Stock-specific growth rates of lake herring, *Coregonus artedi*, in western Lake Superior

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**Synopsis**

We constructed environmental growth histories, termed biochronologies, for lake herring, *Coregonus artedi*, from four areas of western Lake Superior using scale samples from historical collections. We created chronologies using a linear growth model (LGM) to describe individual somatic growth as the sum of both intrinsic and environmental factors. We built a master chronology using all possible scale samples age five or younger, then examined subsets of the data according to collection site (Bayfield Wisconsin, Black Bay Ontario, French River Minnesota, and Thunder Bay Ontario). The LGM best fit the site-specific data, indicating statistically different stock-specific growth rates. These differences were primarily due to environmental growth, as age effects were similar across sites. We show that the LGM is a useful tool for identifying lake herring stocks in western Lake Superior, a situation where genetic stock identification techniques have been unsuccessful. Our findings demonstrate that the stocks at these four sites are growing at different rates and therefore require different management strategies according to the unit stock concept. Further refinement of these chronologies and coupling with abundance data may allow managers to determine the degree of stock rehabilitation.

**Introduction**

We present a new analytical method for identifying discrete stocks of fish and quantifying stock-specific growth rates. We explore these objectives using the lake herring, *Coregonus artedi*, of western Lake Superior. It has long been suspected that careful management at the stock level may be necessary to sustain long term productivity or facilitate restoration of valued Great Lakes fishes, including the lake herring (Todd 1981, Bronte et al. 1996), making this fish a logical selection with which to test this technique.

The lake herring is a pelagic planktivore native to the Great Lakes (Dryer & Beil 1964). This species plays an important role in Lake Superior trophic interactions, providing a crucial forage base for piscivores such as the lake trout, *Salvelinus namaycush* (Dryer et al. 1965, Cohen et al. 1987). Lake herring have a long history of commercial importance in Lake Superior (Dryer & Beil 1964, Fleischer 1992). The fishery thrived until the 1940s when individual stocks began to collapse (Dryer & Beil 1964). This collapse is attributed to the process of sequential overfishing, in which one stock at a time was fished out until lake-wide abundance dropped severely (Lawrie & Raher 1972, Selgeby 1982, MacCallum & Selgeby 1987). Fishing up was not detected in the initial stages because fishing effort was simply redirected as individual stocks collapsed.

Recently, lake herring abundance in Lake Superior has increased (Fleischer 1992, Bronte et al. 1996). Careful management at the stock level is necessary to facilitate the continued recovery of the stocks and
to prevent another collapse (Bronte et al. 1996). Here, we define a stock as a reproductively discrete group of fish with definable characters (Begg et al. 1999). These characters may be of genetic or environmental origin. Genotypic stock differentiation is problematic for coregonids, particularly in Lake Superior (Snyder et al. 1992, Turgeon & Bernatchez 2003). Therefore, phenotypic stock identification using a measurable life history parameter such as growth rate is a crucial step in applying the unit stock concept to lake herring management (Booke 1981, Begg et al. 1999). The Great Lakes biological community has endorsed the stock concept for the management of Great Lakes fishes, including Lake Superior fishes (Kutkuhn 1981).

Stock identification and quantification of specific growth rates is possible through application of Weisberg’s Linear Growth Model (LGM) (Weisberg 1993). This model decomposes individual growth into separate age-specific and environmentally influenced components. Once the age component of growth is removed, environmental growth histories, termed biochronologies, may be constructed (e.g., Cyterski & Spangler 1996, Ostazeski & Spangler 2001). Comparison of environmental growth histories between putative stocks (subsets) allows for phenotypic stock identification and stock-specific management recommendations based on differences in growth rates (Weisberg 1993).

Examination of density dependent responses is possible through comparisons of growth histories to abundance (Bowen et al. 1991). In many organisms, an increase in population abundance may result in a density dependent decrease in growth, reflecting increased competition between individuals for limited resources. Absolute abundance is often difficult to measure for pelagic fish species such as the lake herring. Catch per unit of fishing effort (CUE) is used instead as a relative index of abundance under the assumption that observed trends in CUE reflect real trends in population size.

In this paper, we apply the LGM to a collection of growth increments from lake herring populations sampled from regions of western Lake Superior, then subset by site. We show that the LGM can identify discrete stocks of lake herring and that stock-specific growth rates differ between sites. These site-specific growth differences, due to environmental effects, yield implications for future lake herring management at the stock level.

Methods

Sample collection and preparation

We used scales from lake herring taken from commercial or assessment gill nets set in four areas of western Lake Superior (Figure 1). The appropriate management agency (Minnesota and Wisconsin Departments of Natural Resources, Ontario Ministry of Natural Resources) performed all sampling and primary data collection at four locations in the lake (Table 1). Most collections occurred during the fall spawning season in gill nets ranging in mesh size from 3.05 to 9.53 cm stretched measure. Some samples collected in Black Bay before 1972 were taken in bottom trawls.

![Figure 1](image-url). Map of Lake Superior. Study sites are labeled. Latitude/longitude for each site is as follows: Bayfield (46.7/90.8), Black Bay (48.6/88.5), French River (46.9/91.9), Thunder Bay (48.4/89.0).