Report as of FY2006 for 2003ND25B: "Evolution of Fish Growth and its Response to Climate Change"

Publications

Project 2003ND25B has resulted in no reported publications as of FY2006.

Report Follows

EVOLUTION OF FISH GROWTH AND ITS RESPONSE TO CLIMATE CHANGE

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. Fossils can be used to examine the effects of climate change on fish because of the long-term nature of the data. North Dakota boasts some of the best long-term data sets in the form of a fossil record to measure the effects of climatic warming on fish populations. This dissertation research will provide insight for fishery biologists and wetland ecologists concerning the long-term response of contemporary fish growth and population trends in North Dakota given potential climatic changes.

LITERATURE SUMMARY AND PRIOR WORK

Aspects of 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). In a relatively 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 2003). However, there are no contemporary species within the genus *Joffrichthys* to use as a reference for a comparative growth analysis and the data only represent one population. More recently, I have conducted research with an extinct form of pike and compared its growth to living forms of *Esox* (i.e., northern pike and muskellunge). The procedure has since been repeated for yellow perch and the hiodontids (goldeyes) in the fossil record. The research details a correlation between growth and mean annual temperature and has the potential to elucidate the effects of climate change on fish growth.

Climatological processes strongly influence growth rates of fish and as a result climatic warming may have a long-term impacts on fish populations. Growth can vary depending on aquatic and ambient mean annual temperatures (Gillooly et al. 2002). Air temperature strongly influences surface water temperature (Livingstone and Lotter 1998) and therefore fish growth. Temperature has a strong influence on metabolic rate (Q_{10} relationship) and growth of 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). A quantification of the relationship between growth of certain fishes and temperature will provide a greater understanding of the effects of climatic warming on fish.

My dissertation research focuses 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. 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 am studying 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.

Numerous studies have modeled growth of individual populations of yellow perch, members of Hiodontidae (goldeyes), and the pikes (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 analyze. The combined growth curves will provide a correlation between growth and mean annual temperature and thus provide an index to estimate the effect of climate change on fish growth. My dissertation research will provide insight to fishery biologists and surface water ecologists about the effects of temperature change on contemporary fish populations in North Dakota and other areas.

SCOPE AND OBJECTIVES

The overall objective of my dissertation research is to describe changes in fossil fish growth by comparing fossil specimens to extant fish populations and to relate the changes in growth in the fossil record from a variety of fossil fish sites to climatic change using unrelated paleoclimate data. 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 understand the effects of climate change on fish.

These objectives will be repeated for numerous other localities, represented in museum collections, and containing the following taxa: the mooneyes and goldeyes of *Hiodon*; and the members of the pikes, *Esox*. These genera are represented in the present North American and North Dakota fish assemblages, 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; 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 (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 total lengths in this study for each age class:

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

where: TL_t = Total length (cm) at t (age in years); L_∞ = maximum total length; K = the Brody growth coefficient; t = time (i.e., age in years); t_0 = time at age zero (time at theoretical zero length).

Fish growth data was taken from the published literature to contrast extant growth curves. 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 fish to obtain a correlation between MAT and growth:

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

where: $\mathrm{Ln}(TL_{\mathrm{Age\,t}})$ = natural log transformed total length (TL cm) at (t) 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. Furthermore, ultimate total lengths, growth coefficients, and longevities can be used in place of total length at a given age and the relationships to MAT can also be used to quantify the effects of climate change on aspects of life history.

ANTICIPATED RESULTS AND BENEFITS

Trends in growth characteristics through time will provide insight into the evolutionary trends of fish, while the geographic patterns (i.e., movement) of closely related taxa in the geologic record will provide a better understanding of the response of fish to climate change. Fish respond to climate through variable growth, however, growth rates are only plastic to the extent of genetic variability. A changing climate will force fish to geographically relocate to maintain thermal constancy as in other poikilotherms.

The effects of climatic warming on contemporary fish species can be better understood with an investigation of extant fish growth in relation to temperature; and additional insights will be gained from an examination of the responses of fish in the geologic record during a changing climate. Quantification of growth characteristics in relation to MAT of several living taxa will provide a new and/or more comprehensive understanding of fish growth in relation to their environment. Given the potential for global warming and the questions surrounding the response of fishes, an understanding of fish growth in relation to temperature, and the correlations between fossil fish, evolution, and climatic warming in the geologic record will provide insight into the effects of climatic warming on contemporary fish species. Additionally, fishery biologists will be able to reference the mathematical relationships produced from this research and determine if management strategies (i.e., slot sizes, bag limits, etc.) need to be modified to maintain a healthy fishery. Potential growth rates are often used among other variables to determine biomass yield in a fishery, which is important to consider if harvest rates are too high. For example, a fisheries biologist in North Dakota could use this research to compare the growth and size of fish predicted for the fishery at a particular MAT. The relationship between growth and temperature could offer a new method to determine if management strategies need to be modified.

The results of this study will provide a better understanding of evolution of natural processes to biologists studying the pothole region in North Dakota. New climatic information from this study will be of interest to researchers studying changes in temperature and wet/dry cycles in North Dakota. The results of this study will be published in a series of publications.

PROGRESS OF RESEARCH

As an overview, I have nearly completed my data collection but I have recently found two new collections to visit next summer. In all, I have examined thousands of specimens and aged hundreds of fish fossils. I have 1) correlated contemporary yellow perch (*Perca flavescens*), muskellunge (*Esox masquinongy*), northern pike (*Esox lucius*), chain pickerel (*Esox niger*), goldeye (*Hiodon alosoides*), growth to temperature, 2) showed that climatic events such as that at the Cretaceous / Tertiary boundary and the Early Eocene Thermal Maximum are coincident with evolutionary events, 3) showed the effects of climate change on fossil fish colonization, biogeography, and population trends of fishes.

The results have been presented at eight scientific meetings from 2003 and 2005 (i.e., International Union for Quaternary Research, Society of Vertebrate Paleontology, Northern Plains Biological Symposium, North Dakota Wildlife Society, Dinosaur Park Symposium, Mesozoic Fishes 4). Two papers have been published to date: A paper detailing the effects of climate change on fish colonization and population trends, Canadian Journal of Fisheries and Aquatic Sciences 61:1807-1816 and a techniques paper, "Recognition of annular growth on centra of Teleostei with application to Hiodontidae of the Cretaceous Dinosaur Park Formation" published in the Dinosaur Park Symposium (Newbrey and Wilson 2005). Some example results: centra from Cretaceous (70 million years old) hiodontids and are significantly smaller than those of 50 million year ago. Those centra in the Cretaceous and Eocene are both significantly smaller than those from ND today. As the climate has been cooling since the Cretaceous, hiodontids have been getting significantly larger, a pattern also seen in the pike family (Newbrey et al. 2005: extended abstract). The comparison of *Esox* and esocoid growth patterns was presented at the last international Mesozoic Fishes Meeting in Madrid, Spain, August, 2005. A 64+ page manuscript is in preparation for submission to the symposium proceedings as part of a prestigious set of articles that come our every four years.

Furthermore, major climatic shifts in the geologic record have been correlated in my data with evolutionary shifts in the hiodontids and the pikes, which both inhabit North Dakota today. Life spans have been getting longer for both groups, and growth rates have been changing. The interesting correlation is that more ancestral, living members of these groups show similar significant trends and characteristics in growth, lifespan, total length at age four and other ages, and ultimate total length with regard to temperature across their ranges today. These significant relationships provide numerical models with which to quantify the effects of climate change on fish. The data suggests that as the climate warms fish will mature sooner at smaller sizes thereby suggesting effects on population dynamics, predator-prey relationships, and ultimately our fishery stocks!

An oral presentation was given to Society of Vertebrate Paleontology Annual Meeting (an international organization): "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." and the Northern Plains Biological Symposium in 2005. This research addresses the trends in fish movement across latitude and through time, which is my dissertation research objective 2. The results are being used to interpret and corroborate the results from my other dissertation objectives concerning evolutionary shifts in growth patterns. I have constructed the largest freshwater fossil fish database to date, which is nearly double the size of previous fish reviews published in 1981 and 1986 and consists of nearly 400 taxonomic entries. Preliminary results are very interesting and suggest that fish dispersal is tracking with climate. The age – latitude relationships for 54 taxa within 37 families of freshwater fishes were examined from over 150 fossil localities from the Late Cretaceous to the Pliocene (~100 to 2 mya) in North America. To examine the long-term effects of climate, we compared the changes in latitudinal data with changes in paleotemperatures based on the oxygen isotope analyses of benthic foraminifera. A regression analysis indicates the paleolatitude distribution of fishes is negatively correlated with paleotemperature. This relationship suggests that fish populations are shifting in response to changing thermal conditions, which may help explain many of the patterns in long-term fish dispersal. WRRI was acknowledged in both presentations and will be in the subsequent manuscript. The manuscript will be submitted to the journal Nature.

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