Report for 2003ND25B: Comparative Study of Fossil and Extant Fish Growth: Including Analyses of Mean Annual Temperature in the Geologic Record

- Articles in Refereed Scientific Journals:
    - Newbrey, M.G., A.C. Ashworth, and M.V.H. Wilson (2004) “Geographic trends in North American Freshwater Fishes from the Cretaceous to the Pliocene”, Society of Vertebrate Paleontology 64th Annual Meeting. Journal of Vertebrate Paleontology 24(supplement to 3):98A.
    - Newbrey, M.G. and A.C. Ashworth. 2004. A fossil record of colonization and response of lacustrine fish populations to climate change. Canadian Journal of Fisheries and Aquatic Sciences 61(10):1807-1816.
- Conference Proceedings:
    - Newbrey, M.G., A.C. Ashworth, and M.V.H. Wilson (2005) “Geographic trends in North American Freshwater Fishes from the Cretaceous to the Pliocene: A climatic effect?” Presented at Northern Plains Biological Symposium, Fargo, North Dakota.

Report Follows

COMPARATIVE STUDY OF FOSSIL AND EXTANT FISH GROWTH: INCLUDING ANALYSES OF MEAN ANNUAL TEMPERATURE IN THE GEOLOGIC RECORD
(Full Renewal)

DESCRIPTION OF THE REGIONAL WATER PROBLEM

It is important to consider the implications of climatic change on surface water resources in light of potential consequences of global warming. North Dakota boasts some of the best long-term data sets in the form of a fossil record to measure the effect of climatic warming on a single population of fish. A fossil lake bed near Jamestown, ND will provide perhaps thousands of years of continuous data of fish growth during a warming climate. This research will provide insight for fishery biologists and wetland ecologists concerning the long-term response of contemporary fish growth in North Dakota given potential climatic changes.

LITERATURE SUMMARY AND PRIOR WORK

Population dynamics have rarely been studied from ancient ecosystems. However, fossils can provide information about growth, mortality, and numerous other ecological processes that have been examined in contemporary systems (Ricker 1975). A recent study, which detailed the ageing of *Joffrichthys triangulpterus* scales and the subsequent modeling of their growth, provided insight into the population dynamics of an extinct osteoglossid fish (Newbrey and Bozek 2000; 2003). However, there are no contemporary species within the genus *Joffrichthys* to use as a reference for a comparative growth analysis. More recently, I have conducted research with an extinct form of pike (*Esox tiemani*)(Wilson 1980) and compared its growth to living forms of *Esox* (i.e., northern pike and muskellunge). The procedure has since bee repeated for yellow perch in the fossil record. The research details a correlation between growth and mean annual temperature and introduces a new procedure to estimate mean annual temperature in the fossil record. Much of the methodology presented in this proposal is derived from the pike and yellow perch growth research.

Climatological processes strongly influence growth rates of fish. For example, growth can vary depending on aquatic and ambient mean annual temperatures (Gillooly et al. 2002). Air temperature strongly influences surface water temperature (McCombie 1959; Livingstone and Lotter 1998) and therefore fish growth. Temperature has a strong influence on metabolic rate (Q_{10} relationship) and growth on ectothermic taxa; a temperature increase of 10°C increases the metabolic rate two to three fold and reaction rates increase 100-200% (Cossins and Bowler 1987). The pike and yellow perch research indicates that temperature is correlated with latitude. Pike and yellow perch grow more slowly in northerly latitudes because of cooler and shorter growing seasons and more quickly in the warmer-longer growing seasons of southern latitudes. The relationship between growth and temperature will provide a greater understanding of the effects of climatic warming on fish.

My dissertation research will focus on a comparative growth of several groups of fish. Specifically, I will contrast growth of fish in the fossil record to that of living fish to determine mean annual air temperature change in the geologic record. The analyses are important for fishery biologists and ecologists in North Dakota who are interested in the implications of climatic change on surface water resources and fish. For example, I will study a fossil glacial lake site in North Dakota that has produced fossil specimens of contemporary fish species. The environment of the fossil lake changed from a cool wet climate with tamarack, black spruce, birch and aspen to a contemporary prairie-pothole region. The change occurred over a period of about a thousand years thus giving us insight into ecological processes that are affected by current climate changes.

A site of particular interest in North Dakota represents a glacial, 11,000 year old fossil lake bed containing extremely well preserved fish (yellow perch, *Perca flavescens*), which are still living in ND today. Some of the best-preserved late Pleistocene/early Holocene fossils ever reported, come from a 11,000 calendar year-old site (Seibold site) underlying an ephemeral wetland on the Missouri Coteau, near Buchanan, North Dakota. Cvancara et al. (1971) described the geology and paleolimnology of one lake deposit called the Seibold site (SW¼ NW¼ Sec. 21, T141N, R67W), Stutsman County, North Dakota. The Seibold site represents the remains of a small basin (100m in diameter), which was probably part of large lake complex during the late Pleistocene /early Holocene. The site has excellent preservation of terrestrial and aquatic plants and animals, which permits taxonomic assignments of the fossil remains to the generic and specific levels. Study of plant specimens have revealed that the lake was initially surrounded by a spruce-dominated assemblage that was replaced by a mixed assemblage of deciduous trees, shrub, herbs, and grasses (Cvancara et al. 1971). Animals recovered from the site include five species of fish, frogs, muskrat, and evidence of beaver (Cvancara et al. 1971)(see fossils http://www.ndsu.nodak.edu/instruct/ashworth/SEIBOLD.pdf).

The changes in pollen indicate this site is ideal for a long-term study of fish growth in a North Dakota lake, where all data can be gathered in one excavation. During the period of lake sediment deposition, while the climate was warming and the glacier was retreating to Canada, the botanical environment around the lake changed (Cvancara et al. 1971). Fossil pollen indicates that the plant community changed from a forest to prairie ecosystem around 9,500 calendar years ago. As the lake warmed over a few thousand years, measurable change in patterns of growth should be detectable for yellow perch. Numerous studies have modeled growth of individual populations of yellow perch (i.e., Scott and Crossman 1973; Becker 1983; etc.) and, in all publications combined, from a variety of latitudes and ambient mean annual temperatures providing a spectrum of growth curves to assemble and analyze. The combined growth curves will provide a correlation between growth and mean annual temperature and thus provide an index to estimate mean annual air temperature change in the fossil record. This study site and others in my dissertation will provide insight to fishery biologists and surface water ecologists about the effects of temperature change on fish populations in North Dakota and other areas.

SCOPE AND OBJECTIVES

The overall objective of this Fellowship research is to describe changes in the paleoclimate and fossil fish growth by comparing fossil specimens to extant fish populations. For example, some site-specific objectives include: 1.) to conduct an excavation at the Seibold site near Jamestown, ND to collect fossil yellow perch; 2.) to describe growth of fossil yellow perch; 3.) to compile and analyze contemporary yellow perch growth data in order to contrast growth in relation to the fossils; and 4.) to analyze contemporary yellow perch growth in relation to ambient mean annual temperature in order to calculate a chronological series of estimates of ambient mean annual temperature.

These objectives will be repeated for numerous other localities, represented in museum collections, and containing the following taxa: bowfin, *Amia calva*; the mooneyes and goldeyes of *Hiodon*; and the members of the pikes, *Esox*. These genera are represented in the present North American fish assemblage, in the fossil record from the Cretaceous to the present, and in museum collections.

METHODS, PROCEDURES, AND FACILITIES

Numerous publications contain the information needed to locate specimens (e.g., Grande, 1984; Grande and Bemis, 1998; Grande, 1999; Li et al., 1997; Wilson, 1980, 1981, 1984; etc.) suitable for data. Typically, hard structures (i.e., scales, otoliths, cleithra, fin rays, spines, and vertebrae) from captured fish are aged and growth is calculated using the relation between growth of these structures and fish total length (Van Oosten, 1941; Carlander, 1969). Total length is the distance from the anterior-most tip of the head to the vertical plane of the posterior caudal fin tips. For this study, fossil scales and vertebrae will be aged in the lab and from museum collections by counting annulus marks or light and dark pairs of bands on bones. Fishery biologists use Von Bertalanffy growth curves (Von Bertalanffy, 1938) to assess growth rates. The curve is fit to the maximum total lengths for each age class:

$$\mathrm{TL_t} = \mathrm{L_\infty}[1\text{-}\mathrm{e}^{-\mathrm{K}(\mathrm{t}-\mathrm{t_0})}]$$

where:

$\mathrm{TL_t}$ = Total length (cm) at t (age in years);
$\mathrm{L_\infty}$ = maximum total length;
K = the Brody growth coefficient;
t = time (i.e., age in years);
$\mathrm{t_0}$ = time at age zero (time at theoretical zero length).

Yellow perch growth data will be taken from Scott and Crossman (1973), Becker (1983), and a list of other sources to contrast extant growth curves. Because male and female yellow perch have different growth rates and life spans all data from extant populations will be combined for both sexes. This is done to standardize error to match that of the fossil material. Site specific mean annual temperature (MAT) data rounded to the nearest 0.1°C will be taken from the WorldClimate© web site and when possible checked for accuracy with Northern Oceanic and Atmospheric Administration (NOAA) data. Ambient MAT will be used in a linear regression analysis and regressed to the natural log transformed total lengths (cm) of age three of yellow perch to obtain a correlation between MAT and growth:

$$\mathrm{Ln}\left(TL_{\mathrm{Age\,3}}\right) = m \times \sqrt{\mathrm{MAT}_E + 10°\mathrm{C}} + b$$

where:

$\mathrm{Ln}(TL_{\mathrm{Age\,6}})$ = natural log transformed total length (TL cm) at 3 years of age;
m = slope parameter of linear regression;
MAT_E = mean annual temperature (MAT) at sites of extant (*E*) populations;
b = intercept parameter of linear regression.

Von Bertalanffy total length will be used because it includes the growth parameters and describes more variation in growth than individual equation parameters alone. Age three total lengths will be used for analysis because this age represents a stable portion of the curve where the effects of the parameters $\mathrm{L_\infty}$ and $\mathrm{t_0}$ are reduced while still providing a range of sizes to contrast prior to asymptotic length. To estimate the ambient MAT of the fossil site, the linear regression equation was algebraically rearranged:

$$\mathrm{MAT}_F = \left(\frac{\mathrm{Ln}(TL_{\mathrm{Age\,3}}) - b}{m}\right)^2 - 10°\mathrm{C}$$

where:

MAT_F = mean annual temperature (MAT) of the fossil (*F*) site;
$\mathrm{Ln}(TL_{\mathrm{Age\,3}})$ = natural log transformed total length (TL cm) at age three;
b = intercept parameter of linear regression;
m = slope parameter of linear regression.

ANTICIPATED RESULTS

As the glacial lake matured to a modern pothole wetland and as the climate changed from a cool moist environment to a dry warmer environment there were quantifiable changes occurring in fish growth. Because there is a correlation between ambient air temperature and water temperature within the first meter of depth (McCombie 1959; Livingstone and Lotter 1998), we hypothesize that growth of fossil yellow perch will initially be slow in the cool climate and then increase as the climate warmed. Mean annual temperature change will be modeled from contemporary fish growth by a mathematical relation to temperature. The correlation will then be used to predict mean annual temperature change over a few thousand years. This information will provide a better understanding of evolution of natural processes to biologists studying the pothole region in North Dakota. New climatic information will be of interest to researchers studying changes in temperature and wet/dry cycles. The information and analyses obtained from the glacial lake will be presented at a scientific meeting and will ultimately be submitted to a peer-reviewed journal for publication. The procedures will be repeated for the other taxa of fish being examined in my dissertation in order to better understand relations between changes in MAT and fish growth.

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PROGRESS OF RESEARCH

I have accumulated data on growth of contemporary bowfin, mooneye, goldeye, northern pike, muskellunge, and yellow perch from about 65 populations/publications representing a variety of latitudes. Museum collections contain about 39 fossil fish populations related to the candidate taxa from a range of geologic ages. Recently, I have been focusing my efforts on yellow perch in order to publish the methods to aid in procuring funding.

Contemporary yellow perch growth responds significantly to air temperature variation across their range from central Manitoba to North Carolina. This not only shows that growth will respond to climatic warming but also that yellow perch can be used as paleothermometers. I have used fossil yellow perch, recovered from the Seibold site, as indicators of temperature. The mean annual air temperature estimates include values from –5° to 0°C, which correspond with the types of fossil vegetation from the site. This research was presented at the International Union for Quaternary Research in July 2003 and in part at the Society of Vertebrate Paleontology annual meeting in October 2003. I am currently working on a manuscript describing growth of yellow perch in relation to changes in climate and their use as paleothermometers.

When the Seibold site was originally excavated data was collected on the types and abundance of fish, which has been analyzed to gain a better understanding of the effects of climate on fish. Fossil fish abundance, stratigraphy, pollen, and charcoal were analyzed to provide information about postglacial colonization and subsequent population fluctuations during a time of climatic warming. The sequence of colonization for each species was correlated with individual thermal and relative water velocity tolerances. Fish abundance fluctuated six times during an approximate 1000 year depositional history. Charcoal abundance, representing fires, was inferred to represent episodic droughts during which nutrient levels were reduced and fish abundance declined. The fluctuations followed an overall trend to increased abundance during a time when the lake-marginal vegetation changed from a spruce to a deciduous forest in response to climatic warming. This information was submitted in manuscript to the Canadian Journal of Fisheries and Aquatic Sciences, which is a contemporary fisheries journal.

I am attempting to use the analyses and the manuscript described to demonstrate in an NSF proposal that a re-excavation of the site will provide a greater understanding of the effects of climate change on the Seibold fish and other biota found associated with them.

I will be running an analysis for another taxa after I finish the yellow perch, either bowfin (Amiidae) or the mooneyes (Hiodontidae). The amiids are a very primitive group and they are represented by only one living species. The amiid range extends north to about the US/Canadian border and are relegated to relatively warmer climates. The hiodontids are more derived and they are represented by two living species. The hiodontids range north to the Northwest Territories, Canada.