

## Long-term cycles of growth in *Sebastes*: Extracting information from otoliths

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George W. Boehlert  
NMFS, Southwest Fisheries Center  
Honolulu, Hawaii  
and  
Mary M. Yoklavich  
Oregon State University  
Newport, Oregon

Time series of information about fish populations are useful in understanding their natural fluctuations and responses to variation in physical factors. Most time series on fish, however, concern population size, typically estimated from historical catch records. We describe a technique by which growth information can be extracted from otoliths of long-lived species such as *Sebastes* through sectioning and careful measurement. As an example, data from recently collected *Sebastes diploproa* and *S. pinniger* are used to describe growth at ages 1 through 6 during several decades of this century. We describe the technique and its limitations, and make suggestions for application of the resulting data.

### Introduction

The study of long-term changes in marine fish populations has recently received a great deal of attention. Understanding the responses of fish populations to physical and biotic variability can lead to predictive capability; indeed, many current studies in fisheries oceanography examine the causes of past population change with the goal of modeling future trends in populations. Obviously such information can be most useful for purposes of fisheries management.

Several categories of long-term change in marine fish populations have been investigated. Population or stock size has generally been estimated from historical catch records of fisheries, and data from many decades are available, as for some Pacific salmonid stocks (Mysak et al. 1982) and several North Atlantic fisheries (Cushing 1982). Species assemblages and biotic interactions have been described on the decade scale by current work of the California Cooperative Oceanic

Fisheries Investigations (Loeb et al. 1983; H. G. Moser, Southwest Fisheries Center, National Marine Fisheries Service, NOAA, La Jolla, CA 92038 pers. commun.), and on the century scale by Soutar and Isaacs (1974) for the same region.

Methods of data collection for developing time series either come from continuous data collection or extraction of naturally stored information. The former often occurs over generations of biologists. Since starting a new series may not allow achievement of objectives for 30 or more years, available time series (which are often collected for other purposes) are used. In some cases, however, naturally stored information can be used to extract historical population information. A classic example of this approach is the study of cycles of population abundance for Engraulis, Sardinops, and Merluccius by Soutar and Isaacs (1974). By measuring the abundance of scales in anoxic sediments, they were able to define natural cycles of abundance of these species for 150 yr. Information is also stored in the otoliths of individual fish (Radtke 1984). The study of age in fishes and the use of otoliths for back calculation are simple examples of extraction of historical information, and others have used isotopic composition to define thermal habitats occupied by individual fish (Mulcahy et al. 1979).

The study of growth in fishes has typically been concerned with relatively short-term growth of cohorts or populations, most often with fished stocks. Differences in growth may exist between stocks (Templeman and Squires 1956; Borisov 1979), geographical regions (Boehlert and Kappenman 1980), and among years (Margetts and Holt 1948). Such growth differences may be genetically based (Borisov 1979), the result of density dependence (Margetts and Holt 1948), or caused by several environmental factors, most importantly temperature (Brett 1979). Unfortunately, comparisons of growth with time often come from different studies, frequently made difficult by changes in sampling, ageing methodology, or interpretation (Boehlert and Kappenman 1980).

Because estimates of fish growth are generally made at a single point in time, time series on the order of several decades do not exist for any species. Since otoliths act as recording chronometers, however (Radtke 1984; Campana and Neilson 1985), back calculation techniques allow one to establish growth patterns early in the life history of fishes, even in older fish. Extreme longevity has recently been confirmed in the scorpaenid genus Sebastes (Bennett et al. 1982), and ages in excess of 80 yr have been reported for several species (Archibald et al. 1981; Boehlert and Yoklavich 1984; Leaman and Beamish 1984). Thus otoliths of these species hold the potential to derive estimates of growth from several decades ago. In this paper we describe a modification of back calculation techniques, from which historical growth patterns can be obtained, and we apply this technique to two species, the splitnose rockfish, Sebastes diploproa, and the canary rockfish, S. pinniger.

#### Materials and Methods

Otolith samples were collected during rockfish surveys conducted by the Northwest and Alaska Fisheries Center, National Marine Fisheries Service, NOAA, during 1977 (Boehlert 1980), 1980 (Boehlert and

Yoklavich 1984), and 1983 (Wilson 1985). Collection techniques followed Gunderson and Sample (1980). Since one objective was to represent as many years of growth as possible, we based otolith selection upon age alone; old fish in this study thus greatly outweigh their relative abundance in a random sample. Otoliths were sectioned and age determined as outlined in Boehlert and Yoklavich (1984).

Back calculations and measurement of growth increments were limited to the first 6 yr of growth. This limit was imposed because otolith increments become smaller with increasing age; eventually, linear growth stops and the otolith begins to thicken (Bennett et al. 1982; Boehlert 1985). We used two different techniques for otolith measurement. For *S. diploproa*, whose otoliths are typically more opaque and increments smaller, we measured from dorsal to ventral distal edges of annuli 1-6. In the faster-growing *S. pinniger*, in which otoliths are clearer, we measured from the focus to the dorsal distal edge of each increment (Fig. 1).

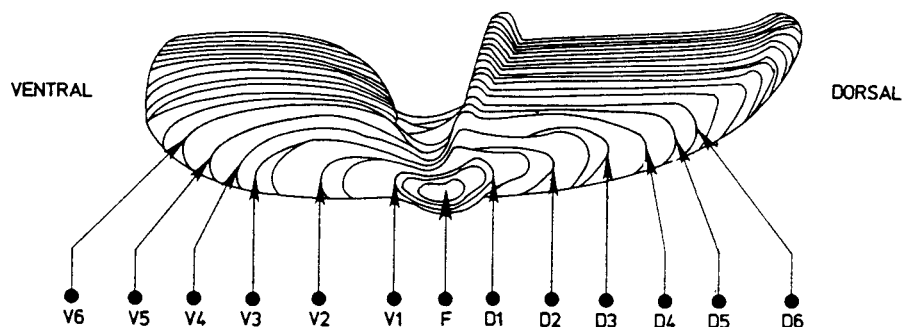


Figure 1. Schematic drawing of an otolith section from *Sebastes* showing the axes of measurement used in the current study. Measurements for *S. diploproa* were from dorsal to ventral distal margins (i.e., V2 to D2); measurements used for *S. pinniger* were from focus to dorsal distal margin) (i.e., F to D2).

#### Data analysis and Interpretation

Available data included sex, length, date of collection, location information, total age, and widths of the measured annuli for ages 1-6. The growth increment (GI(*i*), where *i* = 1 to 6, determined by subtraction of measurements of adjacent annuli rather than the full measurement), was used so that growth in a given year was not cumulative and therefore did not reflect past growth. Age was subtracted from year of collection to determine the year of birth. For each fish, each growth increment (1-6) was associated with a specific "year of growth." Data on 6 yr of growth were therefore available for each fish with the exception of those younger than six at the time of sampling. As an example, a fish collected in 1980 and aged as 40 yr was born in 1940; growth measurements from this individual were therefore available for years 1940 through 1945. Table 1 demonstrates a subset of the data array available for this series.

Table 1. A subset of the data array for growth increments used in the present study. The numbers under growth increment represent the years of birth for these growth years. The first growth increment is defined to occur in the year of birth, the second growth increment in the following year, and so forth.

Growth year	Growth increment, GI					
	1	2	3	4	5	6
1940	1940	1939	1938	1937	1936	1935
1941	1941	1940	1939	1938	1937	1936
1942	1942	1941	1940	1939	1938	1937
1943	1943	1942	1941	1940	1939	1938
1944	1944	1943	1942	1941	1940	1939
1945	1945	1944	1943	1942	1941	1940
1946	1946	1945	1944	1943	1942	1941

The majority of specimens used in the study were males. To increase the sample size, however, otoliths were collected from both males and females. Since growth, particularly after sexual maturity, differs between sexes for these two species (Boehlert and Kappenman 1980), it was necessary to test for differences in the growth measurements to allow a combination of growth data from males and females independent of the years tested. We separated the data by sex and then aggregated the data for each growth increment such that each year of birth had a single, mean value. Differences in growth between sexes were tested by comparing the respective growth increments with a paired t-test for all years where both male and female data were available. The results of this test showed that no differences were evident between sexes for either species.

Yearly means of GI(i)'s were calculated and these were the values upon which further calculations were made. A long-term average and standard deviation were calculated for each series of yearly mean growth increments and the standardized growth anomalies A(i) were calculated as follows:

$$A(i) = \frac{[GI(i) - (\text{mean } GI(i))]}{(SD \text{ } GI(i))}$$

These anomalies have a mean of zero and a standard deviation of one, allowing comparison of the growth anomalies in different growth years without concern for the effects of growth increment magnitude. Comparisons between species would also be facilitated by this conversion.

#### Results and Discussion

A total of 802 *S. diploproa* (651 males and 151 females) and 942 *S. pinniger* (616 males and 326 females) were used in this study. The *S. diploproa* ranged in age from 1 to 86 yr and had a birth date distribution from 1896 to 1979 (Fig. 2A). Specimens of *S. pinniger* ranged in age from 2 to 60 yr and had a corresponding birth date

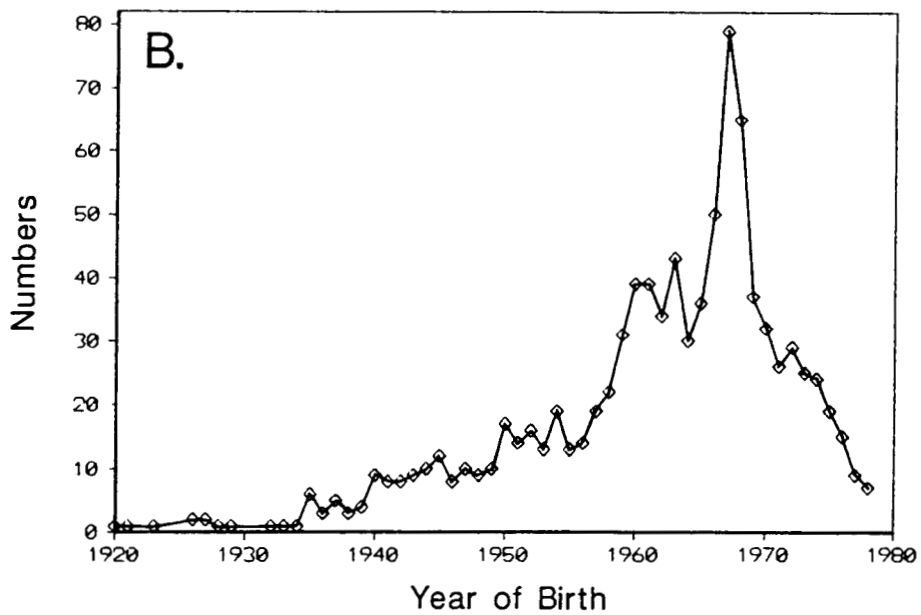
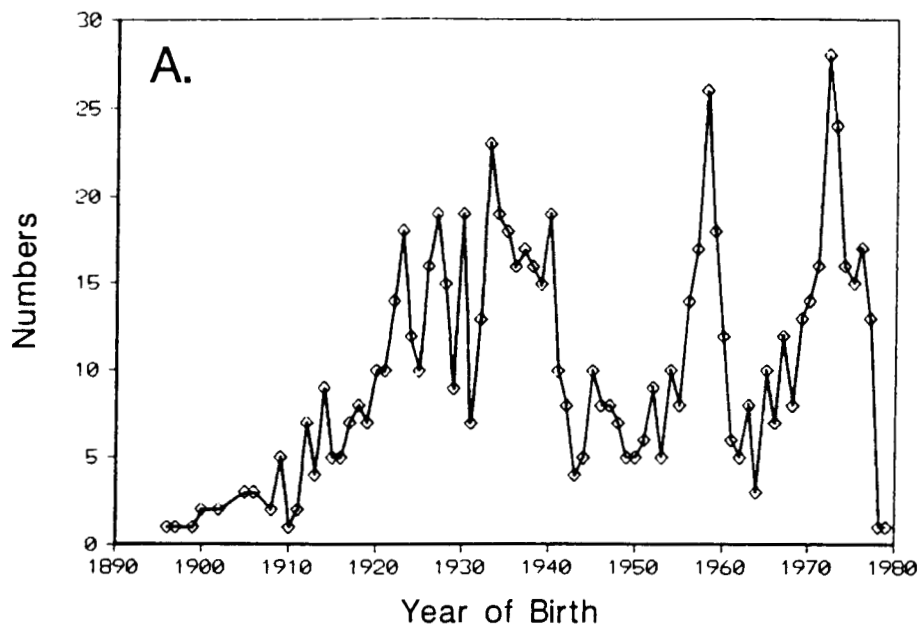


Figure 2. Distribution of the years of birth of specimens used in the present study. Males and females are combined. A. *Sebastes diploproa*. B. *S. pinniger*.

distribution from 1920 to 1978 (Fig. 2B). The total numbers of growth increments available were 4,714 for S. diploproa and 5,600 for S. pinniger. In the discussion of the results to follow, several sources of error contribute to the variability of these results. From a methodological standpoint, three errors are quickly apparent. First, minor changes in the location of the section of the otolith (Fig. 1) may result in slightly different increment measurements; we expect this to introduce relatively minor errors, however, since the sectioning technique (Boehlert and Yoklavich 1984) was consistent throughout the study. The second source of error occurs in the estimate of total age. Errors in this estimate will result in assignment of the incorrect year of birth and subsequent years of growth for each growth increment (Table 1). Finally, errors in annulus selection while making measurements on the section can occur. None of these errors are expected to be systematic, however, and their cumulative effects should not significantly mask trends in the data.

A concern from a biological standpoint is the implicit assumption that there is no linkage of longevity and growth. That is, if long-lived individuals are characterized by either faster or slower growth rates during the first 6 yr of life than individuals with shorter lifespans, we can encounter problems when comparing young with old fishes. A genetic basis for such a difference in growth and age at sexual maturity has been suggested for cod (Borisov 1979). An investigation into the biochemical genetics of S. diploproa using electrophoresis at 29 loci showed no variation associated with age (Wishard and Boehlert, unpubl. data). Although negative results cannot rule out a difference, our growth results do not show a consistent trend which would support a genetic basis for growth differences.

As one would expect from growth data, there is definite variability in the growth anomalies for both species (Figs. 3,4). No clear trends in either faster or slower growth over the full time series are apparent for either species. The 5-yr running averages, however, show an interesting pattern. In S. diploproa (Fig. 3), most of the age classes show a trend of positive anomalies before about 1925, and negative anomalies from about 1955 to 1970; positive anomalies after 1970 are also apparent in most of the records. The relationships among the age classes are also of interest. Generally, there is a relationship among anomalies 2-6 for this species, but the anomaly for year 1 is uncorrelated with growth in any other year. Sebastes diploproa is a deeper living member of this genus as adults, but the first year is spent in surface waters (Boehlert 1977); thus the factors which are important in growth in the first year may differ from those which determine growth in subsequent years. Temperature, which can have an important impact on juvenile rockfish growth (see summary in Boehlert and Yoklavich 1983), may differ between deep and shallow water (Kruse and Huyer 1983).

For S. pinniger, the record is somewhat shorter but shows interesting trends (Fig. 4). For age classes 1-4, there appears to be a positive anomaly through about 1952 followed by a period of negative growth until about 1970. Age classes 5 and 6, however, seem to show the opposite trend during these periods. All age classes show concordance, however, in the pattern of positive anomalies after about 1970. This same trend, although much weaker, was observed for S. diploproa (Fig. 3).

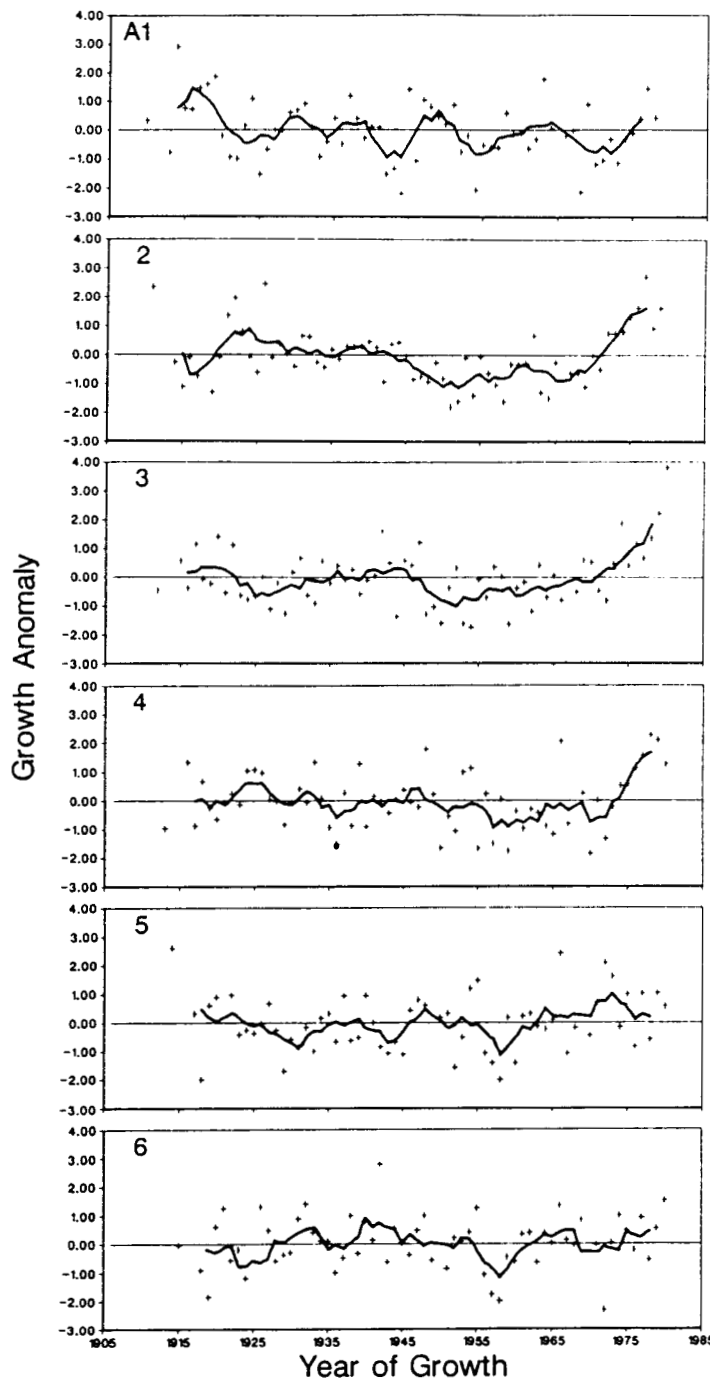


Figure 3. Plot of growth anomalies in years of growth 1-6 for Sebastes diploproa. The data points represent the yearly growth anomalies. The curve represents the 5-yr running average of these data. Only years where mean growth increment was based upon four or more observations were used in these figures.

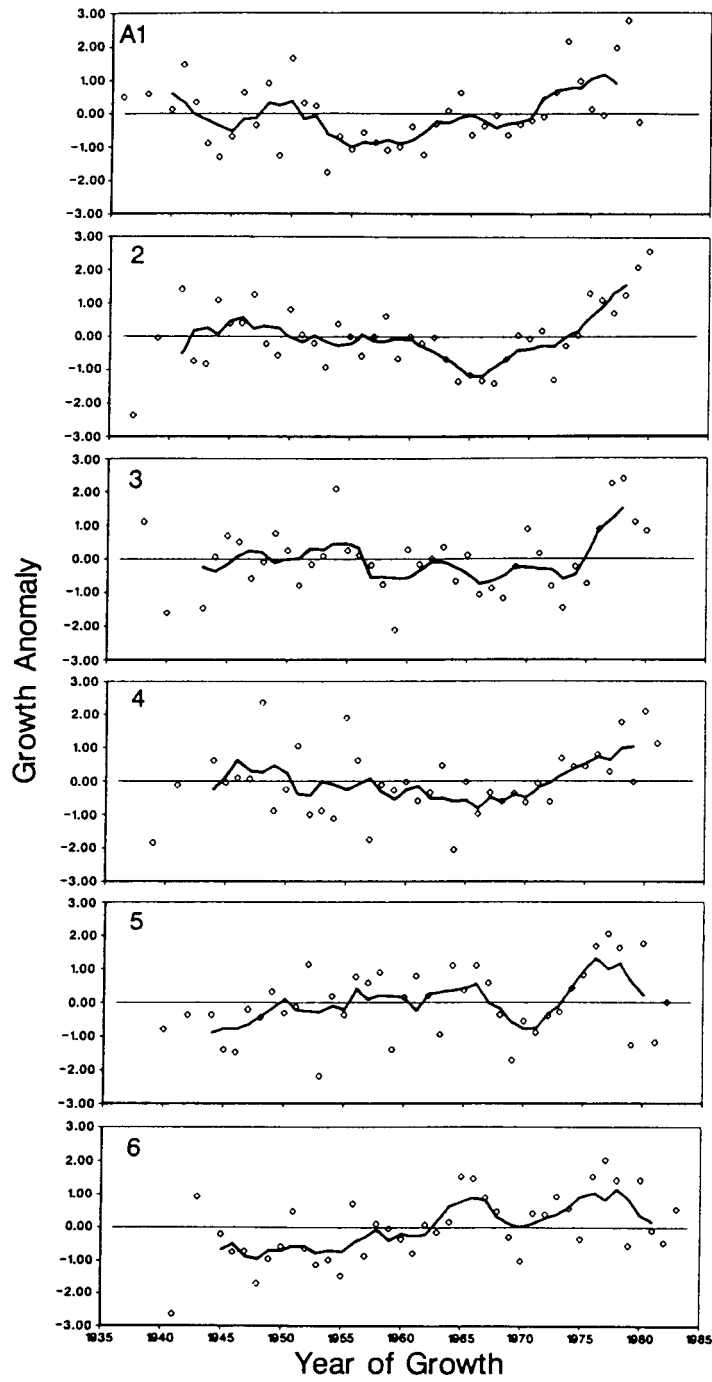


Figure 4. Plot of growth anomalies in years of growth 1-6 for Sebastes pinniger. The data points represent the yearly growth anomalies. The curve represents the 5-yr running average of these data. Only years where mean growth increment was based upon four or more observations were used in these figures.



The technique which we describe in this paper allows development of time series of growth for long-lived species of fishes. The results we have presented for these two species will need further statistical analysis to discern trends in the data and to investigate the possible sources of variation in growth patterns. For example, time series analysis may show relationships with physical factors, as described by Chelton et al. (1982) and Mysak (1986). Biological causes for growth variation may also be implicated. In this regard, it is significant that the apparent increase in growth after 1970 (Figs. 3,4) is temporally related to the depletion of coastal stocks of Sebastes as described by several papers in this volume. Does this hint at density dependent growth patterns? Future research on this data base will address these questions.

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