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ECONOMIC IMPACTS OF GLOBAL CLIMATE CHANGE ON MINNESOTA FISHERIES THROUGH DECREASES IN LAKE ICE

by

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Rabi J. Vandergon

Global climate change has recently come into popular light. It is becoming widely accepted as a problem that must be addressed for a wide variety of reasons. This study provides an in-depth analysis into the impacts that global climate change may pose to Minnesota fisheries and recreational anglers. The literature review covers a range of topics from biological impacts on recreational fisheries to economic impacts. The main goal of this study is to determine what impact climate change may pose to recreational benefits provided by the activity of angling. Creel surveys from the Minnesota Department of Natural Resources Creel Database were utilized to determine statewide angler effort and preferences for certain species. Lake ice duration observations were gathered to determine current trends and future projections. These data were utilized and combined with fishing valuation literature to determine an economic impact from climate change. Statistical analysis shows that lake ice duration is significantly decreasing statewide. Since more anglers fish during the summer months, this could lead to a net economic gain. On the other hand, bodies of water such as East Upper Red Lake seeing more anglers during the ice-fishing season could potentially see an economic loss. The project also utilized creel surveys to test the hypothesis indicating a statewide decline of trout species and northeastern shift of largemouth bass and sunfish from the onset of climate change. A multiple regression was performed on historical creel data to determine if there was a change in effort over time across different climate regions by species group. These variables were tested to see their influence on the amount of fish caught. The regression indicated a positive relationship between the amount of effort and the amount of yield, but effort does not appear to be shifting regionally in response to climate change predictions.

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Chapter 1: INTRODUCTION

Overview of the Research

The Intergovernmental Panel on Climate Change (IPCC) has revealed a wide body of evidence that indicates human influences have caused a significant increase in the amount of carbon dioxide in Earth's atmosphere that has accelerated during recent years (International Panel on Climate Change [IPCC], 2007). The IPCC has also indicated that increasing the amount of carbon dioxide (among other green house gasses) in the atmosphere has caused an increase in radiative forcing, the act of trapping heat within the atmosphere (IPCC). Unchecked, the amount of contributing factors to increases in radiative forcing have continued to increase and this increase has caused an increase in the global average temperature (IPCC).

Besides increases in global temperature, there are other predicted impacts on natural systems from this atmospheric change. One particular change is the amount of lake ice that is present in the winter time. The literature review and the results sections show that this change is already taking place globally and in Minnesota.

Beneath the surface of lakes, fish populations may also potentially be impacted by a changing climate. This paper discusses current findings in Minnesota indicating changing abundance of largemouth bass, sunfish and trout populations. In addition, the literature review discusses how increases in runoff from climate change (due to changes in precipitation patterns) and increases in temperature both have potential to decrease the amount of dissolved oxygen (DO) in water bodies, which could potentially impact fish populations.

These changes in fish populations and ice conditions are important concepts for the state to consider, due to the high popularity of the activity of angling statewide. The U.S. Fish and Wildlife Service estimated that Minnesota residents and nonresidents spent roughly 24 million days fishing in 2006 (U.S. Department of the Interior [USDI], Fish and Wildlife Service [FWS], and U.S. Department of Commerce, U.S. Census Bureau [USCB], 2008). In addition, each season has different numbers of people enjoying angling, which can be seen below in the results section. Changing the amount of available fish or the conditions required to enjoy a certain type of this sport, such as ice fishing, could potentially change these numbers.

Fishing as an activity has an economic value. This value can be determined through a variety of different means, which are covered in the literature review below. For example, by conducting interviews on trip expenditures, the U.S. Fish and Wildlife Service estimated that individuals spent roughly $35 per day on the activity of fishing in Minnesota (USDI, FWS, USCB, 2008). The same study estimated that roughly $466 million was spent on angling activities in Minnesota by nonresidents alone (USDI, 2008). Changing the abundance of available fish for the sport as well as the conditions in which an angler may pursue his or her prey could both potentially have an economic impact on the state.

This study utilized statewide statistics from creel surveys and from lake ice observations to determine a potential economic impact on the recreational benefits of angling. The economic estimate was performed utilizing benefit transfer, which is an economic tool for estimating value when the resources for conducting a primary study do not exist. Three different scenarios were tested to determine potential impacts to recreational benefits: these scenarios took into account the variation in the amount of use that some lakes see in each season, whether each day was worth the same amount of money per angler regardless of season, and if there might have been a change in the amount of species present in these lakes. This analysis attempted to provide an estimate of potential impacts under these three different scenarios, which aimed to broaden the base of current climate change literature and provide direction for the focus of future state dollars.

CHAPTER 2: LITERATURE REVIEW

The following literature review covers a wide range of topics that were used in the construction of this thesis project. The review covers all of the necessary subjects that explain the state of affairs with the given scenario that have lead to a need for this type of work to be completed. In addition, the review covers the building blocks that were necessary for this project. Concepts are introduced such as benefits transfer, willingness to pay, the travel cost method, climate change and potential impacts to freshwater systems (including changes in ice, water chemistry and aquatic populations). This review explains and shows that exact work of this nature has not been completed previously. This project hopefully adds a new component to the body of climate change literature.

Climate Change

First, the overarching concept of climate change is discussed below, as it is the sole cause for the need for this type of study. The main organization leading the wave of information on this global concept is the Intergovernmental Panel on Climate Change (IPCC), which is a group of government officials and scientists from around the world organized through the United Nations (IPCC, 2007). The IPCC has released four different versions of their comprehensive study on climate change, which cites statistical evidence of noticeable alterations in Earth's climate (IPCC). The Fourth Assessment Report (FAR) contains a few main concepts in relation to current projections in Earth's climate.

The first topic discussed concerns chemical compounds causing radiative forcing. Radiative forcing may be associated with the commonplace term, the greenhouse effect

(IPCC, 2007). This process involves gasses that are causing heat to be retained that is normally radiated away from Earth's surface into the atmosphere (IPCC). This is occurring due to certain chemicals' properties that inhabit the stratosphere (IPCC). These chemical compounds, such as CO_2, SF_6 and CH_4, have been and are continuing to increase in concentration over time (IPCC).

The IPCC has concluded two robust findings in respect to compounds responsible for radiative forcing. The first finding stated that it is evident that the concentration of these chemicals is rising (IPCC, 2007). This was explained through analysis of ice cores that serve as a historical record of previous climate. These cores have properties that enable atmospheric composition to be examined from thousands of years in the past (IPCC). The second main robust finding is that these rising concentrations of chemicals causing radiative forcing are anthropogenic in nature, which indicates human behavior is the main driver of potential shifts in climate (IPCC). These chemicals have made a noticeable change on sea level and temperature and are predicted to continue their projected impacts as time passes (IPCC). Several climate scenarios were indicated in the Fourth Assessment Report, which is the most recent publication of the IPCC. Even with drastic global reductions in chemicals causing radiative forcing, it is predicted there will be noticeable continued effects seen through changing temperatures and precipitation (IPCC).

Research has also been conducted in regards to climate change in Minnesota. Skaggs & Blumenfeld (2005) divided Minnesota into nine climate divisions, as established by other researchers on this project. These researchers divided temperature and precipitation data into four different seasons that pertain to natural systems and conventional divisions. These researchers chose the climate regions from the four corners of the state and analyzed precipitation and temperature trends since 1891. These trends were translated into z-scores, which are the number of standard deviations from the mean. The trends were highly variable from the beginning of the analysis. However, there were consistently warmer summers since 1995 in all corners of the state.

These researchers, in their z-score analysis of temperature and precipitation, mainly focused on the difference between biological and meteorological summers. They found many differences between meteorological and biological summer, which is an extended time period beyond meteorological summer. Biological summer yielded differences in precipitation and temperature. These differences have not been consistent over time. For example, the evidence suggested that the extended summer definition yielded results that indicated that there was more precipitation during the early and late part of the summer season in the SE region of the state in the early part of the 20th century.

These researchers also analyzed the trends from climate regions in the northwest and southeast corners of the state. They discovered that warmer summers are usually correlated with dry or normal precipitation. They also found that wet summers were correlated with cool or normal temperatures. Both of the above trends were the same for both regions of the state, which indicated a consistent trend. Overall, this source did not provide evidence in regards to a clear upward or downward trend in precipitation or temperature. However, these researchers indicated useful climate regions, clear visualizations of year-to-year variability in temperature and precipitation, and relationships between temperature and precipitation.

Lake Ice and Climate Change

Lake ice is an excellent tool for explaining the current evidence of climate change. Lake ice is highly dependent on the surrounding temperature for its formation (De Stasio, Hill, Kleinhans, Nibbelink, & Magnuson, 1996). Furthermore, increasing temperatures have been linked to significant decreases in the presence of lake ice (Anderson, Robertson, & Magnusin, 1996; Hodgkins, James, & Huntington, 2002; Johnson and Stefan, 2006; Latifovic and Pouliot, 2007; Magnuson, Robertson, Benson et al., 2000; Moore, Hampton, Izmest'eva et al., 2009; Schindler, Beaty, Fee et al., 1990). These changes have been studied using two main techniques. The first type of analysis involves on the ground reports of yearly formation and break-up. Perhaps the most comprehensive study combining these reports is the work of Magnuson et al. (2000). This study published in *Science* is the collaboration of the work of a large number of scientists that analyzed trends in ice formation and break-up in northern latitudes (one of these researchers provided lake ice data for this project). These researchers were able to develop an assessment to compare current trends in ice formation to historical trends. A warming trend was evident prior to 1850, but the rate increased after the onset of the industrial revolution. Statistical analysis revealed a significant reduction in the total period of ice presence. Delayed freeze date and earlier breakup date were listed to be increasing by 5.8 and 5.6 days respectively per 100 years (Magnuson et al.).

The second type of lake ice analysis was exemplified by the work of Wynne and Lillesand (1993). These researchers illustrated how satellite observations could be used to analyze ice conditions. These researchers showed that certain wavelengths can be associated with different surfaces or materials such as clouds, ice and snow. These wavelengths were then transferred into a temperature value. The presence of lake ice was coupled with data from the National Oceanic and Atmospheric Administration (NOAA) weather stations around the state of Wisconsin. This provided a linkage between the presence of lake ice and the influence of surrounding weather conditions. Although these researchers could not determine the date of ice formation (because of cloud and fog interference), these scientists were able to provide a correlation between temperature and ice break-up. January through March provided the most influence in the event of break-up. This indication of the influence of temperature on the presence of lake ice clearly showed the need for this type of study given the current climate change problem.

Climate Change and Freshwater Fisheries

Warming climate has the potential to impact the water temperature of freshwater lakes containing fish; Chu, Mandrak, and Minns (2005) showed how different species of freshwater fish were impacted from global climate change in Canada. A number of different variables were indicated to have a potential effect on freshwater fish populations. These researchers chose a select group of species (brook trout, walleye, and smallmouth bass) and attempted to model the effects on each population from the interaction of several variables. Variables of influence were selected by a correlation matrix. The model combined these variables to predict the occurrence of a species by region. For example, dew point, growing degree days, precipitation, and average hourly wind speed were included for determining the presence of walleye. This source indicated that cool water species will be threatened by warming water temperatures. These researchers further determined that previously existing warm-water species may expand their range northward, which may cause disruptions in previously existing population dynamics. For example, walleye and smallmouth bass may extend their range northward and prey upon previously undisturbed species.

These impacts that may occur are primarily due to changes in water temperature and changes in the levels of nutrients that may be present in the water bodies (Ficke, Myrick, & Hansen, 2007; Lettenmaier, Major, Poff, & Running, 2008). Changes in water temperature have been predicted to occur due to interactions between the changing air temperature and the surface water temperature (Lettenmaier et al., 2008). Changing the surface water temperature was predicted to cause a change in the amount of dissolved oxygen (DO) that is present in a water body (DeStasio, Hill, Kleinhans, Nibbelink, & Magnuson, 1996).

Changing the amount of DO and its effects on fish populations was illustrated by Ficke, Myrick, and Hansen (2007) who illustrated that variables such as oxygen content and temperature have an effect on the well-being of fish populations. Specific ranges required for a population's health were indicated for these variables. Variations of effects were illustrated for both lentic (lakes and ponds) and lotic (rivers and streams) systems taking into account changes in precipitation, water availability and temperature. These researchers focused on the effects of eutrophication, which may occur from increased temperatures. Eutrophication was predicted to lower DO in systems. The effects of decreased DO depend on the fish's ability to adapt to these changes (Ficke et al., 2007). In addition, specific effects of the stratification of lentic systems were indicated to possibly place higher stress on fish species. This entails a decreased amount of habitable area in a water body during warmer months due to the expansion of an uninhabitable, warm upper layer (Ficke et al.). On the other hand, these researchers indicated warmer air temperature may also have the impacts of increasing water temperature, which may provide more food and optimal growth conditions for fish during the winter months (Ficke et al.). In addition, this may decrease the amount of stress placed on fish during the winter months (Ficke et al.).

Two separate Minnesota studies have examined the impacts of climate change on freshwater fisheries. In the first study, Schneider, Newman, Card, Weisber, and Pereira (2005) examined the impacts on changing ice-out conditions in Minnesota on walleye spawning timing. These researchers found that there is a significant relationship between the change in ice-out and the change in the time that walleye lay eggs. This piece of literature combined ice-out data from lakes around the state with data concerning egg-take from walleye populations. The researchers found that for every one day decrease in the presence of lake ice there was a .5 to 1 day decrease to the day that a walleye lays its eggs. These authors postulated that this may have an impact on the well-being of the fishery if there is a mistiming in the availability of prey with a change in spawning timing. It is not clear if this change in timing was also correlated with a change in spawning duration.

In the second study, Schneider, Newman, Weisberg, and Pereira (2009) examined the current trends in fish communities in response to changing climate in Minnesota. Several temperature variables were compared with the abundance of species in 35 different lakes. Some of these variables included summer temperature, average annual temperature and temperature extremes. The methods of this study utilized catch per unit effort (CPUE) from gillnet and trapnet surveys. These researchers discovered that the majority of fish species were expanding their range northward except smallmouth bass. In addition, these researchers discovered that increases in average summer temperature were correlated with increases in bass and sunfish abundance. Moreover, increasing air temperature was correlated with a decrease in the abundance of whitefish and trout.

Impacts to Water Resources

Lettenmaier, Major, Poff, and Running (2008) examined the near term impacts of global climate change on water resources in the United States (US) for the next 25 to 50 years. This piece of literature mainly examined variables including streamflow, evaporation, drought, precipitation, runoff and water quality. In the analysis of streamflow, trends from 393 stations were plotted on maps. These stations showed statistically significant flow increases reported in the central portion of the United States, which included source stations in Minnesota. Two separate studies in this report indicated an overall increase in precipitation in this region. However, studies examining Great Plains states to the near south of Minnesota showed a reversal of this upward trend.

Lettenmaier, Major, Poff, and Running (2008) explored runoff rates by reporting US Geological Survey (USGS) statistics on runoff for trends from 1901 to 1970. These were projected into the future, which suggested an overall increase in the central US. Runoff was further examined by region. The central portion of the US was shown to be likely to see an increase in runoff in the Upper Mississippi basin (Lettenmaier et al., 2008). Besides runoff rates, water quality was also examined. Changes such as eutrophication from increased nutrient loads and increased temperature were discussed. Nutrient loading was indicated to possibly occur from increased runoff and more highly variable heavy precipitation events. In addition, these authors found that decreased consistent precipitation could cause eutrophication from the increased levels of nutrients without adequate consistent flows.

The above claims were mirrored by Heino, Virkkala, and Toivonen (2009), which indicated that global climate change has the potential to impact biodiversity in freshwater regions. Four main variables were examined in respect to the differing impacts of climate change. These variables included the effects of climate change on acidification, eutrophication, land cover change, and an increase in exotic species. Acidification effects were indicated to have the potential to increase or decrease depending on the region, and changes in acidification were indicated to have the potential to impact fish populations. Sources cited within this article also indicated that climate change is predicted to cause increases in overall precipitation in northern latitudes. As mentioned above, these increases in precipitation can cause increases in runoff, which can lead to an increase in nutrient loading in water bodies (Heino et al., 2009). This increase in nutrients can have a potentially negative effect on the biodiversity of a freshwater body, depending on the starting point of the system (Heino et al.). For example, if a lake is initially oligotrophic, additional nutrients may cause an increase in diversity in the system. These researchers concluded that increasing nutrients can lead to a decline in biodiversity in southern boreal regions. Conversely, Heino et al. also indicated that land cover may be altered from climate change. In northern regions, deciduous trees may eventually replace existent coniferous varieties. Since deciduous leaves contain more bio-available nutrients, this change in vegetation structure can potentially provide more nutrients to the biological communities in these areas (Heino et al.).

Two separate Minnesota studies also pointed to some indications of effects on freshwater fisheries. In the first study, Stefan, Hondzo, and Fang (1993) used meteorological and lake quality information from sites around the state of Minnesota to examine the impact of changing air temperature on the dissolved oxygen content and stratification (or temperature) of a variety of lakes. Minnesota data was used due to its high level of data quality. Among many findings, these researchers discovered that increasing temperature decreased the amount of dissolved oxygen in the upper layer of lakes (which agrees with the above studies). In addition, increasing temperature also prolonged the period of stratification, with the turnover occurring earlier in the spring and later in the fall (Stefan et al., 1993). A prolonged stratification was predicted to lead to a lower amount of DO in the hypolimnion (Stefan et al.).

The second study by Stefan, Fang, and Eaton (2001) examined the impacts of climate warming on several different lake types across the contiguous United States. Conclusions were derived concerning the well-being of cold, cool and warm-water fish types and their responses to climate change. The lake type (such as mesotrophic or eutrophic) and the lake depth both determined the well-being of cold and cool-water fish habitats. Only deep lakes along the northern border are expected to retain their cool and cold-water fish habitats. These researchers also indicated there may be a predicted increase in summer kill due to increased temperatures. On the other hand, snow and ice prevent the interchange of atmospheric oxygen to a water body, and so climate warming was also expected to yield an expected decline of winterkill that results from decreased DO (Stefan et al., 2001).

Two reports by Dedaser-Celik and Stefan (2007, 2008) indicated two main findings. First, water levels were rising in some Minnesota lakes (Dedaser-Celik & Stefan, 2007). Second, precipitation in Minnesota had a trend that is increasing in intensity and amount (Dedaser-Celik & Stefan, 2008). These findings were similar to those predicted that indicate climate change may cause precipitation and runoff rates to increase in northern latitudes. However, these implications were contradicted by the study below.

Dedaser-Celik & Stefan (2009) analyzed trends in streamflow in Minnesota since 1946 using gauges from five different rivers across the state. The trends observed did not match those predicted by other climate change literature such as increased high flow due to increased runoff. However, these researchers did determine that rivers located in areas with higher rates of precipitation showed increases in streamflow.

In summary, changes in water temperature and variables impacting the amount of DO in a water body are the main factors that may potentially impact fish populations from the onset of climate change. The studies near the end of this section indicated that Minnesota is not currently seeing some of the predicted impacts found in the broader climate change literature. These potential impacts remain tangential to the research project at hand. However, the well-being of these populations influences the economic benefits from fishing. For example, studies discussed below indicate that catch rate had a significant impact on willingness to pay (Stevens, 1966). If fish populations are negatively impacted from climate change there may also be an economic impact.

Economic Impacts of Climate Change on Freshwater Fishing

The work of Pendleton and Mendelsohn (1998) established ground work for studying how global climate change can create an economic impact through changes in fisheries. These researchers indicated that global climate change has the potential to impact sportfisheries in freshwater regions in the northeastern U.S. These potential impacts were predicted to have economic influences depending on the magnitude of climate effects as well as other variables. Three different groups were examined: rainbow trout, all other trout species, and panfish.

Pendleton and Mendelsohn (1998) attempted to economically model the potential impact of climate change on sportfisheries using two different models. The first was the hedonic travel cost method. This used different characteristics involved with the resources expended to reach a certain recreation location to estimate a value for a certain area. The second method used was a random utility model (RUM), which combined income, the travel cost function and a random variable for site location. These variables were combined to form a function explaining utility. This study was unique from others in that it was origin specific for its calculated RUM. The results of the analyses indicated that a decline in the catch rates of the types of fish could have a negative economic impact on the people fishing. However, this study found that some Northeastern states may see a potential increase in welfare from the onset of warming. This was dependent on the preferences of anglers (Pendleton & Mendelsohn, 1998). For example, although rainbow trout were predicted to decline from climate change impacts, all other trout species and panfish were predicted to increase. This study revealed that climate change could positively impact the economics of the region, depending on which climate scenario was selected. These researchers indicated that climate change impacts may not be completely negative, which is determined in the analysis below.

Creel Surveys

In general, creel surveys are a method to predict and represent an entire population fishing in a particular body of water, which is based on interviews conducted from a sample (Cook and Younk, 1998). These surveys have all come from different sources and have been collected from different researchers with different methodologies (See Tables 26 & 27). For example, the sampling methodology from a large lake is different from the sampling methodology of a smaller lake. Any method utilized to represent a population from a smaller sample may be prone to bias, as illustrated below. Therefore the process of creel survey interviews and the associated biases are further discussed below.

Creel Survey History

Creel surveys have been conducted to create generalizations of a population of anglers on a certain body of water through the use of statistical analysis (Cook and Younk, 1998). Creel surveys are generally utilized for management implications and may reflect details such as fishing pressure, catch rate, species composition and demographic information on anglers (Cook and Younk).

Creel surveys in Minnesota have transitioned from initial reporting of personal accounts of fishing trips into more comprehensive surveys (Cook and Younk, 1998). These surveys have been initiated partly due to concerns over the well-being of fisheries and the increased access that was given to many lakes upon the completion of roadways with the onset of logging in the 1930s (Cook and Younk). These rudimentary surveys have transitioned over time. In the beginning there were no established techniques for surveying anglers (Cook and Younk). In the 1950s a technique was formulated involving statistical selection and gathering data both by interviewing anglers and also by conducting visual counts (Cook and Younk).

Over time, these methods of surveying transitioned to be applied over a wider range of lakes and were compared across a known population (Cook and Younk, 1998). These initial surveys, over the chronological history of creel survey data, have transitioned between agencies that were responsible for conducting and analyzing the research (Cook and Younk).

In 1964, a team of researchers published a report that covered the technique for conducting a roving creel survey using incomplete trip information and instantaneous counts. Cook and Younk (1998) indicated that the above report served as a baseline for conducting methodology in many creel surveys around the state and that it was one of the most commonly cited sources in the methods sections of these reports.

Most of the surveys initially took place on small lakes (Cook and Younk, 1998). In the 30's there were many individuals available through the Civilian Conservation Corps. The availability allowed for an almost complete record of all fishing trips to Lake Winnibigoshish (Cook and Younk). When the availability of personnel waned, airplanes were combined with interviews to provide counts of the anglers (Cook and Younk). However, airplane usage became costly, which led to the creation of access based pressure estimates (Cook and Younk). This probability-based design has been indicated to still be utilized today except on lakes that have shoreline that may encumber the validity of using this design type (Cook and Younk). In the 1970s a method was developed to sample a number of lakes and streams all at a specific period of time, specifically when usage was predicted to be at its highest (Cook and Younk). For example, the time period just after fishing opener and for a time thereafter was assumed to be the time period that would obtain information from the majority of anglers (Cook and Younk).

Also in the 1970s, individual lake management grew with increasing popularity, which sparked an increase in the number of creels conducted on individual lakes (Cook and Younk, 1998). This increase in the number of lakes continued into the 1990s along with the ongoing change in the structure of how the creels were conducted (Cook and Younk). In the mid-1990 a general report format was established along with a computer program utilized by the state to statistically analyze the creel reports (Cook and Younk).

Creel survey validity

The validity of creel surveys as an estimation technique could be challenged as a whole. However, the DNR has utilized survey designs written by accomplished individuals in the field and these researchers have utilized sampling techniques from reputable sources such as Pollock, Jones, and Brown (1994). For example, Pollock et al. (1994) illustrated the roving creel survey design that was utilized for larger lakes such as East Upper Red Lake and Lake of the Woods (Standera, 2009; Heinrich, 2007).

The large variety of different dates from the database in which the surveys were conducted could be questioned as to their statistical validity. The MN DNR utilized two main types of survey techniques (See Tables 26 & 27). The first type was the roving creel and the second type was the access point survey design. Newer surveys also employed an aerial-access design where an airplane was utilized to conduct counts and in-person interviews were utilized to determine all other variables (K. Reeves, personal communication; See Tables 26 & 27). For some lakes in the dataset, if there were many different access points to a certain lake such as by shoreline, then a roving creel survey design proved to be more favorable (Pollock, Jones, & Brown, 1994).

The three above methods all had their own respective methodologies for conducting and gathering survey data. These three methods also were subject to error that can apply generally to all types when conducting a survey. The following discussion of the shortcomings of creel survey design were reported in Pollock, Jones, and Brown, (1994), which was utilized by DNR creel survey reports for methodological construction (Standera, 2009).

Survey error

Pollock, Jones, and Brown (1994) illustrated three main types of errors that could have occurred in the interview process: sampling, response and nonresponse errors. Sampling error consists of errors that are made in the selection process in which anglers are selected to be interviewed (Pollock et al., 1994). This includes problems such as incorrect sampling techniques such as choosing a convenience sample that is easiest to reach (Pollock et al.). This also includes avidity bias and length-of-stay bias (Pollock et al.). Avidity bias refers to individuals that may fish more often than other anglers (Pollock et al.). If more anglers were selected who fished more frequently than other anglers, this could have potentially biased the pressure estimate. Similarly, length-of-stay bias is another type of sampling error that could have occurred (Pollock et al.). Anglers who were located on the ice for longer periods of time had a greater probability of being selected than anglers who fished for shorter periods of time (Pollock et al.). Therefore, anglers who fished for longer periods of time were also more likely to have biased the pressure estimate in an upward direction.

Another type of survey error that could have occurred is in the category labeled response errors (Pollock, Jones, & Brown, 1994). Response errors for the creel surveys could have taken place in a multitude of forms and could have impacted pressure estimates (Pollock et al., 1994). Pressure estimates could have been impacted by recall bias, prestige bias, rounding or digit bias, lies or intentional deception and question misinterpretation (Pollock et al.).

The following paragraph discusses five main types of response errors. The first type is recall bias, which consists of anglers being unable to recall past events accurately. This may not have severely impacted pressure estimates due to the fact that it may have been easier to remember the events that occurred during the same day the interview was conducted as opposed to events that took place over a longer period of time (Pollock, Jones, & Brown, 1994). The next type of bias is prestige bias, which would have impacted harvest estimates through the means of exaggerated catch rates (Pollock et al., 1994). However, some individuals could also have claimed longer periods of time fishing (impacting pressure estimates) in the winter during cold days to have appeared macho or tough. The third type of bias is rounding or digit bias, which could have occurred when changing a smaller number to a larger number. For example, this could have taken place when rounding a smaller number to a multiple of five, which could have occurred with pressure estimates. The next type of response error involves lies or intentional deception. This could have occurred due to the hope that a false response would have potentially benefited the angler, the angler had conducted some sort of violation, or the angler harbored hard feelings toward the interviewing agency (Pollock et al.). The last type of response error impacting pressure estimates is question misinterpretation (Pollock et al.). If the clerk did not phrase the question in understandable terms or the respondent did not understand the question, the angler may not have elicited a viable or accurate response (Pollock et al.).

The last type of error outlined by Pollock, Jones, and Brown (1994) that could have occurred is a nonresponse error. However, these types of errors are less likely to occur with in-person interviews and have occurred more often with mail surveys (Pollock et al., 1994). These specifically may have taken place when a respondent did not understand the question or if he or she simply chose not to answer (Pollock et al.). Some of the estimations of pressure were conducted using indirect counting methods, which are further discussed below.

Creel survey methodology

The following discussion shifts from pointing out potential biases of surveys to explaining the methodology of the creel surveys, specifically focusing on access point surveys and roving creel surveys. An access point survey consists of interviewers gathering information based on a trip that has occurred in the immediate past (Pollock, Jones, & Brown, 1994). This information is considered complete (Pollock et al., 1994). Information being complete refers to the fact that an angler has already gone through the fishing experience (Pollock et al.). On the other hand, a roving creel survey consists of interviewing anglers while the trip is still in progress (Pollock et al.). Therefore the data from a roving creel survey is based on incomplete information. However, instantaneous counts made by a creel clerk could have eliminated this potential bias in the results

(Vaughan and Russell, 1982). Instantaneous counts and roving creel surveys are discussed below.

The methods for access point surveys may have varied depending on the type of site (Pollock, Jones, & Brown, 1994). For example, some lakes may have had a multitude of different access points that allowed anglers to go on and off of a body of water (Pollock et al., 1994). The amount of time spent at these access points depends on the individual study's methods (Pollock et al.). There are many different types of ways that an access point survey may have been constructed that can account for the type of lake being examined. For example, a large lake with many access points could have utilized a "bus stop" method for access point surveys (Pollock et al.). This method entails a schedule that is laid out for a creel clerk to spend specific amounts of time at each sampling location and then move on to the next. This allowed the clerk to be more engaged with the project and also a greater sample area may have been included with the results. Access points could also have been randomly selected for time and location, thereby giving statistical accuracy to a project (Pollock et al.).

The sampling days and times may also have been chosen to better reflect the actual population of anglers when an access point survey was conducted. Days of a month, days of the week and day periods (such as AM or PM) may have been chosen randomly (Pollock, Jones, & Brown, 1994). The careful construction of temporal and spatial location could also have helped to lead toward a better representation of a creel survey. However, access point surveys may still have been subjected to bias. Access point surveys are prone mainly to avidity bias with their questioning (Pollock et al.). However, this does not appear to be a major factor in respect to estimating pressure

(Pollock et al.). The methods of this type of study are discussed for their strengths and weaknesses below.

Roving creel surveys, unlike access point surveys, are mainly prone to length-of-stay bias. This is due to the fact that anglers who spend more time on the ice have a greater probability of being sampled than anglers who spend less time on the ice (Pollock, Jones, & Brown, 1994). These surveys are also subject to lacking a complete amount of trip information, since the interviews are conducted during the trip (Pollock et al., 1994). Therefore, other methods have been utilized that estimate the amount of trip length. These include techniques such as estimating the expected trip length and instantaneous counts (Pollock et al.). Trip estimation is subject to large amounts of bias because there may be other extraneous variables that impact the amount of time spent fishing such as changes in weather and enthusiasm (Pollock et al.). Therefore, effort estimations are generally not conducted in the interview process. Instead these are calculated as counts, either progressively or instantaneously. These counts are then multiplied by the number of fishing hours in a day to estimate effort (Pollock et al.).

Instantaneous, aerial and progressive counts:

This project relied heavily on the estimation of total fishing pressure (time spent fishing) that was statistically analyzed from the creel survey database. The following is a discussion of the methods that were used to conduct pressure estimates in the absence of an access creel survey.

Instantaneous and progressive counts could have occurred while conducting a roving creel survey (Pollock, Jones, & Brown, 1994). These counts are used to estimate the total amount of effort or fishing pressure on a given body of water (Pollock et al., 1994). An instantaneous count consists of a creel clerk counting the number of anglers that are fishing at a particular moment in time. These types of counts generally take less than 15 minutes to complete (Pollock et al.). If the count takes longer than an hour to complete, it is referred to as a progressive count. A progressive count consists of selecting interval time periods to take scheduled counts of anglers (Pollock et al.).

Both of these types of counts are subject to bias. Each of the counts assumes that all anglers are fishing when they were counted on the water. Some may have been along with a party and not fishing at all. In addition, some estimates of effort may not have been able to adequately account for the total number of anglers in a party (in a boat or in an ice-house). Therefore, the total number of hours being fished could have been misrepresented. In addition, Pollock, Jones, and Brown (1994) stated that the amount of anglers is multiplied by the number of hours in a fishing day. This assumption of how long an angler would stay could have been incorrect. However, the discussion surrounding Pierce and Bindman (1994) indicated that instantaneous counts could have been highly accurate in regards to estimating the total amount of fishing pressure.

Pierce and Bindman (1994) provided defensible material in regards to the validity of instantaneous counts as a method to estimate effort. These researchers conducted a creel survey in which creel clerks used a stratified-random creel sampling design. This involved the creel clerk counting the number of anglers on the lake at a randomly specified time from different areas of the lake. This estimate was then compared against an absolute estimate that was derived by the clerk keeping a complete record of all anglers on the lake and noting their arrival and departure times. It was found that the instantaneous method was a reliable estimator of pressure in comparison to the absolute method. The conclusion was derived off of the statistical results that supported a one-to-one ratio with a high level of confidence. These results meant the same amount of time spent angling was found through each method.

Aerial counts comprise another method that was utilized to estimate the total amount of pressure on some Minnesota lakes. This method is beginning to replace the utilization of snowmobiles in the winter (roving creel surveys) due to issues with safety (K. Reeves, personal communication). Aerial counts utilize a progressive roving design and are able to cover a large amount of area in a sampling period (Pollock, Jones, & Brown, 1994). However, there are a number of biases and complications to the aerial design. For example, observer error can occur and individuals can be missed (Pollock et al., 1994). In addition, these counts are extrapolated much like the instantaneous and progressive designs: it is assumed these counted anglers are present for the entire fishing day. The observer also may not be able to discern multiple anglers in a party (Pollock, et al.). For example, a fishing boat could have more than two people, which would give the count of one fishing boat an underestimation of effort if it was assumed that only one angler was present.

Sampling techniques

Many types of sampling techniques have been implemented with the access, roving and aerial survey designs. In the database, all the creel surveys were coded according to the method utilized (See Table 26). These techniques are discussed in the following paragraphs. The first technique is stratified random sampling, which is implemented along with a roving creel. This type of sampling is best conducted with prior knowledge of the fishery in order to properly proportion the amount of sampling that took place during specified periods (Pollock, Jones, & Brown, 1994). Different strata that could have been chosen include the months, days in the week, weekends versus weekdays and time periods in a day such as AM and PM. If prior knowledge of effort was known, these different strata could have been sampled in relative proportion to previous effort (Pollock et al., 1994).

The second type of sampling that was utilized for roving surveys was nonuniform probability, which is also referred to as unequal probability sampling (Pollock, Jones, & Brown, 1994). This type of survey takes place when some areas of a sample are expected to see a higher volume of activity than others. This statistically complex type of sampling method allows a greater focus to be paid toward certain areas over others (Pollock et al., 1994).

The third type of survey design utilized was systematic sampling, which is also referred to as systematic random sampling (Pollock, Jones, & Brown, 1994). Instead of randomly selecting from a sample, a selected interval is chosen that is utilized to draw from a sample. Pollock et al. (1994) gave the example of selecting fishing licenses at a random interval versus randomly selecting the sheets of paper, which could be more costly in respect to time.

The two types of access surveys utilized were nonuniform probability (discussed above) and no probability. No probability access surveys may have been utilized if there was only one access point to a certain body of water (Pollock, Jones, & Brown, 1994). These types of surveys are useful when the body of water is very small (Pollock et al., 1994).

Some of the surveys conducted may also have been through the process of angler diaries or through volunteers reporting information. As mentioned above, volunteer data may have been subject to bias if the individual had motivation to influence policy in his or her own favor (Pollock, Jones, & Brown, 1994). In addition, this survey method is prone to several other shortcomings that involve nonresponse bias and the likelihood that avid anglers may be more prone to complete these surveys than others (Pollock et al., 1994). Despite its ease of use, this survey technique was listed as being rare by Pollock et al. and did not take a high priority in the MN DNR creel database.

Validity of pressure estimates

As mentioned above in the dialogue surrounding the Pollock, Jones, and Brown (1994) discussion of bias, there are many factors that could have influenced the validity of a creel survey. Validity of creel surveys was also touched upon and is defensible from works such as Pierce and Bindman (1994). These biases that were presented by each of these survey types are addressed above. While there was no perfect sampling technique in respect to estimating effort, these estimates of fishing pressure have undergone scrutiny in design and have been developed by accomplished researchers. These estimates helped to provide a baseline of estimated fishing pressure for different climate regions throughout Minnesota, with the hope to have modeled the potential effect of decreased lake ice on the activity of ice fishing.

Fisheries Valuation

Besides the intrinsic enjoyment of the activity, recreational fishing has been valued economically. The U.S. Department of the Interior (2008) estimated in 2006 roughly $2.7 billion was spent in Minnesota on goods associated with angling. Besides this widely cited study, other researchers have aimed toward estimating the valuation of fisheries. However, none of these studies appeared to solely focus on the activity of ice fishing. These studies utilized random utility models and the hedonic travel cost method. While these external studies were useful for discussion concerning valuation literature, the USDI value for a fishing day was utilized in the model due to its prevalent application in DNR literature, its simplicity of use, and the sound statistical methods, which are discussed below.

As seen below, the process of attempting to provide a value to a fishery has been conducted numerous times. This process utilizes information from anglers that has been ascertained through direct or indirect measures (Chen, Hunt, & Ditton, 2003). The reliability of the data depended upon the methods used to collect the information from the anglers. A brief description of studies that have attempted to model the economic benefits of angling is described below.

Chen, Hunt, and Ditton (2003) sought to provide an estimate for the total economic value for a largemouth bass fishery for a reservoir in Texas. Information from creel survey data was obtained in order to perform follow up surveys asking for willingness to pay (WTP) estimates. These estimates were derived by asking anglers questions such as how much was spent during their trip on certain activities and resources such as food, gas, lodging, and boat rental. In addition, anglers were asked to indicate where they were traveling from and how many miles were traveled to reach their destination. These methods created a WTP estimate for the anglers as well as an estimated total expense that was incurred by the anglers while recreating. The estimates of WTP were separated by direct and indirect expenditures. Indirect expenditures encompassed activities that were not directly related to the fishing experience such as lodging and dining. In addition, estimates from out of state, local and non-local residents were individually reported. Out-of-state and non-local residents spent the most on their trips. The majority of the anglers were non-local residents from in-state. The breakdowns of expenditures were reported by percentage of total costs. In addition, an estimate was provided of total dollars generated by supporting businesses. The subsequent creation of jobs was also estimated. This study illustrated the clear economic value and generation of revenue that has been created from a fishery.

A large number of studies have been associated with the estimation of WTP for recreational fishing. Johnston, Ranson, and Helm (2006) compiled and reviewed a large number of these dissertations, journal articles and one book and determined what variables had an influence on the final WTP estimate. The authors concluded that research methodology played an important role in determining the final value. The main variations in research methodology involved the means by which the estimate was calculated: these were the hedonic travel cost method, the random utility method (RUM), and stated preference. The authors discovered that the year the study was conducted also played an important role in the final estimate; the more recent studies had a higher WTP. In addition, it was found that the variables of year and the type of study had an effect on the final value of the estimate. The estimated WTP varied considerably between fish species. Trout species exceeded WTP over species such as panfish and walleye. This study provided a quality assemblage of information that showed consistent positive economic valuation for fisheries.

Stevens (1966) examined the effect of quality on the economic valuation of sport fishing in the Willamette Valley of Oregon. The author theorized that a change in quality could have negatively impacted the economic valuation of the sport fishery. This was predicted to occur, because decreases in quality could have negatively affected the catch rate (Stevens). In turn, catch rate was proportional to effort made by anglers. Effort made by anglers was calculated into an economic valuation through analysis of opportunity cost of time and expenditures made to reach and enjoy a recreation destination. Stevens found a decrease in quality would impact these expenditures through reduced catch rates. This author used calculations of willingness to pay to estimate reduction from decreased quality. Although this project did not examine catch rates, this study validated the potential economic impact from potential changes in fish populations caused by climate change.

Vaughan and Russell (1982) covered an overview of the methodology involved with calculating the value of a fishing day using the travel cost method. The authors focused on the economic methods used to derive the travel cost estimate. They pointed out that travel to a site is based on several characteristics. One of these is the type of fish being sought. The type of fish was predicted to impact the WTP value. Other characteristics that affected travel cost included the socioeconomic status of the anglers and the site characteristics. The authors concluded there was a potentially significant difference between the WTP dependent upon species sought.

The USDI (2008) provided a large database of information on economic valuations for fishing, hunting and wildlife associated recreation. These valuations were divided by each state, with a large amount of information available for Minnesota.

Individual estimations were provided for each recreation sector, and these were combined together to create an aggregate estimate. Interesting numbers included total estimated statewide anglers, dollars spent on angling, and days spent fishing. These numbers provided a justification for the relevancy of the research question depicted above. Numbers were broken down into expenses on specific equipment, days spent on each recreation activity and miles spent traveling. However, winter-specific information was not discernable from the information provided.

The methods behind the estimates made by the U.S. Census Bureau took place through a multistep process. Procedures were utilized to prevent bias in the estimates. These included using statistically sound sampling techniques. The selection process involved the utilization of sampling units for the entire United States. Each of these units were then divided into different stratum. Each selected unit within a stratum was used to estimate the entire stratum. The sample size for the Minnesota sample consisted of 778 households. Sportspersons were chosen through a screening process that selected these respondents apart from non-sportspersons. The individuals selected were then chosen to be interviewed, predominantly in-person. The response rate of these interviews was 90 percent. The average trip expenditure per day for residents and nonresidents of Minnesota was estimated to be $35. This estimate served as a baseline in the economic analysis that was performed below.

Travel Cost Method

The estimation provided by the U.S. Census Bureau utilized the travel cost method (TCM) to derive the total valuation for a fishing day in Minnesota. The travel cost technique is the utilization of expenditures incurred upon traveling to a recreation destination to indirectly determine the economic value of the recreation activity (Brown and Mendelsohn, 1984). The travel cost value was the backbone of this project. The sources discussed below cover the intricacies surrounding this valuation method.

Agnello and Han (1993) explored the methodology related to conducting an analysis of recreational fishing values in Long Island when the opportunity for substitutes existed. The researchers discovered that the availability of substitutes lowered the potential value of consumer surplus. The majority of this paper focused on the methodology utilized to perform an analysis of this recreational fishery. However, these researchers indicated the effect of substitutes, which had an impact on a travel cost value.

Randall (1994) also analyzed the technique of valuing non-market goods, specifically through the TCM. A variety of weaknesses were indicated, which were clearly illustrated. These included problems with joint costs and the effects of substitutes on the final valuation. In addition, different inclusions of variables lead to different estimates for the same non-market good. Also, there could have been variability in certain costs such as the price of equipment over time. The weaknesses lead Randall to conclude that the travel cost method could only most appropriately have been used in an ordinal scale, and anything more would have been biased. However, the travel cost technique may have held to be viable since the availability of substitutes may not have existed when a fishing day was valued for the entire state.

Benefit Transfer

The baseline value for ice fishing that was used to determine the potential economic impact from climate change was calculated by using a technique referred to as benefit transfer. This is the process of using values from a previously existing study and “transferring” the values to another realm of policy. This technique is especially useful when a project is limited for time and resources (Kirchhoff, Colby, & LaFrance, 1997).

Desvousges, Naughton, & Parsons (1992) provided a critical discussion related to the benefit transfer technique. These authors primarily focused on analyzing the method through an experimental design focused on water quality. However, the concepts discussed throughout the essay were relevant across disciplines. The discussion revolved first around the basic premises involved in performing a benefits transfer. The premises related to the differences between the study site and the policy site. The study site was where the initial empirical work took place and the policy site was where the valuation was applied. The variables included sound methodologies, similar socioeconomic characteristics, similar site characteristics and the inclusion of the effects of substitutes. The authors drew on information from an earlier version of the Department of the Interior’s census, which was cited above. However, it was noted that users typically travel to the sites nearest to their location, and a national (or statewide) average may have skewed these characteristics. In addition, these authors evaluated transfers based both on contingent valuation (CV) and the TCM. They indicated that there was no specific criterion for evaluating the reliability of existing studies that a benefit transfer would have been based upon.

The benefit transfer technique was further embellished upon by Bergstrom and Civita (1999). These authors provided an overview of the reliability of benefit transfer in North America. The authors used their background from Environment Canada and economics to effectively draw on a wide variety of literature. Benefit transfer methodology was covered along with its flaws. In addition, the authors provided a literary analysis of studies that have evaluated the reliability of benefit transfer. These evaluations used two different types of techniques. One method evaluated the values by comparing the results from individual studies across study sites to see if they were comparable. The authors concluded that benefit transfer equations were more reliable than unit transfers. The authors also indicated the shortcomings of many benefit transfer values when applied to a policy site from a study site. Last, the paper provided informative discussion on the necessity for accuracy. For example, a high level of accuracy was not required when broad policy statements were being made from the transfers. This latter concept especially applied to this research project, as the estimate derived simply aimed to provide an estimate of potential impacts.

CHAPTER 3: METHODS

Creel Surveys

Periodically, the Minnesota Department of Natural Resources (MN DNR) has conducted summer and winter creel surveys to assess the amount of use certain lakes were experiencing (Cook & Younk, 1998). These surveys analyzed how many hours were spent recreating and how many fish were caught and released by anglers (Cook & Younk). A large sample of these surveys were gathered from the statewide creel survey database.

As mentioned in the literature review, creel surveys provided a means to represent the characteristics of a population of anglers on a particular body of water (Cook & Younk, 1998). These surveys could have been prone to several types of biases including response, nonresponse and sampling errors (Pollock, Jones, & Brown, 1994). However, with proper survey design, these biases may have been addressed and avoided.

As can be seen from the analysis of the history of creel surveys, the methods have been constantly changing and improving. The modern creation of a statistical program and general reporting format provides evidence of this improvement. The state has utilized a wide variety of different sampling designs for conducting their creel surveys (see Appendix 1). Each of these surveys has been associated with potential respective biases (Pollock, Jones, & Brown, 1994). Therefore, no estimate derived from this data may have been taken to be completely accurate.

As analysis of the surveys continued, it became evident that the creel surveys were not without their imperfections. For example, some of the lakes may not have been selected evenly or randomly statewide. In addition, some lakes may have had more extensive creel information than other lakes. Furthermore, some lakes may not have been accounted for due to sampling or selection techniques. Lastly, some lakes and lake classes have had sparsely collected data. If a minimal amount of data existed for some lakes, it was considered a potential bias in the benefit transfer process. In other words, a biased amount of pressure may have impacted the final dollar value estimate.

Despite these biases, analyses of the validity of some creel survey designs such as instantaneous counting methods have yielded defensible results (Pierce & Bindman 1994). Therefore, while these surveys may have had some potential weaknesses, they still may have proved to be useful in calculating an estimate of the potential impact of climate change on recreational benefits.

In the survey database, information was provided on fishing pressure gathered from 763 lakes. Out of these lakes, 400 contained information regarding winter pressure. These lakes are found dispersed throughout Minnesota (Cook & Younk, 1998). Many of the surveys in the database were based on methods from Pollock, Jones, and Brown (1994), which was discussed above and in the literature review.

Main Hypothesis and Scenarios

The hypotheses tested in this thesis are represented by the function: $B = f(x_1, x_2, x_3, x_4)$. The components of this function include:

B = Recreational benefits from fishing
x_1 = Ice-on days
x_2 = Open-water days
x_3 = Angler hours per acre
x_4= Species

Recreational benefits are hypothesized to be a function of the above variables. When one of these variables is shifted, it is assumed that there will be an impact on the recreational benefits (B). In other words, it is assumed that a change in ice-on days, ice-off days and angler hours per acre will all have an impact on recreational benefits. These assumptions are represented below:

Assume: $\Delta B/\Delta x_1 > 0; \Delta B/\Delta x_2 > 0; \Delta B/\Delta x_3 > 0$

As mentioned above, three different scenarios are tested. The first tests the notion that the change in recreational benefits from a change in ice-on date is equal to the change in marginal benefits from a change in ice-off date. In other words, ice-fishing is not worth any more than open-water fishing.

Scenario 1: $\Delta B/\Delta x_1 = \Delta B/\Delta x_2$

The second scenario looks at the possibility of the change in recreational benefits being unequal from a change in ice-on and ice-off dates. Scenario 2a represents the case of locations such as East Upper Red Lake, MN, which have seen a higher proportion of anglers visiting in the winter than in the summer (MN DNR, 1997). This difference is mainly due to the ease of access in the winter. In the summer the geography of the lake results in large waves when wind is present, which makes open water fishing difficult.

Scenario 2a: $\Delta B/\Delta x_1 < \Delta B/\Delta x_2$

Scenario 2b applies to other areas around the state. The statistical analysis of fishing activity in Minnesota reveals a higher amount of angler hours on lakes during the summer months (see results). Therefore, an increase in the amount of ice-off days will have a greater positive impact on recreational benefits than the loss due to fewer ice-on days.

Scenario 2b: $\Delta B/\Delta x_1 > \Delta B/\Delta x_2$

The third scenario examines the impact of species on the marginal recreational benefits. The literature has indicated that certain species have had a higher willingness to pay (WTP) by anglers than others (Johnston, Ranson, & Helm, 2006). For example, trout species have had a higher WTP than species such as panfish and walleye (Johnston et al., 2006). Under this assumption, a change in abundance of one species, or decrease in abundance of another may have a significant impact on the recreational benefits.

Scenario 3: $\Delta B/\Delta x_4 > 0$

The following are the methods for the hypotheses being tested in this thesis. Using ice duration statistics (including ice-on and ice-off data), the estimated impact on the total number of days fished was determined. There are three different scenarios that were examined (mentioned above). Lake ice records were tested to see if the ice duration was significantly increasing or decreasing.

Lake Ice Observation Methodology

Lake ice records were obtained from Dr. Virginia Card at Metropolitan State University, Saint Paul, MN. Her ice records were gathered from the Minnesota Pollution Control Agency (MPCA) and the Minnesota Ice Records Database. The Minnesota Ice Records Database consists of a combination of observations recorded in newspapers and from individual correspondence. She submitted to this project data from 40 lakes that contain both ice-on and ice-off observations dates, which made it possible to estimate ice duration. These 40 lakes are a set from another subset of her data consisting of 106 lakes. The set of 106 lakes were chosen from her dataset, because they contain information regarding gill net and water quality data. Any missing observations in this dataset were estimated by a comparison modeling procedure against nearby lakes (within 50 km).

This included using a set of 6-10 lakes to estimate the ice-on or ice-out date of the modeled lake. The modeling procedure yielded an error rate less than 2-3 days when the procedure was compared against actual observations (Card, 2009).

Observation error and typographical errors are perhaps the largest weaknesses in regards to ice duration data. Her data was checked in three separate ways to account for these potential weaknesses. Dr. Card checked errors “by comparison of ice-out records from one lake by two or more independent observers; by comparison of multiple redactions of the same record; and by comparison of each year of a very long ice-out record to contemporary reports of ice-out dates from archival record at the Minnesota Historical Society” (Card, 2009). Through her analysis, she discovered untrained observers would make errors on average of 1-2 days per year. When recording proved to be in error, this occurred every 1 in 20 dates with an average of 2-3 days being off of the actual date (Card).

The ice trends, which were reported in days lost or gained, determined how many angler days were impacted. Using the creel survey data, the average number of angler hours per season per acre was determined. The total amount of angler days was determined using the number of angler hours per fishing trip in the open-water and ice-fishing seasons (separately). The average number of angler days in each season per acre was then extrapolated with the total acreage of lakes in Minnesota.

In order to determine an impact on the number of open-water days and ice-on days, a baseline for the current total number of these days needed to be determined (seen below in the equation). To create this baseline, data from 1971-2000 was utilized from the 40 lakes in the ice coverage dataset. Using the previous 30 years of data ending on the most recent zero year represents a climate normal in meteorology (Hulme, Dessai, Lorenzoni, & Nolson, 2009). Normals were created for each climate region by averaging the length of ice-on and open water days for lakes in the ice duration dataset. Some climate regions had several lakes to be averaged, while others had only a couple. Climate region 7 and 9 had no ice duration observations. These climate regions were estimated by using the number of days in the horizontally adjacent climate region containing data (climate region 8).

Total Lake Acreage

The total lake acreage was determined using a GIS layer obtained from the GIS coordinator for the MN DNR, Lyn Bergquist. The layer contains all lakes that have division of waters (DOW) identification numbers, which totals to 16,141 lakes. This layer was specifically prepared to represent Minnesota lakes acreage. The portions of lakes that exist outside state boundaries were excluded from the acreage assessment. Out of these lakes, the DNR has surveyed (not creel surveys) the fish populations on 4,295 lakes. Using the sum feature in GIS, the acreage for the group of 16,141 lakes and the group of 4,295 lakes were each determined. The acreage for the 16,141 lakes is 4,555,898.54, and the acreage for the 4,295 lakes is 3,923,292.62. The different acreage estimates provided by the upper and lower bound numbers provide a sensitivity analysis for the total amount of lake acreage in Minnesota.

Explanation of Benefits Calculation

The result of combining angler days with the total lake acreage provided an estimate of the total number of trips (angler days) that occurred in the open-water or ice-fishing seasons for the entire state. The total estimate was then divided by the number of days in a season, which yielded the average number of trips per day. The number of trips per day was multiplied by the number of lost or gained days using the ice duration statistics. This provided an approximation of the number of angler days lost or gained from changing ice duration.

The estimated lost or gained fishing days was then transferred into an economic estimate to represent the economic gain or loss. Data from the U.S. Census Bureau valuing a fishing day was utilized as an estimate at $35 per day. Since a fishing day may be variable between seasons, the number of hours in a fishing day was found for each season using statistical analysis.

As mentioned above, the U.S. Fish and Wildlife Service has conducted a national survey in collaboration with the U.S. Census Bureau every five years (USDI, 2008). In this survey, individuals were contacted and interviewed with a variety of questions regarding their participation in activities such as fishing, hunting, wildlife viewing or any combination of these activities. In questioning, the respondents were asked a variety of questions regarding their expenditures related to these activities. Through these inquiries an estimation of a value for each activity was created (USDI). This USDI estimate for the value of a fishing day was utilized to form a baseline in the equation mentioned below, which determines the projected impact from climate change. The estimate is $35 per day by Minnesota residents and nonresidents in 2006 dollars (USDI).

Mathematical Description of Benefits Calculation

The procedure, mentioned above, for estimating the potential economic impact is as follows:

$X1_w$, $X1_s$ = Mean angler hours per acre per season
$X2$ = Total fishable acres (two estimates)

$X3_{w}$, $X3_{s}$ = Mean angler hours per trip in each season (trip length)
$X4_{w}$, $X4_{s}$ = Angler days per season in each climate region
$X5_{w}$, $X5_{s}$ = Days lost or gained in each season per decade
X6 = Value of a fishing day
$Y1_{w}$, $Y1_{s}$ = Total trips/season
Y2 = Average trips/day
$Y3_{w}$, $Y3_{s}$ = Trips lost/gained per season
$Y4_{w}$, $Y4_{s}$ = Economic estimate per season
Y5 = Total economic impact

$X5_{w} + X5_{s} = 0$
$Y3_{w} + Y3_{s} = 0$

$Y1_{w/s} = X1_{w/s} * X2/X3_{w/s}$
$Y2_{w/s} = Y1_{w/s} / X4_{w/s}$
$Y3_{w/s} = Y2 * X5_{w/s}$
$Y4_{w/s} = X6 * Y3_{w/s}$
$Y5 = Y4_{w} + Y4_{s}$

Multiple Regression of Species Shift over Time

In addition to the above hypothesis, another hypothesis proposed by Schneider, Newman, Card, Weisberg, and Pereira (2009) was examined. This hypothesis indicated that largemouth bass and sunfish are predicted to shift their range north and east in response to climate change. In addition, the literature indicated trout species are predicted to decline in abundance. Angler surveys provided species-sought percentages and species yield (in pounds) that were examined across climate regions over time. Species included in the analysis were walleye (due to its high economic demand), largemouth bass, sunfish, and all trout species. These species elicited some of the highest rates of preference by anglers from the creel database (See Table 25). Some of these values totaled to more than 100% due to multiple responses being coded for 100% in the same category. These inaccuracies were corrected for the benefits estimation calculation. Any remaining species were categorized as “other species.” The variables examined were species, percentage of “species-sought”, climate region and year. These variables were placed in a multiple regression (using dummy variables for climate regions and species) to determine their impact on total yield across the state. The multiple regression equation reads as follows:

$Y = f(x_1, x_2, x_3, x_4)$

Y = Weight$_{species}$
x_1 = Hours$_{species}$
x_2 = Climate region
x_3 = Survey year
x_4 = Percentage of anglers seeking each particular species

The hours each angler spent fishing for each species was determined by multiplying two variables together: the percentage of anglers in each creel that fished for the above mentioned species and the total amount of angler effort (pressure). This calculation was extended vertically in one column labeled “spphrs”. In addition, the total catch for each of the above mentioned species was also extended vertically in one column labeled “spplbs”. Each of these cases were identified with a dummy variable indicating their respective climate region and species. This process was performed individually for the entire compilation of creel data for the state, for the big 9 walleye lakes and for East Upper Red Lake (due to its uniquely high winter pressure compared to summer). Two cases were removed from the Red Lake dataset. One case was from 1995 when the reported yield of walleye harvest was 0. The other case was from 1980 when the reported yield for all other species was reported as 0. The big 9 walleye lakes include Lake Vermillion, Lake Mille Lacs, Cass Lake, Lake Winnibigoshish, Rainy Lake, Leech Lake, East Upper Red Lake, Lake of the Woods and Kabetogama.

Geographic Information System (GIS) Procedure

To perform both of the above analyses, the data of fishing pressure on Minnesota lakes were input into geographic information systems (GIS) software, ArcGIS 9.3 to visually represent lakes in the study. In addition, ArcGIS was used to join datasets together using Strata ID and each lake's division of waters (DOW) number as a unique identifier between different datasets.

GIS was utilized to assign all of the survey lakes to a climate region. This was a multistep process. First, the Minnesota counties layer was dissolved by climate region (designated by the LCCMR – see report). These climate regions were then used to perform a spatial join with the Minnesota lakes layer provided by the MN DNR. Lakes on the edges of these regions, or those contained within multiple regions were assigned a climate region depending on which county they resided within.

For the first equation estimating recreation benefits from changing lake ice, the Minnesota lakes with assigned climate regions were paired with the most recent creel surveys in each season. For example, in each season, although there were multiple years of data for some lakes, only the most recent was chosen using GIS. The lakes data were joined with the most recent summer and winter creels. This was accomplished by matching the DOW number on the lakes table and the creel tables.

The second hypothesis, the multiple regression tracking changes in species over time and location, utilized a separate dataset that was queried from the creel survey database. This dataset included all possible years of data, and included "species-sought" percentages, catch (lbs) by species and total effort (pressure). This dataset was joined by the attribute of DOW number to the lakes layer with assigned climate regions. Besides running a multiple regression on all Minnesota lakes, a separate regression was run on Red Lake, as well as 9 out of 10 of the large walleye lakes in Minnesota that are important for economic reasons (MN DNR, 1997).

After preparing the data and assigning climate regions in ArcGIS, these data were input into Statistical Package for the Social Sciences (SPSS) 16.0. SPSS was used to calculate the variables and multiple regression results for the equations referred to above.

CHAPTER 4: RESULTS

The following is a disclaimer to the results that are listed below in the following section.

- The results contain information from DNR data that was aggregated into seasonal estimates. The conclusions drawn from the results would have been more accurate if they were drawn from stratified seasonal data. For example, the conclusions assume that every day experiences the same amount of pressure throughout a season. Since there are differences in use in different periods of a season, the results in this section must be considered only a representation of a potential method to model climate change impacts.
- The following results assume that an ice-fishing day is worth the same as an open-water fishing day. A travel cost analysis for ice anglers could reveal a different valuation for an ice-fishing day. In fact, statistical evidence shows that an ice-fishing day is slightly longer than an open-water day, which suggests a higher valuation by anglers.
- The following results also assume that a fishing day is worth the same regardless of the species being sought. Willingness-to-pay literature provides evidence to the contrary. For example, trout species are more highly valued than average and are amongst the most vulnerable in Minnesota to the effects of climate change.
- The multiple regression testing the hypothesis of shifting species ranges and abundance was based on DNR data that contained many empty fields. The results were statistically significant, but were not based on a complete dataset.

Results from Benefits Calculation from Changing Ice Duration

The components with values determined for the equation mentioned in the methods are the following:

$X1_w$, $X1_s$ = Mean angler hours per acre per season
X2 = Total fishable acres
$X3_{w,}$ $X3_s$ = Mean angler hours per trip in each season (trip length)
$X4_w$, $X4_s$ = Angler days per season in each climate region
$X5_w$, $X5_s$ = Days lost or gained in each season per decade
X6 = Value of a fishing day

The mean number of angler hours per acre in each season proved to be significantly different from one another at the 1% level when equal variance was assumed and when it was not assumed (See Table 1). This was discovered by using an independent samples t-test for the variable in each season. The mean angler hours per acre in the summer were 45.14 hours and in the winter were 8.88 hours.

As mentioned above in the methods section, there are two estimates for total fishable acres. The first estimate is 4,555,898.54 acres, which includes all lakes in Minnesota with a DNR DOW assigned number. The second estimate for the total includes all lakes that have been surveyed for their fish populations, which is 3,923,292.62 acres.

The third value calculated is X3, the mean angler hours per trip in each season. An independent samples t-test was also performed for this variable. It was determined that the trip length is significantly different at the 1% level when equal variances are assumed and when they are not assumed. Summer trip length was a mean of 3.35 hours and winter trip length was slightly longer with a mean of 3.77 hours (See Table 2).

A one sample t-test was performed on the average number of days of changing lake ice duration for the 40 lakes in the dataset. Each lake in the dataset represented a different case. Dr. Card provided the average number of days lost or gained of ice duration from the period of 1970 to 2008 for each of the 40 lakes in her dataset. These averages were input into a one sample t-test. The null hypothesis was that there is no change in the amount of ice duration. It was found that lake ice duration in the Minnesota sample is significantly decreasing at a mean rate of 3.3 days per decade from the time period of 1970 to 2008. This mean rate of change is significantly different from zero at the 1% level of significance (See Table 3). A stem and leaf diagram further solidifies these results by showing that all of the cases elicited negative values for the direction of changing ice duration (See Table 4).

As mentioned above, the average trip expenditure for Minnesota residents and nonresidents for the activity of angling in the state is $35 per day in 2006 dollars. This value represents the variable X6 in the model.

The methods section laid out the meaning of each individual variable. The results for these variables are discussed above, and are indicated next to their variable names below. In addition, an upper and lower bound estimate are shown for each season in accordance with the variation in acreage presented from the MN DNR. The estimates represent the potential impacts per decade, as these were units of the predicted shifts in ice duration.

$X1_w$, $X1_s$ = 8.88, 45.14 hours per acre
X2 = 3,923,292.62, 4,555,898.54 acres
$X3_w$, $X3_s$ = 3.77, 3.35 hours
$X4_w$, $X4_s$ = Climate Region (CR) 1: 148.85 days(d), 216.40 d; CR 2: 146.26 d, 219.00 d;
CR 3: 152.50 d, 212.76 d; CR 4: 149.43 d, 215.83 d; CR 5: 134.22 d, 231.03 d;
CR 6: 133.17 d, 232.08 d; CR 7: 136.23 d, 229.02 d; CR 8: 136.23 d, 229.02 d;
CR 9: 136.23 d, 229.02 d
$X5_w$, $X5_s$ = -3.3, 3.3 days per decade
X6 = $35 per day

$Y1_{w,}$ $Y1_s$ = lower bound: 9241071.2, 52864904.1 trips per season; upper bound: 10731135.0, 61389032.9 trips per season

Climate Region 1

Ice Fishing Season

Lower bound acreage estimate

$Y2_w$ = 62,083.1 average trips/day
$Y3_w$ = 204,874.2 trips lost
$Y4_w$ = -$7,170,599.4 per decade

Upper bound acreage estimate

$Y2_w$ = 72,093.6 average trips/day
$Y3_w$ = 237,908.9 trips lost
$Y4_w$ = -$8,326,812.8 per decade

Open Water Season

Lower bound acreage estimate

$Y2_s$ = 244,292.5 average trips/day
$Y3_s$ = 806,165.3 trips gained
$Y4_s$ = $28,215,787.5 per decade

Upper bound acreage estimate

$Y2_s$ = 283,683.1 average trips/day
$Y3_s$ = 936,154.3 trips gained
$Y4_s$ = $32,765,403.4 per decade

Total Economic Impact

Lower bound acreage estimate

Y5 = $21,045,188.1 per decade

Upper bound acreage estimate

Y5 = $24,438,590.5 per decade

Climate Region 2

Ice Fishing Season

Lower bound acreage estimate

$Y2_w$ = 63,182.4 average trips/day
$Y3_w$ = 208,502.2 trips lost
$Y4_w$ = -$7,297,577.7 per decade

Upper bound acreage estimate

$Y2_w$ = 73,370.2 average trips/day
$Y3_w$ = 242,121.8 trips lost
$Y4_w$ = -$8,474,265.6 per decade

Open Water Season

Lower bound acreage estimate

$Y2_s$ = 241,392.2 average trips/day
$Y3_s$ = 796,594.4 trips gained
$Y4_s$ = $27,880,805.6 per decade

Upper bound acreage estimate

$Y2_s$ = 280,315.2 average trips/day
$Y3_s$ = 925,040.2 trips gained
$Y4_s$ = $32,376,407.7 per decade

Total Economic Impact

Lower bound acreage estimate

Y5 = $20,583,227.8 per decade

Upper bound acreage estimate

Y5 = $23,902,142.0 per decade

Climate Region 3

Ice Fishing Season

Lower bound acreage estimate

$Y2_w$ = 60,597.1 average trips/day
$Y3_w$ = 199,970.7 trips lost
$Y4_w$ = -$6,998,975.2 per decade

Upper bound acreage estimate

$Y2_w$ = 70,368.0 average trips/day
$Y3_w$ = 232,214.7 trips lost
$Y4_w$ = -$8,127,515.3 per decade

Open Water Season

Lower bound acreage estimate

$Y2_s$ = 248,472.0 average trips/day
$Y3_s$ = 819,957.6 trips gained
$Y4_s$ = $28,698,516.7 per decade

Upper bound acreage estimate

$Y2_s$ = 288,536.5 average trips/day
$Y3_s$ = 952,170.5 trips gained
$Y4_s$ = $33,325,969.6 per decade

Total Economic Impact

Lower bound acreage estimate

Y5 = $21,699,541.5 per decade

Upper bound acreage estimate

Y5 = $25,198,454.2 per decade

Climate Region 4

Ice Fishing Season

Lower bound acreage estimate

$Y2_w$ = 61,842.1 average trips/day
$Y3_w$ = 204,079.0 trips lost
$Y4_w$ = -$7,142,767.3 per decade

Upper bound acreage estimate

$Y2_w$ = 71,813.7 average trips/day
$Y3_w$ = 236,985.5 trips lost
$Y4_w$ = -$8,294,493.0 per decade

Open Water Season

Lower bound acreage estimate

$Y2_s$ = 244,937.7 average trips/day
$Y3_s$ = 808,294.4 trips gained
$Y4_s$ = $28,290,304.5 per decade

Upper bound acreage estimate

$Y2_s$ = 284,432.3 average trips/day
$Y3_s$ = 938,626.7 trips gained
$Y4_s$ = $32,851,935.7 per decade

Total Economic Impact

Lower bound acreage estimate

Y5 = $21,147,537.1 per decade

Upper bound acreage estimate

Y5 = $24,557,442.7 per decade

Climate Region 5

Ice Fishing Season

Lower bound acreage estimate

$Y2_w$ = 68,850.1 average trips/day
$Y3_w$ = 227,205.5 trips lost
$Y4_w$ = -$7,952,195.8 per decade

Upper bound acreage estimate

$Y2_w$ = 79,951.8 average trips/day
$Y3_w$ = 263,841.0 trips lost
$Y4_w$ = -$9,234,436.7 per decade

Open Water Season

Lower bound acreage estimate

$Y2_s$ = 228,822.6 average trips/day
$Y3_s$ = 755,114.8 trips gained

$Y4_s$ = \$26,429,019.7 per decade

Upper bound acreage estimate

$Y2_s$ = 265,718.8 average trips/day
$Y3_s$ = 876,872.3 trips gained
$Y4_s$ = \$30,690,530.6 per decade

Total Economic Impact

Lower bound acreage estimate

Y5 = \$18,476,823.9 per decade

Upper bound acreage estimate

Y5 = \$21,456,093.9 per decade

Climate Region 6

Ice Fishing Season

Lower bound acreage estimate

$Y2_w$ = 69,393.0 average trips/day
$Y3_w$ = 228,997.0 trips lost
$Y4_w$ = -\$8,014,896.1 per decade

Upper bound acreage estimate

$Y2_w$ = 80,582.2 average trips/day
$Y3_w$ = 265,921.3 trips lost
$Y4_w$ = -\$9,307,247.0 per decade

Open Water Season

Lower bound acreage estimate

$Y2_s$ = 227,787.4 average trips/day
$Y3_s$ = 751,698.4 trips gained
$Y4_s$ = \$26,309,446.8 per decade

Upper bound acreage estimate

$Y2_s$ = 264,516.6 average trips/day
$Y3_s$ = 872,905.0 trips gained

$Y4_s$ = $30,551,677.4 per decade

Total Economic Impact

Lower bound acreage estimate

Y5 = $18,294,550.6 per decade

Upper bound acreage estimate

Y5 = $21,244,430.3 per decade

Climate Region 7

Ice Fishing Season

Lower bound acreage estimate

$Y2_w$ = 67,834.3 average trips/day
$Y3_w$ = 223,853.2 trips lost
$Y4_w$ = -$7,834,865.4 per decade

Upper bound acreage estimate

$Y2_w$ = 78,772.1 average trips/day
$Y3_w$ = 259,948.2 trips lost
$Y4_w$ = -$9,098,187.5 per decade

Open Water Season

Lower bound acreage estimate

$Y2_s$ = 230,830.9 average trips/day
$Y3_s$ = 761,742.1 trips gained
$Y4_s$ = $26,660,974.7 per decade

Upper bound acreage estimate

$Y2_s$ = 268,050.9 average trips/day
$Y3_s$ = 884,568.1 trips gained
$Y4_s$ = $30,959,886.8 per decade

Total Economic Impact

Lower bound acreage estimate

$Y5$ = \$18,826,109.2 per decade

Upper bound acreage estimate

$Y5$ = \$21,861,699.3 per decade

Climate Region 8

Ice Fishing Season

Lower bound acreage estimate

$Y2_w$ = 67,834.3 average trips/day
$Y3_w$ = 223,853.2 trips lost
$Y4_w$ = -\$7,834,865.4 per decade

Upper bound acreage estimate

$Y2_w$ = 78,772.1 average trips/day
$Y3_w$ = 259,948.2 trips lost
$Y4_w$ = -\$9,098,187.5 per decade

Open Water Season

Lower bound acreage estimate

$Y2_s$ = 230,830.9 average trips/day
$Y3_s$ = 761,742.1 trips gained
$Y4_s$ = \$26,660,974.7 per decade

Upper bound acreage estimate

$Y2_s$ = 268,050.9 average trips/day
$Y3_s$ = 884,568.1 trips gained
$Y4_s$ = \$30,959,886.8 per decade

Total Economic Impact

Lower bound acreage estimate

$Y5$ = \$18,826,109.2 per decade

Upper bound acreage estimate

$Y5$ = \$21,861,699.3 per decade

Climate Region 9

Ice Fishing Season

Lower bound acreage estimate

$Y2_w$ = 67,834.3 average trips/day
$Y3_w$ = 223,853.2 trips lost
$Y4_w$ = -$7,834,865.4 per decade

Upper bound acreage estimate

$Y2_w$ = 78,772.1 average trips/day
$Y3_w$ = 259,948.2 trips lost
$Y4_w$ = -$9,098,187.5 per decade

Open Water Season

Lower bound acreage estimate

$Y2_s$ = 230,830.9 average trips/day
$Y3_s$ = 761,742.1 trips gained
$Y4_s$ = $26,660,974.7 per decade

Upper bound acreage estimate

$Y2_s$ = 268,050.9 average trips/day
$Y3_s$ = 884,568.1 trips gained
$Y4_s$ = $30,959,886.8 per decade

Total Economic Impact

Lower bound acreage estimate

Y5 = $18,826,109.2 per decade

Upper bound acreage estimate

Y5 = $21,861,699.3 per decade

Statewide Mean Total Impact across all Regions and Bounds = $21,339,302.71 per decade

Total Impact Statewide (Across all Climate Regions)

The values below were calculated by summing the results above in each climate region. The difference was determined between seasons individually for the upper and lower bounds.

Lower Bound = $177,725,196.9 per decade

Upper Bound = $206,382,251.8 per decade

Multiple Regression Results

Regression Results for the State

The multiple regression shows several main points (See Table 5). The model was created to show how angler effort has an impact on yield (in pounds) across climate regions over time. The aim was to see if yield per unit of effort of some species in some areas was improving in the climate regions with greater abundance as predicted by Schneider et al (2009). First of all, the model has a relatively high R-squared value of .505, indicating a relatively good fit. The F-statistic is very high, yielding a result that indicates that the model is significant at the 1% level. Although not significant, the constant was very high, which represents the background rate of pounds harvested. A sensitivity analysis was run on the model by eliminating the constant from the regression, which is discussed below. The variable of effort (spphrs) was significant at the 1% level, indicating for every extra hour spent fishing .002 pounds of fish were caught. This finding was significant and the slope was identical in both of the regressions, with and without the constant.

The dummy variables for each species were significant at the 1% level. This indicated that the amount of effort that was devoted to angling for a specific species resulted in a significant relationship with the amount of yield. In other words, more time spent fishing for a certain species represents a relationship with the amount of catch for that species. The negative numbers for each species represents a significantly lower amount of influence from the four main species categories in comparison to the “other species” category (the “other species” category was the baseline, and assigned a zero in each of the four dummy categories). This result suggests that the influence of the “other species” category dominated the results for the weight category. Table 7 indicates that the mean species pounds per hour is .0021. The four species categories are all lower than this value, except for sunfish (See Table 8-11). This implies that the “other species” category has a higher rate of pounds per hour (to balance out the mean). Therefore, the high rate of categorized “other species” is responsible for the negative “slope coefficients” on the dummy variables for the four species categories.

The dummy variables for each climate region were not significant in the model. The closest variable was climate region 2, which would be significant at the 10% level with a one-tailed test. These results indicate that the affect of angling effort on the amount of yield is not significantly different across climate regions statewide. Interestingly, the amount of pounds caught in climate region 2 was the highest out of all of the other 7 climate regions (excluding climate region 9), which can be seen in Tables 12-19. Climate region 2 has over double the amount of fish caught in comparison to the mean (See Table 7 and 13). This high rate of activity is the cause for the significant result in climate region 2.

Regression Results without the Constant

Eliminating the constant from the equation above resulted in a few changes in the statistical output (See Table 6). First, the R-squared value increased from .505 to .524 in the adjusted model. Second, the F-statistic increased from 181.952 to 196.411, still resulting in a significant model at the 1% level. Third, the amount of effort anglers performed resulted in an identical slope from the first model, .002 pounds for every extra hour of effort. Fourth, all of the significance levels from the previous model decreased (meaning more significant results), which yielded climate region 2 to be significant at the 5% level with a one tailed test. Again, this significance is most likely due to the high amount of activity that took place in this climate region (See Table 13). All of the previously significant variables proved to be robust upon the adjustment that took place.

Regression Results for the Big Nine Walleye Lakes

This model excluded some of the climate regions from the analysis, due to the lack of large walleye lakes in these regions (See Table 20). The model was significant at the 1% level and also had a relatively high R-squared value of .515, indicating a relatively good fit. The F-statistic was 41.61, indicating the model was significant at the 1% level. All of the species dummy variables were significant in this model at the 1% level. Climate region 2 was significant at the 1% level, again most likely for similar reasons indicated above. The amount of effort (spphrs) yielded similar results to the first regression. For every extra hour spent angling, .002 pounds were caught.

Regression Results for East Upper Red Lake

All other climate regions were excluded from this model, since East Upper Red Lake is located in one climate region. The R-squared value was very high at .924 (See

Table 21). The F-statistic was slightly smaller than the previous two models, but still proved that the model is significant at the 1% level. The species dummy variables were all insignificant, as well as the year (which was insignificant in all of the previous models). This indicates that effort over time for a specific species did not have any statistical influence on the amount of a certain species that was caught. However, the amount of time spent fishing in general had a significant amount of impact (at the 1% level) on the yield.

Results from Each Scenario

Scenario 1

The results from the benefits estimation calculations above indicate that this scenario will not prove to be likely. All climate regions reveal that there may be net positive benefits from the onset of climate change and decreasing ice duration. However, this does not mean this may be a preferable result for those who enjoy the activity of ice fishing in the winter.

Scenario 2a

Results from East Upper Red Lake, seen in Table 22, show that there are differences in the amount of pressure between the winter and the summer. The statistical analysis of this data did not yield significant results (due to holes in the creel survey database). However, a larger sample size would most likely indicate robust findings concerning this estimate. Since Red Lake sees such a higher use in the winter months, the onset of climate change through decreasing lake ice will likely have a net negative impact on recreational benefits from use of this lake.

Scenario 2b

Other large walleye lakes as well as statewide data show that summer effort significantly exceeds effort in the winter (See Table 23). In addition, statewide results mimic this finding (See Table 24). The benefits calculation estimated above yields results that align well with this scenario. A higher amount of angler effort in the open-water season is likely to lead to a net positive impact from the onset of climate change.

Scenario 3

The results from the multiple regressions did not show significant results for a change in yield per unit of effort in response to change in species abundance over certain regions of the state over time. Despite these results, more accurate testing of fisheries abundance by research conducted outside this project has yielded results suggesting that there is indeed a change in abundance (Schneider, 2009). Further examination of whether effort is increasing in these regions would be a topic for further research. As mentioned in the literature review, certain species, such as trout, have a higher WTP than walleye and panfish (Johnston et al., 2006). Therefore, a change in these species abundances could have a significant impact on the WTP by anglers. For example, fewer trout (which are predicted to decline from climate change) would be detrimental to recreational benefits. The net impact from these changes in species abundance and the economic consequences that result are beyond the scope of this project. However, further inquiries into these suggestions would provide interesting additional research opportunities.

CHAPTER 5: DISCUSSION OF RESULTS AND CONCLUSION

Statement of the Problem

This project attempted to discover the potential impact of climate change on the recreational benefits provided by open-water and ice fishing. Three main scenarios were tested regarding these different scenarios. Lake ice, species abundance, and regional and seasonal usage all played a role in determining the impacts from climate change on recreational benefits. Below is a discussion of the results from the analysis conducted above.

Discussion of the Findings

This project has covered a wide range of topics and multiple hypotheses have been tested determining the potential impact of global climate change on Minnesota fisheries and anglers. Some conclusions have been reached from relatively strong statistical output, while others need improvement. The datasets upon which these conclusions are based are by no means perfect, yielding potential areas for enhancement for future studies.

The creel survey data is not without its areas for needed improvement. Due to different methodology of different fisheries offices and creel clerks, there is a lack of continuity in the type of information that is collected. For example, thousands of cases were missing species-sought data that was used in the multiple regression analysis above. Making uniform methodology and reporting systems could have the potential to benefit the state by providing more accurate information on characteristics of anglers. In addition, changes to lake ice duration impact the fishing that occurs at the beginning and the end of the ice season. Maintaining a strong dataset with these types of divisions would aid with understanding how much usage occurs at these periods of the ice fishing season. For example, some anglers may fish more at the beginning of the ice fishing season when fish such as walleye may be biting and then wane off as the season progresses. In the spring, a renewed effort for species such as perch and crappie may ensue. Knowledge of these behaviors would help with further studies of the valuation process.

The economic estimate of a fishing day provided by the U.S. Department of the Interior is not without its areas for needed improvement. No distinct value for an ice fishing day was provided. Angling on the ice has its own set of expenditures such as ice houses, augers and tackle that could amount to different travel cost estimation for individuals participating in this type of activity. Valuing ice fishing at a different rate would have the potential to alter some of the estimates reached above.

Another point to touch on is the significant difference in trip length between winter and summer. The strongest statistical conclusion (1% level) was found on the comparison of trip length. Winter trip length is longer than summer, which points to a possible higher valuation of ice fishing in comparison to open-water fishing. These findings and the lack of unique valuation studies published in economic journals point to the need for further inquiry into this subject.

The lake ice calculations were generalized in regards to estimating the number of days in a season. Lakes with a greater depth and a larger surface area may have different ice-on an ice-off dates than those used in this estimation, which would change the mean number of days in each season. Changing the starting point of the number of mean days in a season would have impacted the final dollar estimate for each season. To refine this idea further in future work, a researcher could determine the ice duration for particular lakes (such as the big 9 walleye lakes) and individually determine the potential impacts. Despite these generalizations, the lake ice statistics did show that lake ice has been decreasing in duration over the last 30 years, which matches climate change predictions mentioned in the literature review.

The seasonal impacts were also generalized. An increase or a decrease in the number of days of ice is assumed to have a proportional impact on the amount of fishing that takes place during this period and a proportional economic impact. However, a decrease or increase in the amount of days of ice in the spring or fall does not necessarily mean an increase in the amount of open-water or ice fishing. For example, a large percentage of the angling population may be off of lakes after Labor Day (Drewes, H., personal communication). To further accurately explore these impacts, creel data would need to be determined for more specific strata such as early spring, late fall, early winter and late winter.

The multiple regression yielded results that were mostly intuitive. A higher amount of effort results in a significant positive relationship with the amount of yield. More time spent trying to catch fish results in a greater number of fish caught. However, the slope coefficient indicates that a relatively low number of pounds of fish were caught for every additional hour that was spent fishing (.002 pounds per extra hour). This slope coefficient could be due to inaccurate survey methods, lack of quality sampling methods, or missing data in the database. Specific effort for a particular species proved to have less impact on yield than the baseline, “other species.” This was most likely due to the influence of the “other species” category. In further analysis, this category could be explored to determine the particular species that has a stronger weight of influence on the amount of yield.

Climate region 2 was the sole area of the state that showed a significant difference from other regions in respect to the amount of yield that was produced. The tables of activity by climate region indicate the reasons for this relationship. Climate region 2 had the highest amount of species yield in comparison with all of the other climate regions in the state. Lake of the Woods, Red Lake, Cass Lake and Winnibigoshish all lie in climate region 2, which could be the reason why these yield rates are high in this region.

The multiple regression results were highly dependent upon the quality of the creel data. The historical data contain many holes for reasons mentioned above. An improvement of this system could be beneficial for reaching more defensible results from studies concerning angling in Minnesota. For example, a large percentage of the cases were missing data in the “species-sought” category. A greater amount of information could have been provided this area, which would have yielded more defensible results.

Conclusion

Although a net positive gain was found for anglers with the onset of climate change, potential issues remain with the biology of fish populations and the behavior of anglers. Increasing temperatures of water bodies, decreasing levels of dissolved oxygen and increases in runoff have the potential to alter the aquatic ecosystems statewide. As mentioned above, the magnitude of the impacts depends on the starting point of the water body (if it is oligotrophic, mesotrophic, or eutrophic). However, it will be a gamble to play with the outcome of these impacts.

Angler behavior may also have an uncertain future. Many anglers may value the first days of ice-on to be the best ice fishing days due to fish behavior. In the springtime when crappie are active, anglers may have uncertain responses to changes in fish behavior due to ice-changes. Some anglers may be uneasy about fishing on unstable ice. On the other hand, more anglers may be able to fish on open water (and their success could depend on fish species behavior). In addition, earlier ice-off may cause changes to spawning behavior of walleye, as mentioned above. Leaving a walleye opener to be in May could cause a mistiming in the peak activity (post spawning) for these trophy fish, which would leave an underutilization of this natural resource. The Minnesota DNR may have to take these issues into account in the upcoming decades when dealing with the after-effects of global climate change.

In relation to valuing a fishing day, certain days of the year may be worth more money to some anglers than others. This project values all days to be equal. For example, a day lost to ice-fishing is worth the same as a day gained for open water fishing. It is unclear if these days are of equal proportional worth. This empirical question is beyond the scope of this project. However, asking if certain days are worth more than others would be a worthwhile question for future studies estimating the value of angling in responses to climate change.

These potential forecasted impacts, both biological and economic, give ideas as to what could be expected for future scenarios from the onset of global climate change. However, these attempts at forecasting the economic future cannot be altogether certain. As mentioned above, certain times of the year may be worth more to an angler than others. Policy makers must be cognizant that certain decisions can be made to avoid increasing contributing factors for climate change. Choosing not to act to prevent these impacts could potentially be an expensive wager in regards to fish biology as well as angler behavior.

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Appendix A: Tables of Results

Table 1

Independent samples t-test of variables $X1_w$ and $X1_s$

Group Statistics

	Season	N	Mean	Std. Deviation	Std. Error Mean
AngHrsAc	WI	400	8.8768	13.82285	.69114
	SU	763	45.1388	84.29788	3.05179

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
AngHrsAc	Equal variances assumed	75.318	.000	-8.542	1161	.000	-36.26205	4.24533	-44.59143	-27.93267
	Equal variances not assumed			-11.589	837.960	.000	-36.26205	3.12907	-42.40379	-30.12031

Table 2

Independent samples t-test of variables $X3_w$ and $X3_s$

Group Statistics

	Season	N	Mean	Std. Deviation	Std. Error Mean
TripLength	SU	98	3.3535	.84311	.08517
	WI	74	3.7723	1.04980	.12204

s

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
TripLength	Equal variances assumed	5.353	.022	-2.901	170	.004	-.41883	.14437	-.70383	-.13383
	Equal variances not assumed			-2.814	136.972	.006	-.41883	.14882	-.71310	-.12455

Table 3

One sample t-test of variable $X5_w$

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
1970-2008 Ice Duration (d/d)	40	-3.30676788122881E0	1.111868838372952E0	1.758018994312076E-1

One-Sample Test

	Test Value = 0					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
1970-2008 Ice Duration (d/d)	-18.810	39	.000	-3.306767881228813E0	-3.66236078693348E0	-2.95117497552414E0

Table 4

Stem and leaf diagram of variable $X5_w$

```
1970-2008 Ice Duration (d/d) Stem-and-Leaf Plot

 Frequency    Stem &  Leaf

     1.00       -5 .  5
     2.00       -5 .  02
     5.00       -4 .  67889
     3.00       -4 .  013
     7.00       -3 .  5556677
     5.00       -3 .  00223
     6.00       -2 .  555789
     6.00       -2 .  112234
     4.00       -1 .  6899
     1.00       -1 .  3

 Stem width:  1.000000
 Each leaf:       1 case(s)
```

Table 5

Multiple Regression Results for Minnesota

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.710[a]	.505	.502	26256.37969

Note. a. Predictors: (Constant), Dclmt8, Dwae, Dclmt1, Dclmt7, Dclmt5, SurveyYr, Dclmt2, Dlmb, spphrs, Dclmt4, Dsun, Dclmt3, Dtrt, Dclmt6

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.710[a]	.505	.502	26256.37969

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.756E12	14	1.254E11	181.952	.000[a]
	Residual	1.724E12	2501	6.894E8		
	Total	3.480E12	2515			

Note. a. Predictors: (Constant), Dclmt8, Dwae, Dclmt1, Dclmt7, Dclmt5, SurveyYr, Dclmt2, Dlmb, spphrs, Dclmt4, Dsun, Dclmt3, Dtrt, Dclmt6. b. Dependent Variable: spplbs

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	99621.440	121037.324		.823	.411
	SurveyYr	-45.858	60.516	-.011	-.758	.449
	spphrs	.002	.000	.689	47.110	.000
	Dlmb	-9592.286	1792.790	-.090	-5.350	.000
	Dsun	-9513.854	1602.922	-.105	-5.935	.000

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.710[a]	.505	.502	26256.37969

	Dtrt	-11014.143	1606.623	-.121	-6.855	.000
	Dwae	-12610.019	1607.478	-.140	-7.845	.000
	Dclmt1	-66.374	9371.390	.000	-.007	.994
	Dclmt2	12371.982	7728.626	.110	1.601	.110
	Dclmt3	1810.100	7678.988	.019	.236	.814
	Dclmt4	1840.808	7714.342	.017	.239	.811
	Dclmt5	2061.490	7800.169	.016	.264	.792
	Dclmt6	735.620	7643.355	.009	.096	.923
	Dclmt7	1835.628	8479.097	.007	.216	.829
	Dclmt8	1292.708	7856.836	.009	.165	.869

a. Dependent Variable: spplbs

Table 6

Multiple Regression Results for Minnesota without constant

Model Summary

Model	R	R Square[b]	Adjusted R Square	Std. Error of the Estimate

1	.724[a]	.524	.521	26254.68711

Note. a. Predictors: SurveyYr, Dclmt1, Dclmt7, spphrs, Dclmt8, Dclmt5, Dlmb, Dclmt2, Dclmt4, Dsun, Dtrt, Dclmt3, Dwae, Dclmt6. b. For regression through the origin (the no-intercept model), R Square measures the proportion of the variability in the dependent variable about the origin explained by regression. This CANNOT be compared to R Square for models which include an intercept.

ANOVAc,d

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.895E12	14	1.354E11	196.411	.000[a]
	Residual	1.725E12	2502	6.893E8		
	Total	3.620E12	2516			

Note. a. Predictors: SurveyYr, Dclmt1, Dclmt7, spphrs, Dclmt8, Dclmt5, Dlmb, Dclmt2, Dclmt4, Dsun, Dtrt, Dclmt3, Dwae, Dclmt6. b. This total sum of squares is not corrected for the constant because the constant is zero for regression through the origin. c. Dependent Variable: spplbs d. Linear Regression through the Origin

Coefficients[a,b]

Model	Unstandardized Coefficients	Standardized Coefficients	t	Sig.

Model Summary

Model	R	R Square[b]	Adjusted R Square	Std. Error of the Estimate
1	.724[a]	.524	.521	26254.68711

Note. a. Predictors: SurveyYr, Dclmt1, Dclmt7, spphrs, Dclmt8, Dclmt5, Dlmb, Dclmt2, Dclmt4, Dsun, Dtrt, Dclmt3, Dwae, Dclmt6. b. For regression through the origin (the no-intercept model), R Square measures the proportion of the variability in the dependent variable about the origin explained by regression. This CANNOT be compared to R Square for models which include an intercept.

		B	Std. Error	Beta		
1	Dlmb	-9622.061	1792.309	-.096	-5.369	.000
	Dsun	-9499.157	1602.719	-.115	-5.927	.000
	Dtrt	-11002.064	1606.453	-.133	-6.849	.000
	Dwae	-12591.675	1607.220	-.155	-7.834	.000
	Dclmt1	791.186	9312.689	.002	.085	.932
	Dclmt2	12902.994	7701.154	.121	1.675	.094
	Dclmt3	2360.212	7649.352	.027	.309	.758
	Dclmt4	2510.283	7670.846	.025	.327	.744
	Dclmt5	2808.998	7746.616	.022	.363	.717
	Dclmt6	1392.505	7601.083	.022	.183	.855
	Dclmt7	2341.107	8456.281	.009	.277	.782
	Dclmt8	2118.763	7791.968	.015	.272	.786
	spphrs	.002	.000	.687	47.112	.000

Model Summary

Model	R	R Square[b]	Adjusted R Square	Std. Error of the Estimate
1	.724[a]	.524	.521	26254.68711

Note. a. Predictors: SurveyYr, Dclmt1, Dclmt7, spphrs, Dclmt8, Dclmt5, Dlmb, Dclmt2, Dclmt4, Dsun, Dtrt, Dclmt3, Dwae, Dclmt6. b. For regression through the origin (the no-intercept model), R Square measures the proportion of the variability in the dependent variable about the origin explained by regression. This CANNOT be compared to R Square for models which include an intercept.

	SurveyYr	3.851	3.821	.202	1.008	.314

Note. a. Dependent Variable: spplbs. b. Linear Regression through the Origin

Table 7

Mean Species Pounds and Species Pounds per Hour

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
spplbs	6716	.00	977228.00	6864.6532	36598.84119
spplbsperspphr	3777	.00	.15	.0021	.00801
Valid N (listwise)	3777				

Table 8

Mean Pounds per Hour for Largemouth Bass

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
spplbsperspphr	693	.00	.01	.0001	.00081
Valid N (listwise)	693				

Table 9

Mean Pounds per Hour for Sunfish

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
spplbsperspphr	878	.00	.07	.0021	.00522
Valid N (listwise)	878				

Table 10

Mean Pounds per Hour for all Trout Species

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
spplbsperspphr	603	.00	.00	.0000	.00017
Valid N (listwise)	603				

Table 11

Mean Pounds per Hour for Walleye

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
spplbsperspphr	845	.00	.01	.0008	.00116
Valid N (listwise)	845				

Table 12

Mean Pounds Caught in Climate Region 1

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
spplbs	190	.00	24733.00	1871.3453	3461.62685
Valid N (listwise)	190				

Table 13

Mean Pounds Caught in Climate Region 2

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
spplbs	1115	.00	599760.00	14945.7165	54539.28063
Valid N (listwise)	1115				

Table 14

Mean Pounds Caught in Climate Region 3

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
spplbs	1770	.00	172392.00	3475.2702	13759.72086
Valid N (listwise)	1770				

Table 15

Mean Pounds Caught in Climate Region 4

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
spplbs	755	.00	55453.00	3450.9691	6905.07233
Valid N (listwise)	755				

Table 16

Mean Pounds Caught in Climate Region 5

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
spplbs	475	.00	78995.80	2854.3945	7333.68505
Valid N (listwise)	475				

Table 17

Mean Pounds Caught in Climate Region 6

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
spplbs	1966	.00	977228.00	9118.9576	51112.48791
Valid N (listwise)	1966				

Table 18

Mean Pounds Caught in Climate Region 7

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
spplbs	60	.00	50903.00	1846.5000	7165.63713
Valid N (listwise)	60				

Table 19

Mean Pounds Caught in Climate Region 8

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation

spplbs	360	.00	43953.10	2583.6844	5822.30248
Valid N (listwise)	360				

Table 20

Multiple Regression Results for the Big Nine Walleye Lakes

Warnings

For models with dependent variable spplbs, the following variables are constants or have missing correlations: Dclmt1, Dclmt4, Dclmt5, Dclmt7, Dclmt8. They will be deleted from the analysis.

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	SurveyYr, Dwae, Dclmt6, Dsun, Dclmt2, Dlmb, Dtrt, spphrs[a]	.	Enter

Note. a. Tolerance = .000 limits reached. b. Dependent Variable: spplbs

Model Summary

Warnings

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.717[a]	.515	.502	67214.62708

Note. a. Predictors: (Constant), SurveyYr, Dwae, Dclmt6, Dsun, Dclmt2, Dlmb, Dtrt, spphrs

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.504E12	8	1.880E11	41.612	.000[a]
	Residual	1.419E12	314	4.518E9		
	Total	2.923E12	322			

Note. a. Predictors: (Constant), SurveyYr, Dwae, Dclmt6, Dsun, Dclmt2, Dlmb, Dtrt, spphrs
b. Dependent Variable: spplbs

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	686999.307	1030333.251		.667	.505
	spphrs	.002	.000	.698	12.532	.000
	Dlmb	-59926.223	12016.593	-.247	-4.987	.000
	Dsun	-59151.036	12010.124	-.243	-4.925	.000

Warnings

Dtrt	-60128.090	12018.495	-.247	-5.003	.000
Dwae	-68975.559	13106.728	-.302	-5.263	.000
Dclmt2	23744.502	8148.802	.122	2.914	.004
Dclmt6	-9905.060	12785.822	-.035	-.775	.439
SurveyYr	-317.771	516.721	-.024	-.615	.539

Note. a. Dependent Variable: spplbs

Excluded Variables[b]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	Dclmt3	.[a]	.	.	.	.000

Note. a. Predictors in the Model: (Constant), SurveyYr, Dwae, Dclmt6, Dsun, Dclmt2, Dlmb, Dtrt, spphrs b. Dependent Variable: spplbs

Table 21

Multiple Regression Results for Red Lake

Warnings

For models with dependent variable spplbs, the following variables are constants or have missing correlations: Dclmt1, Dclmt2, Dclmt3, Dclmt4, Dclmt5, Dclmt6, Dclmt7, Dclmt8. They will be deleted from the analysis.

Variables Entered/Removed[b]

Model	Variables Entered	Variables Removed	Method
1	SurveyYr, Dwae, Dtrt, Dlmb, Dsun, spphrs[a]	.	Enter

Note. a. All requested variables entered.
b. Dependent Variable: spplbs

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.961[a]	.924	.868	4244.85461

Note. a. Predictors: (Constant), SurveyYr, Dwae, Dtrt, Dlmb, Dsun, spphrs

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.761E9	6	2.935E8	16.290	.000[a]
	Residual	1.442E8	8	1.802E7		
	Total	1.905E9	14			

Note. a. Predictors: (Constant), SurveyYr, Dwae, Dtrt, Dlmb, Dsun, spphrs
b. Dependent Variable: spplbs

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-188479.135	486204.386		-.388	.708
	Dlmb	-1671.553	3783.434	-.059	-.442	.670
	Dsun	-1671.553	3783.434	-.059	-.442	.670
	Dtrt	-1671.553	3783.434	-.059	-.442	.670
	Dwae	-3633.945	9565.123	-.129	-.380	.714
	spphrs	.003	.001	1.021	2.692	.027
	SurveyYr	94.901	243.076	.046	.390	.706

Note. a. Dependent Variable: spplbs

Table 22

Independent samples t-test for total angler hours between seasons on East Upper Red Lake

Group Statistics

	Season	N	Mean	Std. Deviation	Std. Error Mean
AngHrs	SU	7	118107.14	62610.324	23664.478
	WI	4	86893.50	89299.646	44649.823

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
AngHrs	Equal variances assumed	.732	.414	.686	9	.510	31213.643	45507.699	-71731.924	134159.209
	Equal variances not assumed			.618	4.735	.565	31213.643	50533.298	-100901.004	163328.290

Table 23

Independent samples t-test for total angler hours between seasons on the big 9 walleye lakes

Group Statistics

	Season	N	Mean	Std. Deviation	Std. Error Mean
AngHrs	SU	124	572679.73	486284.997	43669.682
	WI	50	912197.88	849624.529	120155.053

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
AngHrs	Equal variances assumed	41.571	.000	-3.311	172	.001	-339518.154	102553.626	-541943.851	-137092.458
	Equal variances not assumed			-2.656	62.366	.010	-339518.154	127844.741	-595046.284	-83990.025

Table 24

Independent samples t-test for total angler hours between seasons statewide

Group Statistics

	Season	N	Mean	Std. Deviation	Std. Error Mean
AngHrs	SU	867	1.110503E5	2.6666392E5	9.0563817E3
	WI	482	1.039292E5	3.8689016E5	1.7622364E4

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
AngHrs	Equal variances assumed	4.437	.035	.398	1347	.691	7.1211660E3	1.7891969E4	-2.7977987E4	4.2220319E4
	Equal variances not assumed			.359	739.955	.719	7.1211660E3	1.9813272E4	-3.1775757E4	4.6018089E4

Table 25

Mean rates of “species-sought” statewide

Case Processing Summary

	Cases					
	Included		Excluded		Total	
	N	Percent	N	Percent	N	Percent
Percent * Species	2899	100.0%	0	.0%	2899	100.0%

Report

Percent

Species	Mean	N	Std. Deviation
BAS	14.1000	2	2.96985
BLC	11.5327	237	13.41761
BLG	11.4778	209	12.19294
BLH	.5400	4	.78043
BNT	3.2000	1	.
CAP	2.4000	5	2.97069
CAT	1.1000	1	.
CCF	1.3667	3	1.19304
CRP	19.3122	271	21.29177
FRD	.4000	1	.
HSF	10.2600	5	11.95232

LAT	43.6750	4	46.64814
LKW	14.7000	3	.36056
LMB	13.5361	64	12.34311
MUE	8.0143	14	9.32225
NOP	14.5478	653	13.48272
NPS	4.6000	8	5.91439
OTS	1.0000	1	.
PAN	17.1221	208	17.37646
PMK	4.9455	11	9.11618
RBS	10.8000	1	.
RBT	20.6000	1	.
RKB	2.9509	35	3.10750
SMB	5.3653	30	5.73570
SUN	18.5226	292	17.10178
TLC	3.7000	2	1.83848
TRT	16.0543	7	28.48856
WAE	43.7395	613	28.66025
WHB	.5000	3	.26458
WHC	3.6000	1	.
WNP	2.3222	9	3.36518
WTS	.3000	1	.
YEP	7.5276	199	13.83888
Total	20.3447	2899	22.73019

Table 26

Creel Types

Crl_Type	CreelType	Desc_Crl_Type
1	STRATOM	Roving - Stratified Random
2	SYSMTIC	Systematic Sampling
3	AERIAL	Aerial Fishing Pressure
4	NONPROB	Access - Nonuniform Probability
5	UNKNOWN	Unknown Methodology
6	ACCESS	Access - No Probability
7	NETTING	Coregonid Netting Survey
8	VOLUN	Volunteer or Angler Diaries
9	TOURN	Fishing Tournament
10	MIXED	Mixed Methodology
11	HABEVAL	Habitat Evaluations
12	NONROV	Roving - Nonuniform Probability

Table 27

Frequency table of creel types

Crl_Type

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	2	.1	.1	.1
	1	2119	62.1	62.1	62.1
	2	364	10.7	10.7	72.8
	3	231	6.8	6.8	79.6
	4	205	6.0	6.0	85.6
	5	153	4.5	4.5	90.0

	6	136	4.0	4.0	94.0
	7	68	2.0	2.0	96.0
	8	49	1.4	1.4	97.5
	9	42	1.2	1.2	98.7
	10	41	1.2	1.2	99.9
	11	1	.0	.0	99.9
	12	3	.1	.1	100.0
	Total	3414	100.0	100.0	

Appendix B: Figures

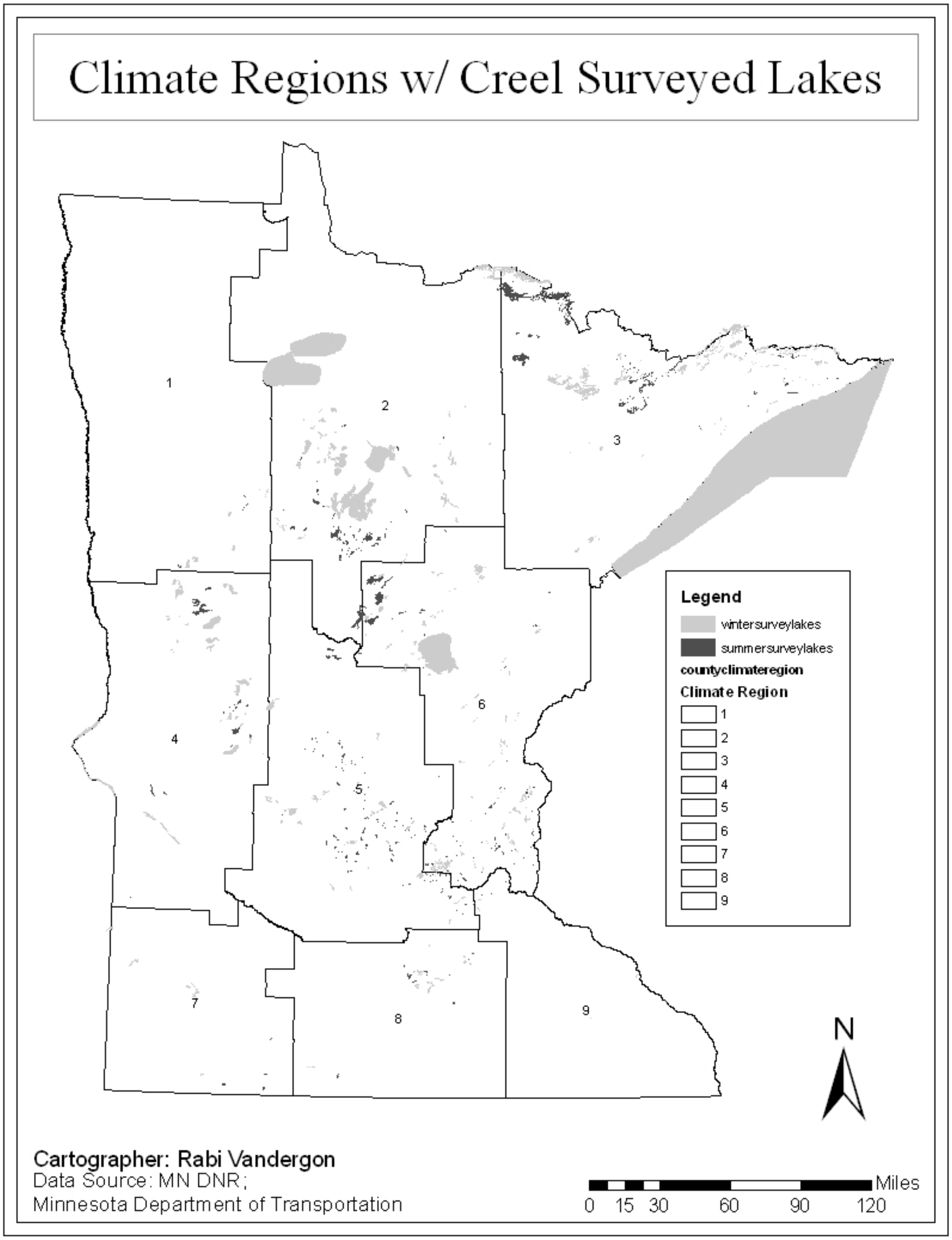

Figure 1. Climate Regions with Creel Surveyed Lakes

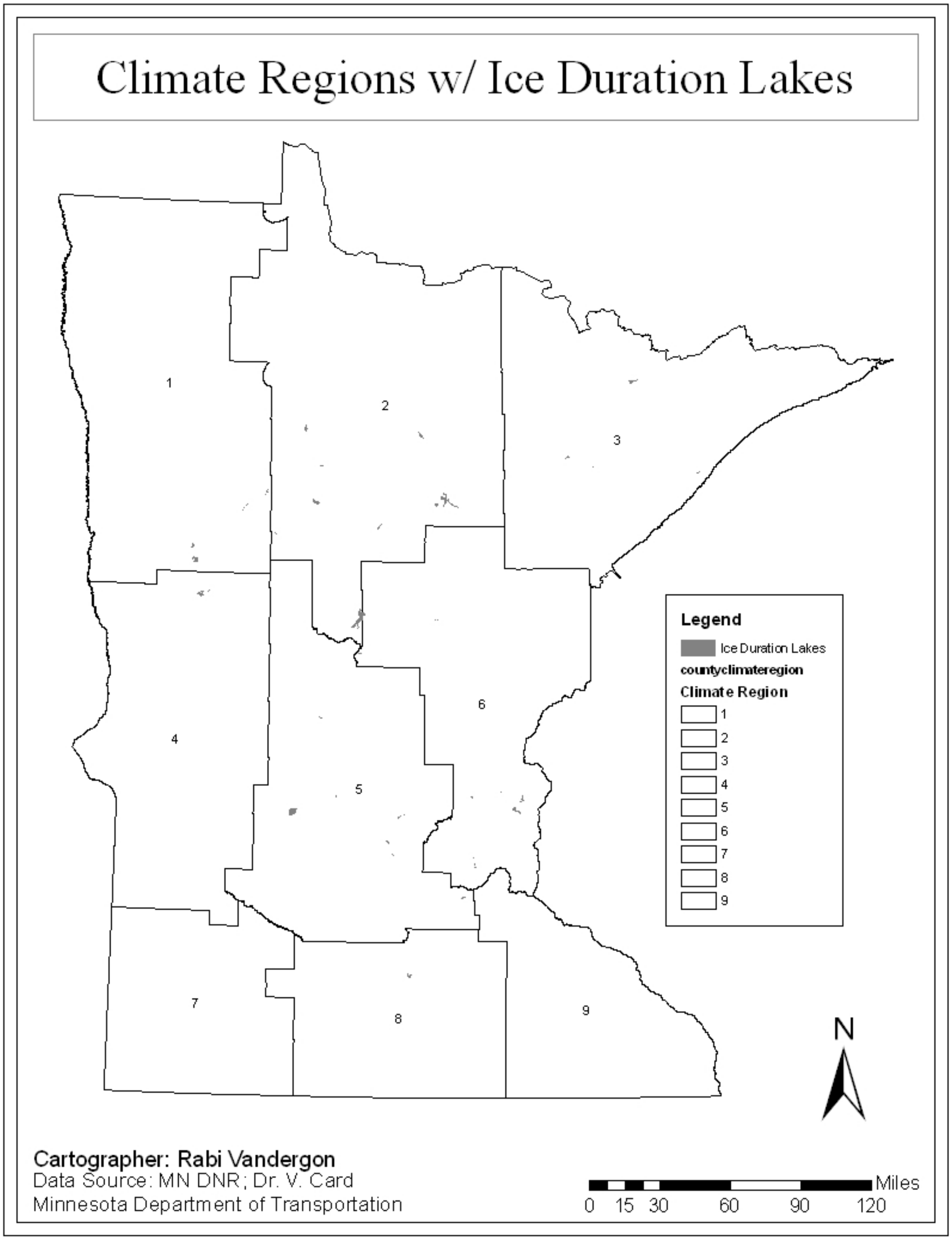

Figure 2. Climate Regions with Observed Ice Duration Lakes

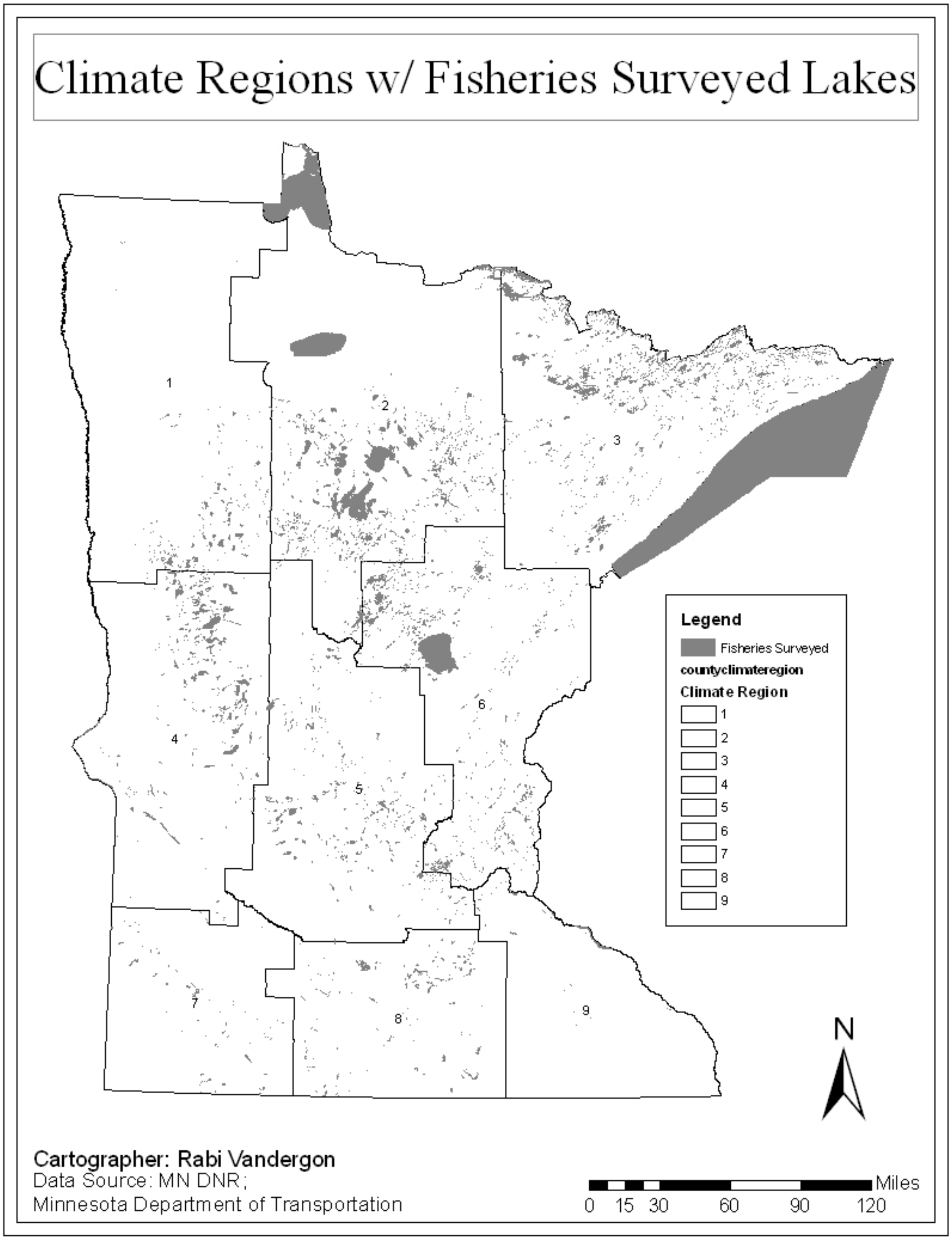

Figure 3. Climate Regions with Fisheries Surveyed Lakes

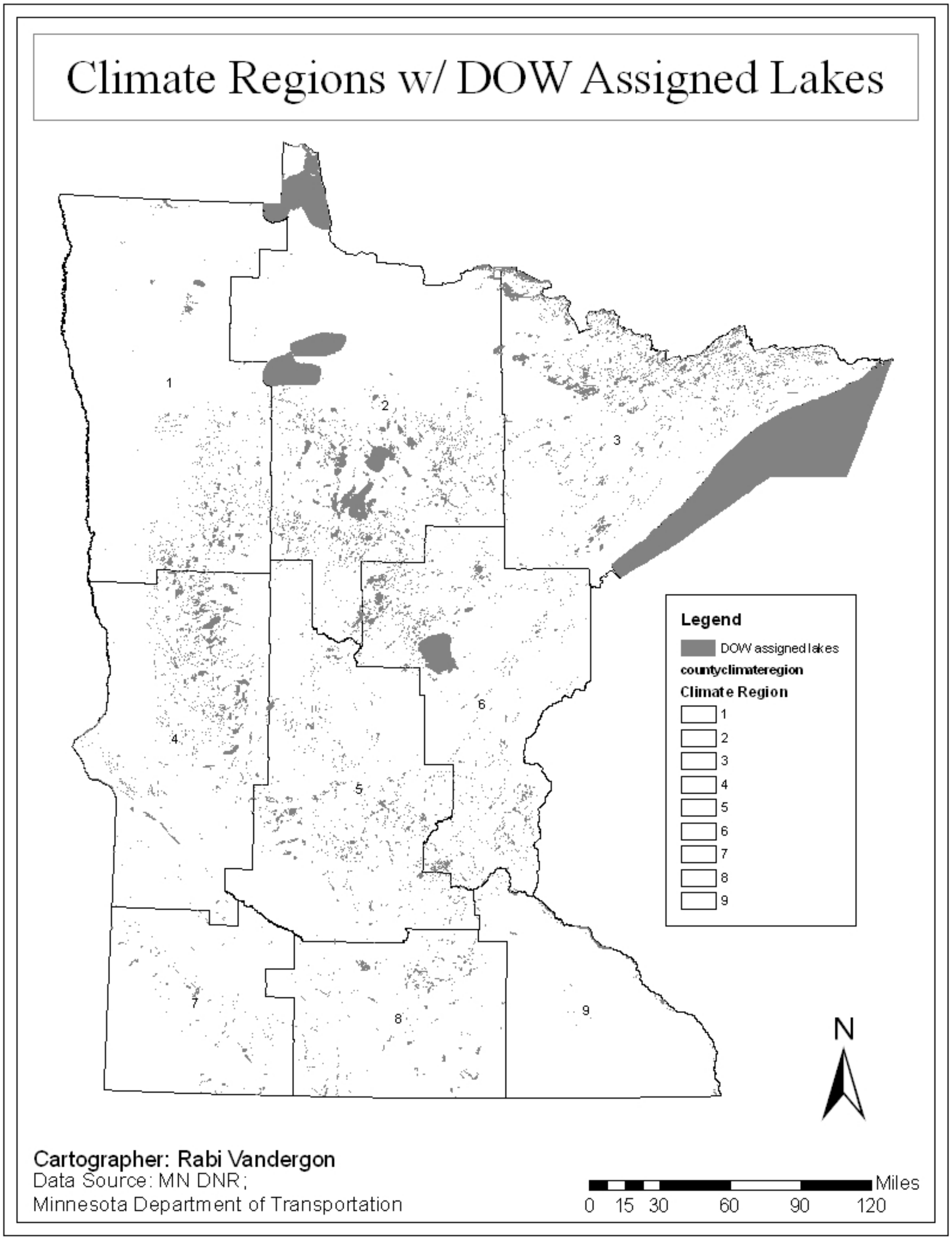

Figure 4. Climate Regions with Division of Waters (DOW) Identified Lakes