Age and Growth in the Hornyhead Turbot (*Pleuronichthys verticalis*) off Orange County, California

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The hornyhead turbot *(Pleuronichthys verticalis)* occurs from Magdalena Bay, Baja California Sur, Mexico to Point Reyes, California at depths from 9 to 201 m (Eschmeyer *et al*. 1983). It is randomly distributed over the bottom at a density of about one fish per 130 m^2 (Luckinbill 1969). The species typically lies partially buried in the sediment and feeds primarily on sedentary, tube-dwelling polychaetes and clam siphon tips (Luckinbill 1969, Allen 1982, Cross *et al*. 1985, Cooper 1994). Its larvae occur in the nearshore plankton throughout the year (Gruber *et al*. 1982, Barnett *et al*. 1984, Moser *et al*. 1993).

In Southern California, the County Sanitation Districts of Orange County (CSDOC) and City of Los Angeles Environmental Monitoring Division (CLAEMD) measure the bioaccumulation of trace metals and chlorinated hydrocarbons in muscle and liver tissue of hornyhead turbot as part of their receiving-water monitoring programs (CLAEMD 1989, CSDOC 1991, Mearns *et al*. 1991, CLAEMD 1992, CSDOC 1992). The National Marine Fisheries Service (NMFS) has also monitored these contaminants in hornyhead turbot livers from Santa Monica and San Pedro Bays as part of the National Oceanic and Atmospheric Administration (NOAA) National Status and Trends Program (Varanasi *et al*. 1989). In 1991, *p,p'*-DDE averaged 362 µg/kg wet weight in hornyhead turbot liver and 5 µg/kg dry weight in the sediments off Orange County (CSDOC 1991). In the same year in Santa Monica Bay, *p,p'*-DDE averaged 7800 µg/kg wet weight in liver and 81 µg/kg dry weight in the sediments (CLAEMD 1992).

Despite the importance of the hornyhead turbot in local monitoring programs, its life history (including age, growth, and reproduction) has received little attention. Traditionally age and growth studies have been used as a stock management tool. Coupled with reproductive data, stock managers can set limits in size and number of fish available to the fishery. However, hornyhead turbot is not exploited commercially as a fish stock and is rarely taken by the sport angler. Therefore the age of these fish and hence the length of time they may be exposed to contamination is not known.

Understanding the age-at-length structure of the hornyhead population would permit coupling with reproductive data to show age of maturity, long term recruitment, and length of time the fish could potentially have been accumulating contaminants.

The objective of this study is to describe age and growth of hornyhead turbot as part of a larger study on the life history of this species.

MATERIALS AND METHODS

Collection and Processing of Fish

Thirty-one hornyhead turbot were collected at depths of 25 to 35 m off Huntington Beach, California at random time intervals in May of 1992 for purposes of age validation and 160 more fish were collected at random intervals in 1994 for ageing (Figure 1). Fish were collected with a 7.6 m headrope otter trawl with a 1.2 cm cod-end mesh. In the laboratory, fish were weighed to the nearest 0.1 g and measured to the nearest millimeter standard length (SL).

The relatively large mesh size of the cod-end of the otter trawl did not permit collection of any young-of-the-year fish. Plankton tows were conducted at night using a 1 m diameter plankton net on the 23 m isobath outside of Los Angeles Harbor. Plankton tows did yield a single larval

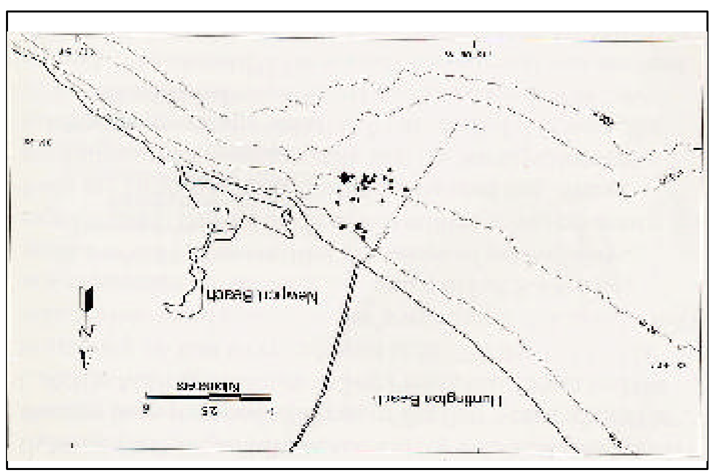

FIGURE 1. Map of the study area off Orange County California. The ♦ symbol represent the stations where hornyhead turbot (*Pleuronichthys verticalis*) were collected.

turbot; however it was a spotted turbot (*Pleuronichthys ritteri*). No other turbot younger than two years old was collected.

Collection and Processing of Otoliths

Both sagittal otoliths were removed and stored in a coin envelope. The left sagittal otoliths were cleaned and embedded in a resin (Embed 812®). Right sagittal otoliths were used if the left was missing or damaged. The embedded otoliths were then cut on a cross section through the focus of the sulcus. The thin sections were mounted on microscope slides using thermal plastic cement. A dissection scope with cross-polarizing filters was used to evaluate the number of increments in each cross section. Because otoliths from spotted turbot are similar in morphology to those of hornyhead turbot, the otolith from the larval spotted turbot was used to estimate the location of the primordial nucleus of the sagittal otoliths.

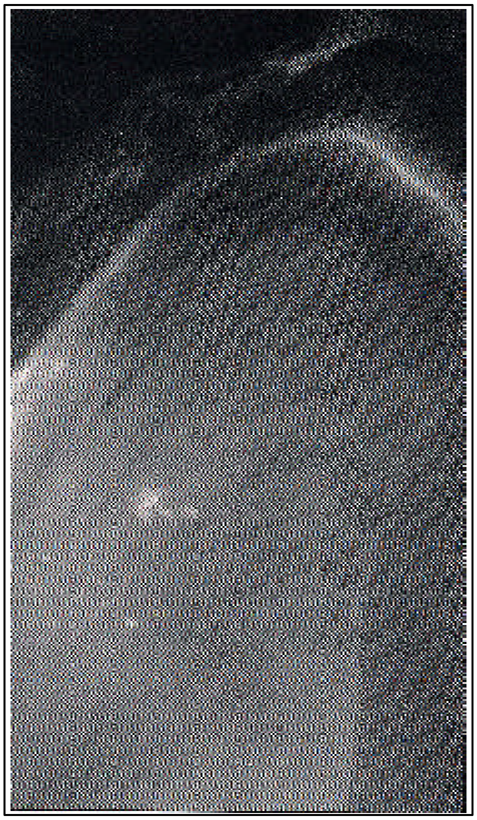

FIGURE 2. Photograph of the tetracycline mark on sagittal otolith of hornyhead turbot (*Pleuronichthys verticalis*). The fluorescent band is the result of oxytetracycline incorporated into the otolith. The area outside of the band represents one year of growth.

Validation

Thirty-one hornyhead turbot were tagged, injected with oxytetracycline (OTC) (100mg/kg), and cultured for one year. OTC acts as a calcium analog and is incorporated into the calcified structures of the fish. Upon examination with fluorescent lighting the OTC will fluoresce and the calcified structure is thereby time stamped. Fifteen of the fish were cultured at Cabrillo Marine Museum in San Pedro, California and the remaining 16 fish were cultured at SCCWRP. The OTC was administered in fish Ringer's solution (Lockwood 1964) at a concentration of 2 mg/mL and a pH of 8.44. The uptake of OTC was verified in a series of preliminary experiments. During the year mortalities were removed from the culture and the otoliths dissected out. These mortalities were used to verify that the tetracycline was incorporated into the otoliths. At the end of that year, the three surviving fish were sacrificed and their otoliths removed. The otoliths were prepared as sagittal sections and examined under ultraviolet light. The material deposited on the area outside of the fluorescent band represents one year of growth (Figure 2). This growth band was used in determining the visual characteristics of a single annual increment. The edges of the otoliths were examined for opacity to determine if they were hyaline or opaque in an effort to detect a seasonal signal in otolith development.

Otolith Reading

Expert readers at National Marine Fisheries Service (NMFS) Southwest Fisheries Science Center, La Jolla, California and Moss Landing Marine Laboratories (MLML), Monterey, California, were consulted for interpretation of otoliths prepared in cross-section from the 160 fish collected in 1994. The cross-sections were taken at the focus of the sulcus to ensure that the nucleus was included in the section. A subset of 10 (from the set of 160) otoliths representing eight size classes was presented to the expert readers on separate occasions and were read in a double blind test. We examined the subset on several occasions and reread the otoliths in that set until my readings agreed with those of the experts. We did this self-calibration before each of the two examinations of the entire set of sectioned otoliths.

The set of 160 otoliths was read on two separate occasions, three months apart. Increments were counted using a dissecting scope fitted with cross-polarizing filters. The polarized light gave better resolution of the increment structure in the thin cross sections (Figure 3). Thirty-three of the prepared otoliths were not read because they were too thick and shattered with additional polishing. There was a high degree of agreement between both readings (69% ± 4). Discrepancies were subsequently resolved by a third examination.

Growth Model

Growth equations were fit to age and length data of the fish. The regression models included logistic, von Bertalanffy, Gompertz, and a generic curvilinear equation (all members of the Richard's family of ecological models) (Appendix 1). A fit of the von Bertalanffy equation was made to the standard lengths and plotted. The equations were fit to the data using the Marquardt method as applied in Sigma Plot® for Windows, version 2.0 (Marquardt 1963).

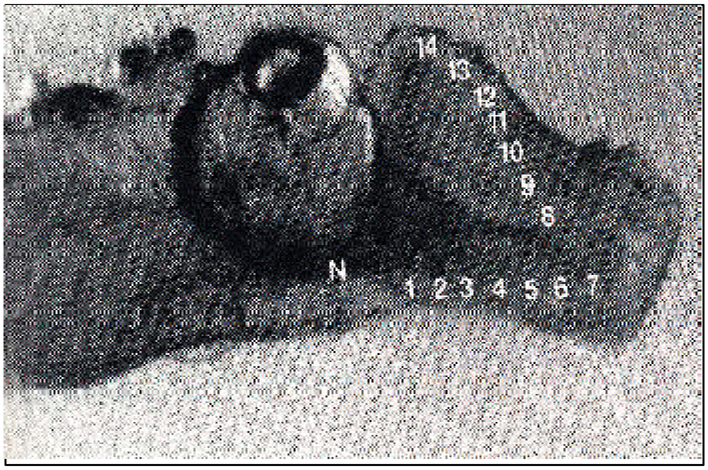

FIGURE 3. Cross section of a typical sagittal otolith with annual increments labeled. N is is the nucleus of the otolith in hornyhead turbot (*Pleuronichthys verticalis*). Each number represents one annual increment.

RESULTS

The 160 hornyhead turbot collected in this study ranged in size from 53 to 237 mm SL, and in weight from 13 to 503 g.

All of the fish marked with OTC had a fluorescent band in the otoliths and a definite area of growth outside of the OTC band (Figure 2). No overall pattern of opacity or signal of seasonality could be detected in the margins of the thin sections of otoliths examined.

Otolith readings by the expert readers from NMFS and MLML had a high correlation coefficient ($r^2 = 0.91$, $p < 0.05$) and were therefore considered reliable. Of 160 (79%) sectioned otoliths, 127 could be read.

Of the three growth equations, logistic and von Bertalanffy, equations (Appendix 1) both fit the data well with r^2 of 0.865 and 0.863, respectively whereas, the Gompertz model fit the data poorly ($r^2 = 0.695$ $p<0.05$). Because the von Bertalanffy is the most commonly used equation for fitting length and age data, the parameters from this equation are reported for comparability to the parameters reported by other researchers for other species (Figure 4). The von Bertalanffy equation yielded predicted maximum length (L_∞) = 335.32mm, instantaneous growth rate (k) = 0.0369, and theoretical size at age 0 (t_0) = -2.72.

Based on this information, hornyhead turbot has a slow almost linear growth rate (Figure 4). It grows from 10 to 15 mm SL per year and lives for a maximum of 25 yr. The fish collected in this survey ranged in age from 2 to 25 yr.

DISCUSSION

Thin sectioning of hornyhead turbot otoliths provides an adequate method for assessing the age of the fish at length. The use of OTC validation of annual increment formation has become a common practice in fisheries science (Ralston and Muyamoto 1983, Yoklavich and Boehlert 1987, Fowler 1989, Sogard, 1991, Tzeng and Yu 1992). The distinctive fluorescent band made by OTC leaves little doubt as to the time the fish was tagged by injection. The formation of annual increments outside the fluorescent band indicates a coupling of somatic growth with otolith growth in laboratory cultured fish. The low survival rate of the cultured fish (n=3) is of concern; however, the main goal of validation is to determine if the fish does indeed form annual increments. If the fish forms annual increments, then how do they appear in the sectioned otolith. Tropical species exhibit many rings that cannot be attributed to a seasonal pattern. The surviving fish from the culture showed distinct annual increments.

Hornyhead turbot spawn all year long with two peaks in February and July (Cooper 1994). Since there is no distinctive spawning time, alternating hyaline and opaque zones on the margins of the otoliths made marginal analysis difficult or impossible. Other species with distinctive spawning seasons generally have hyaline or opaque zones

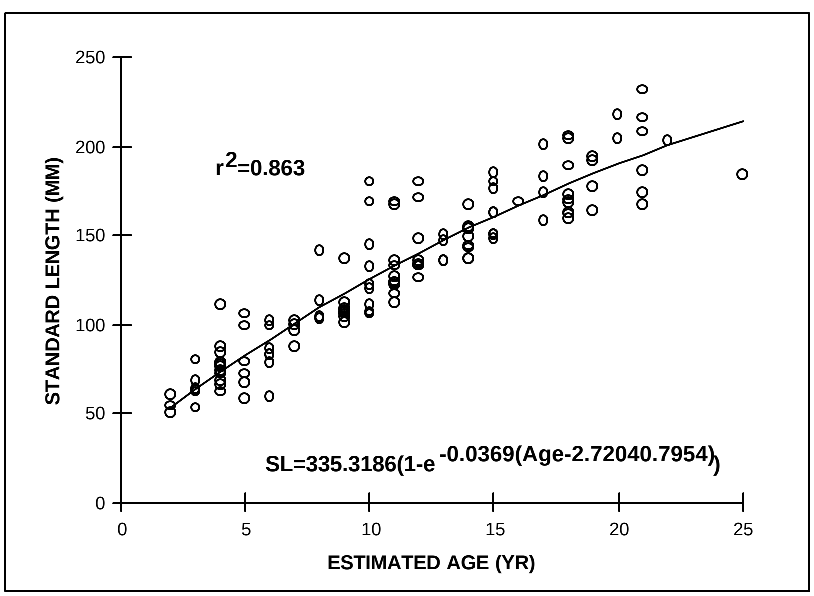

FIGURE 4. The von Bertalanffy equation fit to the age and growth data of hornyhead turbot (*Pleuronichthys verticalis*). The regression line represents the fits predicted by the model.

on their otolith margins (for example, *Pagrus auratus*, Ferrell *et al*. 1992).

Compared with hornyhead turbot, Dover sole lives twice as long, grows about twice as fast, and grows 100 to 400 mm longer. Dover sole larvae are planktonic for up to two years (Markle *et al.* 1992). They settle to the bottom at 43-79 mm (Moser 1996) and grow rapidly for the first three to five years of life, becoming mature at 320-350 mm total length (TL) (Hagerman 1952). Hunter *et al.* (1990) gave the following von Bertalanffy parameters for female Dover sole: L_i = 437 mm; k = 0.089; and t_0 = -4.7 yr. The maximum reported length is 762 mm (Miller and Lea 1972). Hunter *et al.* (1990) indicated that the species lives for at least 56 yr.

In contrast, hornyhead turbot larvae are probably in the plankton for about a month. They settle to the bottom at approximately 10 mm TL (Sumida *et al.* 1979) and then grow to a length of 50 to 60 mm SL in their first two years. Subsequently, they grow at 10 to 15 mm per year, becoming mature at 150 mm SL (Cooper 1994). As a species, hornyhead turbot demonstrates an almost linear slow growth, with the following von Bertalanffy parameters: L_i = 335 mm; k = 0.0369; and t_0 = -2.72 yr. The maximum reported length is 370 mm (Eschmeyer *et al.* 1983). The present study estimated that it lives for at least 25 yr.

Obvious discrepancies exist between the maximum reported lengths and the estimated maximum lengths for both species. The maximum reported length of hornyhead turbot is 370 mm (Eschmeyer *et al.* 1983) and the estimated length is 355 mm. The latter length is standard length; it is not known whether the former is total or standard length. If it is total length, then both maximum lengths may be consistent. Total length is longer (extending from the snout to the end of the caudal fin) than standard length (which extends from the snout to the base of the caudal fin). Hence, the two could differ by the length of a caudal fin.

In contrast, the maximum reported length of Dover sole is 762 mm (Miller and Lea 1972) whereas the estimated maximum length of Hunter *et al.* (1990) is 437 mm. The maximum size given in Eschmeyer *et al.* (1983) appears to fall outside of the growth curve described by Hunter *et al.* (1990), suggesting that the latter study did not sample the full size range of the species. However, based on their data, a 762 mm fish would be much older than 56 yr.

The slow growth rate of hornyhead turbot might be attributed to its diet of clam siphon tips and polychaetes which may not provide sufficient energy for rapid growth (Cooper 1994). However, Dover sole also have small mouths and feed on similar prey (Allen 1982) but grow much faster. Although the reason for the difference in growth rates is unknown, the difference in the growth rates and maximum sizes of the two species may be reflected in their movements. Dover sole undertake onshore-offshore migrations (Hagerman 1952) but such movements have not been observed for hornyhead turbot.

Although the movement patterns of hornyhead turbot are not known, the potential for long term exposure to contaminants is evident from the moderately long life span (i.e., 25 yr) of the species. Hence, the high levels of contaminants in hornyhead turbot from some areas may be the result of bioaccumulation over a relatively long period of time.

CONCLUSIONS

Hornyhead turbot grow to a maximum standard length of 370 mm and reach a maximum age of 25 yr. Growth is slow and almost linear. The logistic model describes the growth data the best, but it is not significantly better than the von Bertalanffy model. Hornyhead turbot sagittal otoliths are best prepared for examination using cross sections through the nucleus.

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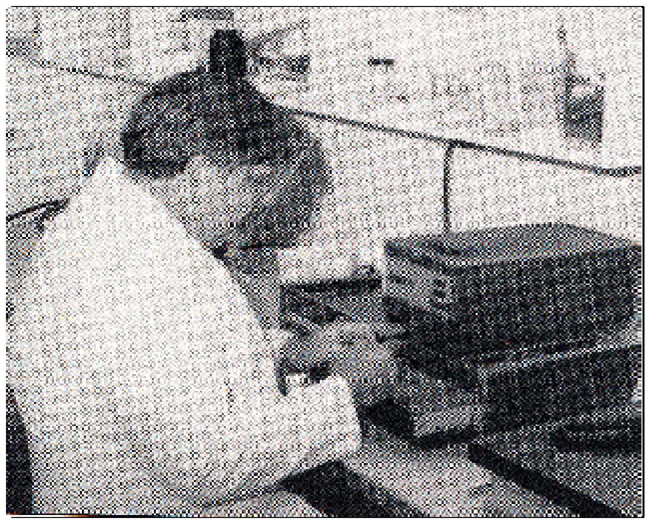

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APPENDIX 1.

Equations and fits to Equations

Growth equations used in analysis where

- k = the growth rate in millimeters per year standard length
- L_∞ = predicted maximum length in millimeters reached by the fish
- t = time in years
- a,b = constants

Logistic Equation

$L = L_\infty / (1 + be^{(-a*Age)})$ (Ricker 1975)

$L = 219.8412 / (1+3.7259e^{(0.1543*Age)})$

Gompertz Equation

$L = L_\infty e^{be\wedge(a*Age)})$ (Ricker 1975)

$L = 244.8873\ e^{1.7787e\wedge(-0.00973- Age)}$

von Bertalanffy Equation

$L = L_\infty (1 + e^{-k(t-t_0)})$ (von Bertalanffy 1938)

$L = 335.3186(1+e^{-0.0369(Age -(- 2.720))})$