LAKE LEVEL EFFECTS AS MEASURED FROM AERIAL PHOTOS

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ABSTRACT: Rising Lake Michigan water levels were found to negatively influence the amount of wetlands and beaches in the Straits of Mackinac area of Lake Michigan. The effects of long-term fluctuation in water levels were determined from measurements of wetlands and beaches on seven sets of historical aerial photographs (1938–1980). Analysis of aerial photographs demonstrated a 380 acre (154 ha) difference in total wetland and beach areas at the highest lake level sampled, as compared to the total at the lowest lake level sampled, or a range of 4 ft (1.2 m). A linear model between total wetland and beach areas and water levels (ΔH) indicated an increase of 1 ft (0.3 m) would result in a decrease of 80 acre (32 ha) or 18% of the 439 acre (178 ha) of wetlands and beaches in the study area. This methodology, which includes measurements from historical aerial photographs, acquisition of small format aerial photographs, and determination of local hydrological conditions, was useful for quantifying change in these lacustrine wetlands.

INTRODUCTION

Waves interact with long-term fluctuations of Great Lake water levels to influence the hydrology of wetlands in the Straits of Mackinac between Lakes Michigan and Huron (Fig. 1). Long-term water fluctuations are related to climatic change and occur within a time range of 10–30 yr (6). Extremely high lake levels were experienced during the early 1950’s, and the early 1970’s. Extremely low lake levels were experienced during the 1930’s and the early 1960’s. The interval between periods of high and low lake levels varies in time, as does the length of such periods (8). These changes in lake level will continue to occur, and their effects on coastal resources has received a minimum of study.

Fluctuations in Lake Michigan water levels have been found to influence the extent of coastal wetlands (7,8,9,13). High water levels alter the hydrological conditions in wetlands which can kill vegetation, or they destroy barrier beaches which protect the wetlands from wave action (7). In a study of seven different varieties of Great Lakes wetlands, a decrease of 29% of wetland area was found between the lowest and highest lake levels that were studied (9). It is clear that long-term fluctuations in water level can cause an increase or decrease in total area of wetlands. Information concerning the effects of lake levels on wetlands and beaches is necessary for resource management, and a methodology for quantifying local effects is required to supply data for engineering projects.

To determine the effects of Lake Michigan water levels, it was necessary to establish the relationship between historic water levels and the presence of wetland areas. There were three objectives, which included:

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(1) Measurement of the extent of wetland and beach areas from historical aerial photographs; (2) use of the measurements to develop a model of the presence of wetlands and beaches versus lake levels; and in addition (3) the relationship between lake levels, flooding, soil chemistry, and the presence of wetland plants were established through soil, hydrological and plant ecological analyses.

Results from the latter objective, that of determining relationships between soil, plant elevational and hydrological conditions, were described by Lyon (14) and are subject of a future publication. Achieving this third objective established the scientific basis to use water level data and measurements of plant communities from historical aerial photographs for study of change in coastal resources. The results of objectives 2 and 3 demonstrated that the presence of wetland plant species was as an indicator of hydrological characteristics of the site. Therefore, it was possible to measure the presence of historical wetlands and beaches from aerial photographs and to determine the effect of lake levels on coastal resources.

**BACKGROUND**

The type or combination of plant species found in a wetland are influenced by environmental variables such as flooding, elevation, pH, ox-
idation-reduction potential, and type of soil (2,5,14). The characteristic plant species combinations can indicate a particular type of wetland, and certain soil and hydrological conditions that occasion the presence of the wetlands. If the tolerance of, or the characteristic distribution of each plant species is determined, the location of plant species or combinations of plant species (communities) can be an indicator of certain environmental conditions. These differences in plant characteristics and the presence of plant species can be used to divide wetlands into communities, each having a characteristic species composition and each representative of certain environmental conditions.

Aerial photographs provide a synoptic view of wetlands and beaches such that individual plant species or combinations of species (communities) can be identified and mapped (17). Many wetland communities exhibit distinct shapes (canopy configurations) that can be interpreted, and have distinct reflectances in the near infrared and visible portions of the spectrum (17,18). These changes in reflectance are evident on aerial photographs as different textures, tones, and colors.

Aerial photo interpretation of wetland plants provides a means to classify patterns of plant communities as to type. This process of classification provides a capability for mapping, and the methodology employs map units that are based upon indicator species or communities. As patterns of wetland communities are related to environmental factors such as flooding, changes in the species composition often are indicators of wetland boundaries (12,17). With field research, these indicator species or communities can be used to map wetland boundaries, and can be used to infer soil and hydrological characteristics of a particular area. Definition of these relationships allow engineers and resource managers to use the distribution of wetland species and communities to assist in determining site characteristics (3,11).

The utility of indicator species and mapping plant communities was tested in a preliminary study of the Straits of Mackinac area (Figs. 1(a) and (b)). Along the Lake Michigan coast of the Straits, a change in wetland and beach area was found between years of high and low water levels (13). Using two sets of historical aerial photographs, a 720 acre (292 ha) decrease in wetland types was determined to have occurred along the 22 mile (37 km) shoreline from Mackinac City to Cross Village, Michigan. The change occurred during the period between high water (1952, 580.92 ft, 177.06 m) and relatively lower water (1965, 576.86 ft, 175.83 m), or a range of 4.06 ft (1.24 m).

From the preliminary study of the Straits of Mackinac, there appears to be a direct relationship between lake levels, and the presence of wetland plant communities and beaches. To further test the hypothesis that water levels influence the presence of wetland areas required investigation of longer-term influences over a number of years and a number of different lake levels. A determination of the long-term effect of water level fluctuations on wetland communities was completed through measurements of wetland areas from historical aerial photographs, and comparisons with water level data.

**METHODOLOGY**

The historical distribution of wetland and beach areas were measured
from aerial photographs acquired during periods of low water (1938, 1958, 1955), high water (1952, 1973), and average lake level conditions (1954, 1977, 1980). Use of these photographs allowed a 40-yr period for analysis, and provided several examples of each water level from different decades. The exact dates, scales and water levels are presented in Table 1.

This intensive sample of wetland areas was completed along the southern shore of Waugoshance Point using enlarged copies of aerial photographs (Table 1). The study area (Fig. 1(b)) was a shoreline of 3.8 mile (6.1 km). Fig. 1(a) is a map of the Northern Lower Peninsula of Michigan, and Lakes Michigan and Huron. A broad arrow indicates the general location of the Straits of Mackinac. The Waugoshance Point study area is presented in greater detail in Fig. 1(b). The open arrows indicate the location of the study area, along the shore of Sturgeon Bay.

Boundaries of wetland and beach areas were interpreted and traced onto Mylar from enlarged aerial photographs, using a drafting pencil with 0.33 mm (0.013 in.) point. Area measurements were made with a random dot grid (18), and corrected for actual photo scale to produce determinations of area. For each photo, the equation for calculating scale versus acres per dot was solved to yield an exact value.

Historic water level data were obtained for the area from the class 1 weather station at Mackinaw City, Michigan (NOAA number 5088), which was ten mile (16.1 km) from the study site (16). To measure local fluctuations in lake level and flooding, a station was erected for a liquid level gage at the Waugoshance Point study area. A model F552 Water Level Recorder of the Richards type was purchased from Weathermeasure, Inc., of Sacramento, Calif. Two months of data were obtained in 1980 and in 1981 (mid-June to mid-August). The strip-chart records were digitized at hourly intervals and the data encoded for statistical analyses.

Regression analyses and Pearson correlations were employed to evaluate the relationship between lake levels and area of wetlands and beaches as determined from historical aerial photographs. All analyses were accomplished by using the MIDAS (Michigan Interactive Data Analysis System) statistical software at The University of Michigan (4).

It is important to note that tides have a very small effect on the Great Lakes water levels. Wind or pressure generated events (e.g., seiches or storm surges), and long term changes in lake water levels from rainfall,
create lake level fluctuations which influence hydrology of wetlands (6,8). Local water level and flooding data were collected to establish the hydrological conditions of individual wetland species and wetland plant communities (reported by Lyon, 14). As elevation greatly influences duration of flooding for individual sites, a survey was made of the study area. Using a transit, a 50 × 50 ft grid (15.2 by 15.2 m) of elevations was established for the study area. Elevations were measured at the grid nodes and the elevations were referenced to a nearby U.S. Lake Survey benchmark (200 ft or 61 m from the study area). The initial survey point was used as the standard elevation (100.0) and the elevation of the other sites were reported as a relative value in tenths of inches.

The extent of flooding influences the location of a wetland or beach. Therefore, it was important to establish the relationship between the extent of flooding, elevation, and water level measurements at the study site. Several times each week, the local water levels and the extent of flooding were determined for each node of the grid. By correlating this information with the hourly data from the water level gage, a flooding history could be developed for each node in the study area grid. The development of a flooding history involved the use of elevation, water level, and flooding data, to determine the relative duration of flooding of each wetland plant species and plant community. This established a

![FIG. 2.—Identification of Wetland and Beach Areas: (a) Enlargement of USGS Aerial Photograph of Wetlands and Beaches; (b) 1:4,800 Scale Small Format, Large Scale Photograph](image-url)
relationship between current water level data, relative elevation and local flooding. It was important to establish the relationship between flooding characteristics and the species of plants that were found, and subsequently use these plant species as indicators of historical, hydrological conditions.

To evaluate seasonal change in vegetation, as well as current conditions, small format large scale aerial photographs were acquired in 1980. Three missions were flown to provide images for interpretation, and to determine film types for identification of wetland and beach areas (Fig. 2). The photographs were collected from a Cessna 172 aircraft using a vertical camera mount (Econ Company, Helena, Mont.). The camera was a motor-driven Olympus OM-1 35mm camera with a 100 mm lens (15). Low and high oblique photographs were acquired by a second photographer in the rear of the aircraft, who employed a Pentax MV 35 mm camera with automatic exposure control and 35 mm and 135 mm lens. Small format photographs with color (Ektachrome ASA 64), color infrared (Ektachrome CIR, ASA 125), and black and white (Plus-X ASA 125) films were exposed on three dates (May 24, June 13, and August 16, 1980), using altitudes to produce scales of 1:4,800, 1:7,200 and 1:9,600. Fig. 2(a) is an enlargement of a USGS aerial photograph showing wetlands and beaches during relatively low lake levels (1965). The box in Fig. 2(a) shows the location of Fig. 2(b). Fig. 2(b) is a 1:4,800 scale small format, large scale photograph acquired by the authors.

RESULTS

Area measurements from the seven sets of aerial photographs indicated a decrease of 380 acre (154 ha) of wetlands and beaches from lowest to highest lake levels (Table 1). The 380 acre of wetlands and beaches (154 ha) represent 87% of the total of 439 acre (178 ha) present when the extent of wetland and beach areas were measured at the lowest lake level (576.86 ft or 175.83 m).

A model of the change in long-term lake level versus the quantity of wetlands was developed. Plots of residuals and tests of random variability of the area measurements indicated that a linear regression equation was the correct model ($F$-statistic = 65.22, $R^2 = 0.93$). The model ($y = -80.82 \times +47,059.11$, $x =$ water level in feet, $y =$ acres of total wetlands and beaches) indicated that an increase or decrease in water level of 1 ft (0.3 m) would result in a respective loss or gain of 80 acre (32 ha) of wetlands and beaches. The coefficient of determination of the model of change between lake levels and wetlands and beaches had a very significant value ($R^2 = 0.93, p < 0.01$).

Small format, large scale aerial photographs were found to be useful for interpretation of current vegetation types, and for verifying wetland types found on historical aerial photographs. Comparisons of May, June and August photos of the study area permitted identification of seasonal change in plant species. In May and August, the normal color film provided improved tonal contrast within pre-growth (May) and senescent (August) wetlands. During June, the color infrared photos were valuable for separating different types of emergent plants which had similar green hues on normal color photographs.
Use of small format aerial photographs assisted the interpretation of wetland types from historical aerial photographs. They were valuable for several reasons, as: (1) Interpretation of small format, large scale aerial photographs supplied positive identification of wetland plant communities, boundaries of wetlands and beach soil types; (2) small format photographs provided data on plant seasonal characteristics; (3) the lower altitude coverage offered greater detail than historical photographs; and (4) they provided data for areas where field work was difficult.

The use of a combination of historic water level data from the NOAA station, as well as local data from a water level gage (1980, 1981) provided results on the hydrological conditions of different types of wetland plants and of beach areas. Data from this comparison indicted that wetland plant species and communities have characteristic flooding and elevational characteristics (reported by Lyon, 14). The presence of wetlands and beaches was a useful indicator of areas that were flooded (wetlands) during the prevailing lake water levels.

Use of a combination of water level data, relative elevation data from a survey, and current-year small format aerial photographs provided results on the relationship between water level and presence of wetlands (14). This allowed a detailed understanding of the relationship between short and long term hydrology of the study area, and it provided the scientific basis for use of plant communities as indicators of hydrologic conditions on historical aerial photographs.

**Review**

The regulation of water levels in the Great Lakes region prompts questions concerning the influence of water levels on coastal resources and structures. One of the concerns is whether Lake Michigan water levels result in different quantities of wetlands and beaches. The results of this study indicate there will be a decrease in available wetland and beach areas with increasing water level. At the highest Lake Michigan water level examined (580.92 ft or 177.06 m) there was only 13% of the maximum wetlands and beaches available at the lowest lake level studied (576.86 ft or 175.83 m). The model indicates that a rise in lake level of 1 ft (0.3 m) will result in an estimated loss of 80 acre (32 ha) of wetland and beach. Higher lake levels greatly reduced the area of wetlands and beaches in the Straits of Mackinac area.

Determinations of wetland and beach area using ground procedures requires extensive surveying and mapping. Due to cost, large-area determinations of wetlands have not been repeated with regularity. Less expensive aerial photographic methods can be used to make wetland area measurements, and updates can be accomplished at lower cost than ground methods alone. The method applied here, measurement of wetlands from historical aerial photographs, NOAA daily water level data and small format aerial photography, is potentially useful in areas where relatively flat areas of lacustrine wetlands and beaches are present.

**Conclusions**

Historical aerial photographs, water level data, relative elevation data

from survey, and on-site studies of hydrology were used to establish a model of change in long-term water levels and coastal resources in the Straits of Mackinac. The resulting regression model allows for predicting the total area of coastal wetlands and beaches at a given lake level. By using this model, it should be possible to predict future change in wetland and beach areas at certain water levels, and to verify the change from subsequent analysis of aerial photographs from the Straits of Mackinac area.

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APPENDIX.—REFERENCES