

Richard W. Casteel<sup>1</sup>

Department of Anthropology  
University of Washington  
Seattle, Washington

## Use of Pacific Salmon Otoliths for Estimating Fish Size, with a Note on the Size of Late Pleistocene and Pliocene Salmonids

### Abstract

The otoliths of Pacific salmon provide an excellent means of identification to the species level. In addition, their lengths have been shown to be highly correlated with the live weight of the fish. The present work investigates the nature of the relationship between otolith size and fish size in four of the five species of Pacific salmon native to North America. These relationships are used to examine the size of Late Pleistocene king salmon, and a similar method is applied to the vertebrae of Pliocene salmonids in order to estimate their size. The results indicate Late Pleistocene salmonids with sizes comparable to those taken at present and Pliocene salmonids with weights in excess of 300 lbs.

There are five species of Pacific salmon native to the west coasts of North America (*Oncorhynchus gorbuscha*, *O. keta*, *O. kisutch*, *O. nerka*, and *O. tshawytscha*). These fish are of major economic importance along the Pacific coasts (Hart, 1973; McPhail and Lindsey, 1970).

In an earlier publication (Casteel, 1974b) an illustrated guide was presented, allowing the identification of Pacific salmon to the species level by means of their otoliths. The accuracy of all identifications to the species level was tested and found to range from 94.5 percent to 65.6 percent, depending upon species. Figure 1 illustrates the otoliths of these five species.

In the present work the study of the otoliths of Pacific salmon is extended to cover their use in reconstructing the size of the fish. A number of works (Lebedev, 1960; Tsepkin and Sokolov, 1971) have shown the value of such reconstructions for understanding the changes in fish populations throughout prehistoric times, and the same techniques have been shown to be of value in studies of diet and energetics among marine animals (Fitch and Brownell, 1968; Tatara, Yamaguchi, and Hayashi, 1962).

The potential value of these studies stimulated presentation of data for the prediction of fish size from otolith size. Otolith length (in mm) measured from rostrum to post- or para-rostrum (whichever is the greater) has been shown to be an accurate and efficient predictor of fish size (total weight in grams) (Casteel, 1974a). See Figure 2. As part of continuing research in this area the otoliths of the five species of Pacific salmon were studied. Because of difficulties in obtaining a range of specimens of *O. gorbuscha* of the appropriate sizes data on only four species are reported in this work (*O. keta*, *O. kisutch*, *O. nerka*, and *O. tshawytscha*.)

With both variables transformed as common logarithms, the data can be accurately described by the following simple linear equation:

$$\log_{10} Y = \alpha + \beta (\log_{10} X)$$

<sup>1</sup> Present address: U.S. Geological Survey, 345 Middlefield Road, Menlo Park, CA 94025.

where

Y = the total weight of the fish in grams; and  
X = the length of the otolith in mm.

TABLE 1. Empirical data for predicting fish weight from otolith size in four species of Pacific salmon.

| SPECIES               | $\alpha$ | $\beta$ | r       | N  |
|-----------------------|----------|---------|---------|----|
| <i>O. keta</i>        | 1.2280   | 3.2054  | 0.98591 | 43 |
| <i>O. kisutch</i>     | -0.8927  | 5.9295  | 0.98746 | 19 |
| <i>O. nerka</i>       | 0.2909   | 4.1292  | 0.95089 | 86 |
| <i>O. tshawytscha</i> | -0.5963  | 4.1535  | 0.99101 | 53 |

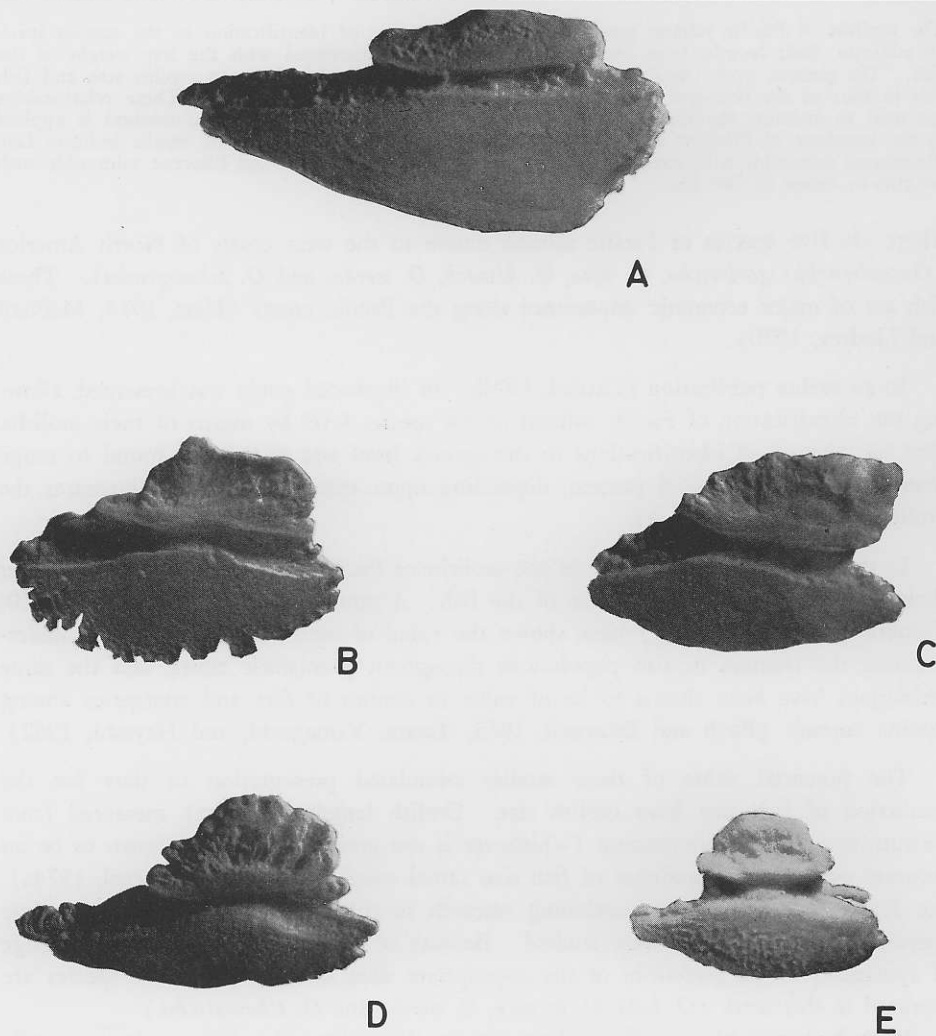


Figure 1. A. Inner face of right sagitta, *Oncorhynchus tshawytscha* (No. 5264) (8x).  
B. Inner face of right sagitta, *Oncorhynchus kisutch* (No. 5481) (10x).  
C. Inner face of right sagitta, *Oncorhynchus nerka* (No. 5681) (10x).  
D. Inner face of right sagitta, *Oncorhynchus keta* (No. 5690) (10x).  
E. Inner face of right sagitta, *Oncorhynchus gorbuscha* (No. 5693) (10x).

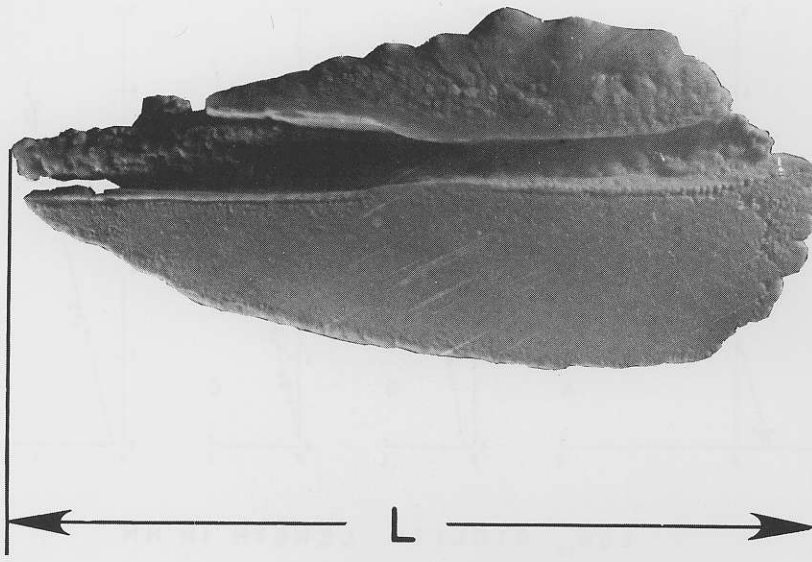


Figure 2. Inner face of right sagitta of *O. tshawytscha* showing measurement of length.

The values for  $\alpha$  and  $\beta$  are presented in Table 1 for each of the four species studied. All correlations are significant at the  $\alpha = .01$  level. Figure 3 presents a graphic representation of these relationships. These figures include specimens of both sexes, all condition factors, individuals at various life stages, and both marine and freshwater points of capture.

There is very little known about the fossil or sub-fossil histories of these valuable fish. Cavender and Miller (1972: 39) have stated that "There is practically no published fossil record for *Oncorhynchus* in North America." As concerns the sub-fossil record, the occurrence of *Oncorhynchus* has been noted from archaeological sites in California, Nevada, Oregon, and British Columbia (Schulz and Simon, 1973; Follett, 1963, 1966; Osborne, Bryan, and Crabtree, 1961; Cressman, 1956, 1960; Casteel, n.d.) dating as far back as 7500 B.P. However, there is yet to be published a detailed study of the size and growth characteristics of these fossil and sub-fossil salmonids.

Because of the anadromous nature of the Pacific salmon, it seems likely that their remains might appear in both freshwater and marine deposits. In fact, this latter type of deposit has produced the only remains of the otoliths of this genus from the Late Pleistocene to date (Fitch, 1970). In a Late Pleistocene marine deposit near Arcata, California, Fitch was able to identify the right sagitta of *O. tshawytscha*. The otolith measured 11.8 mm in length. When the regression equation for this species from Table 1 is applied, the predicted weight of this Late Pleistocene specimen is 7.19 kg (15.9 lbs). Thus, the little evidence available indicates a Late Pleistocene size near that usually obtained by this species today.

During Pliocene times it appears that a giant form of salmonid, *Smilodonichthys rastrosus*, was distributed along the coastal regions of western North America (Cavender and Miller, 1972). The size of this fish can be roughly approximated, assuming that its body proportions were similar to those of modern members of the genus *Oncorhynchus*. I have been able to measure the lateral widths of the thoracic vertebrae

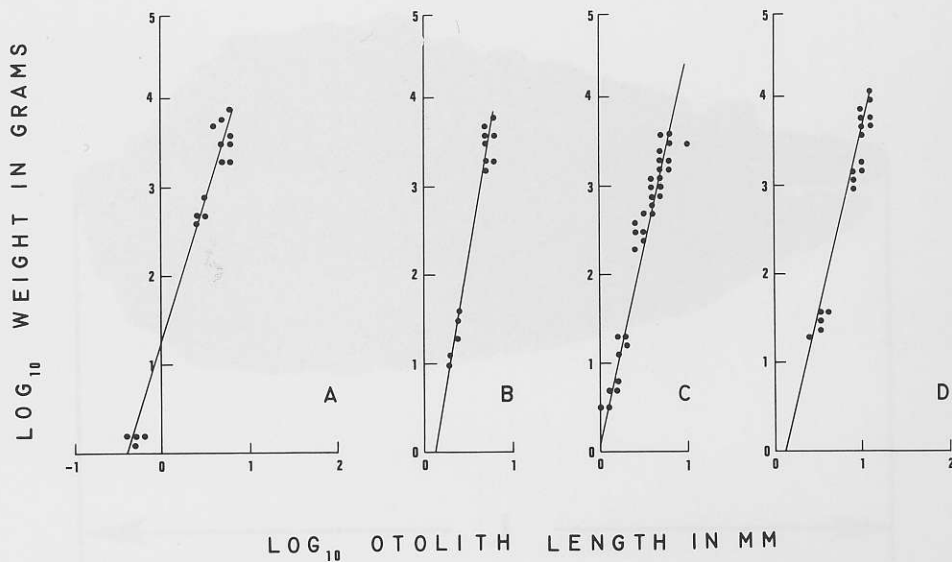


Figure 3. Graphs showing relationship between otolith's length and total live weight of fish (log-log scale).  
 A. *O. keta*.  
 B. *O. kisutch*.  
 C. *O. nerka*.  
 D. *O. tshawytscha*.

of this species in the collections of the University of California Museum of Paleontology, Berkeley. The mean vertebral width is 39.6 mm. Applying the following generalized *Oncorhynchus* spp. regression to predict weight from vertebral width:

$$\log_{10} Y = 0.8490 + 2.7538 (\log_{10} X); (r = 0.99181, N = 3347)$$

the predicted weight for *Smilodonichthys rastrosus* was found to be 177.3 kg (358 lbs). This is almost three times the size of the largest known Pacific salmon—57.27 kg (126 lbs) (Hart, 1973: 124).

Apparently the salmonids of the Pacific coastal region have undergone major changes in size since the Pliocene, and the Late Pleistocene material indicates sizes analogous with those of recent times. Hopefully, further investigations will add substantially to present knowledge of the history of this valuable group of fishes.

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