The validity of the fin-ray method of age determination for lingcod (*Ophiodon elongatus*)

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Abstract–Oxytetracycline (OTC) injections were used in a mark-recapture experiment undertaken to validate the fin-ray method of age determination of lingcod (*Ophiodon elongatus*). In most cases, the number of annuli that formed beyond the OTC mark corresponded to the number of years at liberty. Expected and interpreted annuli counts from fin rays matched in 94%, 92%, 91%, and 75% of lingcod at liberty for one, two, three, and four years, respectively. These results validate the annual pattern of banding in fin-ray sections of fish up to 18 years of age. One of the consequences of not establishing and following age determination criteria is illustrated by the change in age composition due to misidentification of the first few annuli. A change in age composition has implications for stock estimates, such as mortality rates, and harvest strategies. For example, overfishing could result from underestimated mortality rates if fishery managers used a strategy that set fishing mortality equal to natural mortality. It is recommended that age determination criteria be routinely assessed to provide reliable age estimates.

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Lingcod (*Ophiodon elongatus*) are distributed off the west coast of North America in the nearshore waters from Baja, California, to the Shumigan Islands, Alaska. They have been an important component of the commercial fishery off British Columbia since the mid-1880s and a favorite target of recreational anglers since the 1950s. They inhabit nearshore waters and are commonly found along the bottom at depths ranging from 3 to 400 m; however most are found in rocky areas 10 to 100 m. Growth during the first years of life is rapid and up to age 2 it is similar for males and females, both reaching an average length of 45 cm. After age 2, females grow faster than males and the growth of males tapers off at about age 8, whereas females continue to grow rapidly until about age 12–14. For waters off the west coast of Canada, the maximum age recorded for lingcod has been 14 years for males and 20 years for females. Females reach lengths in excess of 100 cm, whereas males rarely exceed lengths of 90 cm.

The fin-ray method for age determination has been used for a wide range of freshwater and marine species such as sturgeon (*Acipenser* spp.), Pacific salmon (*Oncorhynchus* spp.), brown trout (*Salmo trutta*), whiter sucker (*Catostomus commersoni*), lake whitefish (*Coregonus clupeaformis*), channel catfish (*Ictalurus punctatus*), common carp (*Cyprinus carpio*), ide (*Leuciscus idus*), tuna (*Thunnus* spp.), rudd (*Scardinius erythropthalmus*), chub (*Squalis cephalus*), roach (*Rutilus rutilus*), bream (*Abramis brama*), and yellow perch (*Perca fluviatilus*) (Beamish 1981). However, in only a few instances have there been attempts in recent years to validate age estimates with the fin-ray method (Rien and Breamesderfer, 1994; Rossiter et al., 1995; Stevenson and Secour, 2000) despite the caution posed by Beamish and McFarlane (1983) that validation of age determination techniques is difficult, albeit critical.

Beamish and Chilton (1977) developed a method of aging lingcod that used thin sections of fin rays combined with mean annular diameter measurements to locate the position of the first and second annuli. This technique allowed estimates of mortality rates, growth rates, and fecundity to be determined for each age group. These rates strongly influenced assessment and management approaches for lingcod. Preliminary validation of the method was accomplished by using a mark-recapture experiment in conjunction with injections of oxytetracycline (OTC) (Cass and Beamish, 1983). However, this preliminary validation of the method was based on only four recoveries. A second experiment was initiated in 1982 to complete the validation of the fin-ray method for lingcod. Our report presents the results of this second mark-recapture study combined with OTC injections.

During the course of analyzing lingcod age data in the early 1990s, it became apparent that the annular diameter measurement criteria suggested by Beamish and Chilton (1977) were no longer being followed. Resulting parameter estimates based on these age estimates had changed. This resulted in a misunderstanding of growth, mortality, and age at maturity, which had implications for development of management strategies for lingcod. We therefore also report on a re-examination of the measurement criteria proposed by Beamish and Chilton (1977) and show that accurate ages for lingcod can be produced by using the fin-ray method combined with mean annular diameter measurements.

Methods

During 14–27 July 1982, a major tag and release program was conducted on the commercial fishing grounds, La Perouse Bank (48′45°N; 125′55°W), off southwest Vancouver Island. The primary focus of this tagging program was for validation of age determination. Methods and survey design are outlined in Cass et al. (1983). Prior to processing, all fish were anesthetized with tricaine methane sulfonate (MS222). We measured their fork length (mm) and inserted an individually numbered Floy FD68 anchor tag into the connective tissue just below the anterior base of the first dorsal fin.

We injected the tagged fish with a 25 mg/kg body-weight dosage of oxytetracycline into the interperitoneal cavity (McFarlane and Beamish, 1987). Of the injected fish, a random subsample was kept in 3000-L holding tanks for 48 hours to assess short-term mortality due to the OTC injection, then released. We released a random subsample of tagged fish without OTC injections as a control group to assess long-term (6-month) mortality due to OTC injection by comparing recapture rates for the control fish with those for the OTC-injected fish.

Tagged lingcod were recovered by the commercial fishery off the southwest coast of Vancouver Island. Because the first annuli after the OTC mark would form during the winter of 1982–83, only tagged lingcod recovered after 1 January 1983 were used in the validation of age determination. Returned whole fish were measured for fork length (mm), and a portion of the second dorsal fin was removed for age determination according to Beamish and Chilton (1977). Sectioned fin rays were illuminated with ultraviolet light to fluoresce the OTC mark and with regular light to identify annuli.

All recovered lingcod were aged in June and August of 1987. In October 1987, a change in personnel led to an unknowing change in the criteria for determining the first few annuli. Chilton and Beamish (1982) suggested that known average diameter of the first and second annuli could be used to estimate their location. The first and second annuli can be difficult to determine when resorption of the inner portion occurs or if the center becomes obscured by irregular-shaped deposits of opaque material. In addition, the presence of checks can also make it difficult to identify the first two annuli. In all cases, an estimate of the position of the third annulus can be made by measuring the diameter of the first and second annuli from juvenile fish or fish where these annuli are visible (Chilton and Beamish, 1982). By 1988, the primary reader was no longer using the Chilton and Beamish (1982) criteria. The recovered lingcod were re-aged after this change in criteria and second ages (using these criteria) were compared with original ages (not using these criteria) to assess bias. We compared age compositions of a subsample of the lingcod with the two age estimates to illustrate the consequences of not using the Chilton and Beamish (1982) criteria.

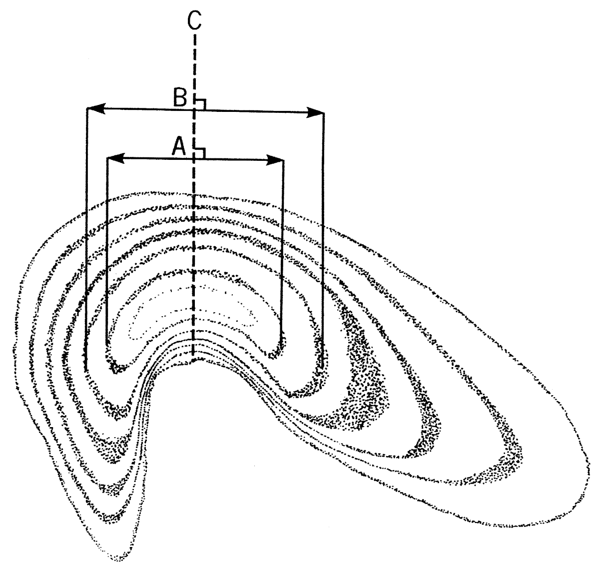

Figure 1

Schematic representation of section of fin ray for measurements of first (**A**) and second (**B**) annular diameters. Measurements should be made along axes perpendicular to the axis (**C**) of the inner groove of the fin ray.

Juvenile lingcod (less than 48 cm) were captured in 1987 in the recreational fishery in the Strait of Georgia. Fork lengths were measured (nearest mm) and dorsal fin rays were sampled during the creel survey program. These juveniles would not likely have resorbed fin-ray centers. The fin rays were sectioned (Beamish and Chilton, 1977), and illuminated with regular light. The diameter to the first and second annuli were measured with a micrometer eyepiece under 40× magnification to the nearest micrometer (μm). Diameter measurements were made along an axis perpendicular to the inner groove of the fin ray (Fig. 1). If an annuli appeared as a thick zone, the range from the beginning to the end of the zone was measured and the median used as the diameter measurement.

Results

A total of 7429 lingcod were tagged and released during July 1982. Of these, 6946 were injected with OTC and 483 were not injected but were released as the control group for assessing long-term (6-month) mortality due to OTC injection. A total of 188 lingcod were held for 48 hours after being tagged and injected with OTC. No mortality occurred prior to release. Within the first six months (i.e. by 31 December 1982) 1442 lingcod were recovered. During this period, the return rates of OTC and non-OTC–injected lingcod were similar (19.5% and 18.4%, respectively) indicating no long-term mortality from OTC injection.

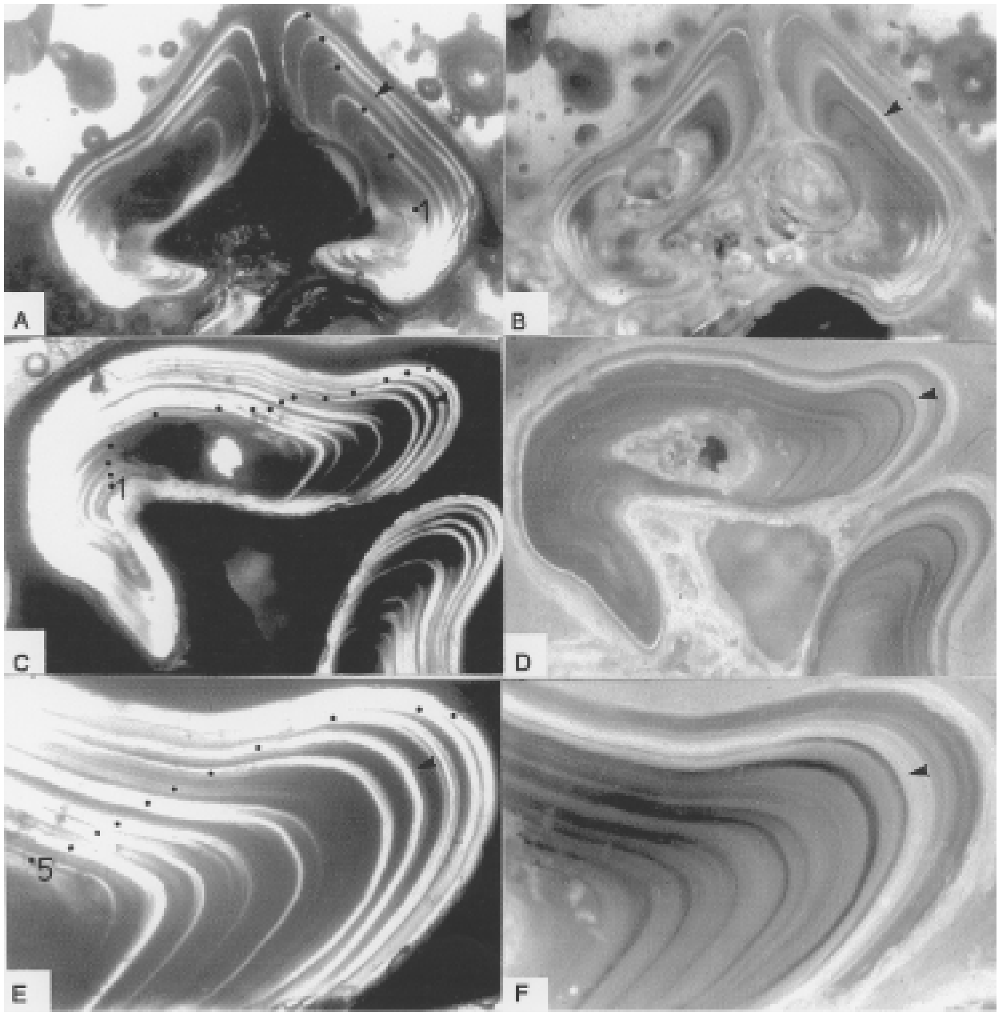

Figure 2

Annuli are indicated by dots, OTC (oxytetracycline) mark indicated by arrow. A, C, E were photographed by using white light and B, D, F were photographed by using ultraviolet light. (**A** and **B**) Fish numbered B8223905 at liberty for 2 years, with OTC mark evident after fourth annulus. Total age was 6+. (**C** and **D**) Fish numbered B8227766 at liberty for 3 years, with OTC mark evident after twelfth annulus. Total age was 15+. (**E** and **F**) Enlargements of sections C and D after the fifth annulus.

Between 1983 and 1986, 1002 tagged lingcod were recovered. From these, 460 lingcod fin rays were obtained for age determination validation: 348 recovered in 1983, 65 recovered in 1984, 43 recovered in 1985, and 4 recovered in 1986. The number of observed annuli after the OTC marks corresponded well to the number of expected annuli based on the number of years at liberty (Table 1). Lingcod recovered in 1983 were expected to have one annulus after the OTC mark and approximately 94% of the samples were estimated to have one annulus. Lingcod recovered in 1984, 1985, and 1986 had estimated annuli after the OTC mark that corresponded to the expected number of annuli in 92%, 91%, and 75% of the samples, respectively.

In most cases, the presence of the OTC mark was easily discernible and appeared as a crisp distinct line. Annuli following the mark were also clearly visible. Fish numbered B8223905 was recovered in July 1984 and aged at 6 years. The OTC mark formed just beyond the fourth annulus (Fig. 2A) and was obvious under ultraviolet light (Fig. 2B). After the OTC mark, two complete annual growth zones were present corresponding to the two years at liberty. Each annual growth zone consisted of an opaque (summer) and a translucent (winter) zone. The OTC mark at the beginning of the summer opaque zone (Fig. 2A) indicated that growth had just begun prior to tagging and injection in July.

Fish numbered B8227766 was recovered in July 1985 and aged at 15 years. As with fish B8223905, the OTC mark was also formed at the beginning of an opaque zone but was a broad band covering the whole summer zone

Table 1

The number of estimated annuli after the OTC mark versus the expected annuli based on years at large. Numbers in bold indicate those samples in which the number of observed annuli equaled the number of expected annuli.

	Expected annuli			
Estimated annuli	1	2	3	4
0	3	1	—	—
1	**328**	3	—	—
2	16	**60**	—	—
3	1	1	**39**	1
4	—	—	4	**3**

Figure 3

Fish numbered B8224635 had resorbed (R) central portion of the fin ray, making identification of the first two annuli (arrows) difficult. Subsequent annuli are indicated by dots. Total age was 9+.

(Fig. 2C) and clearly visible with ultraviolet light (Fig. 2D). This fin ray had three annual growth zones after the OTC mark, each comprising opaque and translucent zones (Fig. 2C). An annual growth zone can contain several distinct translucent zones, i.e. checks. In this example, the tenth labelled annulus did not appear to be continuous and could, therefore, be interpreted as a check (Fig. 1, E and F). Although this area likely contained checks, the thickness and prominence of the labelled translucent zone around most of the fin-ray section (Fig. 2C) indicated that it was the edge of the tenth annulus.

Fish numbered B8224635 was recovered in July 1985 and was estimated to be 9 years old (Fig. 3). Unlike the previous two examples, the first two annuli were difficult to determine because of resorption in the central portion of the fin ray (Fig. 3). We used the diameter measurement criteria of Chilton and Beamish (1982) to locate the first and second annuli.

The 46 juvenile lingcod available from the creel survey in 1987 were used for first and second annular measurements. The mean first annular diameter was 0.40 mm (SD=0.07) and the mean second annular diameter was 0.63 mm (SD=0.11). With one exception, there was no overlap between the measured diameter for the first annulus and those measured for the second annulus and the two means were significantly different (t-test, t=17.46, df=86, P<0.0001). The mean annular diameter did not vary across the range of fork lengths observed (Fig. 4).

Ages determined by using average diameter for the location of first and second annuli measured in the late-1980s were generally one year older than ages determined without using a measurement to locate the first two annuli (Fig. 5). There appeared to be no trend related to age. However, across all ages, the unmeasured estimates ranged from three years younger to three years older than estimates made with the measurement criteria (Fig. 5). This result is likely due to the exclusion of annuli that cannot be recognized or due to the inclusion of checks, mistaken as annuli, in some fish. There was no difference in the number of annuli estimated after the OTC mark. The one-year aging bias is illustrated in the age composition for the lingcod recovered in 1983 (n=341). The age composition for the ages determined with the measurement criteria had a mode of 6 years, whereas the age composition for ages determined without the measurement criteria had a mode of 5 years (Fig. 6). For all of the samples, the estimated ages ranged from three to 18 years.

Discussion

Accurate age determination is essential for proper stock assessment and fisheries management. Although aging inaccuracies of one year might not be critical in long-lived species (e.g. 80-year-old rockfish), they can have serious stock assessment implications for shorter-lived species, such as lingcod. This is likely true because shorter-lived species typically have only four or five year classes that dominant the fishery. It is therefore important to develop accurate methods for age determination and to validate those methods. The fin-ray method first described by Beamish and Chilton (1977) is an accurate method for age determination of lingcod. Annular growth is represented by an opaque (summer growth) and a translucent (winter growth) zone and the edge of the annulus is assigned to the translucent zone (Beamish and Chilton, 1977). Using

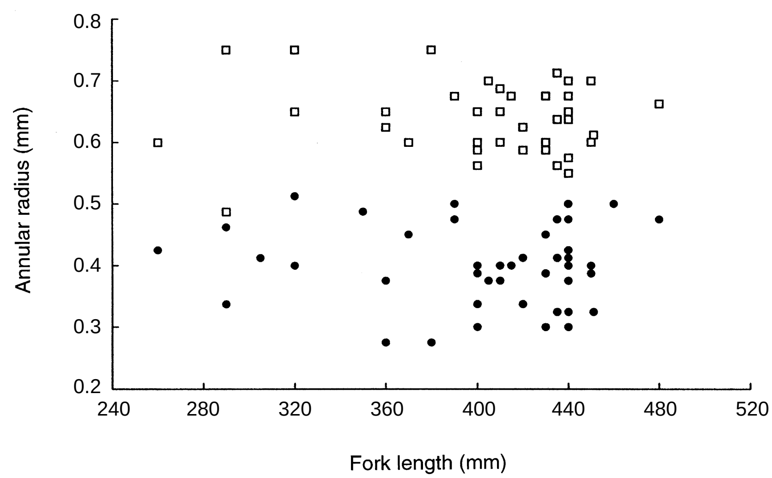

Figure 4

The mean diameter of the first (circles) and the second (squares) annuli are 0.40 mm and 0.62 mm, respectively. The mean diameters do not show a change in value across the fork lengths observed.

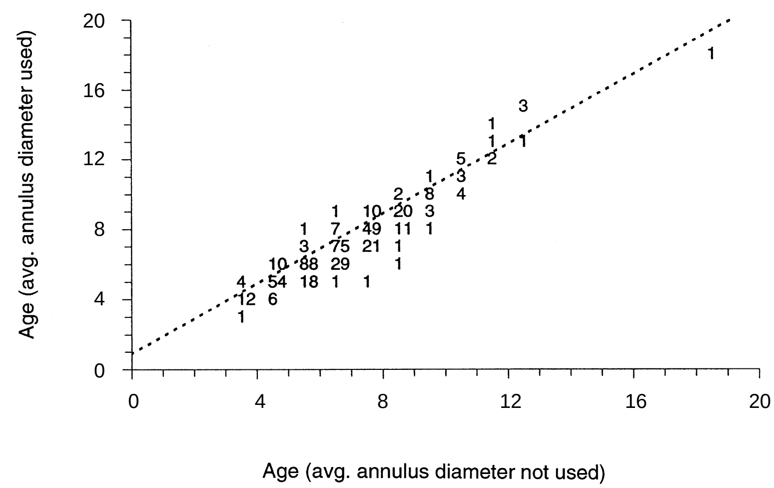

Figure 5

For all recovered lingcod, the ages determined when average annulus diameter measurements were used to estimate the location of the first and second annuli were approximately 1 year greater than ages determined when average annulus diameter measurements were not used (i.e. intercept on regression line=1). Because many data points overlapped, numbers indicate the number of observations at each point.

this method in our validation study, we found that in most cases the number of annuli estimated after an OTC mark corresponded to the number of expected annuli based on years at liberty.

Lingcod, and other species, resorb the central portion of their fin rays, making the identification of the first few annuli difficult in older fish (Beamish and Chilton, 1977). In order to obtain the most accurate ages, mean annular diameter measurements should be used routinely to locate the first and second annuli. We found no significant overlap between the first and second annular diameter measured in juvenile lingcod. It is therefore a useful criterion for age determination and can be used for lingcod inhabiting waters off the coast of British Columbia. The fin-ray method for age determination is routinely applied to other species (Beamish, 1981) and we suggest investigators examine similar criteria to ensure the identification of the first few annuli.

Consistent use of mean annular diameter for age determination of lingcod will enable the best estimation of ages. We have illustrated that when the established criteria are not applied to identify the first few annuli, systematic underaging of approximately one year occurs—a serious consequence for stock assessment. For example, underestimates of age would overestimate mortality rates. If managers set fishing mortality equal to natural mortality (i.e. $F=M$) to estimate fishery yields, then overfishing would result (Tyler et al., 1989). If recruitment were estimated from a catch-at-age analysis, erroneous age composition and overestimates of mortality would lead to gross overestimates of recruitment (Tyler et al., 1989).

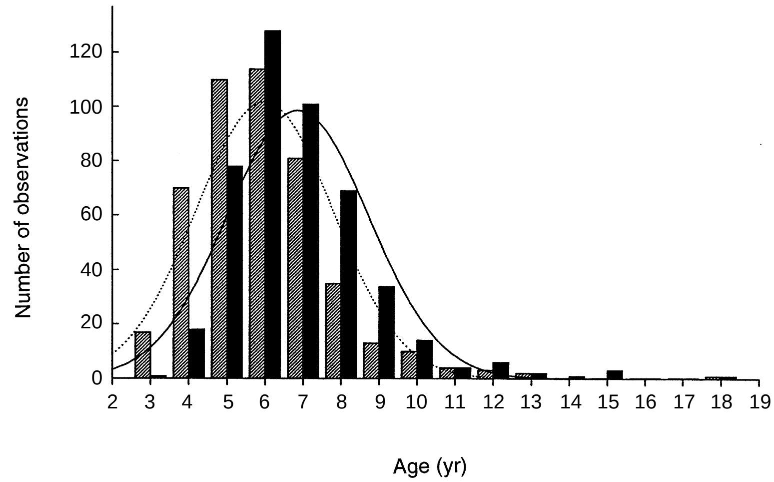

Figure 6

Age composition for the 341 lingcod recovered in 1983 when no measurements were used to estimate location of first and second annuli (striped bars) and when average measurements were used to estimate their location (solid bars).

Recently, rapid and major shifts in marine ecosystems have been shown to have consequences for the biology and behavior of a large number of fish species (Beamish et al., 2000). These shifts can occur within a year; therefore it might be expected that growth of some species could change rapidly because of environmental effects. Examination of growth time series would likely indicate a change coincident with environmental changes. However, we have illustrated that a rapid change in a growth time series can also be the result of the change in aging criteria. Therefore, for age determination to be valid and effective in fishery and ecosystem research, the criteria used should be routinely reviewed and verified.

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