaciated valleys in Glacier National Park, Montana.

Recent expansion in the beaver populations has occurred in North America following a decrease in habitat destruction coupled with conservation and changing fashions since early European-American settlements (Novak 1987). A large portion of the increase in population has occurred on public lands such as National Parks. With rising populations come increasing geomorphic changes in the landscape associated with the building of dams and removal of trees and sediment.

Beavers' capacity to create habitat through stream impoundments is beneficial for wetland creation, and ecosystem richness in diversity. However, it can be at odds with management techniques for protection of human structures or timber supply (Snodgrass 1997). Thus the geomorphic effects of impoundments and fire have positive or negative consequences depending upon management goals. The same idea could be applied to a fire disturbance; however, infill as a result of sedimentation from fire is more likely than expansion spatially.

Beaver impoundments are widespread in Glacier National Park (GNP) and provide sites for comparison with and without some kind of disturbance. Several pond sequences were chosen that are located in glaciated U-shaped valleys with finger lakes, or pseudo-finger lakes, within the park. The purpose of this study is to determine the extent disturbances could impose on spatial growth within pond sequences.

CHAPTER II

LITERATURE REVIEW

Historical and Current Distributions of Beavers

Because this research has the potential for interpreting beaver impacts over a broad spatial, as well as temporal, scale, I will address the literature concerned with the historical and modern distributions in North America. Historical numbers in North American before European settlement were estimated to be between 60-400 million beavers (Naiman et al. 1988). Their range in North America extended from Arctic tree line in Alaska and Canada all the way south to the establishment of deserts in Mexico, with an exception of the Florida peninsula and arid regions in the southwest.

Beavers were primarily trapped for their fur by the newly arrived European settlers. Beaver furs were matted together to create beaver felt hats that were of popular fashion in Europe in the late seventeenth to nineteenth century (Bryce 1904). There was also the opinion by the majority of settlers that wetlands were somewhat of a wasteland and routinely drained, an opinion which held up until about fifty years ago (National Research Council 1995). Beavers, once common occurrences on streams across the country, were soon at risk because of direct hunting and habitat destruction.

The beginning of the twentieth century, however, marked a change in the beavers' fate. Stronger conservations laws, along with changing fashions from beaver felt to silk hats, have allowed beaver populations to respond accordingly. Syphard and Garcia (2001) recognized the importance of conservation trends with beaver populations in regards to agricultural legislation:

> Previous research has demonstrated that the primary cause of wetland loss in the United States had gradually changed from agriculture to urbanization. This shift away from agriculture is reflected in the national policies and regulations. For example, early legislation, such as the Swamp Lands Act, the Illinois Drainage Levee Act, and the USDA Agriculture Conservation Program (1940-1970), encouraged the replacement of wetlands with agriculture. However, as public awareness of wetland value increased, Congress responded by creating programs such as the Farm Security Acts of 1985, 1990, and 1996 that provide incentives to agricultural land owners to protect and restore wetlands. (Syphard and Garcia 2001. 349).

Naiman et al. (1988) also noted that a large portion of the wetlands lost during the period prior to protection were former beaver habitats. Stronger conservation laws against agricultural expansion into wetlands, and the Clean Water Act of 1977, Section 404, set the path for no net loss of wetlands. This has allowed the beaver to reoccupy all of their previous historic range, but at much lower populations densities of around 10% of pre-European levels, estimated from six to twelve million (Naiman et al. 1988). Predicting current beaver populations is difficult because the species is primarily nocturnal, and populations can vary greatly from area to area (Butler 1995). This recolonization of populations has occurred naturally in some areas, and by reintroduction of the species in other locations. Some locations such as Glacier National Park, which have received protection since the park opened in 1910, never reached the estimated extreme lows in populations found in other mountainous locations in North America (Meentemeyer and Butler 1995).

Beaver Constructions

The beaver builds dams to create ponds in order to have a habitat to live in. Ives (1942, 194) explains “the physical work of the beaver is almost entirely concerned with the creation of his preferred artificial environment, even the aspen logs from which he has eaten the bark becoming integral parts of his dams and houses”. Beavers have also been described as opportunistic, and will take advantage of other materials found in the environment such as human trash, and rocks if those materials can aid in the impoundment process (Butler 1995).

The dams are constructed so they appear to be logs piled in a random fashion with little order. However dams do have a pattern, concaving upstream with mud applied to seal the upstream side to restrict water flow (Ives 1942). Dams are reported to have varying lengths summarized by Butler and Malanson (1995, 256-257) with dam sizes “falling in a size range of 15-70m long and 1-2m wide, but dams <1m wide are not atypical”. Dam heights tend to vary as well depending on the environmental conditions. Although dams appear to be fragile, they are quite resilient to many natural destructive forces, such as ice thrusts, and leaks can easily be fixed (Ives 1942).

Site selection is an important factor for the beaver when choosing its habitat. Many studies have investigated the preferred environment in which to build a pond. The site and sounds of running water triggers a beaver's instinct to dam it (Olson and Huber 1994). However, it has been observed that typically beavers build dams on stream of second to fourth order (Naiman et al. 1988). The stream order represents a tradeoff between the maximum pool sizes, while also avoiding the physical constraints of larger discharges. The same tradeoff was represented by Jakes et al. (2001) when describing beaver impoundments in southeastern streams. They found that beavers preferred a watershed size of about 2500ha. Stream gradient can also play a role in site selection, with beavers preferring gradients less than three percent (Olson and Hubert 1994). Appropriate vegetation is required adjacent to impoundments because beaver use this for dam construction as well as for their herbivorous diet. Beavers prefer aspens of medium sized for food and construction (Ives 1942). Temperature, precipitation, and climatic variations are found to be much less important in site selection, but rather the ability of the beaver to maintain a wet condition year round is the most import factor (Hood and Bayley 2008).

Beavers may occupy, abandon, and reoccupy sites at varying temporal intervals (Warren 1932). Beavers may build isolated single dams, or a series of dams that form a step pool sequence. Beavers have also been known to rework abandoned dams by previous inhabitants (Naiman et al. 1988). These generaly are dams of much larger size. The damming of streams in some cases can lead to a completely different drainage pattern for the area (Dugmore 1914). The morphological extent of each dam can vary depending on the environmental conditions. Woo and Waddington (1990) explained four different morphohydrological types of dams:

1. dams with stream-flow overtopping
2. dams with water funneling through gaps in the dam crest
3. underflow dams, where water moves through weakened bottom structure
4. throughflow dams, where water moves through the whole dam

However, no clear pattern appeared between the preferred type of dam structures, other than larger discharge streams tended to have dam types one and two as described by Woo and Waddington (1990).

The structure and function of beaver constructions will ultimately determine the ponds morphology. For this reason a complete morphological description of beaver dams must be included in descriptions of ponds.

Beaver Pond Hydrology

Beavers expand the saturated surface of a stream in order to increase their habitat and food supply as well as for protection from predators (Naiman and Meillio 1984). The area saturated, or open water in wetlands, is closely related with the active number of beaver colonies in the area (Hood and Bayley 2007). This was demonstrated in Hood and Bayley's (2007) study in Elk Island Natural Preserve, which showed that in 1950, when beavers were not present on the landscape, the park had sixty-one percent less open water than in 2002 when the study was conducted. Also the presence of beavers within a watershed accounted for eighty percent of the variability; this was because of their remarkable ability to manage open water successfully. As expected because of the previous results, ponds without active colonies of beavers also had less open water than active ponds that were being managed by beaver.

Meentemeyer and Butler (1999) found that the efficacy of beaver dams to dampen stream flow varies considerably between ponds and locations, and older dams tend to reduce stream velocity and discharge considerably more than younger dams. Average sediment thickness is also greater in older ponds (Bigler *et al*. 2001), which supports Ives' (1942) claim based on the idea that older ponds have longer time to collect the sediments.

Sedimentation varies greatly between ponds and different environments. Ives (1942) stated that an average of 2.5cm per year is deposited into a beaver pond. However Bigler et al. (2001) sampled several ponds in Glacier National Park and found the rates to vary from 2.1cm -27.9cm per year. This was because of the dams being a unique obstruction to flow in mountains streams, and allows the ponds to impound large volumes. However other key factors are the input of energy and surface geology within the drainage area. With beaver populations rising, the riparian environment is beginning to change back to the pre-European landscape. This transformation changes the streams from erosional natured, to a wetland ecosystem that would not be present without beaver's interactions (Butler and Malanson 2005). Meentemeyer and Butler (1999) proposed that the capture of large amounts of sediment could cause a release of under-loaded water downstream so that the stream's capacity to erode is increased, which goes against the idea beaver impounds reduce erosion. However, more research is needed to prove the hypothesis.

However virtually no literature on how constructed structures affect beaver ponds exists, rather it focuses on how beaver ponds can affect human structure. There is also no literature on artificial reservoirs in regards to beaver ponds. The need for my research is underscored by the virtual absence of literature describing these kinds of structures and their relationships to beaver ponds sequences.

Influences on Biodiversity

Beavers are able to influence vegetation succession by building dams that trap sediment, which directly or indirectly kills woody vegetation surrounding the impoundment (Wright and Jones 2002). This vegetation succession was explained by Ives (1942)

> "the normal plant succession, described in very general terms, is grasses, brush, aspen growth and montane forest. Whenever an area is deforested, for any reason, this succession recommences. Whenever a stream is dammed by beaver, the local water table is elevated, and many of the spruce and fir trees of the montane forest are killed. Within a few years, these dead trees fall, and aspen trees, more tolerant to moist subsoil conditions replace some of them" (197-198).

Once the montane forests have died out, the sediment deposited within the beaver pond becomes firmly bound by the roots of the brushes and grasses. This creates a zone of soil that is matted with roots and leads to it not easily being eroded. Once the impoundment is completely in-filled with sediment and matted with brushes, it can become a lasting feature on the landscape (Ives 1942). This matches the descriptions of vegetation explained in other papers, however the temporal scale may be much longer (Ruedemann and Schoonmaker 1938; Johnston and Naiman 1990). Ruedemann and Schoonmaker (1938) explained that given sufficient time, a dam that resists structural failure, such as from a flood, will gradually fill with sediment to form a gentle sloping beaver meadow. Although they do not give a time frame for this succession, it is suggested to be much longer than the few years explained by Ives (1942).

Johnston and Naiman (1990) used a Geographic Information System to analyze how beavers have altered the hydrology and vegetation over a forty-six year period in Voyageurs National Park, Minnesota. They found a dramatic increase in beaver impoundments since the 1940’s; however none of the beaver ponds reverted back to forest during the study period. This lack of woody reinvasion of the ponds goes against Ives’ (1942) succession. Change occurred in forty percent of the preexisting aquatic mosaics and it is suggested this sharp increase was created in the beavers’ search for new food sources. However, when beavers leave, vegetation succession does occur, not as rapidly as expected, but the shifting mosaic leads to increased vegetation diversity on the landscape.

Beavers have the ability to modify aquatic patches and may contribute to more than twenty-five percent of the total richness of herbaceous plant species (Wright and Jones 2002). This large increase in species richness is largely because of the beavers, and the succession that occurs after the beavers impound a stream segment. Green and Westbrook (2009) found that removal of beaver dams on the landscape resulted in a change in the riparian vegetation, from high variety of herbaceous species to low variety resulting in mainly shrubs and conifers.

Effects of Disturbances on Beaver Ponds

There was no literature that focused on disturbances to beaver ponds, rather research that focused on the hazards or disturbances caused from beaver ponds. This is where a clear gap in the literature of beaver pond research exists. Fire has the potential for larger disturbances when compared to human built impoundments. Although not directly applied to beaver ponds, wildfire-induced sedimentation rates because of erosion after the fire, could be as much as one to two magnitudes higher than normal conditions (Shakesby and Doerr 2005). Shakesby and Doerr (2005) stated several of the geomorphic changes that can occur after a wildfire, which include loss of vegetation or litter cover, evapotranspiration and storage of rainfall can be altered, and the chemical characteristics of the soil can take on a water repellency behavior. There can also be considerable increased overland flow on slopes during peak discharge events, which increases soil redistribution into catchments. This redistribution of soil into catchments could have the most profound effect on beaver ponds after a fire, but there is no literature to confirm or reject this. North American fire suppression policies have increased fuel load tremendously, while leading to less frequent fires (Allen et al. 2002). This has led to more severe wildfires, which requires all aspects to be researched, including effects on beaver ponds.

My research, primarily focused on specific pond sequences, can also be thought of in a more broad landscape scale. Pond sequences examined may impact more than just the downstream hydrology and geomorphology, but also the floodplain adjacent to ponds. Few landscape-scale studies exist with specific focus on beaver ponds sequences. No studies exist that focus on disturbances to beaver pond sequences, such as fire and human constructed impoundments. These disturbances have the potential to cause landscape-scale changes, and therefore should be studied at the landscape scale.

CHAPTER III

SITE AND SITUATION

Glacier National Park (GNP) is located in the northwest region of Montana, situated along the Rocky Mountains and Continental Divide, just south of the Canadian border (figure 1). GNP is a 4,082 km^2 park that is nearly all mountainous terrain. To the west of the park is the inland maritime Whitefish Range, and to the east of the park is the northwestern portion of the Great Plains. There are two north-south ranges within GNP, the Lewis Range and Livingston Range. The Lewis Range traverses the entire eastern portion of the park, and is where all studied sites are located. GNP was declared a national park by Congress in 1910. Waterton Lakes National Park, just to the north in Canada, is Glacier's sister park, and was created in 1895. Both parks were designated in 1932 as the Waterton-Glacier International Peace Park. GNP has also been designated as a Biosphere Reserve in 1976 and World Heritage Site in 1995 (Farge 2005). Just to the south of the park is the Bob Marshall Wilderness Complex, which is administered by the U.S. Forest Service. The Bob Marshall Wilderness Complex, designated in 1964, consists of three wilderness area's totaling over 6,100km^2, Bob Marshall Wilderness, Great Bear Wilderness and Scapegoat Wilderness. In addition, The Flathead National

Forest lies to the west of the Glacier with an additional 5,700 km^2 of protected habitat (USDA 2013). To the east of the park lies the Blackfeet Indian Reservation. This has allowed for GNP to be relatively unaltered when compared to other mountainous areas of western North America. With the exception of reduced fire frequency and occasional introduction of exotic plant species, the vegetation of GNP has undergone few changes brought by European settlement, common to many other mountainous areas in North America (Lesica 2002).

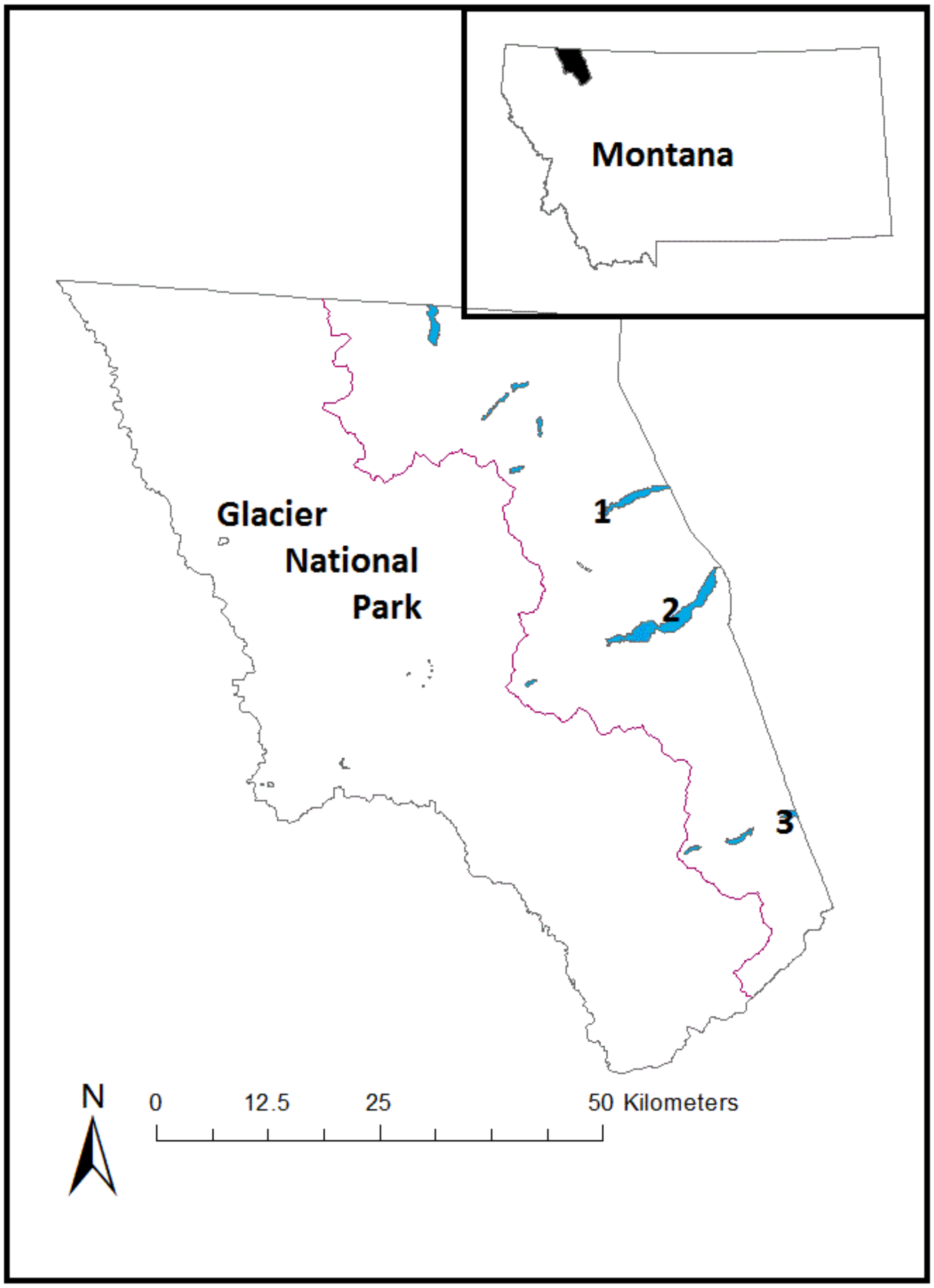

Figure 1: Location of Glacier National Park in Montana. 1: Lake Sherburne Site 2: Saint Mary Lake Site and 3: Lower Two Medicine Site.

Climate

Finklin's (1986) climatic handbook for Glacier provides the following data about the park. Latitude, prevailing wind patterns, extensive mountainous barriers and the position on the North American continent influence the climate of Glacier, as well as small-scale local factors. The local factors include topography, azimuth and vegetation. Overall the climate of GNP is a transition from a northern Pacific, or northern maritime, to continental climate. This is influenced by Pacific storms emerging from the west, and arctic air masses arriving from the north. The strongest of these influences are felt in the high peaks of the Continental Divide, because of the terrain both climates exhibit mountain-climate characteristics overlapped as well. Most of the Pacific moisture brought in falls along the western side of the Continental Divide, with precipitation decreasing farther east from the divide. The cold air masses from the north are usually confined within the eastern portions of the divide. For these reasons there are considerable differences between the climate of the eastern and western portions of the park.

Weather stations data was examined over a 30 year period (1951-1980) for climatic averages. Temperatures are generally higher in the western valleys than the eastern portion of the park. January has the coldest monthly averages from -10°C to -7°C (15°F-25°F). January also represents the month with the highest precipitation totals. Almost all of this precipitation is collected as snow during that month. Snow is persistent in the park and found from November to April in low elevations. Elevations above 5,000 feet can have snow cover well into May. The winter season also brings the highest wind speeds on the eastern side of the park, with averages from 13-15 km/hr. The highest wind speeds for the western portion of the park occur in summer months; however they are still lower than East Glacier wind speed averages for that same time. June is the month with highest flood potential. This is due to discharge peaks from snowmelt, as well as frequent heavy thunderstorms. May and June provide the highest precipitation averages for the eastern side of the park. Glacier only has 2-months of summer, July and August. July is the warmest month, with averages in the park from 15°C to 17°C (59°F-63°F). The prevailing weather patterns allow for large precipitation differences between areas of the park, with some western locations averaging 2500mm/year, to eastern valley locations averaging only 580mm/year. However overall averages in precipitation from the east of the divide to west of the divide are very similar. It is the elevation differences that cause such variations within temperature and precipitation.

Geology and Topography

The topography of GNP has been reshaped by glaciers advancing and receding. The surface geology in the region is mainly sedimentary rocks, with occasional minor intrusions of igneous rocks. At the study sites the surface geology is Pleistocene glacial till, and alluvium. Majority of the formations in the park are part of the Belt Series, which date back to Precambrian age from 800 million to two billion years ago (USGS 1990). The Belt Series was formed when sediments were deposited in a narrow inland sea, stretching from the Arctic Ocean to the Pacific Ocean. The main rocks in the series include limestone, dolostone and red and green mudstone (Ross and Rezak 1959). The

Belt Series was overthrust a minimum of 35 miles to the east, and now lies on top of much younger Cretaceous sedimentary rocks (Alt and Hyndman 2011). The sedimentary deposits were eventual folded and uplifted some 65-70 million years ago (Lessica, 2002). There is a noticeable change between the more resistant steep cliffs of the Belt Series within the park, and the gentle rolling hills of Cretaceous limestone, just east of the park. The noticeable change is the Lewis Overthurst (Alt and Hyndman 2011). Once the rocks were uplifted and folded they were steeply carved by ice, water and wind erosion. Most notable erosional features were caused by the glaciers retreating, leaving sheer-faced cliffs, steep cirques, and narrow trough-shaped valleys, all features found throughout the park. Glaciers also left behind large bands of debris know as glacial moraines. In several locations such as Saint Mary Lake, the glacial moraine was able to dam the narrow valley to create glacial finger lakes. Similar narrow valleys, like the Lower Two Medicine and Sherburne Lake were anthropogenically dammed to mimic a glacial finger lake.

GNP is positioned on the Continental Divide and is the headwaters for streams in the region. West of the divide all the streams are part of the Flathead River tributary, and will eventually drain into the Pacific Ocean. Most of the park east of the divide, including Saint Mary Lake site, and Sherburne Lake Site, drains into Canada through tributaries to the Hudson Bay. The Lower Two Medicine site flows to a tributary of the Missouri River, which eventually joins the Mississippi River into the Gulf of Mexico (Ross and Rezak 1959). The park is divided into three marine basins, marked by Triple Divide Peak, located just south of Saint Mary Lake.

Vegetation

The vegetation of Glacier is highly diverse; this is because of the large variation in elevation within the park. The elevation is responsible for many other factors that inhibit plant growth, such as snow cover, precipitation amount and aspect. There are three basic divisions in vegetation, Lessica (2002) divides them by elevation, similar to Merriam Zones. Montane vegetation ranges from 915-1675m, Subalpine has an elevation range from 1525-2285m, and the highest vegetation lies in the Alpine zone at greater than 1980m. All site locations are within a montane pond or wetland landscape, and vegetation discussed will focus on observed species from field work in summer 2012.

Wetlands can be a common feature in Montane zones; they are associated with glacial ponds and lakes. They are most commonly found along streams or beaver impoundments. Lessica (2002) describes these swampy areas to be dominated by willow and marsh vegetation that developed on saturated to flooded soils. These wetlands occupy a small total amount of GNP, however they support some of the largest diversity of habitat and species in the park.

Fire

Traditionally the U.S. Department of the Interior, which is in charge of the National Park Service, has been given the task of protecting and preserving the natural landscape within the department holdings. This until recently has meant protecting the area for public use, and suppression of wildfires (Finklin 1986). Around the late 1970's the department realized the historic role of fire shaping the vegetation and diversity within the park (Kilgore 1976). Fire management now seeks to allow natural wildfires to burn within prescribed boundaries. There are also routine planned ignitions of fires to achieve the same diversity benefit, but with more control (Finklin). Fire management data was compiled by Barrett (1983) with concerns to the history and Key (1984) researched fire prone areas in the park. Fire management has primarily been focused on the western portion of GNP, due to higher occurrences of fires, and higher visitation. A fire occurred in 2006 at the Saint Mary pond location.

Lake Sherburne Site

Lake Sherburne is located in the Many Glacier region, in the north-eastern portion of the park (figure 2). Lake Sherburne is the larger of the two reservoir lakes, with a capacity of 80,145,000 cubic meters of water. The dam was constructed between 1914-1921 for irrigation purposes, and impounds the Swift Current Creek, just west of the town of Babb (Department of the Interior 2012). Lake Sherburne is a large part of the Milk River project which provides water for irrigation of 48,970 hectares of farm land (US Department of the Interior 2012).

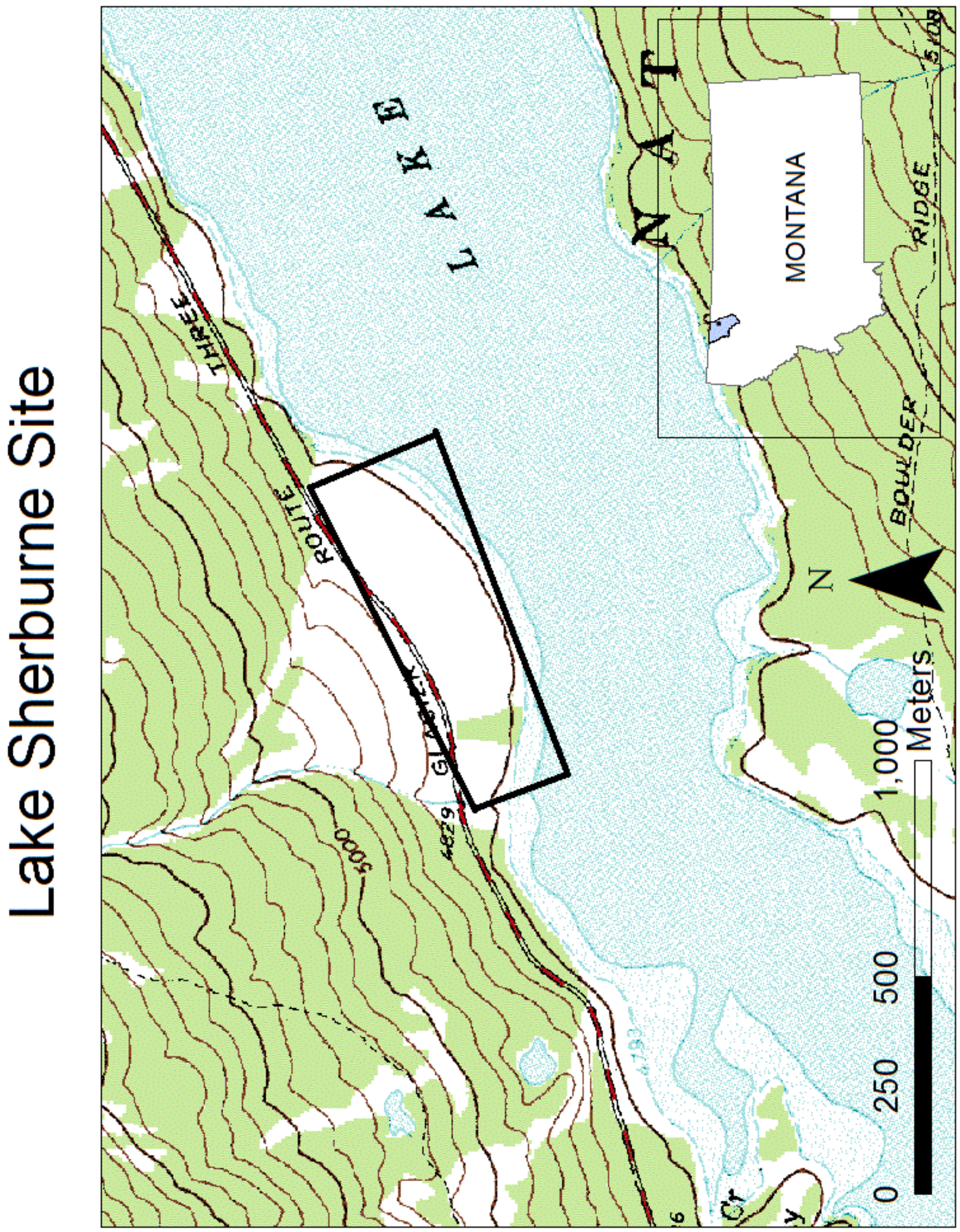

Figure 2: Location of Lake Sherburne Beaver Ponds on USGS 1:24,000 Topographic map.

Saint Mary Site

Saint Mary Lake is located between the other two sites, and is a glacially created finger lake (figure 3). At the end of the last ice age, meltwater deposited an alluvial fan that was able to impound the lake (Alt and Hyndman 2011). Saint Mary Lake is 15.9km in length, and up to 91m in depth. Because of the high elevation (1,367m) and lake depth, the water rarely rises above 10°C.

A large fire occurred in the drainage basin of the Saint Mary site in July into September of 2006. The Red Eagle Fire started at the Head of Red Eagle Lake, located to the south of the study site at Saint Mary Lake. The fire was first reported mid-afternoon on Friday, July 28, 2006. Strong winds and warm temperatures quickly aided the spread of the fire, and caused the small town of Saint Mary to evacuate the following day (Peterson 2006a). Little fire activity has occurred on the east side of the park, with the last major fire occurring in 1919 (Peterson 2006a). The Red Eagle Fire burned up to tree line in several locations such as Red Eagle Mountain, and Curly Bear Mountain more than 2,100 meters in elevation (Peterson 2006a). By August 24, 2006, nearly a month later, the fire was reported to be ninety percent contained by park officials, with the major concern now turning to erosion of stream beds in the park (Peterson, 2006c). Overall the Red Eagle Fire burned over 13,000 hectares, approximately fifty-five percent within national park boundaries, and forty-five percent burned within the adjacent Blackfeet Tribal Trust Lands (Peterson 2006b).

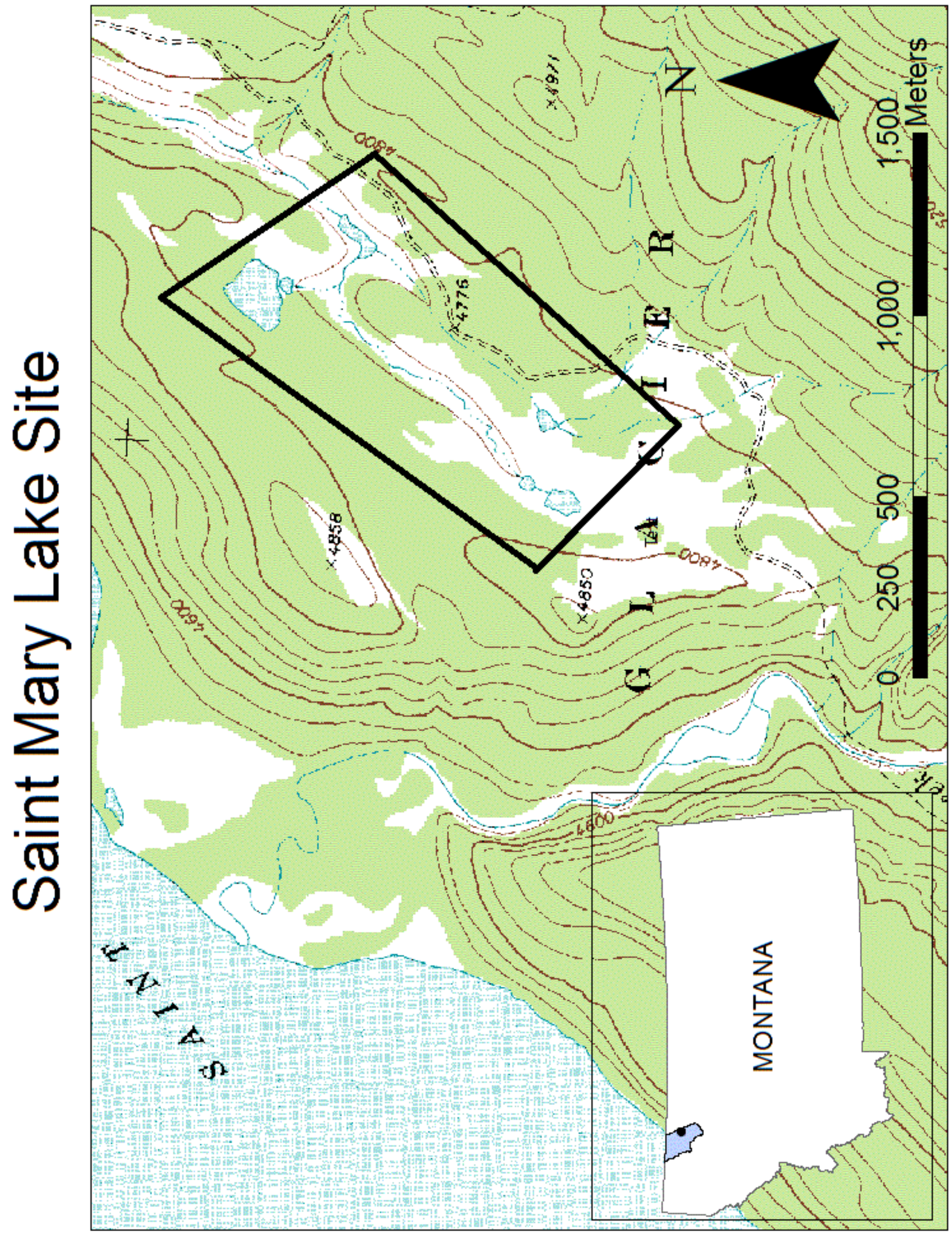

Figure 3: Location of Saint Mary Lake Beaver Ponds on USGS 1:24,000 Topographic Map.

Lower Two Medicine Site

Two Medicine Lake is located to the east of the Two Medicine Pass of the Continental Divide, and is the furthest south site (figure 4). Lower Two Medicine Lake is partially located within the park, but the majority is on the Blackfeet Indian Reservation. The lake is a natural lake, but has a man-made dam to regulate lake level, and reduce downstream flooding. At capacity, the reservoir has the ability to hold up to 19,728,000 cubic meters of water. The dam was constructed between 1908 and 1910 for use of irrigation of a tract of land near the town of Cut Bank (Department of the Interior, 1966). The lake is more somewhat more secluded than the other sites. Unlike many other lakes in GNP, there are not maintained or marked trails surrounding the lake. For those reasons, the pressure on Lower Two Medicine Lake from visitors is less than Lake Sherburne or Saint Mary Lake, which are popular destinations.

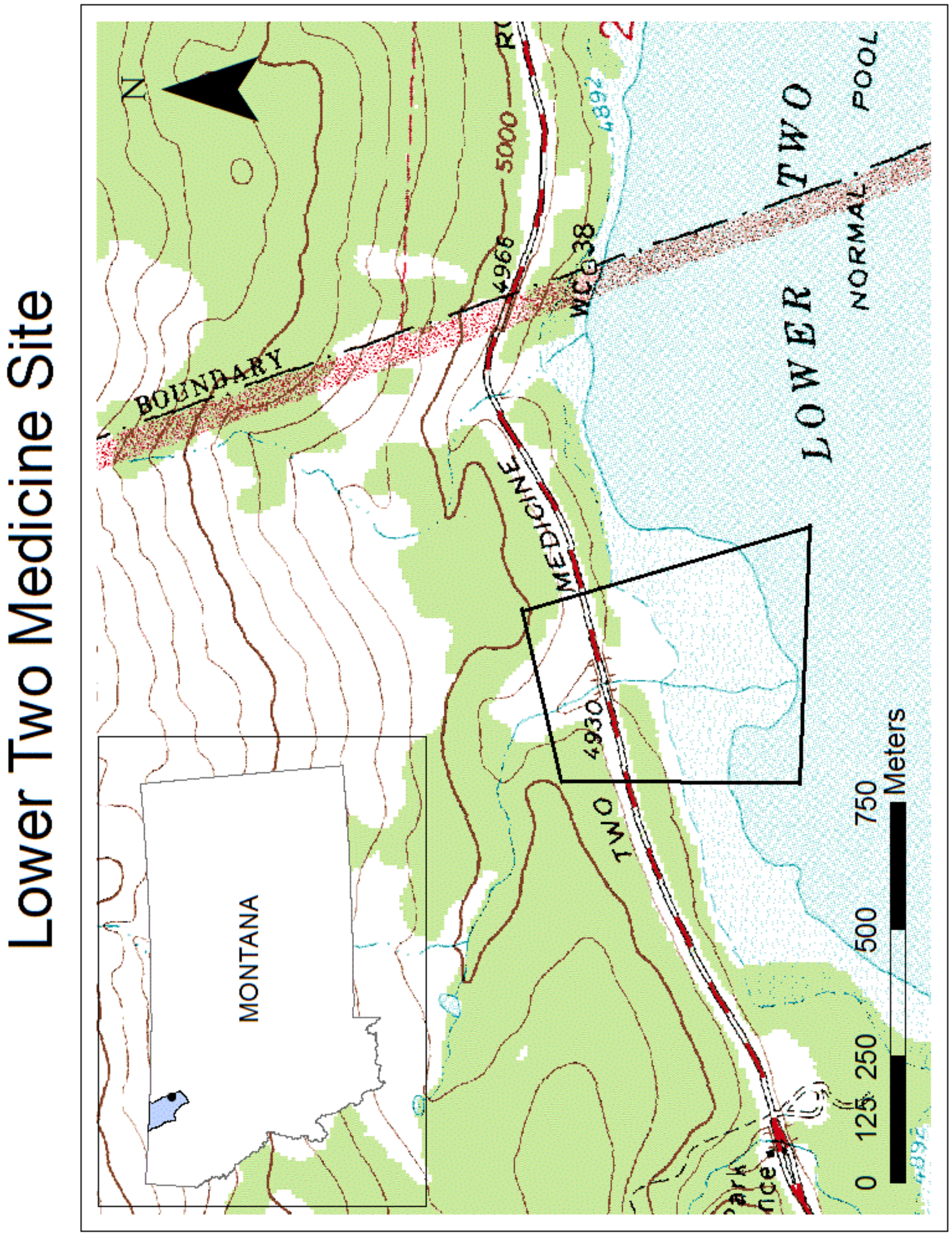

Figure 4: Location of Lower Two Medicine Beaver Ponds on USGS 1:24,000 Topographic map.

CHAPTER IV

METHODS

Data

Once potential sites were identified using GoogleEarth's historical imagery tool, the actual aerial photographs were obtained. All Digital Ortho Quarter Quads (DOQQ) are from the United States Geologic Survey (USGS) Earth Explorer at a scale of 1:24,000. All DOQQ's are projected in North American Datum 1983. The Saint Mary quad, Lower Two Medicine quad, and Sherburne quad were downloaded for the years 1991, 1995, 2003, 2004, 2009 and 2011. DOQQ's after 2006 for the Saint Mary site represent a large change in the environment, following a fire, and increased sedimentation will be considered in analysis.. This is the core data for the analysis for which polygons were drawn and overlaid on beaver ponds onto the DOQQ images.

Additional GIS layers were collected from the Department of the Interior to insure proper site selection. Contour data collected from 1983 insured that all sites were inside a valley in a low point along a stream channel. A boundary of Glacier National Park was obtained for a site map. All data was obtained from a government entity and require no manipulation of the data

Research Methods

New polygon shape files were created for each year; 1991, 1995, 2003, 2006, 2009 and 2011 at three sites. Historical photos through Earth Explorer were used to understand a better range of when the individual pond sequences were first constructed. Because of variation of area among pond sequences, a map for each site representing the pond number was created. Using the editing tool, impoundments were digitized with freehand to allow matching realistic shape more accurately. Once all individual ponds were drawn, they were labeled in the attribute table. An additional field will be added to the attribute table and area was calculated in square meters. The pond polygon layers were overlaid to see the total extent of change represented by shape over the twenty year period.

Statistical analysis of the percent change of the spatial extent of individual ponds and pond sequences were compared for differences in Excel. An equation to calculate percent change was developed:

(B1-A1)/absolute value (A1)

Where A1 represents the previous year's area and B1 is the current yeas area. All solutions were converted into a percentage for better comparison, as well as averages calculated for each year's pond sequence. Comparison periods where a new pond was constructed, and did not exist in the previous year, did not have a comparison percentage. This allows for a uniform comparison between area changes in percentage. Once individual area of ponds at each site was calculated, as well as total area for each year represented, statistical analysis was undertaken. The average area for the 3 sites was examined for statistical difference in the means among years. First a Univariate Analysis of Variance was conducted to detect an interaction between year and site location. Next, two one-way ANOVAs were performed. The first ANOVA explained if the sites vary when compared to area. The second ANOVA examined if there is any variance among years. A Chi-Squared test was used to test for uniformity among pond areas if statistical analysis turns up not significant.

Field Observations were conducted in the summer of 2012 for confirmation of GIS interpretations of pond locations. The plant succession of a beaver pond to beaver meadow begins with grassland species in active ponds. After ponds are abandoned, brush-like vegetation begins to take over, followed by aspen trees and other species adaptable to more saturated soil conditions. The final stage of beaver meadow succession is having complete infill of sedimentation and montane forest at the previous pond site (Ives 1942). Sites were assessed for the presence of grass, brush, aspen or montane forests in photographs taken in 2012. This can also give an estimate of which pond is the oldest or youngest based, on how far along Ives' (1942) plant succession they are. These assumptions can aid in additional investigation with sediment cores from pond locations as follow up research.

CHAPTER V

RESULTS AND ANALYSIS

Saint Mary Pond Sequences

I examined the Saint Mary Pond Sequence using GIS interpretations of eight total beaver ponds. At the Saint Mary site, 1995 was the only year to have all eight ponds present (figure 6). A series of seven maps have been created to display the area and spatial patterns of the pond sequences (figures 5-11). Overall, the changes from one study year to the next at the Saint Mary site were large. On average, ponds from 1991-1995 grew by 47.9 percent (Table 1). The next study year from 1995-2003, on average saw ponds shrink 51.5 percent in area from the 1995 sizes. In 2005, the ponds were expanding again and were 58.9 percent larger than the previous year in 2003. After the Red Eagle Fire in 2006 near Saint Mary, growth totals begin to steady out. By 2009 the ponds decreased in size 45 percent from 2005, the year before the fire. When the ponds were measured again in 2011, there was an additional decrease by another 47 percent from 2009. When compared to the other 2 pond sequences the Saint Mary Ponds were larger than any other, with the exception of 2011, five years after the fire

It appears after the fire in 2006 a large amount of sedimentation, that would most likely occur because of erosion, was able to steady the change in area in the ponds. Before the fire, expansion and reduction in area was variable each study year from 47.9% one year to -51.5% the next and 58.9% in a 14 year period. Once the fire in 2006 happened, the ponds were less variable in study years 2009 and 2011, and shrank at a steady rate of 45-47 percent. In order to understand if the steady rate of decreased area was because of the fire, sediment cores from ponds, and well as additional GIS interpretation before 1991, could be conducted. However, I can speculate that, without the Red Eagle Fire, the Saint Mary ponds would continue to have large variations in area from year to year.

Ponds that were not present one year, but were present the next study year, were not able to be compared with percentages. For example, Pond 8 was not present in 1991, but had an area of 885 square meters in 1995. Using the percent change formula from the methods, it would not be correct to say expansion of 100%. Pond 7, which is located between pond 4 and 8, is just about center in the pond sequence (figure 12). Pond 7 was not present in 1991, 2003, 2009 and 2011. Pond 7 seems to appear periodically, in years 1991 and 2005, additional field analysis could explain why this pond varied in area more than any other. A possible interpretation is pond 7 only occurred in particularly wet years, or was frequently abandoned. Site photos from 1994 to 2012 (figure 11) illustrate the trends explained by the GIS interpretation. In 1994, field photos by David R. Butler, are present, and easy to identify, however, 8 years later in 2002, the ponds are hard to identify. When the author conducted field photos in 2012, the ponds were not visible in photographs, only brush overgrowth.

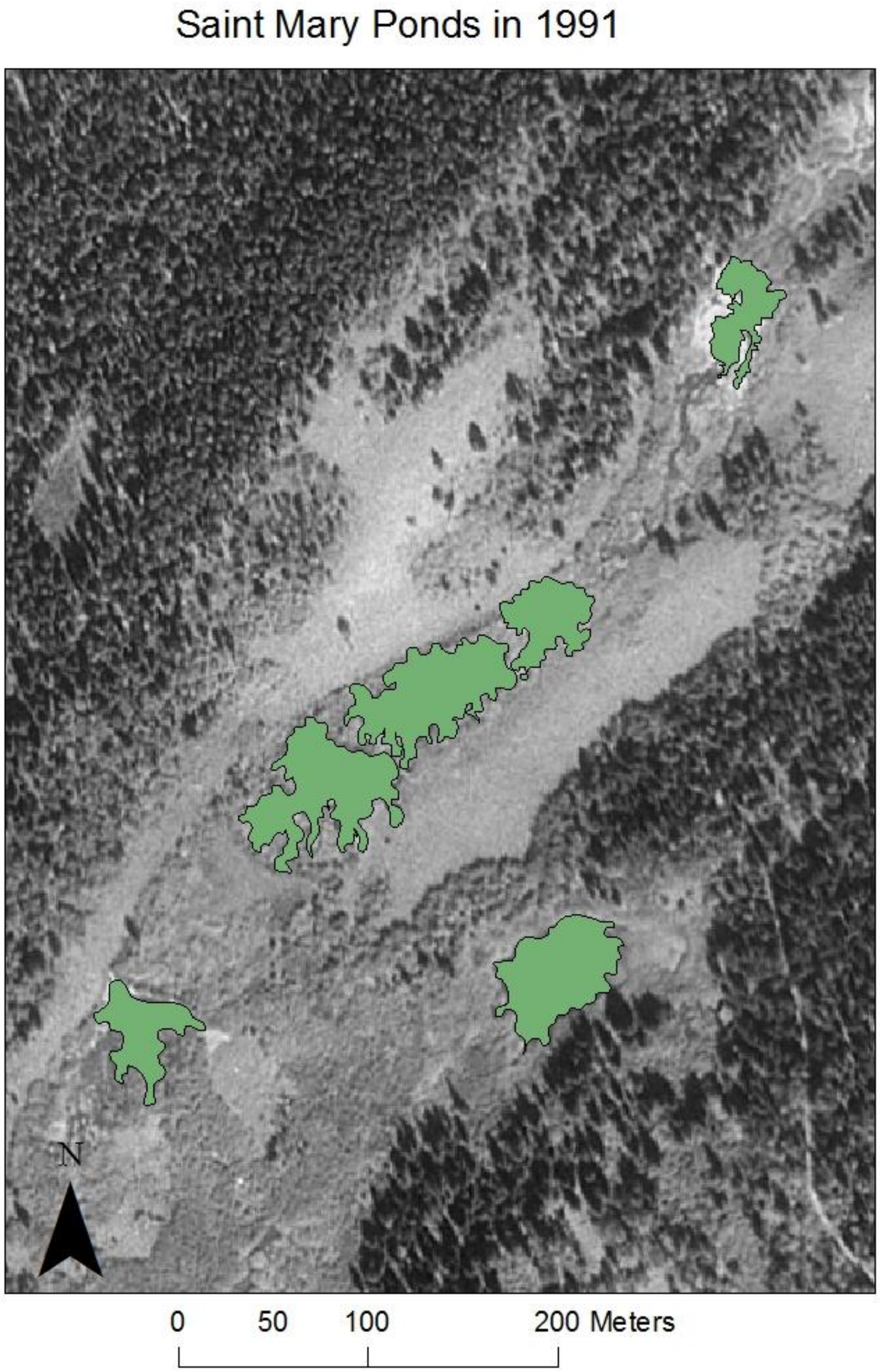

Figure 5: Saint Mary Ponds in 1991.

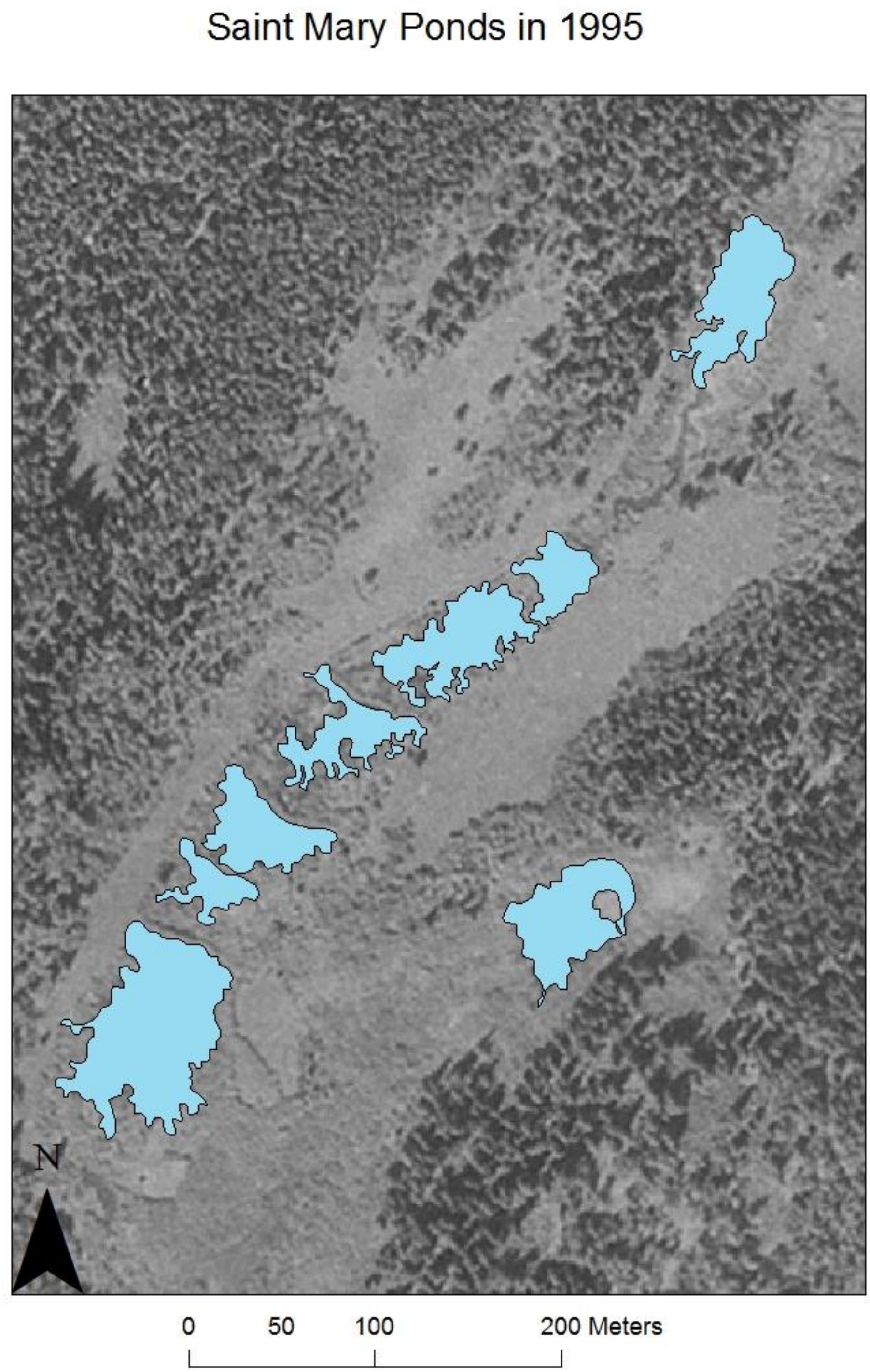

Figure 6: Saint Mary Ponds in 1995.

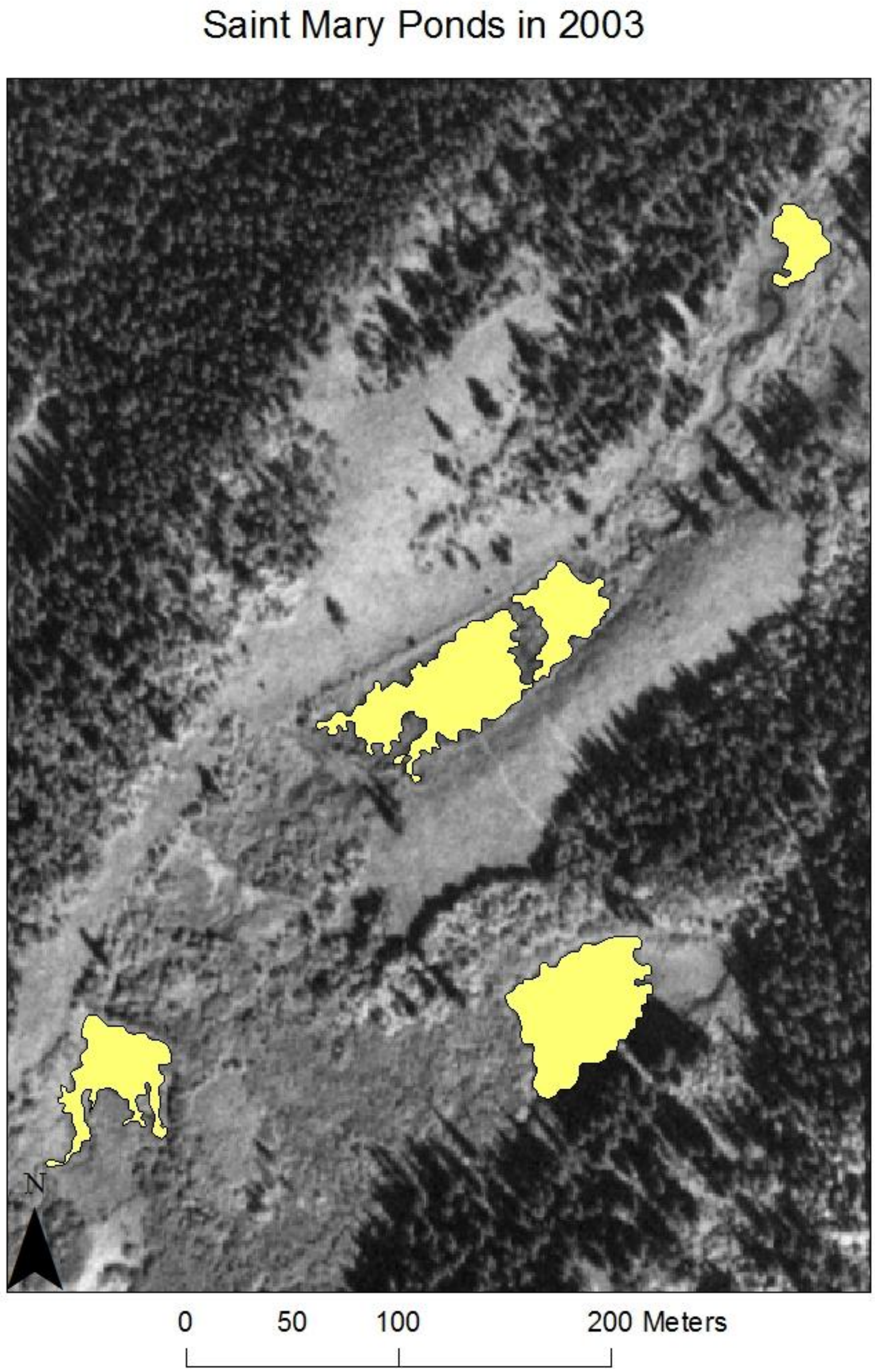

Figure 7: Saint Mary Ponds in 2003.

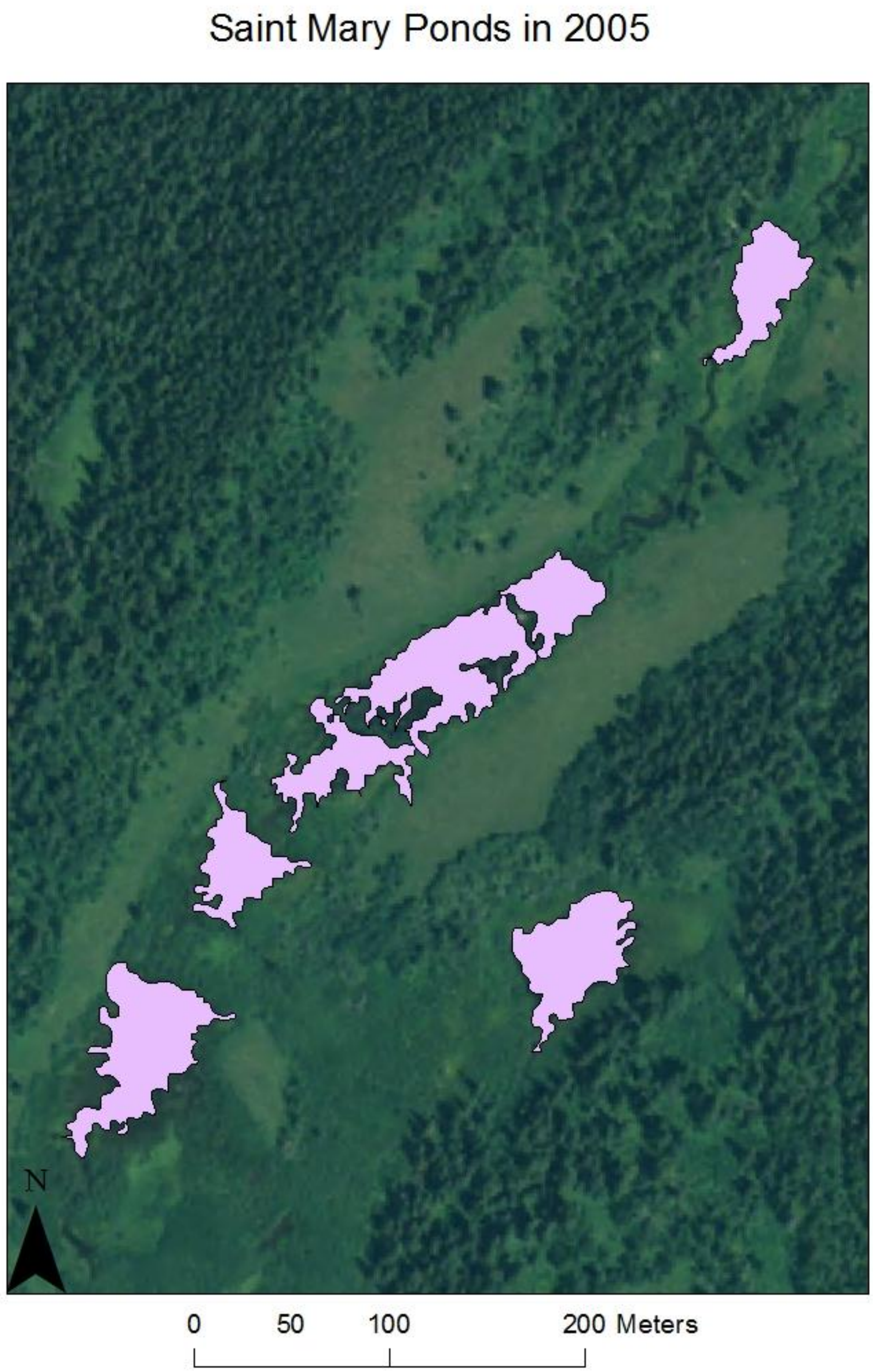

Figure 8: Saint Mary Ponds in 2005.

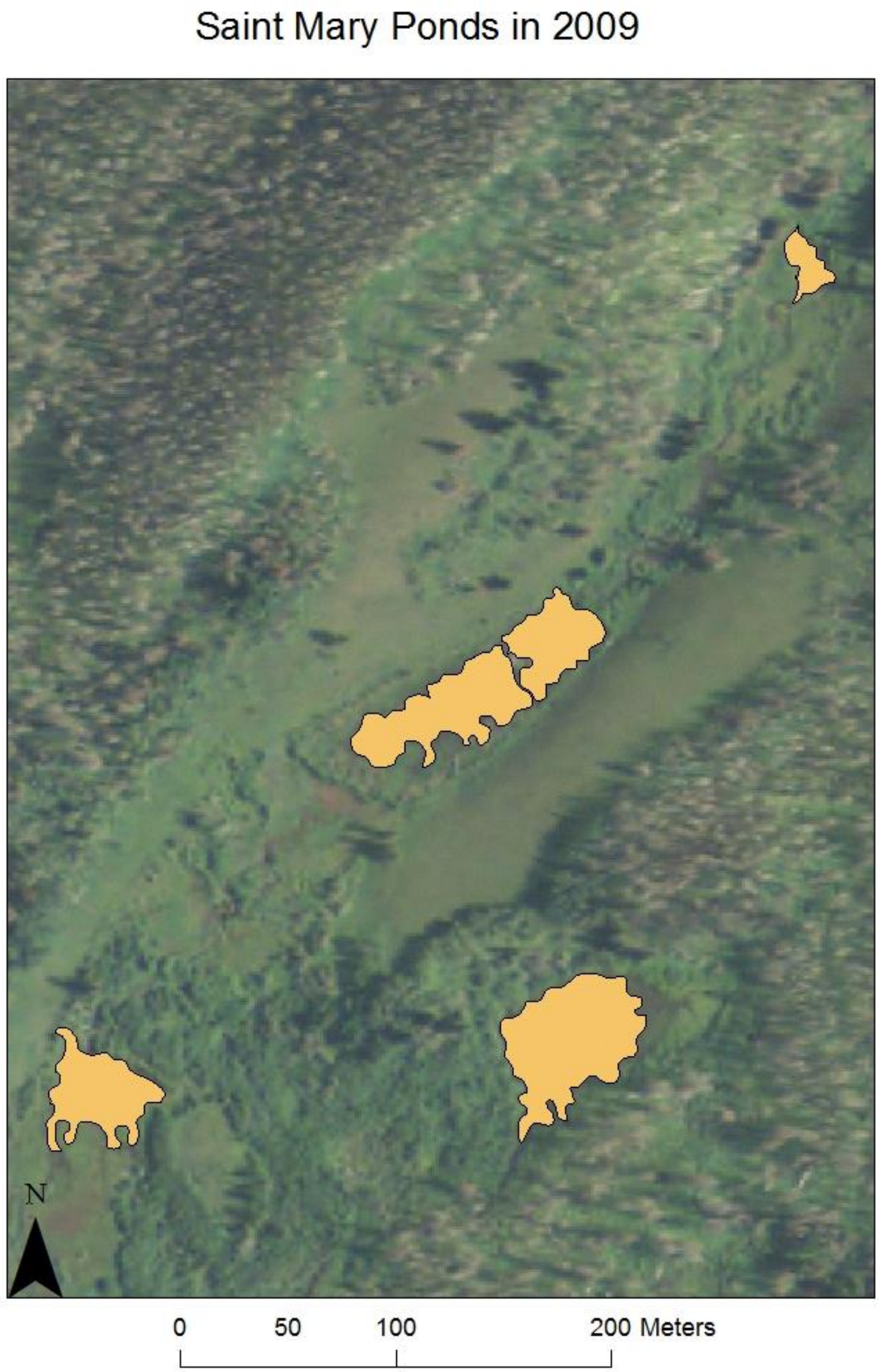

Figure 9: Saint Mary Ponds in 2009

Figure 10: Saint Mary Ponds in 2011.

Figure 11: Site photos of Saint Mary Ponds. Top photo: 1994, Middle: 2002, Bottom: 2012. Photo Credit: Dr.David Butler, 1994 and 2002, 2012 photo taken by Taylor Christian.

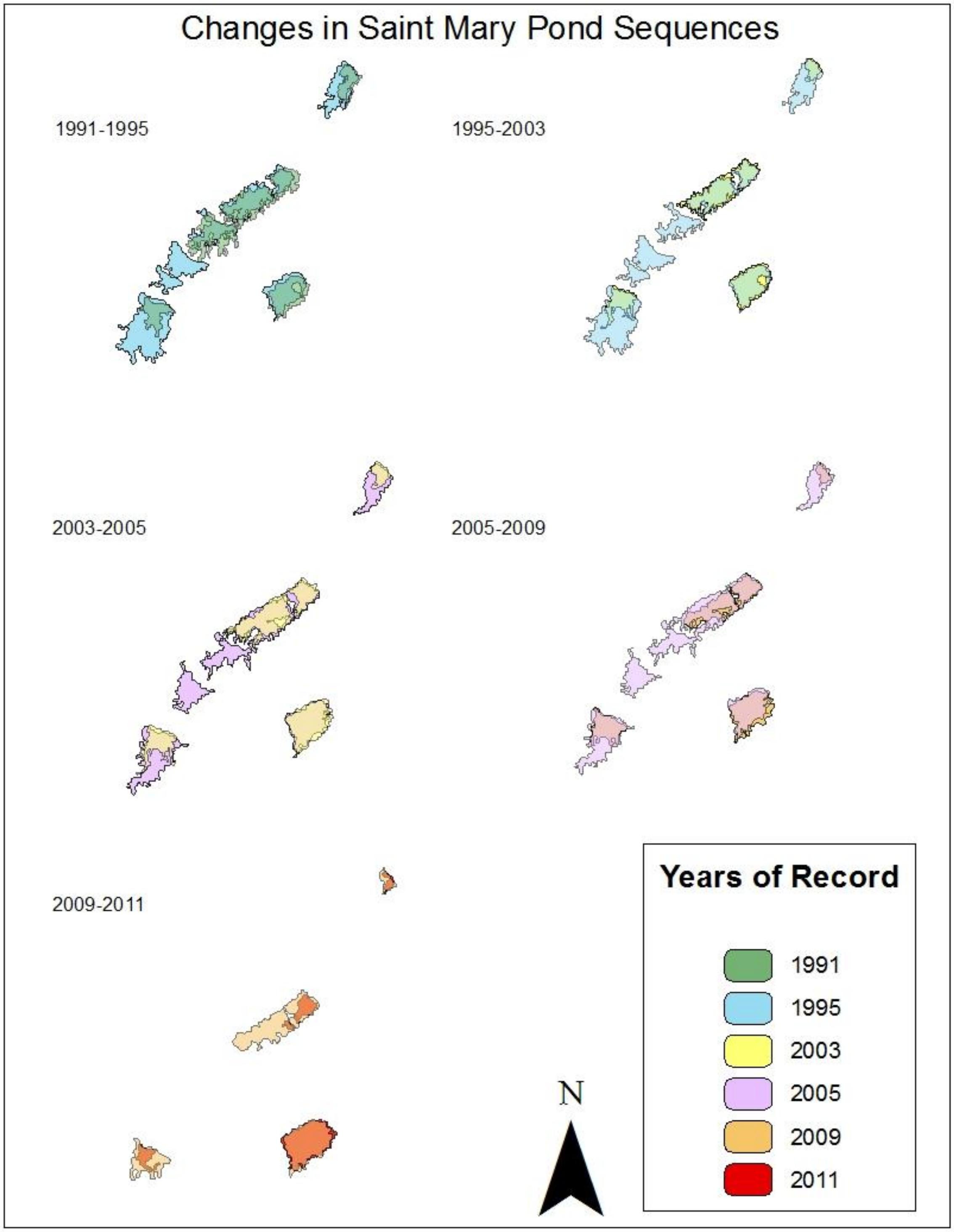

Figure 12: Changes in Saint Mary Ponds from 1991-2011.

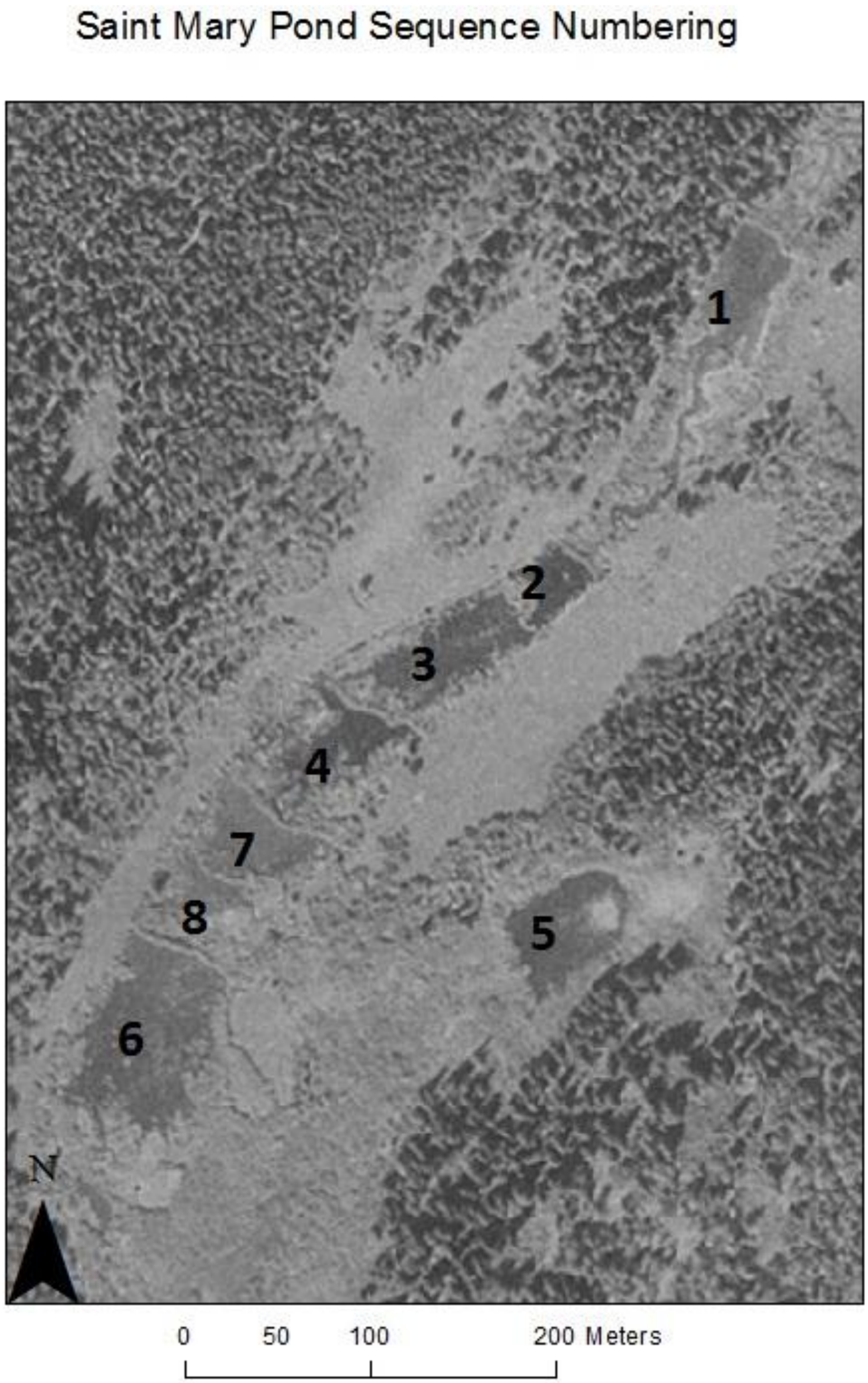

Figure 13: Numbering of Saint Mary Ponds for Analysis.

Table 1: Changes in Saint Mary Ponds in area from 1991-2011. Year to year changes are represented by percentage of expansion or reduction in area from previous year

pond number	1991	1995	1991-1995	2003	1995-2003	2005	2003-2005	2009	2005-2009	2011	2009-2011
1	1258	2638	109.7%	647	-75.5%	1677	159.2%	374	-77.7%	204	-45.5%
2	1485	1130	-23.9%	1147	1.5%	1328	15.8%	1250	-5.9%	578	-53.8%
3	3129	2639	-15.7%	3022	14.5%	3103	2.7%	2132	-31.3%	94	-95.6%
4	3233	1767	-45.3%	0	-100.0%	1586	X	0	-100.0%	0	0.0%
5	2716	2684	-1.2%	3099	15.5%	2593	-16.3%	2970	14.5%	3050	2.7%
6	1465	5896	302.5%	1621	-72.5%	3248	100.4%	1599	-50.8%	493	-69.2%
7	0	2005	X	0	-100.0%	1620	X	0	-100.0%	0	0.0%
8	0	885	X	0	-100.0%	0	0.0%	0	0.0%	0	0.0%
Year Average	1661	2456	47.9%	1192	-51.5%	1894	58.9%	1041	-45.0%	552	-47.0%

Lake Sherburne Pond Sequences

Lake Sherburne pond sequence has a total of 12 ponds that were measured and interpreted with a GIS (figure 13-19). However, unlike the Saint Mary Site, there was not a single year where all ponds were present. The closest was 1995, which had all ponds present except for pond 12 (figure 20). When the Sherburne Ponds are compared to the Saint Mary site, Sherburne has considerably less variation (Table 2). From 1991-1995 the ponds on average had a reduction of 2 percent. The following period from 1995-2003 also had a reduction, larger than before, but still small compared to Saint Mart of 18.2 percent loss. From 2003-2005 the ponds grew 18.4 percent. The percentage change from 1995-2003 and 2003-2005 represent that largest variation from -18.2 percent to 18.4 percent the next period. This is only a 37% total change, the largest variation for Sherburne, however this change is smaller than the least amount of variation at Saint Mary. The period from 2005-2009 again grew, but only 13.5 percent. The final study period from 2009-2011 had an average expansion of 6.2 percent.

Lake Sherburne is the first study site adjacent to an artificial lake. When compared only to Saint Mary it is apparent something different is happening at both sites. Saint Mary experienced large variation before the fire, whereas Sherburne was less variable and steady throughout the 20 year study period.

Pond 1 was present all years, except for 2003. This pond is interesting because it is one of the largest in the pond sequence at the Sherburne site. In 1995 the pond had an area of 2901 square meters, and in 8 years was completely drained. However 2 years later in 2005, Pond 1 reappeared with an area of 2205 square meters. There is not an obvious speculation as to why this would have happened at such a large scale, so quickly. Additional sediment cores from Pond 1, would give estimations of what could have occurred such as a large influx of sediment. Field photos from Lake Sherburne in 2012 (figure 20) provide evidence of recent beaver activity. Unlike the Saint Mary site which was over grown, there was still evidence of a beaver population at the Lake Sherburne site. A recently constructed canal, and several freshly chewed tree stumps indicate the beavers are still present and working.

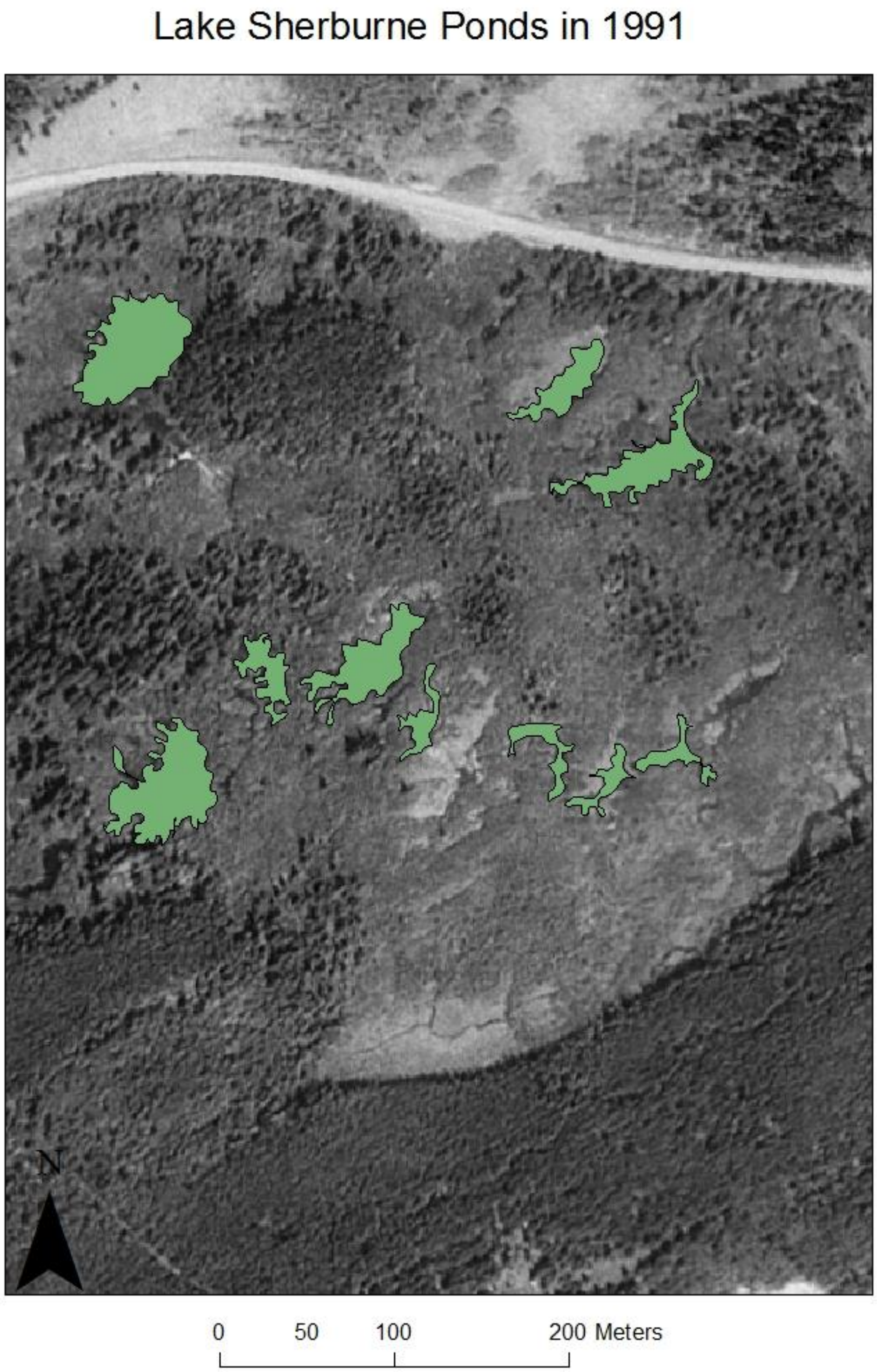

Figure 14: Lake Sherburne Ponds in 1991.

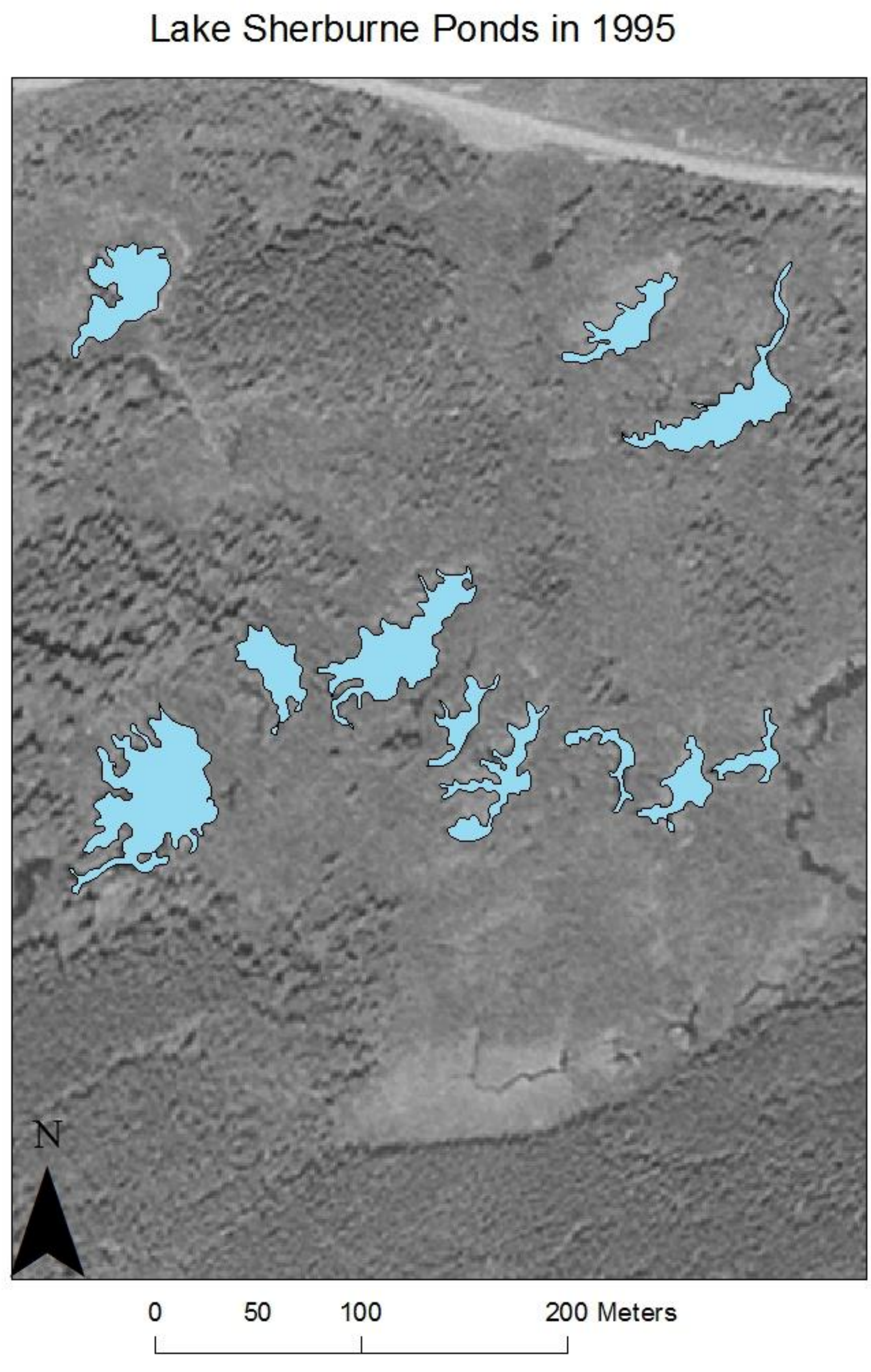

Figure 15: Lake Sherburne Ponds in 1995.

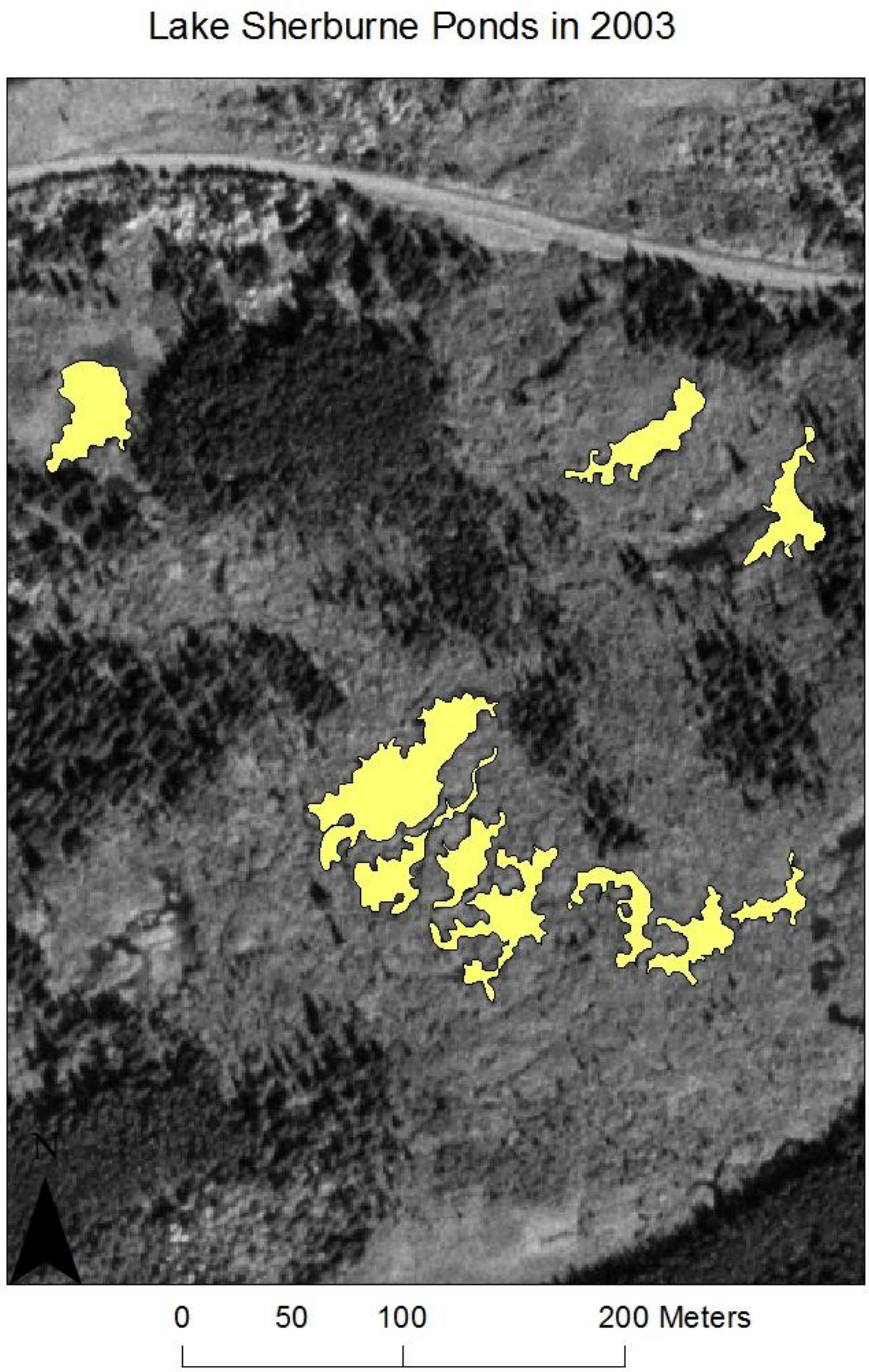

Figure 16: Lake Sherburne Ponds in 2003.

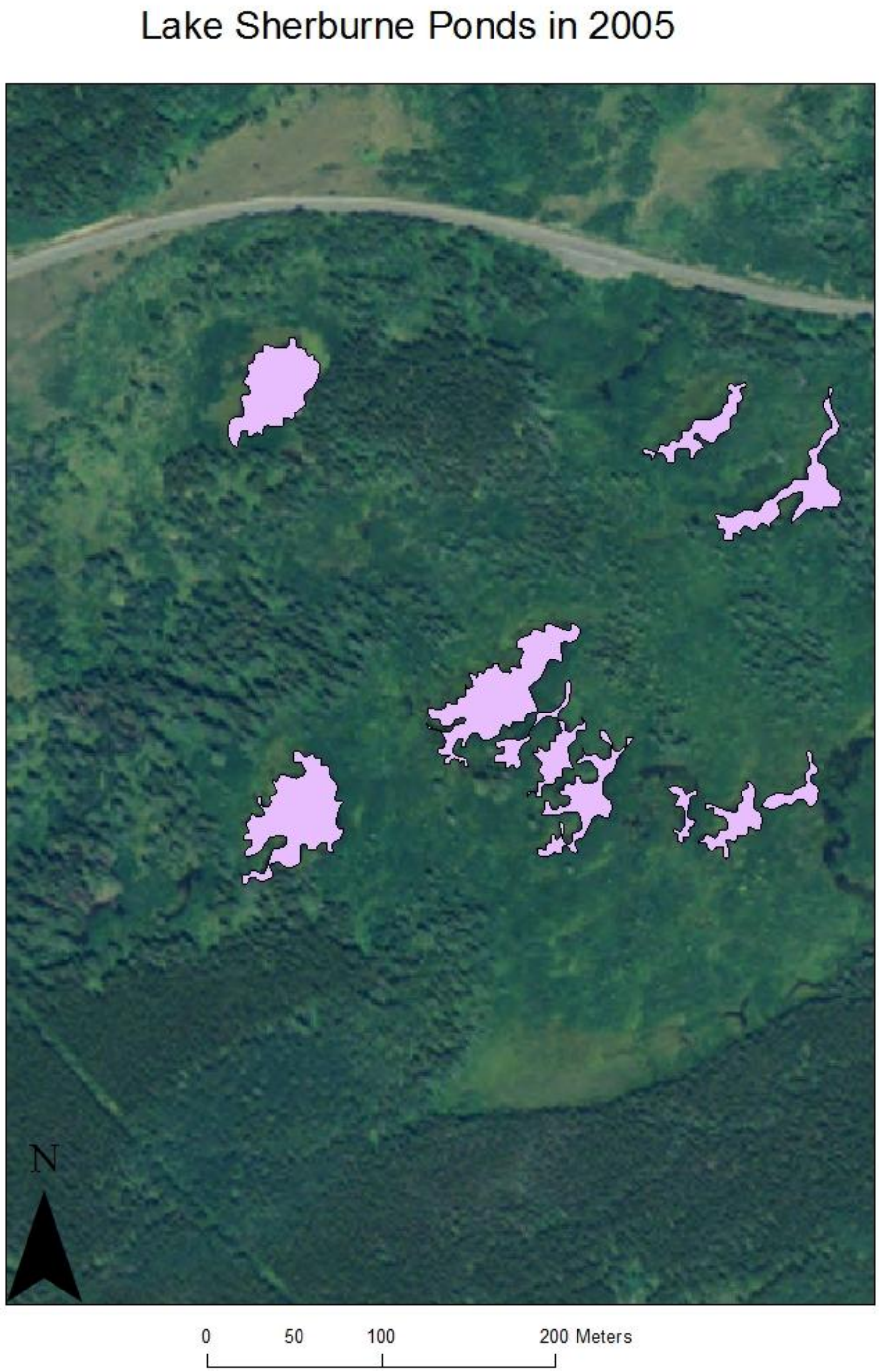

Figure 17: Lake Sherburne Ponds in 2005.

Figure 18: Lake Sherburne Ponds in 2009.

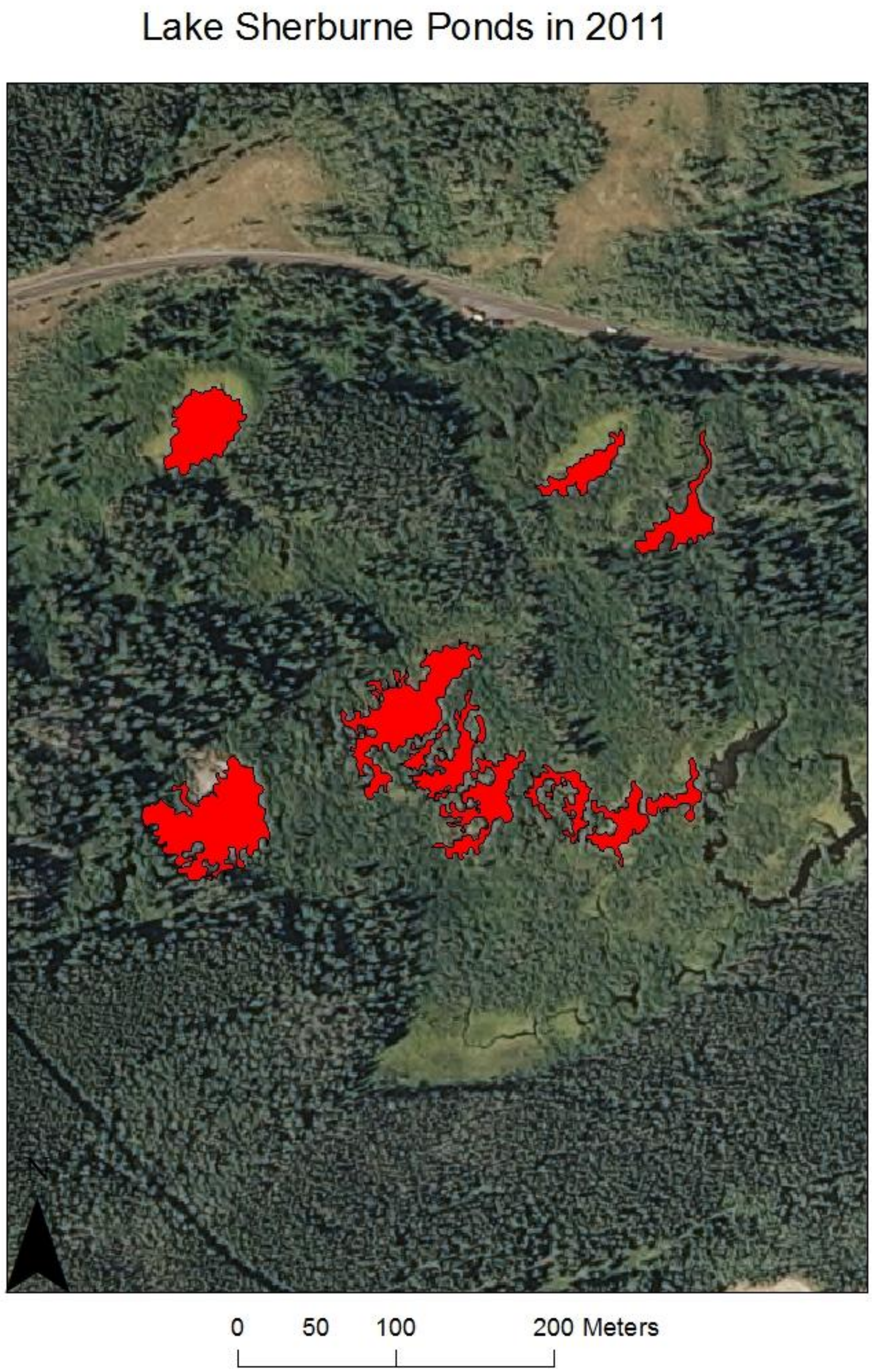

Figure 19: Lake Sherburne Ponds in 2011.

Figure 20: Site Photos of Lake Sherburne Ponds. Still recent evidence of beaver activity in summer of 2012 at Lake Sherburne Site. Top photo: newly constructed canal, middle: large brush growth around pond perimeter, bottom: chewed tree stump from beaver activity. Photo credit: Taylor Christian

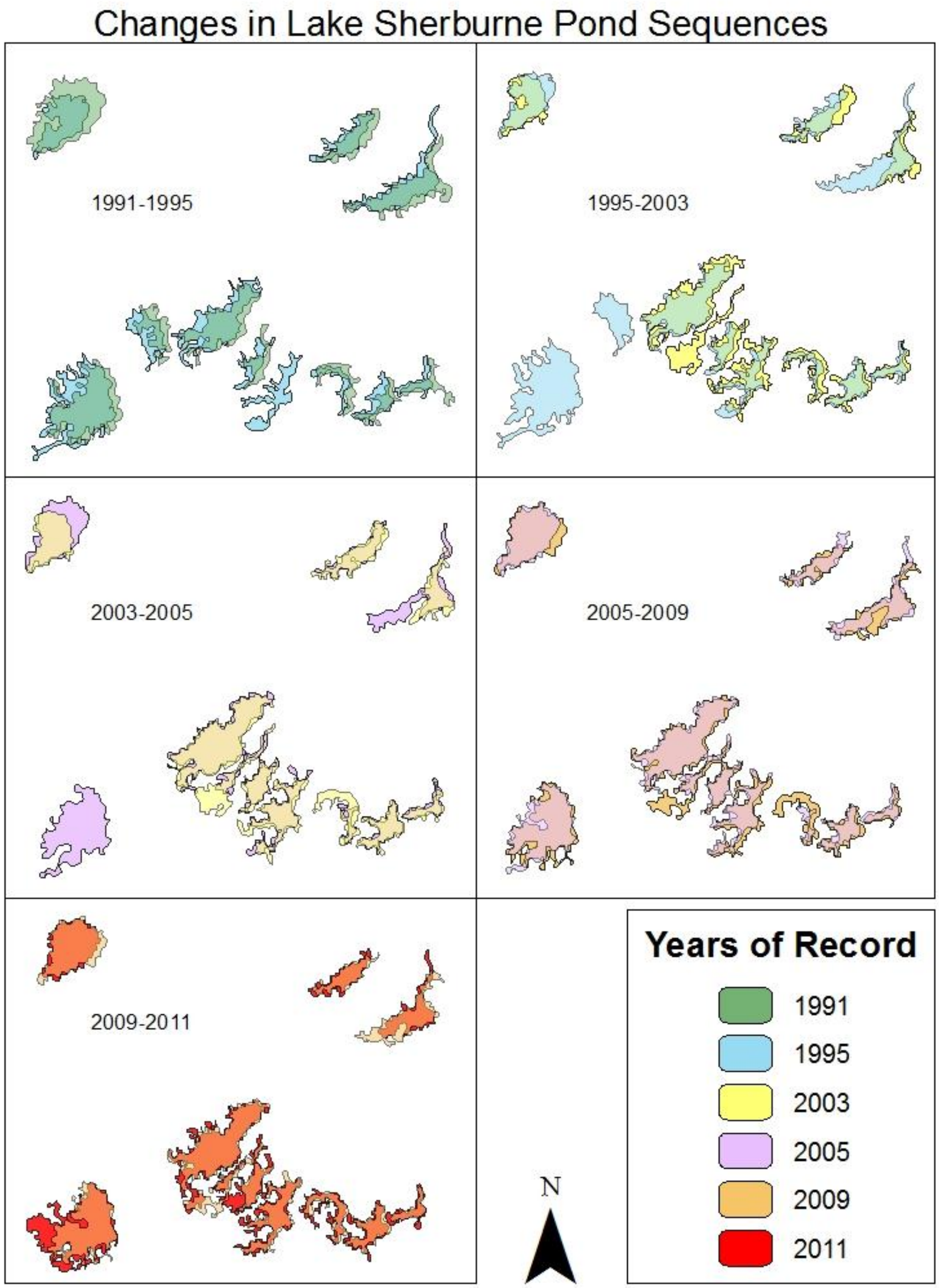

Figure 21: Changes in Lake Sherburne Pond from 1991-2011.

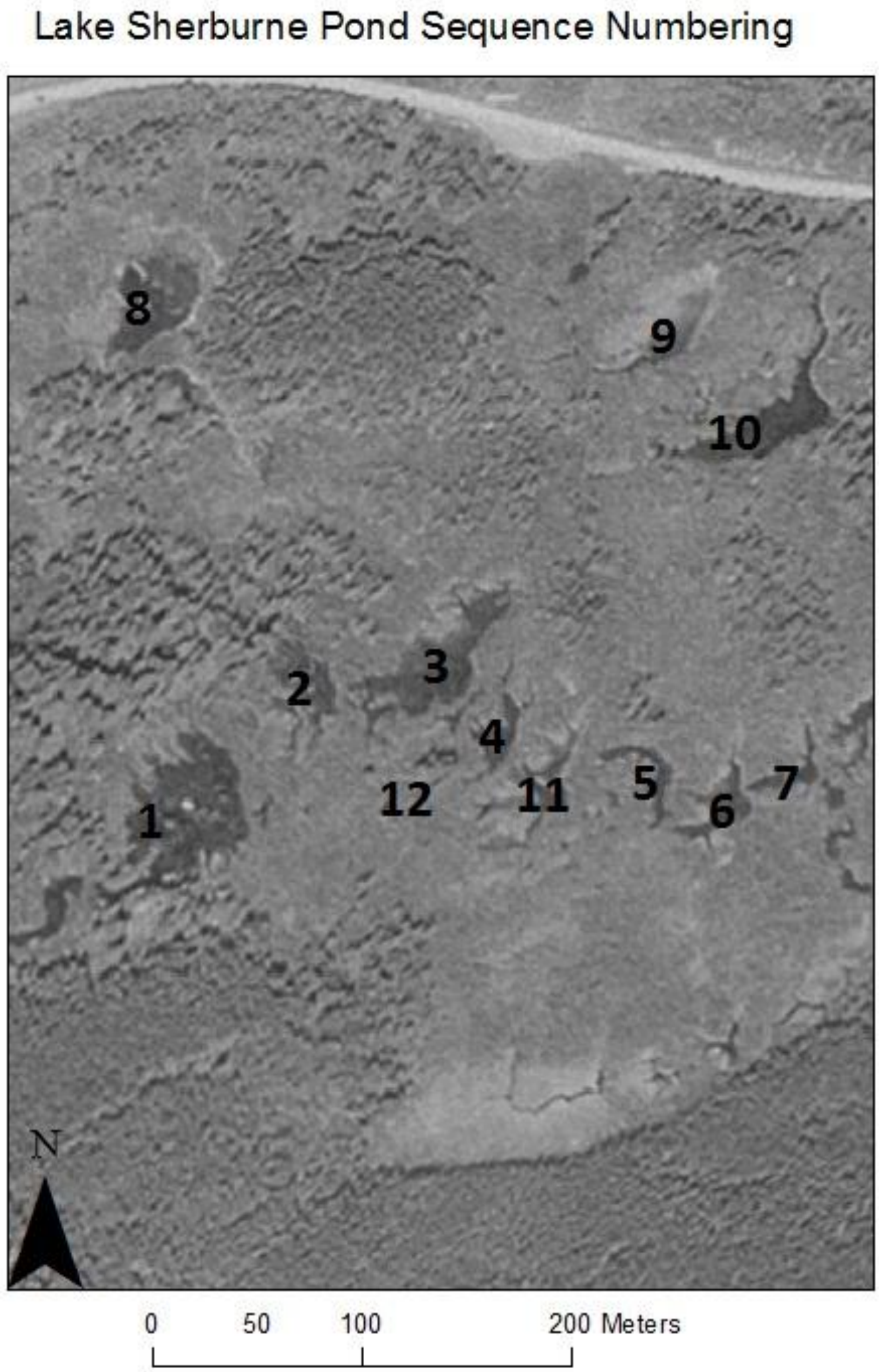

Figure 22: Numbering of Lake Sherburne Ponds for Analysis.

Table 2: Changes in Lake Sherburne Ponds in area from 1991-2011. Year to year changes are represented by percentage of expansion or reduction in area from previous year.

ponds number	1991	1995	1991-1995	2003	1995-2003	2005	2003-2005	2009	2005-2009	2011	2009-2011
1	2514	2901	15.4%	0	-100.0%	2205	X	2294	4.0%	3174	38.4%
2	706	777	10.1%	0	-100.0%	0	0.0%	0	0.0%	0	0.0%
3	1594	1838	15.3%	2403	30.7%	2339	-2.7%	2381	1.8%	2601	9.2%
4	431	421	-2.3%	555	31.8%	480	-13.5%	478	-0.4%	877	83.5%
5	470	302	-35.7%	583	93.0%	191	-67.2%	563	194.8%	609	8.2%
6	384	541	40.9%	633	17.0%	547	-13.6%	672	22.9%	709	5.5%
7	404	315	-22.0%	317	0.6%	316	-0.3%	304	-3.8%	395	29.9%
8	2661	1229	-53.8%	1148	-6.6%	1747	52.2%	1867	6.9%	1725	-7.6%
9	853	728	-14.7%	869	19.4%	633	-27.2%	639	0.9%	704	10.2%
10	1599	1419	-11.3%	788	-44.5%	1166	48.0%	1344	15.3%	933	-30.6%
11	0	822	X	1180	43.6%	1003	-15.0%	1185	18.1%	1265	6.8%
12	0	0	0.0%	762	X	314	-58.8%	690	119.7%	190	-72.5%
year average	968	941	-2.8%	770	-18.2%	912	18.4%	1035	13.5%	1099	6.2%

Lower Two Medicine Pond Sequences

There are a total of 7 ponds in the Lower Two Medicine Pond Sequence (Figure 21-27). The only year all ponds were present was 2011. On average the ponds were smaller in area than the other two sites. In 1991 to 1995 the ponds decreased in area by 20.6 percent. However, in total area it was not a large difference from 126 square meters in 1991 to 100 square meters in 1995. A large percentage increase occurred from 1995-2003, increasing 110 percent from the previous measurement. From 2003-2005 ponds shrank 16.1 percent, and in 2005-2009 increased 55.4 percent. In the final period from 2009-2011 the ponds decreased an additional 18.5 percent. Lower Two Medicine is more similar to Lake Sherburne, because of the adjacency of an artificial reservoir. However, the variation between expansion and reduction is more similar to Saint Mary Ponds.

1991 and 1995 are the years with the least amount of ponds, only two in both study periods. In 2003, the year that doubled in percentage growth from the previous period, several ponds appear. Ponds 3, 5 and 6 all appeared in 2003 (Figure 28) and were present for the rest of the study period. In 2011 pond 7 appeared at a size of 48 square meters, and this represents the only year the pond was present.

Figure 23: Lower Two Medicine Ponds in 1991.

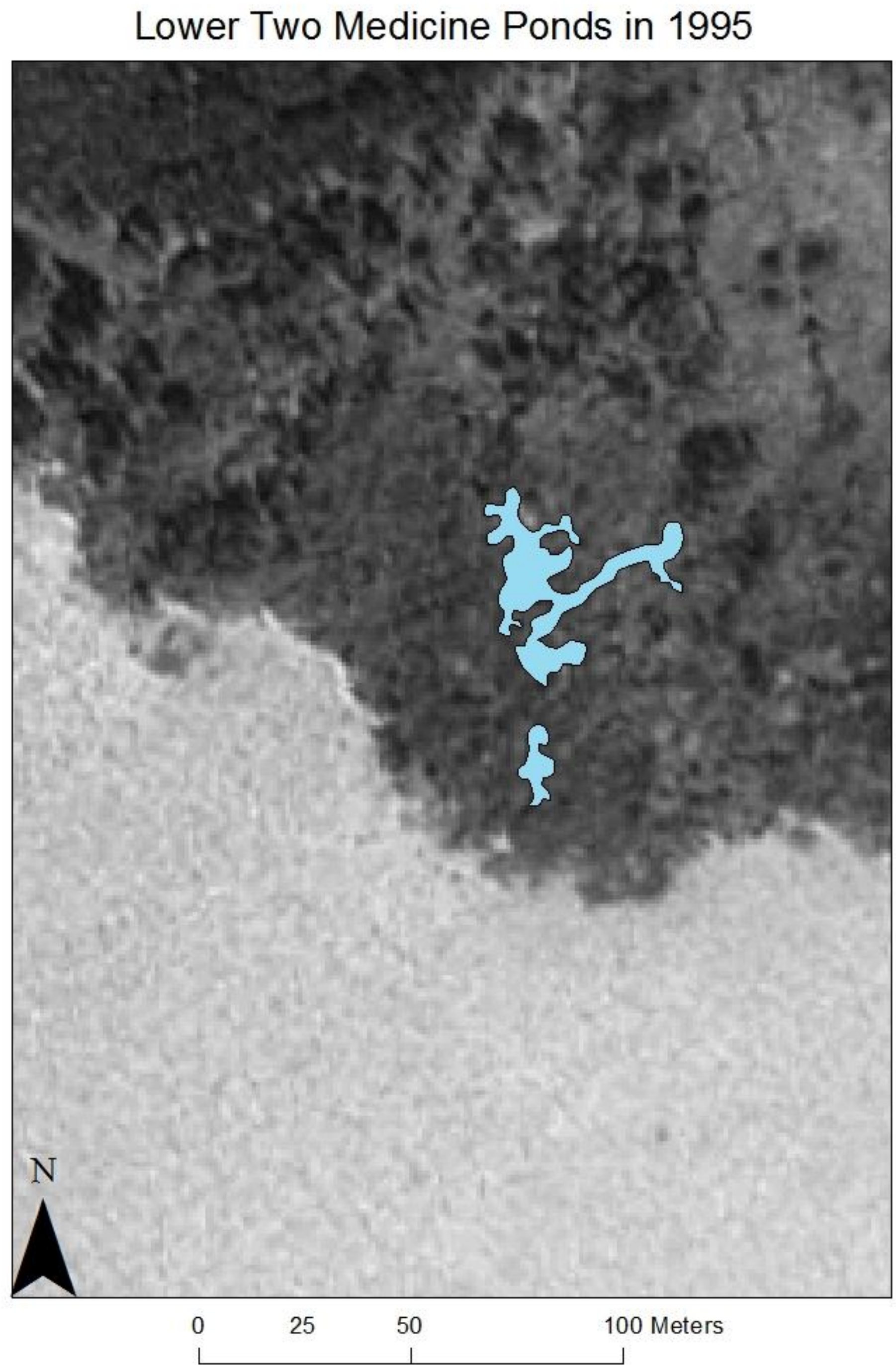

Figure 24: Lower Two Medicine Ponds in 1995.

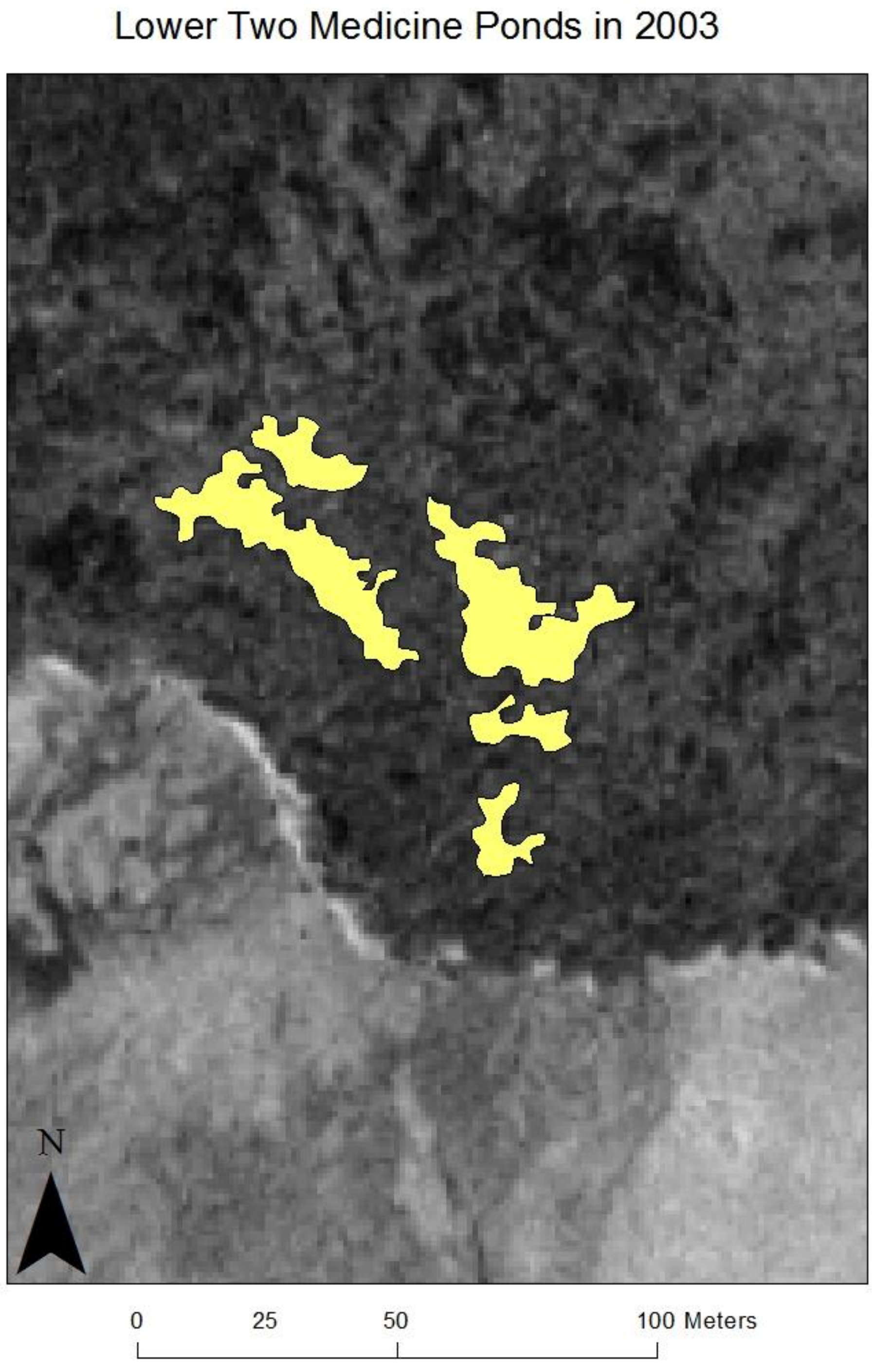

Figure 25: Lower Two Medicine Ponds In 2003.

Figure 26: Lower Two Medicine Ponds in 2005.

Figure 27: Lower Two Medicine Ponds in 2009.

Figure 28: Lower Two Medicine Ponds in 2011.

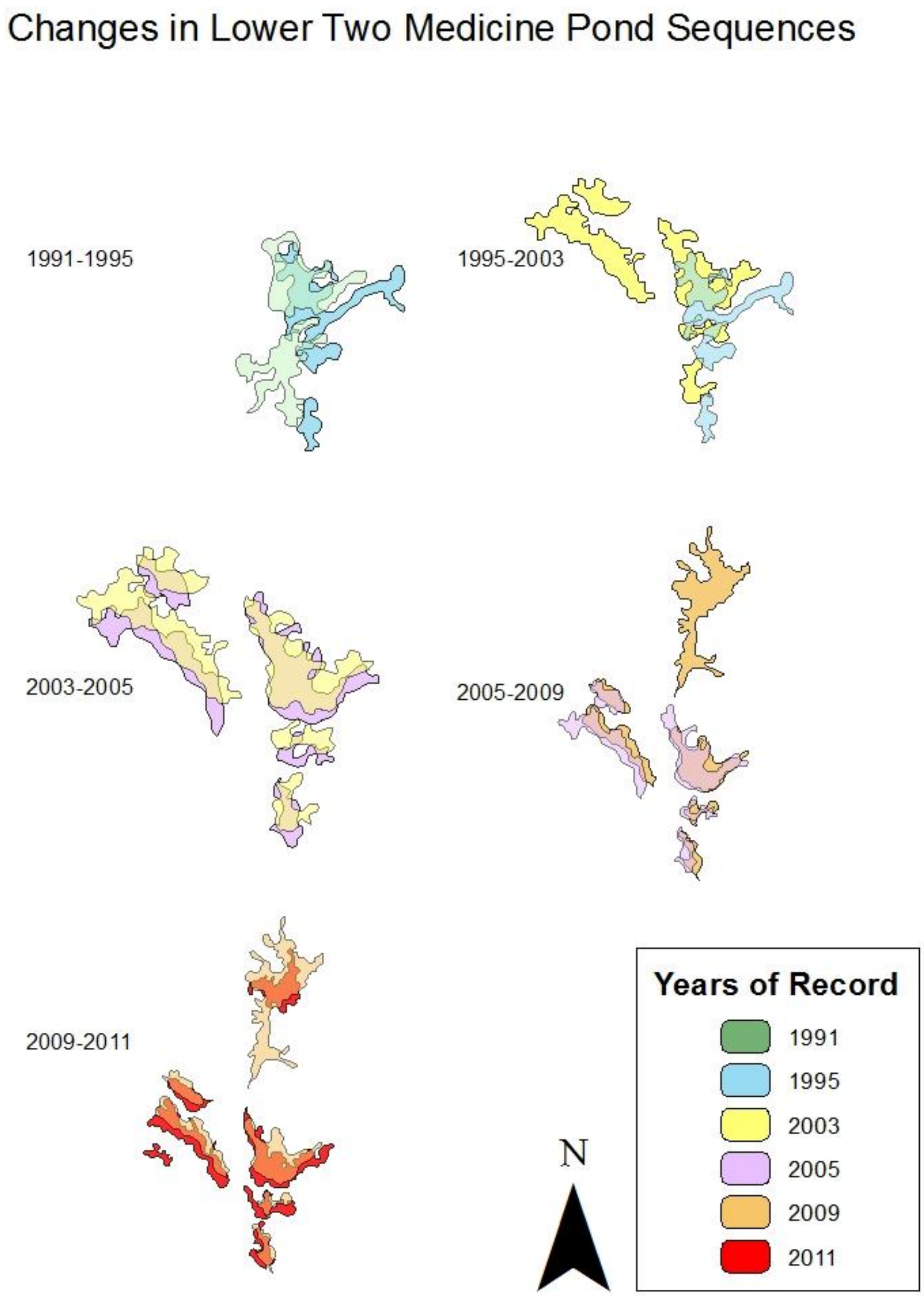

Figure 29: Changes in Lower Two Medicine Ponds from 1991-2011.

Figure 30: Numbering of Lower Two Medicine Ponds for Analysis.

Table 3: Changes in Lower Two Medicine Ponds in area from 1991-2011. Year to year changes are represented by percentage of expansion or reduction in area from previous year.

pond nunber	1991	1995	1991-1995	2003	1995-2003	2005	200-2005	2009	2005-2009	2011	2009-2011
1	0	0	0.0%	0	0.0%	0	0.0%	842	X	279	-66.9%
2	464	615	32.5%	556	-9.6%	538	-3.2%	458	-14.9%	482	5.2%
3	416	0	-100.0%	112	X	76	-32.1%	80	5.3%	143	78.8%
4	0	87	X	119	36.8%	102	-14.3%	98	-3.9%	115	17.3%
5	0	0	0.0%	163	X	144	-11.7%	134	-6.9%	137	2.2%
6	0	0	0.0%	528	X	380	-28.0%	314	-17.4%	362	15.3%
7	0	0	0.0%	0	0.0%	0	0.0%	0	0.0%	48	X
year average	126	100	-20.6%	211	111.0%	177	-16.1%	275	55.4%	224	-18.5%

Statistical Analysis

The average area for the 3 sites were examined for statistical difference in the means among years. Two one-way ANOVAs were performed. The first ANOVA will explain if the sites vary when compared to area. The second ANOVA will examine if there is any difference among years.

Two One-way ANOVA's were set up with area as the dependent variable and site location as the independent variable. The first one-way was set up to examine if the sites vary. When testing for Homogeneity of Variances using Levine Statistic, produced a p-value of 0.001, which is significant and variances of the sites are not homogenous. The ANOVA produced an f-value of 15.729, with an associated p-value of <0.001. Using Tamhane test, I was able to conclude that Saint Mary Site is different from the Lower Two Medicine Site with a p-value of 0.016. Sherburne is also different from Lower Two Medicine Pond Sequences with a p-value of <0.001. This means that Lower Two Medicine is statistically different from the other two sites, but there is not a statistical difference between the Saint Mary and Lake Sherburne sites when area is compared (Appendix 1).

The second one-way ANOVA was set up to compare the dependent variable of area with the independent variable of year. This will answer if the year differs between ponds. The ANOVA has an f-value of 0.206 and an associated p-value of 0.954. The Levene Statistic produced a p-value of 0.467, meaning the sample is homogenous. So there is no statistical difference between area and year (Appendix 2).

CHAPTER VI

CONCLUSIONS

Several articles have reviewed the geomorphic conditions of beavers in Glacier National Park (e.g., Butler and Malanson 1995, 2005; Meentemeyer and Butler 1995, 1999). Meentemeyer and Butler (1995) analyzed the temporal and spatial distributions of several pond sites within Glacier National Park by photographic interpretations. There was a low amount of variability among the impoundments over the time period, and they concluded that the beaver population within the site locations had reached a state of equilibrium. The authors also concluded that it was likely beaver populations never reached the low levels reported elsewhere in North America, and thus the current steady populations. The importance of geomorphic influences of beavers in North America was also illustrated by Butler and Malanson (2005, p. 58) "Even as beaver populations continue to flourish, it must be recognized that the fluvial landscape of modern North America is substantially different than that which was in place prior to European contact. The beavers of North America are the reason why." It has also been suggested that introduction of beavers to damaged stream ecosystems could help reduce sediment transportation, which will rejuvenate the riparian habitat (Meentemeyer and Butler 1999). Beaver ponds at both sites underwent varying amounts of expansion or decline in beaver pond number and area over the study period (Tables 1,2, and 3). Lake Sherburne has more ponds present in all twenty years, as well as a more steady growth rate in the number of ponds as well as surface area of individual ponds than Saint Mary Lake and Lower Two Medicine (Table 2 and Figures11, 19 and 27). Lower Two Medicine had more newly created beaver ponds between study years than did the other two sites (Table 3) and was statistically different in pond area than the other sites.

The results imply that an artificial impoundment can lead to spatial expansion of beaver pond sequences adjacent to it, because all ponds present in 1991 were also present in 2011, with additional impoundments as well, however with the exception of pond 2 at Lake Sherburne Site. Only 5 of the 8 total ponds at Saint Mary were still present in 2011, suggesting either a large storm event or other unknown event may have washed many of the dams out or caused the beavers to abandon the sites, or most likely, that sedimentation rates at the Saint Mary site were largely increased after the Red Eagle Fire. I know of no specific study area variations that could account for such dramatic differences in the rate of sedimentation before the Red Eagle Fire, except for two:

1) The Saint Mary Ponds are oriented along a stream that runs northeast, whereas the Lake Sherburne ponds and Lower Two Medicine ponds are on a south-southeast trending stream; I do not believe this difference in aspect is significant.

2)The Lake Sherburne and Lower Two Medicine Ponds are adjacent to a reservoir with varying lake levels because of irrigation draw-down, whereas the local base level for the Saint Mary ponds remains relatively constant, with very little surface variation in the level of the adjacent Saint Mary Lake.

The fluctuating base level of the Lake Sherburne and Lower Two Medicine sites ensures a dynamic environment for the creek systems at the sites, and the ponds along it, but what exactly are these differences, *i.e.*, why a fluctuating base level would induce expansion of existing ponds and addition of new ponds, remains to be determined. More research will be required to distinguish what could have caused the sharp decrease in overall pond area at the Saint Mary Site.

It is apparent that the presence of an artificial impoundment and its fluctuating effects on local base level had an effect on the temporal and spatial expansion of beavers at the Lake Sherburne and Lower Two Medicine sites. Fieldwork in the summer of 2012 has confirmed that these are actual beaver ponds, but more research will also be required to determine if the spatial expansion of beaver ponds at the Lake Sherburne and Lower Two Medicine sites adjacent to an artificial reservoir is truly unique. With beaver populations on the rise across North America, it is vital to understand the changes on the landscape that will come with increase beaver populations. With beaver populations in GNP reaching equilibrium (Meentemeyer and Butler 1995), it provides a unique opportunity to study possible landscape changes in the coming decades if beaver populations trends continue. Restoration managers with beaver populations in areas adjacent to reservoirs should compare the areal extent and longevity of their ponds with those from areas with more consistent base levels. Temporal change is an integral part of any community, and because beavers are an important agent of these changes, more research to understand their ability to alter ecosystems must be conducted (Johnston and Naiman 1990). The use of a GIS system will make this analysis seamless for wildlife managers of different landscapes, and easier to access.

APPENDIX ONE

```
ONEWAY area BY lake
  /STATISTICS DESCRIPTIVES HOMOGENEITY
  /MISSING ANALYSIS
  /POSTHOC=TUKEY T2 ALPHA(0.05).
```

Oneway

[DataSet0]

Descriptives

area

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum
					Lower Bound	Upper Bound	
Saint Mary	6	1466.00	677.112	276.430	755.41	2176.59	552
Sherburne	6	954.17	112.757	46.033	835.84	1072.50	770
Lower Two Medicine	6	185.50	64.908	26.499	117.38	253.62	100
Total	18	868.56	658.074	155.110	541.30	1195.81	100

Descriptives

area

	Maximum
Saint Mary	2456
Sherburne	1099
Lower Two Medicine	275
Total	2456

Test of Homogeneity of Variances

area

Levene Statistic	df1	df2	Sig.
11.395	2	15	.001

ANOVA

area

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4985004.111	2	2492502.056	15.729	.000
Within Groups	2377042.333	15	158469.489		
Total	7362046.444	17			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: area

	(I) lake	(J) lake	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval
						Lower Bound
Tukey HSD	Saint Mary	Sherburne	511.833	229.833	.099	-85.15
		Lower Two Medicine	1280.500*	229.833	.000	683.52
	Sherburne	Saint Mary	-511.833	229.833	.099	-1108.82
		Lower Two Medicine	768.667*	229.833	.012	171.68
	Lower Two Medicine	Saint Mary	-1280.500*	229.833	.000	-1877.48
		Sherburne	-768.667*	229.833	.012	-1365.65
Tamhane	Saint Mary	Sherburne	511.833	280.237	.328	-451.67
		Lower Two Medicine	1280.500*	277.697	.016	311.24
	Sherburne	Saint Mary	-511.833	280.237	.328	-1475.34
		Lower Two Medicine	768.667*	53.115	.000	609.01
	Lower Two Medicine	Saint Mary	-1280.500*	277.697	.016	-2249.76
		Sherburne	-768.667*	53.115	.000	-928.33

Multiple Comparisons

Dependent Variable: area

	(I) lake	(J) lake	95% Confidence Interval
			Upper Bound
Tukey HSD	Saint Mary	Sherburne	1108.82
		Lower Two Medicine	1877.48*
	Sherburne	Saint Mary	85.15
		Lower Two Medicine	1365.65*
	Lower Two Medicine	Saint Mary	-683.52*
		Sherburne	-171.68*
Tamhane	Saint Mary	Sherburne	1475.34
		Lower Two Medicine	2249.76*
	Sherburne	Saint Mary	451.67
		Lower Two Medicine	928.33*
	Lower Two Medicine	Saint Mary	-311.24*
		Sherburne	-609.01*

*. The mean difference is significant at the 0.05 level.

APPENDIX TWO

```
ONEWAY area BY year
  /STATISTICS DESCRIPTIVES HOMOGENEITY
  /MISSING ANALYSIS
  /POSTHOC=TUKEY T2 ALPHA(0.05).
```

Oneway

Descriptives

area

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
1991	3	918.33	768.704	443.812	-991.23	2827.90	126	1661
1995	3	1165.67	1193.960	689.333	-1800.29	4131.63	100	2456
2003	3	724.33	492.092	284.109	-498.09	1946.76	211	1192
2005	3	994.33	861.456	497.362	-1145.64	3134.31	177	1894
2009	3	783.67	440.528	254.339	-310.67	1878.00	275	1041
2011	3	625.00	442.044	255.214	-473.10	1723.10	224	1099
Total	18	868.56	658.074	155.110	541.30	1195.81	100	2456

Test of Homogeneity of Variances

area

Levene Statistic	df1	df2	Sig.
.983	5	12	.467

ANOVA

area

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	581695.111	5	116339.022	.206	.954
Within Groups	6780351.333	12	565029.278		
Total	7362046.444	17			

```
GET
  FILE='D:\Taylor data.sav'.
DATASET NAME DataSet1 WINDOW=FRONT.
```

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VITA

Taylor Aleece Christian was born in Dallas, Texas on April 18, 1988. Taylor lived in the Dallas Forth-Worth Metroplex until she graduated from high school through the University of Texas's Distance Learning Education Program in 2006. After graduation Taylor moved to Austin, Texas where she received her Bachelor of Science degree in 2010 from Texas State University-San Marcos. In the fall of 2011 Taylor entered the Graduate College of Texas State. While in the graduate program she taught Introductory Geology labs. Taylor also attended several conferences during her graduate career at Texas State. Those included a poster presentation at the Binghamton Geomorphology Symposium, and presented the paper 'Range of Variability in the Life Cycle of Beaver Ponds in Glacier National Park, Montana, as a Context for Restoration" at the Applied Geography Conference in 2012. The paper was then published in the conference proceedings. Taylor completed her degree with a Master of Science in Geography in the summer of 2013.

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