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ANALYSIS OF MATURITY IN LINGCOD, *OPHIODON ELONGATUS*

KELLY R. SILBERBERG, THOMAS E. LAIDIG,
PETER B. ADAMS
National Marine Fisheries Service
Southwest Fisheries Science Center
Santa Cruz Laboratory
110 Shaffer Rd
Santa Cruz, California 95060

and

DOUGLAS ALBIN
California Department of Fish and Game
19160 South Harbor Drive
Fort Bragg, California 95437

Lingcod, *Ophiodon elongatus*, maturity data from northern and central California commercial catch samples were analyzed to determine maturity patterns including length and age at 50% maturity and seasonal patterns in maturation of gonads. Female lingcod attained 50% maturity at 557 mm fork length (FL) and 3.8 years. Males attained 50% maturity at 461 mm FL and 3.2 years. Females matured over a range from 437-725 mm FL and 2-8 years of age, while males matured over a range from 390-664 mm FL and 2-7 years. The abundance of females with mature ovaries began to increase in October, prior to the spawning period, peaked in January, then declined through February. Spent females were most abundant during February and March, directly following the peak spawning period. Ripe males began to appear in September and increased in abundance through March.

INTRODUCTION

Lingcod, *Ophiodon elongatus*, off Washington, Oregon, and California have declined to less than 20% of the numbers considered needed for equilibrium populations (Jagielo et al. 1997[1], Adams et al. 1999[2]). This development calls for immediate action

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[1]Jagielo, T., P. Adams, M. Peoples, S. Rosenfield, K. Silberberg, and T. Laidig. 1997. Assessment of lingcod in 1997. *In* Pacific Fishery Management Council. 1997. Appendix: Status of the Pacific coast groundfish fishery through 1997 and recommended acceptable biological catches for 1998: Stock assessment and fishery evaluation. Pacific Fishery Management Council, 2130 SW Fifth Avenue, Suite 224, Portland, OR 97201.

[2]Adams, P.B., E.H. Williams, K.R. Silberberg, and T.E. Laidig. 1999. Southern lingcod stock assessment in 1999. *In* Pacific Fishery Management Council. 1999. Appendix: Status of the Pacific coast groundfish fishery through 1999 and recommended acceptable biological catches for 2000: Stock assessment and fishery evaluation. Pacific Fishery Management Council, 2130 SW Fifth Avenue, Suite 224, Portland, OR 97201.

by resource managers. Lingcod management has been based on limiting the catch to individuals above a set minimum size, a method widely used to protect the reproductive potential of fish populations (Karpov et al. 1995). The first established California size limit for lingcod was 22 in. (which corresponds to 548 mm FL [Laidig et al. 1997]) for sport caught fish in 1981. In 1995, this limit was applied to the commercial fisheries as well (Jagielo et al. 1997[1]). As the abundance of lingcod continued to decline, size limits were increased to 24 inches (in 1998), and 26 inches (in 2001) for both sport and commercial fisheries.

Size limits are commonly based on length at 50% maturity. This allows managers to set a size limit at which theoretically 50% of the population should reach sexual maturity, and, therefore, have the ability to reproduce. The size limits used for lingcod in California, however, were based on studies using outmoded methods of age determination (surface aging of vertebrae and otoliths) for lingcod and small sample sizes (e.g., Phillips 1959, Miller and Geibel 1973). To strengthen the basis for a given minimum size limit, the current study examined the maturity of large samples of lingcod from northern and central California using the most recently developed methods to determine age.

METHODS

Data collection began in March 1994 and continued through December 1997. Fish were collected from the commercial bottom trawl and hook and line fisheries. Although samples from 1995-1997 were subject to a 22-in total length size limit (Jagielo et al. 1997[1]), a small percentage of undersized fish were included in landings, allowing for the collection of immature fish of both sexes. The sampling area was confined to northern and central California and ranged from Crescent City to Morro Bay. Random 50-lb batches of lingcod were sampled at dockside. Up to four batches were sampled for each trip per vessel. Data collection for each fish consisted of determining gonad maturity stage, sex, fork length (FL) and, when possible, removal of the dorsal fin rays for age determination.

Stage at maturity was determined by visual observation of the gonads. Five different stages (immature, maturing, mature, spent, and transitional) were used for assessing female maturity and three stages (immature, transitional, and ripe) for males. The maturity stages used were defined by the Washington Department of Fish and Wildlife (WDFW) for male and female lingcod (Table 1). All samplers were trained in the identification of the different maturity stages to reduce error. Female and male lingcod were considered mature if they fell into any of the WDFW stages other than immature. Immature female ovaries were characterized by small size, translucent pink to red color, and no distinguishable eggs present. Immature male testes were characterized by small size, round to thin ribbon shape, and a color ranging from translucent to white.

Ages were determined by examining annuli from cross-sections of dorsal fin rays using the methods described by Laidig et al. (2001). Length classes of 20 mm were used for the purposes of determining length at 50% maturity and percentages of immature and mature fish within different length classes. Length and age at 50% maturity were determined for all samples combined and for just those collected between the months of November through February. Length and age at 50% maturity were estimated using the following logistic equation:

$$P = \frac{1}{1 + e^{-a(f-b)}}$$

where P = proportion mature at length or age x;
a,b = model parameters to be estimated; and
f = fork length (mm) or age (years).

Table 1. Lingcod, *Ophiodon elongatus*, maturity stages as defined by the Washington Department of Fish and Wildlife.

	Stages	Descriptions
Female	Immature	Ovaries are small (1.5-2.0 cm). Color ranges from translucent pink to red. Multiple-veined in appearance. No distinguishable eggs present.
	Maturing	Eggs are visible and opaque. Ovaries are swelling with an orange colored egg mass. The ovary wall may or may not be thickened.
	Mature	Ovaries are swollen with a large, pale, sticky egg mass. The ovaries will appear thickened.
	Spent	Thick-walled ovaries are empty and flaccid. They may appear bloodshot. There may be residual eggs inside the ovary.
	Transitional	Ovaries are thick-walled and firming in early stage, progressing to a thinner-walled, multi-veined condition similar to advanced immature ovaries. Eggs are not distinguishable.
Male	Immature	Testes are small, round to a thin ribbon in shape. Color may range from translucent to white.
	Transitional	Moderate sized testes, firm and compact. The color ranges from brown to mottled white. Flowing sperm is not present.
	Ripe	Testes moderate to large, softening and white. Flowing sperm should be detectable by pressure or visible in cut cross-section.

RESULTS

Sample Information

Data are from 1,899 lingcod (all but 50 fish sampled from the commercial bottom trawl fishery), with females accounting for 67% and males 33%. Samples were collected throughout each year with the main concentration in summer and fall corresponding to the times of increased fishing pressure (Fig. 1). Females ranged from 361-1150 mm in length, and from 1-19 years in age, while males ranged from 360-855 mm, and from 2-13 years. No year or seasonal effects were determined, so data from all years were combined.

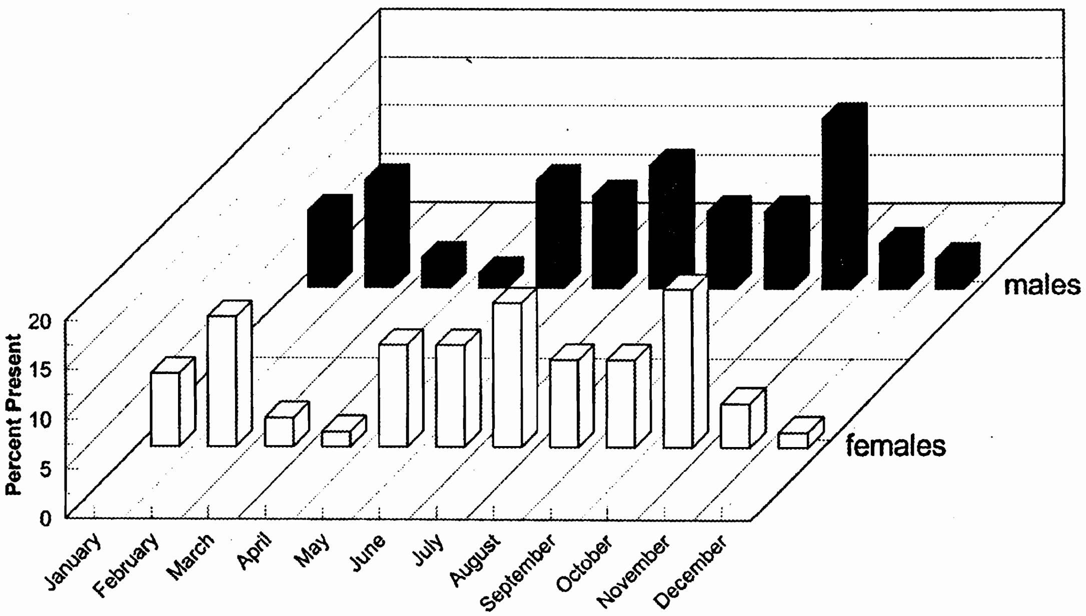

Figure 1. Percent occurrence of male and female lingcod, *Ophiodon elongatus*, samples by month in port samples collected from northern and central California, 1994-1997.

Length at Maturity

Females mature at a greater length than males. The smallest mature female was 437 mm, while the largest immature female was 725 mm (Fig. 2). The female length at maturity relationship increased from an estimated 10% maturity at 452 mm to 50% maturity at 557 mm and to 90% maturity at 661 mm (Fig. 3, parameters given in Table 2). In comparison, the smallest mature male was 390 mm, while the largest immature male was 664 mm (Fig. 4). The male length at maturity relationship increased from an estimated 10% maturity at 324 mm to 50% maturity at 461 mm and to 90% maturity at 598 mm (Fig. 5, parameters given in Table 2). Females reached 100% maturity at approximately 750 mm, while males reached 100% maturity at around 690 mm. The length at 50% maturity for samples collected between the months of November through February was 591 mm for females and 442 mm for males.

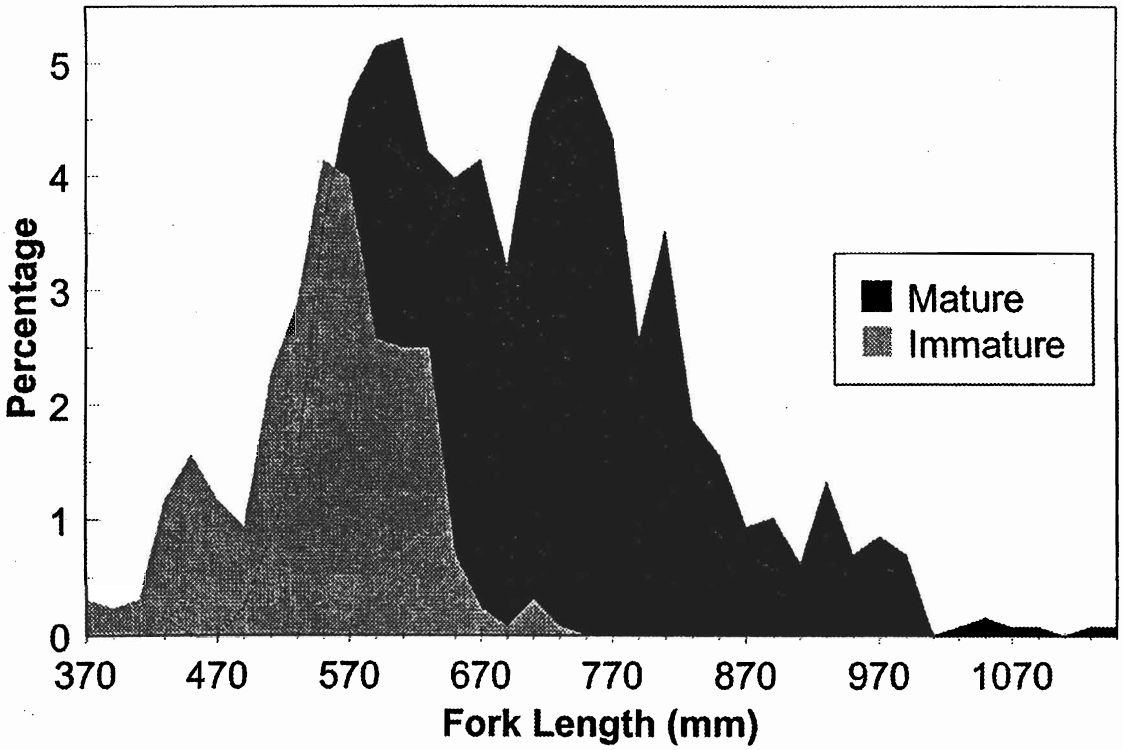

Figure 2. Percentage of immature (n=358) and mature (n=926) female lingcod, *Ophiodon elongatus*, by 20-mm length class from northern and central California, 1994-1997.

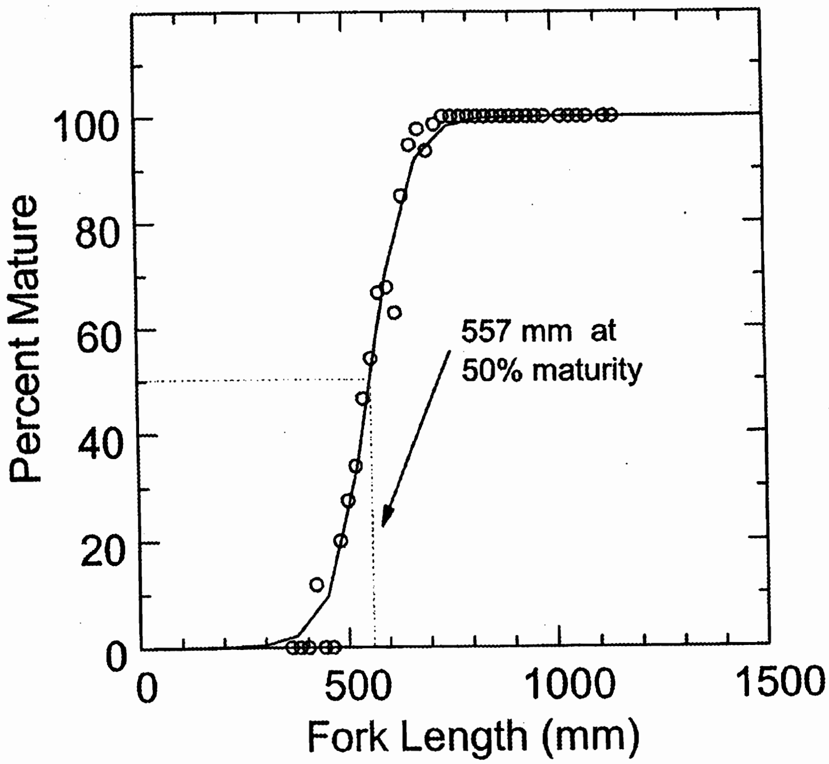

Figure 3. Length at maturity for female lingcod, *Ophiodon elongatus*, (n=1,284) by 20-mm length class from northern and central California, 1994-1997. Circles = actual values; solid line = estimated values; dashed line = length at 50% maturity.

Table 2. Model parameters for lingcod, *Ophiodon elongatus*, fork length and age at 50% maturity estimates.

	Female	Male
Length		
a	0.021	0.016
b	557.318	461.109
R^2	0.994	0.984
Age		
a	1.129	1.240
b	3.814	3.233
R^2	0.994	0.989

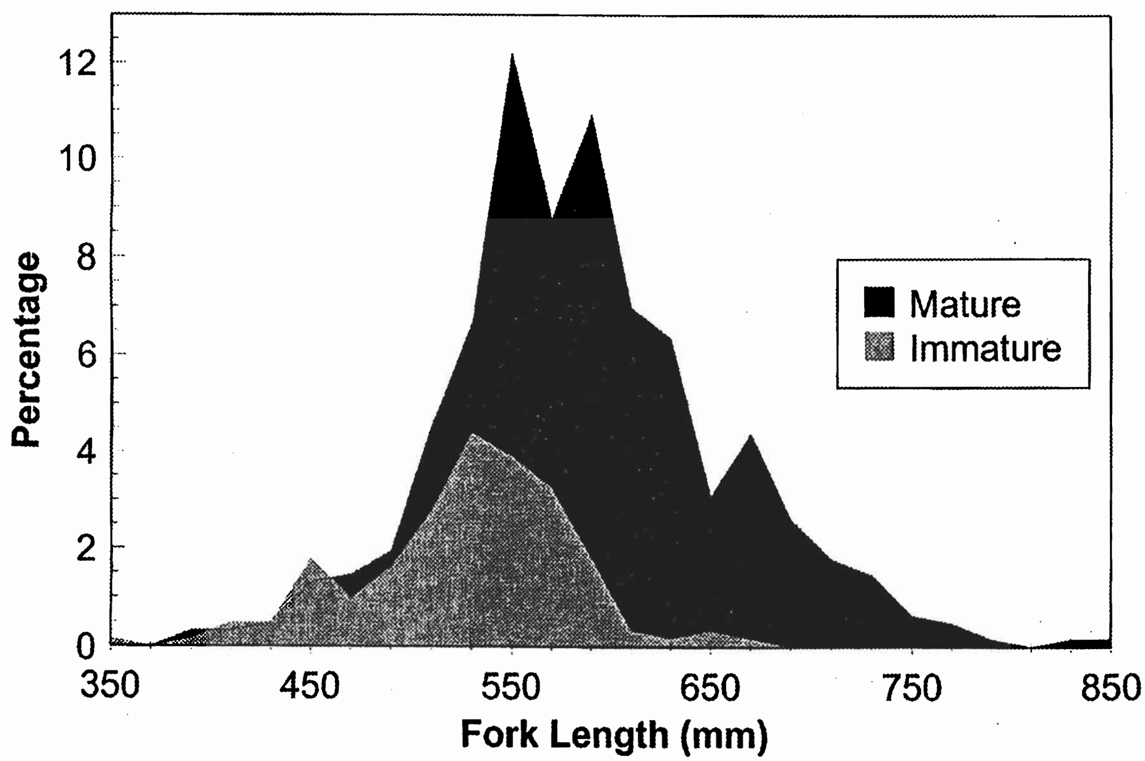

Figure 4. Percentage of immature (n=140) and mature (n=475) male lingcod, *Ophiodon elongatus*, by 20-mm length class from northern and central California, 1994-1997.

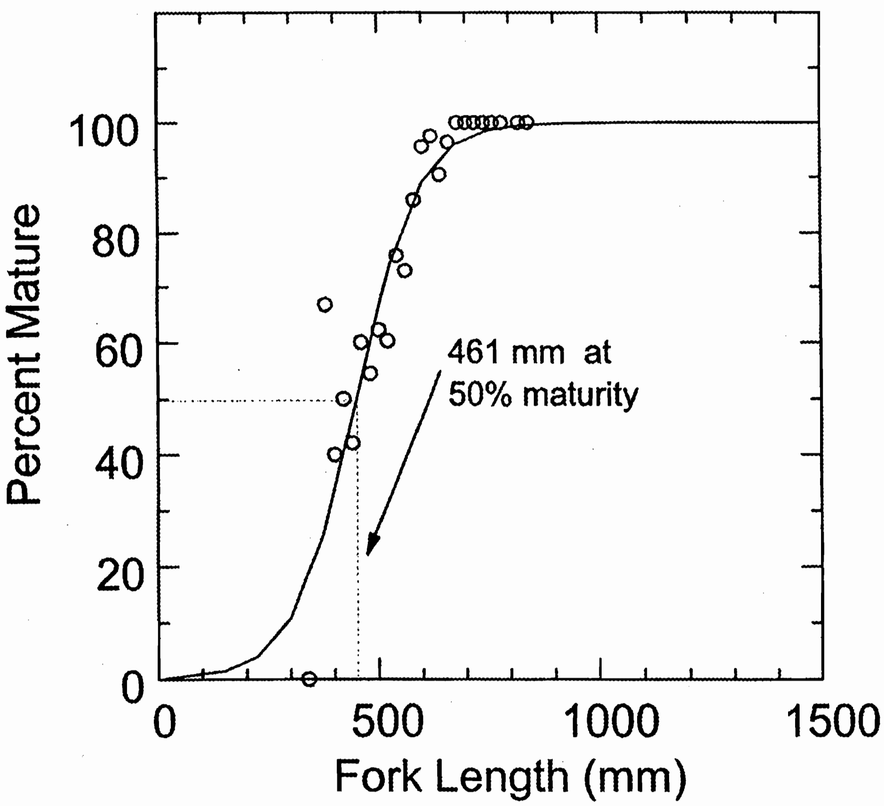

Figure 5. Length at maturity for male lingcod, *Ophiodon elongatus*, (n=615) by 20-mm length class from northern and central California, 1994-1997. Circles = actual values; solid line = estimated values; dashed line = length at 50% maturity.

Age at Maturity

There was less difference between female and male age at maturity than length at maturity, although females matured at slightly greater ages than males. The youngest mature female was two years old, while the oldest immature female was eight years old (Fig. 6). The age at 50% maturity was 3.8 years for females (Fig. 7, parameters given in Table 2). The youngest mature male was two years old and the oldest immature male was seven years old (Fig. 8). The age at 50% maturity was 3.2 years for males (Fig. 9, parameters given in Table 2). Between the ages of three years and eight years, there was a higher proportion of mature males than females. Females reached 100% maturity at nine years of age, while males reached 100% maturity a year younger, at eight years of age. For specimens collected between the months of November through February, the age at 50% maturity was 4.3 years for females and 2.9 years for males.

Seasonality in gonad maturity stage

Mature-stage ovaries began to appear in June, but the percentage of fish observed with mature ovaries increased markedly beginning in October, peaking in January, then

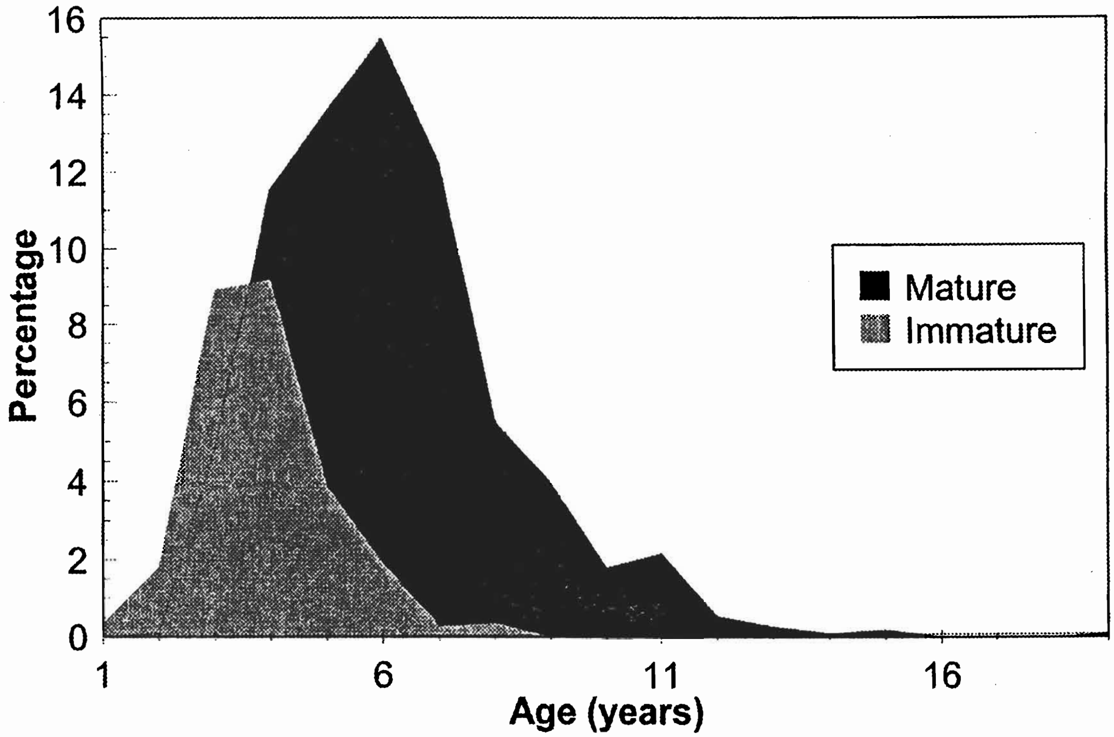

Figure 6. Percentage of immature (n=307) and mature (n=805) female lingcod, *Ophiodon elongatus*, by age from northern and central California, 1994-1997.

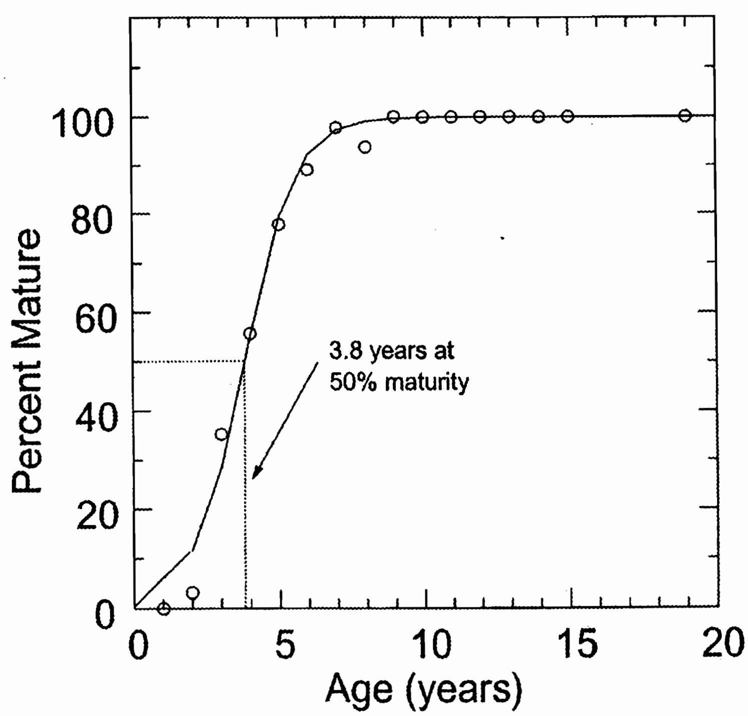

Figure 7. Age at maturity for female lingcod, *Ophiodon elongatus*, (n=1,112) from northern and central California, 1994-1997. Circles = actual values; solid line = estimated values; dashed line = age at 50% maturity.

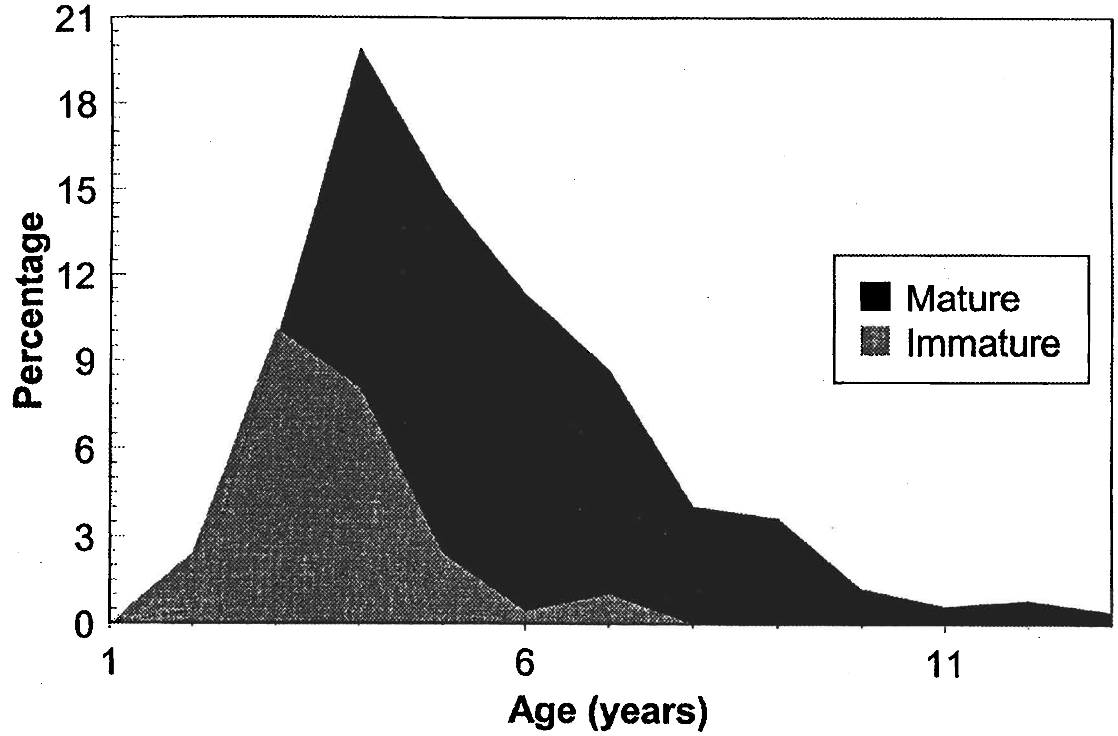

Figure 8. Percentage of immature (n=121) and mature (n=376) male lingcod , *Ophiodon elongatus*, by age from northern and central California, 1994-1997.

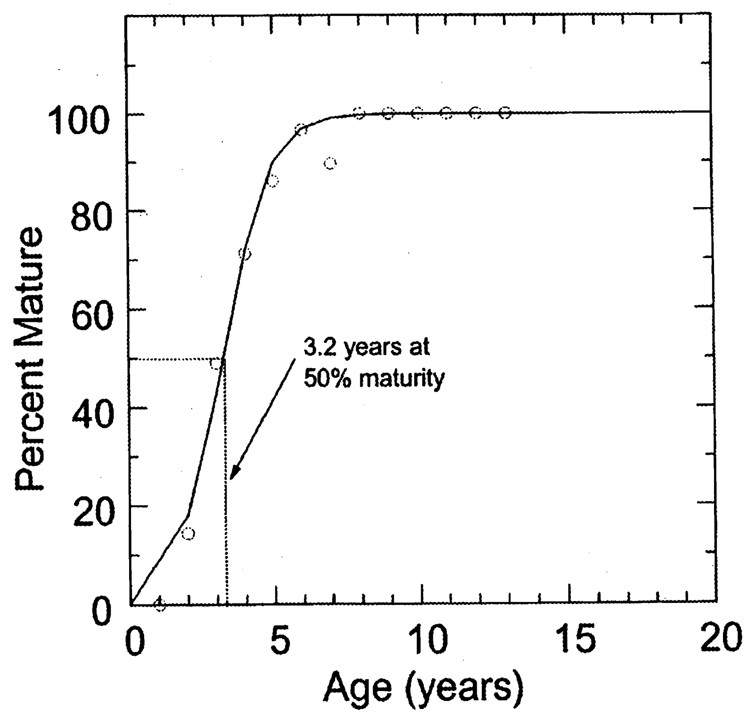

Figure 9. Age at maturity for male lingcod, *Ophiodon elongatus*, (n=497) from northern and central California, 1994-1997. Circles = actual values; solid line = estimated values; dashed line = age at 50% maturity.

declining dramatically (Fig. 10). Spent-stage ovaries were present to some degree throughout most of the year, with the exception of August and December, with the highest frequencies occurring in February and March, directly following the peak spawning period. Transitional-stage ovaries were present throughout the year and immature-stage ovaries were present throughout the year with the exception of December. Ovaries in the maturing stage were present throughout most of the year, but were most prominent during the non-spawning season, particularly from May through September.

Ripe-stage testes began to appear in September and their frequency increased through the end of the spawning period in March (Fig. 11). Immature-stage testes were present throughout the entire year, with a marked increase from April through June. Transitional-stage testes were fairly prominent throughout the year, with a noticeable decline after the peak spawning period from March through June.

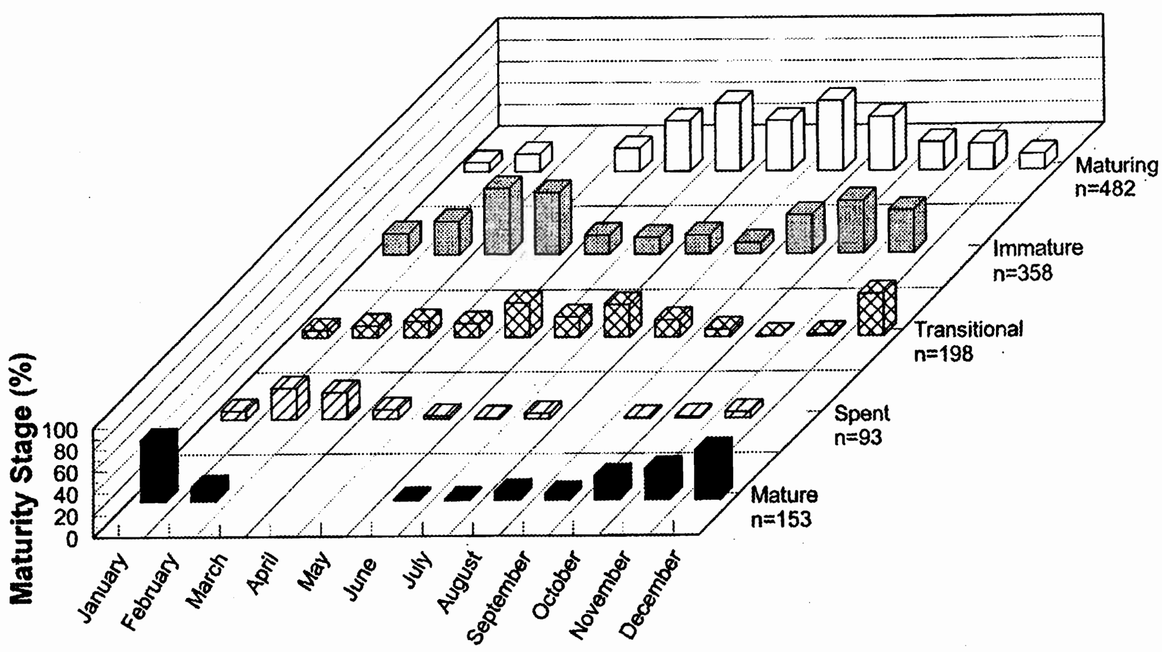

Figure 10. Percent maturity stage by month for female lingcod, *Ophiodon elongatus,* (n=1,284) from northern and central California, 1994-1997.

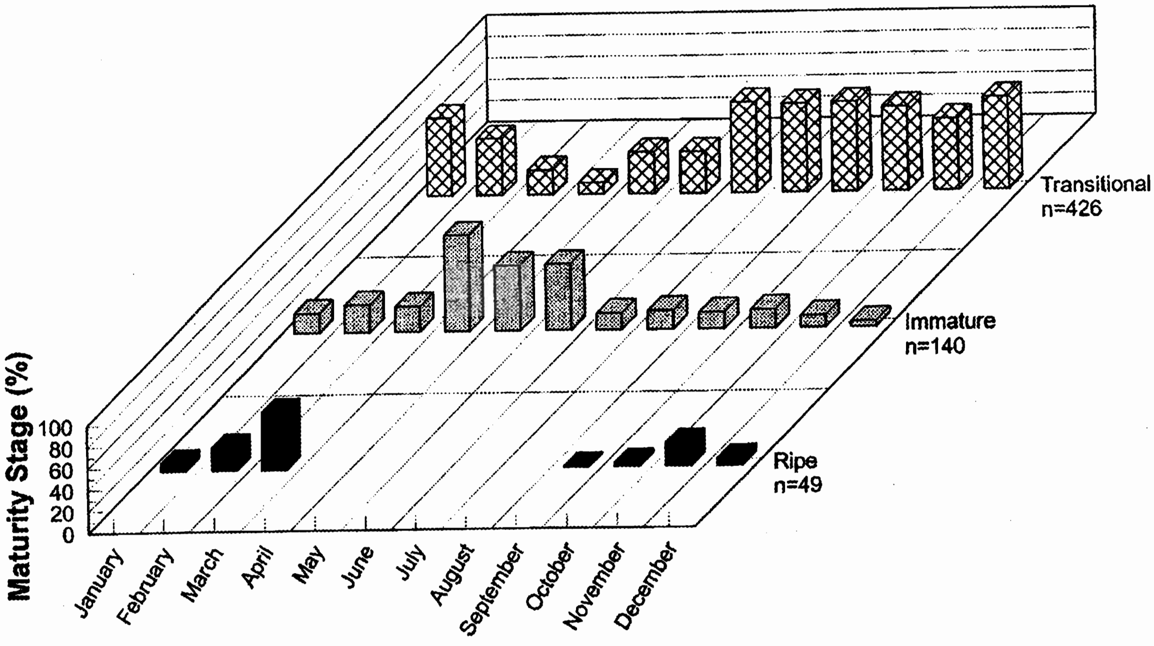

Figure 11. Percent maturity stage by month for male lingcod, *Ophiodon elongatus*, (n=615) from northern and central California, 1994-1997.

DISCUSSION

Lingcod lengths at 50% maturity found here differed somewhat from estimates calculated using earlier data for central California from Miller and Geibel (1973). Estimates of length at 50% maturity from Miller and Geibel's data (n= 291) collected from central California were larger for females and smaller for males, than the values found here (Table 3). Based on our data, 45% of females and 80% of males reach sexual maturity at a size of 22-in (559-mm) TL versus 33% of females and 95% of males based on Miller and Geibel's data. Conversely, at the current 26-in (660-mm) TL size limit, which corresponds to 646 mm FL, data from the current study and from Miller and Geibel's study agree that an estimated 93% of females and 100% of males would reach sexual maturity.

To more accurately compare our data to the time period sampled by Miller and Geibel (1973), the length and age at 50% maturity were calculated using data taken only from the months of November through February. The values for length at 50% maturity for both females and males became very similar between the two studies with a only a 9 mm difference in females and 19 mm difference in males (Table 3). It is interesting that the length at 50% maturity for lingcod remained stable for a period of over 20 years. This occurred while the species was heavily exploited and different size regulations were put in place. The difference in age at 50% maturity may be due to differences in the aging methodology between the two studies. Miller and Geibel (1973) used surface aging of otoliths (which was the best available method at the time) while in this study we examined fin ray cross-sections. The surface aging of lingcod otoliths has been shown to be unreliable by Beamish and Chilton (1977). Therefore, any comparison of age data would be impractical.

Table 3. Estimated fork length and age at 50% maturity for female and male lingcod, *Ophiodon elongatus*, by study area.

Study Area	Female		Male	
	Age (years)	Fork Length (mm)	Age (years)	Fork Length (mm)
Vancouver Island (Richards et al. 1990)	3.9	641	3.5	581
Washington (Jagielo 1994)[3]	4.6	634	3.4	513
Central California (Estimated from Miller and Geibel 1973)	4.7	582	2.2	423
Northern/Central California (current study)	3.8	557	3.2	461
Northern/Central California (current study) November through February.	4.3	591	2.9	442

[3]Jagielo, T. 1994. Assessment of lingcod (*Ophiodon elongatus*) in the area north of 45° 00' N (Cape Falcon) and south of 49° 00' N in 1994. Appendix I. *In* Pacific Fishery Management Council. 1994. Appendix: Status of the Pacific coast groundfish fishery through 1994 and recommended acceptable biological catches for 1995: Stock assessment and fishery evaluation. Pacific Fishery Management Council, 2130 SW Fifth Avenue. Suite 224, Portland, Oregon 97201.

Differences in length and age 50% maturity between year-round sampling and sampling during spawning times may be due to both sampling design problems and biologic factors. In this study, most samples came from the commercial trawl fishery which tends to fish in deeper water. Lingcod have been shown to have a seasonal migration pattern where mature males and females move into shallow water to spawn. After spawning, the females move back into deeper water, while the males remain to guard the nest. After hatching, a segment of mature males remains in shallow water. Therefore, during the spawning season, trawl samples could be biased toward immature females and males, while shallow-water sampling could be biased toward mature fish. Since trawl sample data was primarily used here, a year-round sampling program was used in an attempt to alleviate the bias from spawning migrations. This bias may actually be slight, however, because the difference between our lengths at 50% maturity for samples collected between November and February were similar to those of Miller and Geibel (1973) collected from commercial passenger fishing vessels (CPFV) over the same time period. Since the CPFV samples are typically caught in shallower water than trawls, a difference would be expected between the two sampling methods. However, only slight differences were found. This, then, shows that the bias in sampling method was low.

Many sampling differences exist between this study and the Miller and Geibel (1973) study, which may explain the inconsistencies in length at 50% maturity. The sample size used for this study was six times larger, and samples were collected over a broader geographical range than for the Miller and Geibel data, which were collected only from Monterey and Morro Bays. Furthermore, maturity criteria varied between the two studies. Miller and Geibel's maturity classification included only "near spawning," "spawning," and "spent" individuals. Maturity classes used here were based on the WDFW maturity stages for lingcod (Table 1), and for the purposes of this study fish from all maturity stages except immature were considered to be mature individuals. It is difficult to distinguish between immature and transitional maturity stages and this may have led to errors in the proportions of gonads assigned to these stages. An examination of gonadal histology throughout the year would resolve this problem.

Lingcod length at 50% maturity decreased from north to south for both females and males, but there was no corresponding trend in age at 50% maturity (Table 3). Female length at 50% maturity decreased from 641 mm for Vancouver Island to 557 mm for California. Similarly, for males, length at 50% maturity decreased from 581 mm for Vancouver Island to 461 mm for California. A similar decreasing north to south trend was observed for lengths of the smallest mature fish. Length of the smallest mature female was 700 mm (Forrester 1973) and 768 mm (Wilby 1937) for fish from Canadian waters, while it was 437 mm for California-caught fish. Length of the smallest mature male was 460 mm (Forrester 1973) and 520 mm (Wilby 1937) for Canada and 390 mm in California. Similar latitudinal trends have been observed for rockfish, genus *Sebastes* (Haldorson and Love 1991).

The concept of size at 50% maturity has been used for many species ranging from tanner crabs (Somerton and Donaldson 1996) to Puget Sound rockfish (Beckman et al. 1998) to red drum in the Gulf of Mexico (Wilson and Nieland 1994). The use of the size at 50% maturity ensures that 50% of the population will not be subject to fishing mortality and will have the opportunity to reproduce. Any minimum size limit above the 50% level would allow a greater proportion of the population to survive until spawning. At the current size limit of 26 inches (660 mm FL) in California, all of the male lingcod and all but 3 % of the females will have reached sexual maturity. With this increased reproductive capacity for lingcod, more successful spawning should occur which will give the population a better chance to rebuild.

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