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Inferred Holocene Temperature Changes in the North Coast Ranges of California*

Abstract

The remains of fish scales from two sediment cores taken in Clear Lake, California, have been used to estimate the sizes of fish at various points in time over the last ~12,000 years. Since growth rates of fish are primarily temperature-dependent, their patterns of growth constitute a valuable climatic response record reflecting variations in temperature.

Introduction

The patterns of growth reconstructed from fish scales may provide sensitive climatic response records, indicating fluctuations in temperature. Fish are poikilotherms and their metabolic rates vary positively with the temperature of their environment. Their vital processes are generally accelerated by warmer temperatures and decelerated by cooler ones (Alexander, 1967; Lagler *et al.*, 1962). In temperate regions fish also undergo seasonal fluctuations in growth rates. These seasonal pulses in growth are recorded in bones and scales as annuli (Chugunova, 1959; Ovchynnyk, 1962; McKern *et al.*, 1974) (Fig. 1). Appropriate fish remains can be used to identify type of fish, to reconstruct its size at the end of each year of growth, and, in situations in which data are available for a long period of time, to infer changes in temperature.

Methods

This method was first applied to the materials recovered from a series of eight sediment cores taken from Clear Lake, California, by the U.S. Geological Survey (Sims, 1974). Fish remains from two of these cores have been analyzed. The two cores (numbers 6 and 7) are from the Oaks and Highlands Arms of Clear Lake, respectively (Figure 2). The total number of scale remains from the samples of these two cores is 1580. All scales were mounted in glycerine jelly and identified. From this total approximately 85 percent were identified as belonging to *Hysterocarpus traski* Gibbons (Tule perch), an embiotocid native to Clear Lake (Hopkirk, 1974; Casteel, 1972). The scales of this species were then examined to determine which showed adequate annuli for growth reconstructions. A total of 255 Tule perch scales from both cores were found to be suitable. The annuli were identified on these scales and measurements of the antero-lateral

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radius from the nucleus to each annulus were made (Fig. 1). The standard lengths (in mm) of the fish at each annulus or year of growth were determined from these radial measurements using the regression of standard length on scale radius established from recent specimens of this species. Details of these procedures as well as the basic data have been presented elsewhere (Casteel *et al.*, 1975, 1977, 1977).

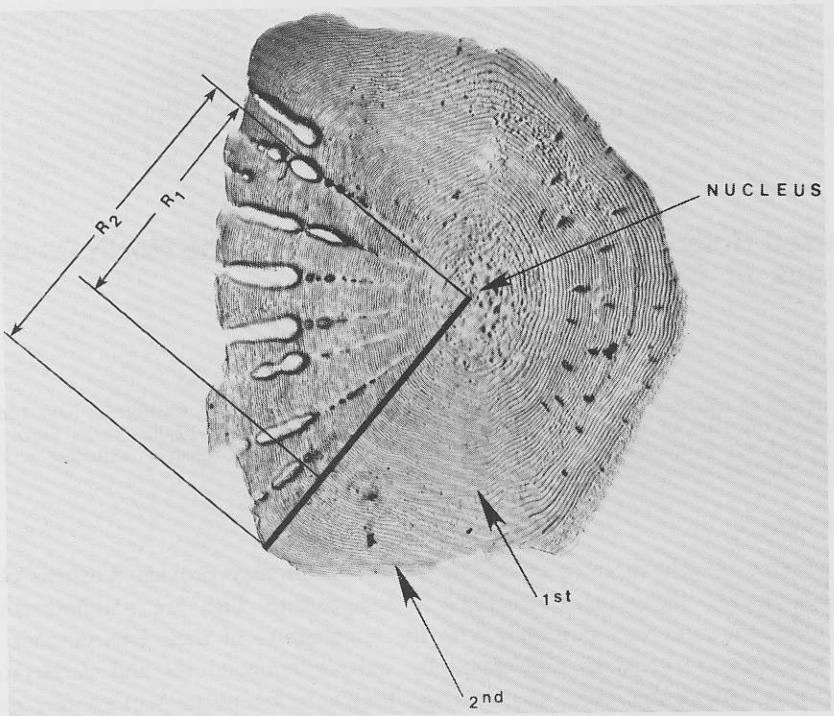

Figure 1. Scale of *Hysterocarpus traski* Gibbons (Specimen 136-13) from Core 7 showing measurement of antero-lateral radius to first (R_1) and second (R_2) annuli (x20). Anterior field of scale is to the viewer's left.

Results

Analysis of the fish scales from Core 7 indicated a period of depressed temperatures between ~9000 and 10,000 BP followed by a relatively steady increase in temperature which peaked between ~4000 and 2800 BP. The data indicated a period of decreasing temperature since ~2800 BP (Casteel *et al.*, 1977). The data from Core 6 indicated the same pattern of temperature change over the last ~11,000 years. Results for the last 3000 years, however, differed between age class 1 and age classes 2 and 3. The former indicated a period of increasing temperature since ~1800 BP, whereas the latter indicated rising temperatures between ~3000 and 1800 BP, followed by a steady and marked decline in temperature (Casteel *et al.*, 1977).

Under the assumption that the records from these cores should be responding to the same general climatic influences of increasing or decreasing temperature, the results of the two independent studies have been combined. The mean standard lengths for each slug from Cores 6 and 7 were plotted against the mean ages for these slugs as determined from estimates of the rates of sedimentation in the relevant Holocene parts of each core. The data were partitioned according to age classes. Only the data for age classes 1 through 3 were examined because those for age classes 4 through 6 were based upon extremely small sample sizes and highly subject to random variations. Since these

Figure 2. Map of Clear Lake, California, study area showing locations of Cores 6 and 7 in the Oaks and Highlands Arms, respectively.

latter age classes constitute only 9 percent of the available data, their exclusion was believed to be justified.

Figure 3 illustrates the result of combining the data from Cores 6 and 7. The general pattern is one of increasing temperature in the North Coast Ranges from ~12,000 to 3000 BP, followed by a general decline in temperature toward the present. Although this pattern is probably least apparent in age class 1 (Fig. 3A), a runs test indicates a significant time trend in the data ($\alpha = .05$) (Siegel, 1956). The mean standard lengths for all three age classes were tested against their representative averages for the entire ~12,000-year period using a χ^2 test and all were found to show significant non-random patterning ($\alpha < .01$).

Discussion and Conclusions

Data for age class 3 probably reflect best the climatic or temperature response record. Here temperature is increasing between ~12,000 and 8000 BP. This period is followed by a period of decreasing temperatures lasting until ~5000 BP. Temperatures then begin to rise to their Holocene zenith between ~5000 and 3000 BP, after which they decline toward the present.

While these results diverge somewhat from the general model of post-Pleistocene temperature/precipitation change for western North America (Antevs, 1952, 1955; Bryan and Gruhn, 1964), they match relatively well with more recent data concerning the termination of the Altithermal and marked cooling since 1000 BP as determined

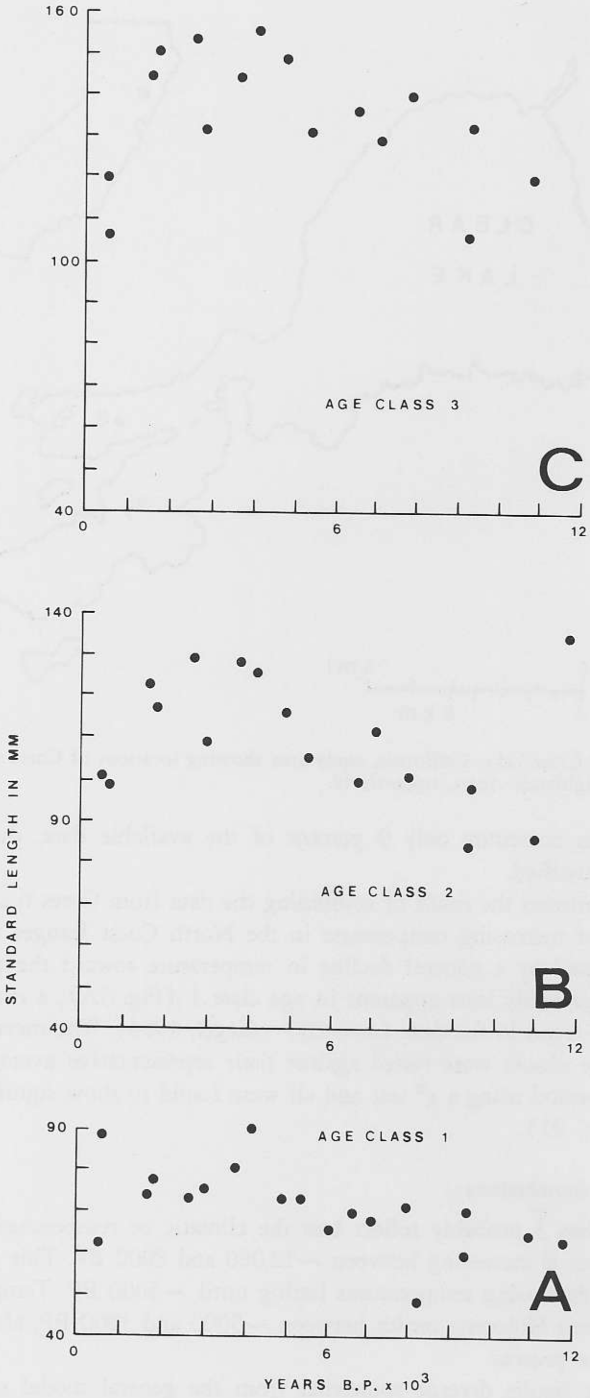

Figure 3. Estimated size (standard length in mm) of *Hysterocarpus traski* Gibbons. Ordinate, estimated mean standard lengths in mm; abscissa, mean age of samples in ^{14}C years BP. A, age class 1; B, age class 2; C, age class 3. Temperature change during this period is inferred to have followed a similar pattern.

from studies of bristlecone pine in the White Mountains of California (LaMarche, 1973, 1974), as well as in Nevada (LaMarche and Mooney, 1967). The results are consistent with those of Adam (1967) and Heusser (1960) and with estimates of the onset of Neoglacial conditions in the Sierra Nevada and California generally by Porter and Denton (1967). Generally, the time period from 2510 to 2760 BP has been seen as a time of increased precipitation and/or decreased evaporation in the Northern hemisphere and a major warming change is said to have occurred between 4230 and 4240 BP (Wendland and Bryson, 1974). These same authors also argue for a probable climatic change between 5900 and 6050 BP (Wendland and Bryson, 1974; Denton and Karlén, 1973). This finding coincides with the period of mid-Holocene temperature depression indicated in Figure 3.

Finally, a recent study of Holocene changes in the water level of Lower Klamath Lake, located approximately 320 km north-northeast of Clear Lake, has indicated periods of high lake levels at 4200 to 6000 BP and 600 to 1000 BP, with low lake levels between 1000 and 4200 BP (Grayson, 1967a,b). These periods of high lake stands coincide very well with periods of decreased temperature indicated in Figure 3. This relationship is also true for the mid-Holocene period of low lake level and the high temperatures indicated in Figure 3. Such an inverse relationship between temperature and precipitation is characteristic of the Köppen-Geiger Csb climates with marked summer/dry and winter/wet seasons (Strahler, 1965; Trewartha *et al.*, 1967). This same pattern was earlier proposed by Martin (1963) with regard to increased Altithermal aridity in California.

These results indicate that the use of fish scales may well provide a further means of inferring temperature changes, thus allowing for a discussion of Holocene temperature change without the need to consider both temperature and atmospheric moisture simultaneously (Deevey and Flint, 1957).

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