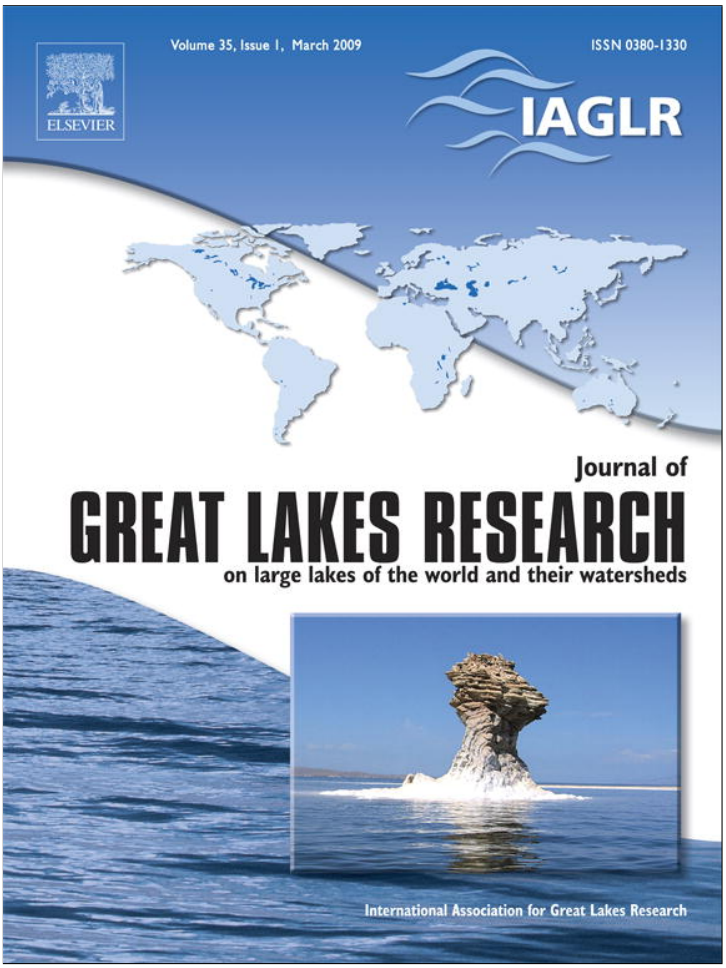

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Note

Changes in Lake Superior ice cover at Bayfield, Wisconsin

Forrest Howk

105 South Seventh Street, Bayfield, Wisconsin, 54814, USA

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ABSTRACT

This research documents a 150-year record pertaining to the duration of closed navigation for Bayfield harbor. Data were gathered recording the opening and closing of navigation in Bayfield, Wisconsin from 1857–2007. Data were primarily collected from the Madeline Island Ferry Line and microfilmed copies of the Bayfield County Press. Analysis of the data indicates that the duration of ice cover on Lake Superior at Bayfield, Wisconsin has decreased over the past 150 years at the rate of approximately 3 days/decade or 45 days over the course of the study. During the past 150 years, the date that the last boat is able to navigate in the Bayfield harbor indicates the onset of ice cover. This date has occurred an average of 1.6 days later every decade. Conversely, the date that the first boat is able to navigate in Bayfield harbor marking the break up of ice cover has come to an average of 1.7 days earlier every decade. Although this represents the overall trend for the past century and a half, the most dramatic changes have occurred since 1975. During this period the ice season has begun an average of 11.7 days later and ended 3.0 days earlier every decade. Bayfield's ice season was compared to the lake's annual maximum ice concentration (AMIC) as compiled in a study by [Assel, R.A., Cronk, K., and Norton, D. 2003. Recent trends in Laurentian Great Lakes ice cover, Climatic Change 57: 185–204, 2003.] The fraction of the potential closed navigation season that the Bayfield harbor is ice covered decreased at a rate of 0.77% a year while the AMIC decreased at a rate of 0.39%/year during the period from 1964–2001. In general, the decline in the ice cover at Bayfield mirrors the pattern shown by the AMIC, suggesting that Bayfield's ice season could be used as a nonspecific indicator of overall lake trends.

Introduction

The city of Bayfield is located in northwest Wisconsin on the south shore of Lake Superior (Fig. 1). When Bayfield was founded in 1856, its founders recognized its potential to become a significant port on Lake Superior. Located on a peninsula, Bayfield is surrounded by a twenty-two-island archipelago known as the Apostle Islands that provides shelter for the Bayfield harbor. The natural deep-water harbor enables it to stay ice free and open to navigation longer than other local ports.

Magnuson et al. (2000) has compiled 150-year data sets of freeze up and break up dates from almost forty varied sites in the Northern Hemisphere. Freeze up and break up dates of ice on lakes and rivers provide consistent evidence of later freezing and earlier break up. Between 1846 and 1995, 38 out of 39 records change in the direction of later freezing and earlier break up dates (Magnuson et al. 2000). This study seeks to determine if the ice cover in Bayfield harbor shows a similar trend and to quantify the degree to which the harbor's closed navigation season could be used as an indicator of overall Lake Superior ice trends.

In Bayfield's early history, the length of the navigation season directly affected its development and economy. Prior to railroad development, boats on Lake Superior were the main source of transportation. Editors of the *Bayfield County Press* frequently noted that Bayfield's navigation season was longer than other local ports.

La Pointe, the community closest to Bayfield, is on an island. Madeline Island is located 2 miles from Bayfield and is the only one of the twenty-two Apostle Islands that has permanent human inhabitants. When the ice in the channel between Bayfield and LaPointe became too thick for the area's wooden hulled fishing tugs to navigate, there was a period of time during which island residents had to wait until the ice was thick enough to walk on to regain contact with the mainland. As winter progressed, the ice in the channel solidified until it became a regular occurrence for the La Pointe postmaster to walk across the channel from Madeline to retrieve the mail. It was often an important topic in the *Bayfield County Press* indicating an unofficial start to “real” winter.

Presently, there are approximately two hundred year-round residents of Madeline Island. The majority of island residents travel to and from Madeline Island most of the year by using the Madeline Island Ferry Line that runs between Bayfield and La Pointe. The ferry line currently consists of four different steel-hulled boats that can carry passengers and between nine and twenty-four vehicles.

Since the 1930s, the ferry line has been the major indicator of when navigation opens and closes. When ice cover forces the ferries to stop running in the winter, it is considered a positive development for both the ferry line and the residents of Madeline Island. The ferry line uses this opportunity to repair and maintain their boats. When the ice is

E-mail address: larsenhowk@centurytel.net.

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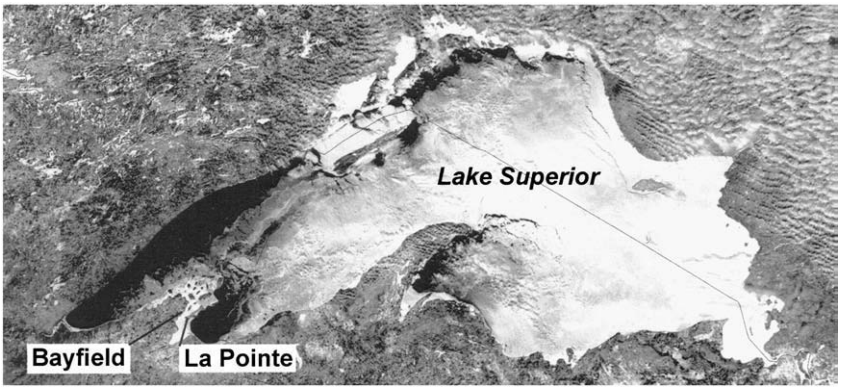

Fig. 1. Satellite image showing the locations of Bayfield and La Pointe, and the extent of ice cover on Lake Superior in mid-March 2003. Photo credit: Jacques Descloitres, MODIS Rapid Response Team, NASA/GSFC.

thick enough, an ice road is plotted between Bayfield and La Pointe allowing auto traffic and freeing the residents of the island from the limits of a ferry schedule.

Methods

This research project analyzes the well-recorded history of the opening and closing of navigation for Bayfield harbor. The documented history of Bayfield's navigation season was used to identify any trends depicting change in the freezing and breaking up of ice. The owners of the Madeline Island Ferry Line were one source for the data set. The ferry line was able to provide the record of the first ferry in the spring and last ferry in the winter going back to 1970. A Madeline Island newspaper called the *Island Gazette* was also a source of data going back to 1964. Fifty years of data provided a good start, but the goal was to acquire a data set reaching back 150 years to the founding of Bayfield. Microfilmed copies of *The Bayfield County Press* were used to acquire data going back to the 1850s.

Finding dates for every year's forming and break-up of the ice was a challenge. In some years the ice data was headline news, in other years the information could be tucked back on the fourth page in the "local chit-chat" column, superceded by more important local, national or international news. The March 10, 1955 issue of *The Bayfield County Press* featured an interesting article by local historian Eleanor Knight. Eleanor was a weekly columnist for the paper; that particular week she published a record of the early history of Bayfield harbor kept by a man named Andrew Tate, one of the first settlers of Bayfield. He had recorded the opening and closing of navigation from 1857 to 1888. Availability of such a span of data for the earlier years added significantly to the statistical analysis.

After the entire set was completed, every date was given a numerical value so averages and linear trends could be calculated. In the numerical system, December 31st was considered day zero and January 1st was considered day one. December 1st was the earliest recorded freeze up date and was listed as day -30. Leap years were taken into account when calculating the length of closed navigation. The data was displayed in scatter plot graphs that included a five-year running mean and a trend line based upon a linear regression equation.

Results

The data spanning from 1856 to 2007 shows that the closing of navigation for Bayfield harbor has generally been occurring later and

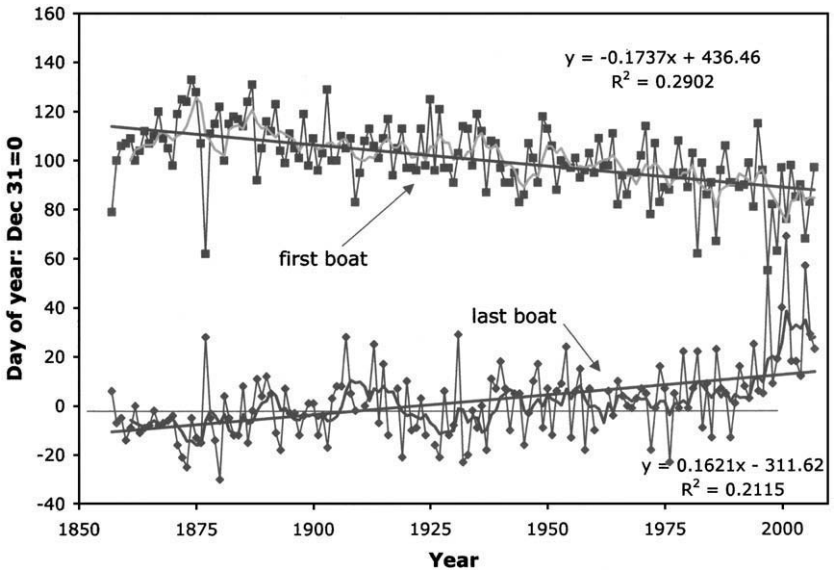

Fig. 2. The opening and closing dates of navigation for Bayfield harbor from 1857 to 2007. For the opening of navigation (square data points), the gray line represents the five-year running mean and the black line is the linear regression line or "trend-line." The closing of navigation (diamond shaped data points) is illustrated by black lines that indicate the 5-year running mean and linear regression line.

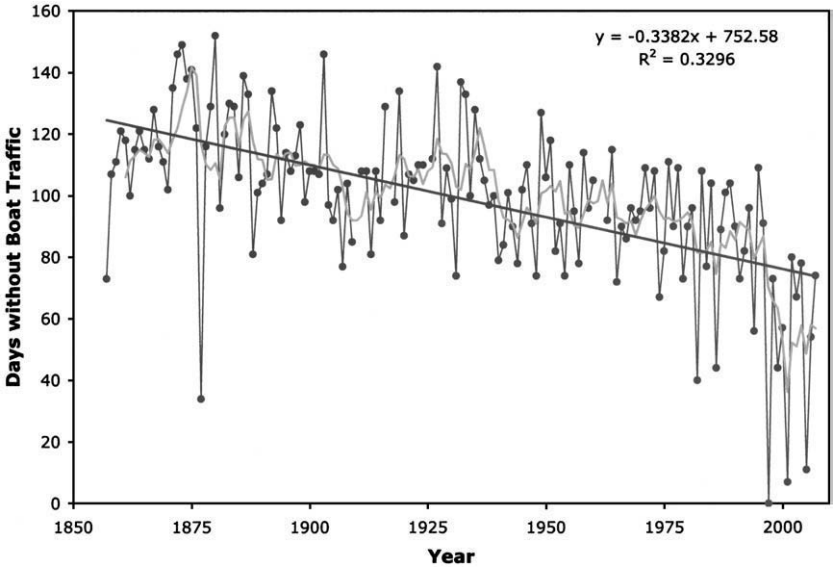

Fig. 3. Duration of closed navigation for Bayfield harbor from 1857 to 2007. The 5-year running mean is shown in gray and the trend line in black.

the opening of navigation has been occurring earlier each year (Fig. 2). Specifically, the closing of navigation has occurred an average of 0.16 days later every winter and the opening of navigation has taken place an average of 0.17 days earlier every spring. In other words, in the past 150 years the closing of navigation comes an average of 1.6 days later and the opening of navigation has occurs 1.7 days earlier every decade; compared to a century ago, the closing of navigation now comes 16 days later and the opening of navigation now occurs 17 days earlier.

The duration of closed navigation for Bayfield harbor is the period of time between the end of navigation indicated by the last boat leaving the harbor in the winter and the start of navigation when the first boat breaks the ice in the spring. Essentially the rate of change in the period of closed navigation is determined by combining the rates of change of both the closing and opening of navigation (Fig. 3). In the past 150 years, on average, the duration of closed navigation has decreased by 0.34 days/year, 3.4 days/decade, or 34 days/century.

Although the rates of change over the last 150 years are substantial, the most dramatic changes have been occurring since 1975 (Fig. 4). Since 1975, the opening of navigation happens an average of 0.30 days earlier/year, compared to the 150-year average of 0.17. Even more dramatically, the closing of navigation now comes an average of 1.17 days later every year, compared to the 150-year average of 0.16 days. Three of the four warmest winters on record have occurred since 1998. Bayfield's harbor was closed to navigation for only 11 days in 2005, for 7 days in 2001, and for 0 days in 1997. The lack of ice between Bayfield and La Pointe required the ferry line to run continuously throughout the winter of 1997–1998.

The rates of change indicated by the data are slopes of linear regression equations utilized to show the trends of the data.

Discussion

One logical cause for the change in duration of closed navigation at Bayfield could be found in the changes and advancements in the

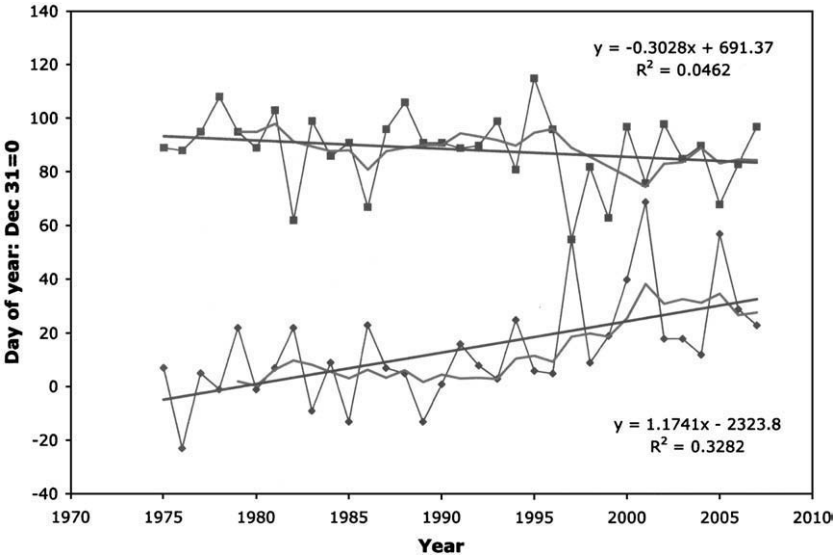

Fig. 4. The opening and closing of navigation for Bayfield harbor since 1975. Square data points indicate opening of navigation and the diamond-shaped points represent closing of navigation. Both 5-year running means for the opening and closing of navigation are shown in black.

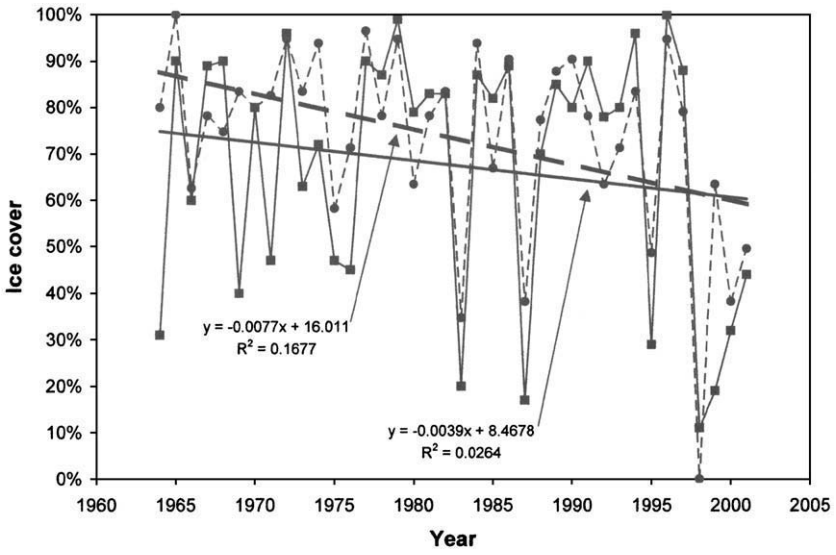

Fig. 5. Lake Superior's annual maximum ice concentration (AMIC) compared with percentage of the potential closed navigation season that the Bayfield harbor was ice covered from 1964–2001. AMIC data and trend line are represented with the solid lines while the Bayfield data and trend line are represented by the dashed lines.

technology of the local vessels. The design, materials, and engineering of boats used today are much different from those of the vessels used in the 1800s. In simple terms, a steel-hulled ferryboat is able to break through more ice (up to 6″ or 7″ thick) than a wooden hulled fishing tug or rowboat. However, advancements in boat technology alone cannot explain the overall trend, and especially the drastic changes in the length of the ice season since 1975. The local ferry line has been running boats of similar power and structure since the 1960s.

Research conducted by Austin and Colman (2007), for instance, showed rapid change in the summer water and air temperatures of Lake Superior over the interval 1979–2006. Lake Superior surface temperatures have increased approximately 2.5 °C during this period, significantly in excess of regional atmospheric warming (Austin and Colman, 2007). It appears that rising air and water temperatures are plausible causes of the gradual change in Lake Superior ice cover at Bayfield in the past 150 years and can also explain the accelerated rate of change that has occurred since 1975.

To discern if Bayfield's closed navigation season could be used as an indicator of overall Lake Superior trends, it was compared to the lakes' annual maximum ice concentration (AMIC) as compiled in a study by Assel et al. (2003). The study analyzed a 39-winter (1963–2001) record of the maximum fraction of lake surface area covered by ice each year. Under the climate of the last four decades of the 20th Century, Lake Superior's median AMIC is 80%, and the average is 68% (Assel et al. 2003). The study did not analyze the trend in AMIC during the period.

Comparing the AMIC record to the length of Bayfield's closed navigation season during the same period required determining the percentage of the season that the Bayfield harbor was covered with ice. The longest period of closed navigation from 1964–2001 (115 days in 1965) represented 100% of potential ice cover. Ice data for Bayfield harbor was not available for 1963. Percentage of closed navigation for all other seasons was determined by dividing the length of the season by 115. When the data for Bayfield ice duration and Lake Superior AMIC were graphed in comparison, each set showed decreasing linear trend lines (Fig. 5). The length of Bayfield's closed navigation season decreased at a rate of 0.77%/year while Lake Superior's AMIC decreased at a rate of 0.39%/year during the same 38-year period. Both data sets show steady decline and share similar percentage patterns from year to year. In general, the decline in the ice cover at Bayfield mirrors the pattern shown by the AMIC since 1964. This suggests that the duration of Bayfield's closed navigation season might be used as an indicator for overall lake-trends.

Acknowledgements

This study began as a high school science project for presentation at regional and national science fairs, culminating in the Intel International Science and Engineering Fair at Atlanta, Georgia in May, 2008, where it was awarded third place in the Earth Science category. Bayfield High School science teacher Richard Erickson encouraged me to conduct the science project, helped me prepare the presentations, and encouraged me to publish my results. Neil Howk, the Assistant Chief of Interpretation and Education at Apostle Islands National Lakeshore, suggested the research topic, provided access to research documents in the National Park Service library, helped fabricate science fair displays, and helped edit my presentations and papers. Dr. John Magnuson from the University of Wisconsin, Madison and Dr. Jay Austin from the University of Minnesota, Duluth reviewed my data and suggested ways that I might analyze it. I am indebted to all these people for helping to shape this research project.

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