Abstract.–Kelp bass, *Paralabrax clathratus*, and barred sand bass, *P. nebulifer*, are major components of the nearshore marine environment in the southern California Bight. Both species are also very important parts of the marine recreational fishery. Surveys at King Harbor, Redondo Beach, California, have shown that kelp bass primarily recruit between August and December. In general, both kelp bass and barred sand bass numbers increased in King Harbor beginning in the late 1970's and continuing into the 1980's. Male and female kelp bass and barred sand bass grow at the same rates, and growth rates of both species are similar. The oldest kelp bass in our sample was 33 yr old, the oldest barred sand bass was 24 yr old. For kelp bass, 50% of males matured at 22.0 cm; for barred sand bass, 50% of males matured at 21.9 cm. For kelp bass, 50% of females matured at 22.6 cm; for barred sand bass, 50% of females matured at 23.9 cm. In both species, males matured between ages 2 and 4 years and females matured between ages 2 and 5 years.

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Aspects of the life histories of the kelp bass, *Paralabrax clathratus*, and barred sand bass, *P. nebulifer*, from the southern California Bight

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Kelp bass, *Paralabrax clathratus*, and barred sand bass, *P. nebulifer*, are major components of the nearshore marine environment in the southern California Bight.

Kelp bass grow to 72 cm total length (TL) and occur between the mouth of the Columbia River, Washington, and southern Baja California, most commonly from Point Conception, California, southward (Eschmeyer et al., 1983). Distributed from intertidal waters to 59 m (Quast, 1968), most fishes live in 3–25 m (Feder et al., 1974). Although usually associated with substrata, kelp bass will often rise into the water column, well away from structure.

Barred sand bass reach 65 cm (TL) and range from Santa Cruz, central California, to southern Baja California (abundant from Pt. Conception southward). This species is distributed from subtidal water to 183 m (Eschmeyer et al., 1983). Barred sand bass are benthic, relatively sedentary fish which, in contrast to kelp bass, are rarely found more than 3 m above the substratum (Turner et al., 1969; Feder et al., 1974; Larson and Demartini, 1984).

Both species are very important parts of the marine recreational fisheries of southern California and northern Baja California (Rodriguez Medrano, 1993; Ally et al.[1];

[1] Ally, J. R. R., D. S. Ono, R. B. Read, and M. Wallace. 1991. Status of major southern California marine sport fish species with management recommendations, based on analyses of catch and size composition data collected on board commercial passenger fishing vessels from 1985 through 1987. Mar. Res. Div., Calif. Department of Fish and Game, 330 Golden Shore, Suite 50, Long Beach, CA, 90802. Admin. Rep. 90-2, 376 p.

Love et al.[2]). Measured by catch per unit of effort, both species rank annually among the top three species in the commercial passenger fishing vessel catch (Love et al.[2]).

The life histories of these two species are poorly understood. While there is some information on habitat preferences, food habits, and reproduction, summarized in Read (1992) and Ono (1992), data on age and growth as well as size and age at first maturity and recruitment are limited. We describe the age and growth patterns and size and age at first maturity relationships for kelp bass and barred sand bass in the southern California Bight. In addition, we provide information on recruitment of kelp bass to a nearshore southern California reef.

Methods

Recruitment and annual abundance

Since 1974, we have used 5-min isobathic diver transects at 3-m depth intervals between 1.5 and 15 m at 8 stations along the breakwater in King Harbor, Redondo Beach, California (Fig. 1) to estimate fish abundance by life history stage. During these transects, divers swam along the vertical face and counted all fishes in a 3-m deep band (1.5 m above and below the diver). Outer harbor transects were 254 m in length, inner ones were 208 m long. Transects were swum monthly in 1974 and 1975 and quarterly after 1976. For the years after 1975, this survey yielded 96 transects per year (8 stations and 3 depths surveyed quarterly).

We obtained data on month of recruitment for kelp bass from 1986 to 1992 by conducting a monthly survey along the inner wall of the Redondo Beach breakwater and along a rock groin within the inner harbor. Three divers (at depths of 0–3, 4–6, and 7–10 m) swam parallel transects along approximately 500 m of rock and closely inspected bottom cover, crevices, and algae for newly settled fishes (Pondella and Stephens, 1994). The survey along the inner rock groin was similar, except that only two divers swam transects (one shallow, one deep), because of the shallower (1–4 m) location. Fishes ranging from 1.5 to 2.0 cm were considered newly recruited. Juveniles were considered to be those fish from 2.1 to 10.0 cm, and subadults ranged from 10.1 to 15.0 cm. Barred sand bass do not recruit from the plankton to the rocky substrate of King Harbor.[3]

[2] Love, M. S., A. Brooks, and J. R. R. Ally. 1996. An analysis of the commercial passenger fishing vessel fisheries for kelp and barred sand basses (*Paralabrax clathratus* and *P. nebulifer*) in the southern California Bight. In review.

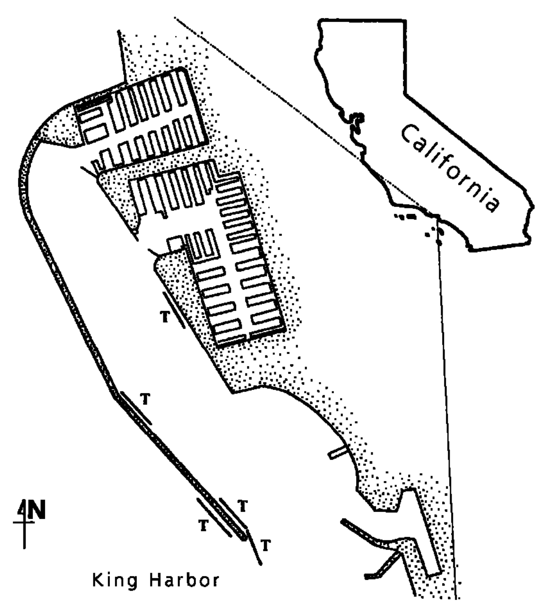

Figure 1
Location of underwater transect sites (marked with a "T"), King Harbor, Redondo Beach, California.

Age and growth

Between 1978 and 1992, we collected kelp and sand bass throughout southern California waters by using hook and line as well as pole spear. These samples were supplemented by fish from commercial passenger fishing vessel (CPFV) catches, from kills at coastal power plant intakes (water heat treatments), from experimental gill-net studies, and from California Department of Fish and Game wardens. Data collected from all fishes included total length, sex, capture location, and collection date. We ascertained whether the fish were mature or not by an inspection of their gonads during spawning season. We also collected otoliths from each fish. In cases where standard lengths were recorded, we converted these to total lengths by using length conversions (Table 1).

Otoliths were embedded in plastic and sectioned prior to being read. We made an embedding mold from 3/4-inch pvc pipe with stoppered ends, cut in half longitudinally. A thin layer of resin (1/4 inch thick) was poured into the mold and allowed to harden. The otoliths were then placed into the mold with a label containing an identification code and

[3] Pondella, D. 1995. Department of Biology, Occidental College, 1600 Campus Rd., Los Angeles, CA 90041. Personal commun.

Table 1

Conversions between standard (SL), fork (FL), and total lengths (TL) for kelp bass (*Paralabrax clathratus*) and barred sand bass (*P. nebulifer*) (each species, n=100). [As an example, to calculate the total length of a kelp bass of 20.0 cm standard length: $TL = b + m(SL) = 1.41 + 1.20 (20.0) = 24.1$ cm.] Maximum and minimum total lengths used in the these analyses were as follows: kelp bass, 12.7 and 48.5 cm; barred sand bass, 17.8 and 49.4 cm.

	r^2
Kelp bass	
FL = 2.38 + 1.10 SL	0.89
TL = 1.41 + 1.20 SL	0.96
TL = 0.83 + 1.01 FL	0.93
Barred sand bass	
FL = 1.11 + 1.17 SL	>0.995
TL = 0.70 + 1.22 SL	>0.995
TL = 0.46 + 1.05 FL	>0.995

covered by additional resin. After curing, the hardened resin bar was taken from the mold.

We used a Buehler Isomet saw with two low-density diamond blades separated by a thin (0.3–0.5 mm) metal shim to section each otolith. Otolith sections were placed in a 50% solution (by volume) of glycerol in water and cleaned in an ultrasonic bath for 2–3 minutes. After cleaning, sections were dried and stored in labelled plastic bags. Sections were later placed on a glass slide, cleaned with 2–3 drops of toluene, and mounted with enough cytoseal to cover the structures and ensure permanent storage.

Many fishes lay down annually an opaque and a hyaline (translucent) zone in their otoliths. Seasonal variations in calcium deposition may be responsible for this zonation (Irie, 1960). By calculating the percentage of fish with otoliths with opaque margins in our monthly samples, we attempted to validate that the bands were formed annually. It seems reasonable to assume that band deposition was seasonal if the bands were present during one part of the year. Kelp and sand bass do appear to lay down seasonal bands, beginning in spring and continuing into fall (Fig. 2). In both species, the first three annuli were usually readable. The fourth one was often more difficult to distinguish; however, bands subsequent to number four were clear.

Lengths at ages were estimated by direct observation of otolith annuli from 261 kelp bass and 137 barred sand bass. Growth was assumed to be described by the von Bertalanffy growth curve model (von Bertalanffy, 1938):

$$l_t = l_\infty\left(1 - e^{-k(t-t_0)}\right),$$

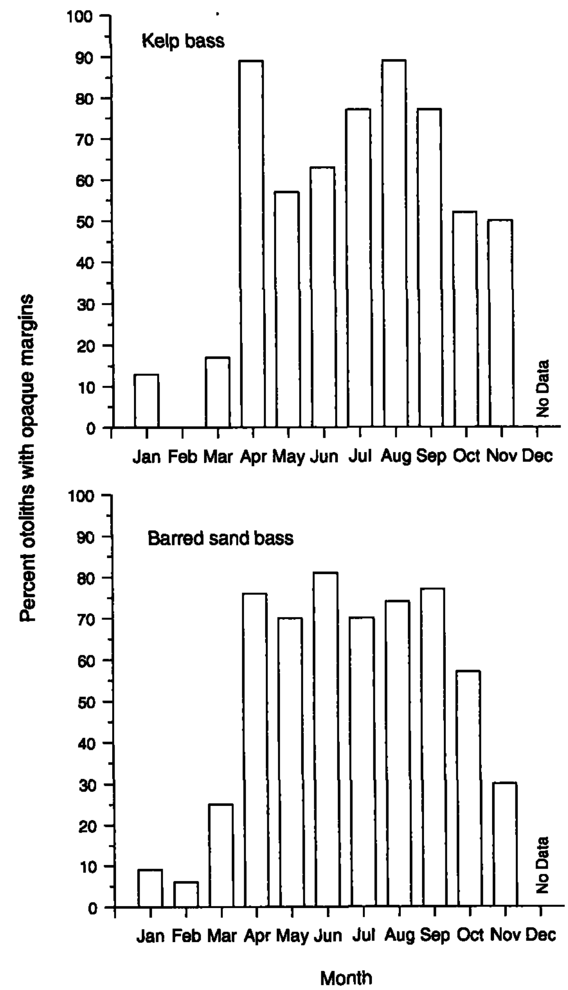

Figure 2

Seasonal deposition of opaque edges in kelp bass (*Paralabrax clathratus*) and barred sand bass (*P. nebulifer*) otoliths from southern California (kelp bass, n =204; barred sand bass, n=238).

where l_t = length at time t;
l_∞ = theoretical maximum length;
k = constant expressing the rate of approach to l_∞; and
t_0 = theoretical age at which $l_t = 0$.

Growth equation constants for the von Bertalanffy growth model were calculated from length-at-age data for each species by using the Marquardt method of iteration in a least-squares, nonlinear regression (SAS, 1988). We were unable to accurately fit these functions separately by sex for either species because of our relatively small sample sizes and, in particular, because of the absence of smaller-size fish that could be unambiguously sexed. We did test the hypothesis that there was no difference between the growth rates of kelp bass and barred sand bass by constructing a "complete" least-squares, nonlinear regression model that fitted the three von Bertalanffy parameters t_0, l_∞ and k separately for each species. We then used an F-test to compare the amount of variance explained by this separate species model with that explained by a "combined-species model," fitting the data for both species to just one set of parameters. A nonsignificant F-value indicated that no significant additional variation was explained by assuming different values for the three von Bertalanffy parameters for each species.

Length and age at first maturity

We sampled kelp and sand bass in July–August 1988–89, July 1991, and June–August 1992. As we have noted previously in rockfishes (*Sebastes* spp., Love et al., 1990), white croaker (*Genyonemus lineatus,* Love et al., 1985), and California halibut (*Paralichthys californicus,* Love and Brooks, 1990), it is often difficult to distinguish immature from mature fishes during their nonreproductive seasons. Thus, we concentrated our sampling on the summer months, well within the spawning seasons of the two species. Most of the sand bass were taken by a 7.6-m semiballoon trawl, by hook and line, or by gill nets between Marina del Rey and San Diego. Kelp bass were taken by hook and line and gill nets between Redondo Beach and Newport Beach and at Santa Catalina and San Clemente islands. Fish were frozen until analyzed, when they were measured (TL) and both sagittal otoliths and gonads were removed. Gonads were examined without magnification to determine sex and gonad state. Annuli from otolith sections were counted under water with a dissection microscope. Sixty-eight male (16–36 cm TL) and 84 female (14–35 cm TL) kelp bass as well as 66 male (12–33 cm TL) and 85 female (13–35 cm TL) barred sand bass were examined.

The relationships between length and maturity and age and maturity were established by using a natural log transformation of the equation

$$p_x = \frac{1}{1+e^{ax+b}}$$

(Gunderson et al., 1980) to yield

$$\ln\frac{(1-1)}{p_x} = ax + b,$$

where p_x is the proportion mature at length or age x, and a and b are fitted parameters. We then plotted x against

$$\ln\frac{(1-1)}{p_x}$$

using simple linear regression (SAS, 1988) to estimate values for a and b. Fifty-percent maturity was calculated by using fitted values of a and b, and by using $p_x = 0.50$ to solve for x.

Results

Recruitment and annual abundance

Kelp bass showed considerable seasonal variation in recruitment at the King Harbor breakwater (Fig. 3). A few newly settled recruits were found in April, more in May, but most were observed during transects conducted in the fall and winter. Surveys of young of the year (YOY), subadult, and adult kelp bass in King Harbor showed a distinct temporal pattern (Fig. 4). Low in the mid-1970's, YOY abundance increased sharply from 1977 to 1979, decreased in the early 1980's, and

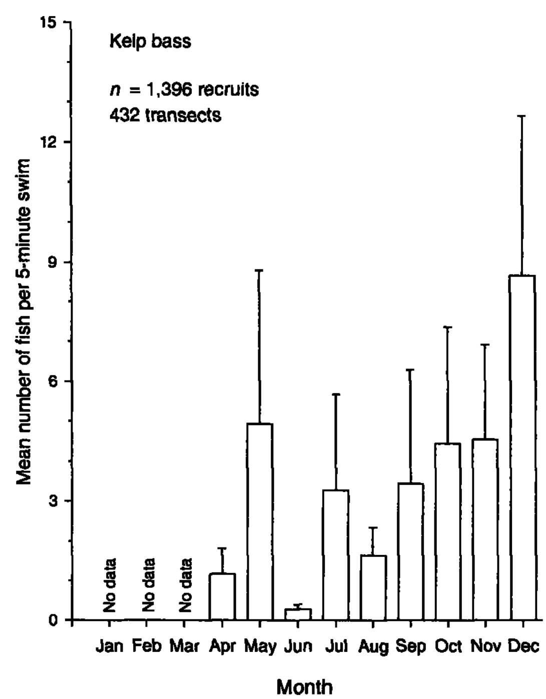

Figure 3
Monthly recruitment of kelp bass, *Paralabrax clathratus,* (1986–92) at the King Harbor (Redondo Beach, California) breakwater. We considered recruitment to any month to have occurred between the 16th day of the current month and the 15th of the next month. Means are based on monthly data from 1986 to 1990. Error bars represent ± one standard error.

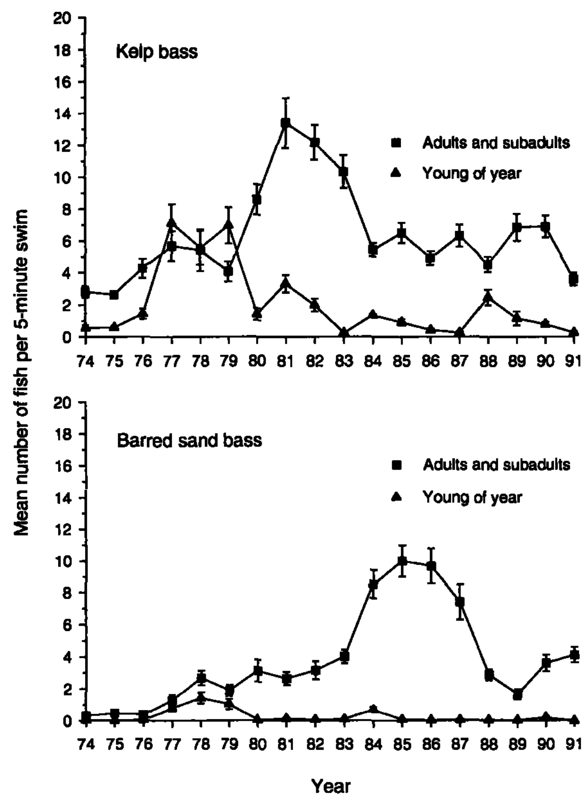

Figure 4
Mean abundance per transect of adults or subadults, or both, and young-of-the-year (YOY) kelp bass (*Paralabrax clathratus*) and barred sand bass (*P. nebulifer*) along the King Harbor (Redondo Beach, California) breakwater 1974–90. Error bars are ± one standard error. Each point represents mean of 96 five-minute diver surveys (8 stations and 3 depths surveyed quarterly).

remained low for the rest of the decade. The abundance of adults and subadults peaked from 1980 to 1983, probably reflecting the successful year classes of the previous few years, then declined somewhat in the mid-1980's. The abundances of barred sand bass at all life stages increased in the late 1970's (Fig. 4). Although the numbers of YOY declined soon after, the population of older fishes increased continuously, reaching a peak in 1985.

Age and growth

For each species, we combined age-at-length data for both sexes. We did this because we were unable to accurately fit the von Bertalanffy growth functions separately by sex because of our relatively small sample sizes and, in particular, because of the absence of smaller-size fish that could be unambiguously sexed. We do not feel that by combining this data undue bias was introduced into our results because the numbers of males and females comprising the combined samples were approximately equal (kelp bass, males = 86, females = 100; sand bass, males = 36, females = 55) and because the separate fits for each sex failed to show a significant difference in growth rates for either species (kelp bass, t=0.059, df=182, P>0.05; barred sand bass, t=0.004, df=87, P>0.05).

We tested the hypothesis that there was no difference between the growth rates of kelp bass and barred sand bass by constructing a "complete" least-squares, nonlinear regression model that fit the three von Bertalanffy parameters t_0, l_∞ and k, separately for each species. We then used an F-test to compare the amount of variance explained by this separate species model with that explained by a "combined-species model," fitting the data for both species to

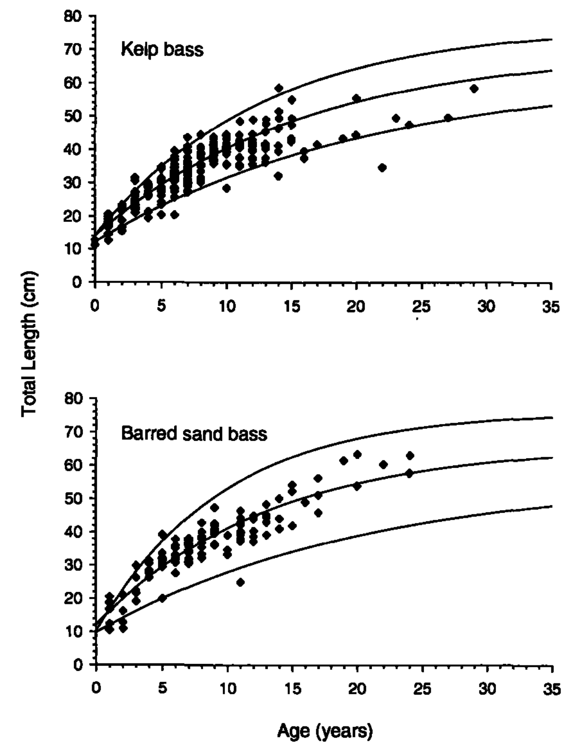

Figure 5

Von Bertalanffy growth curves for kelp bass (*Paralabrax clathratus*) and barred sand bass (*P. nebulifer*) from southern California. Dotted curves are the 95% prediction limits about the von Bertalanffy regression lines.

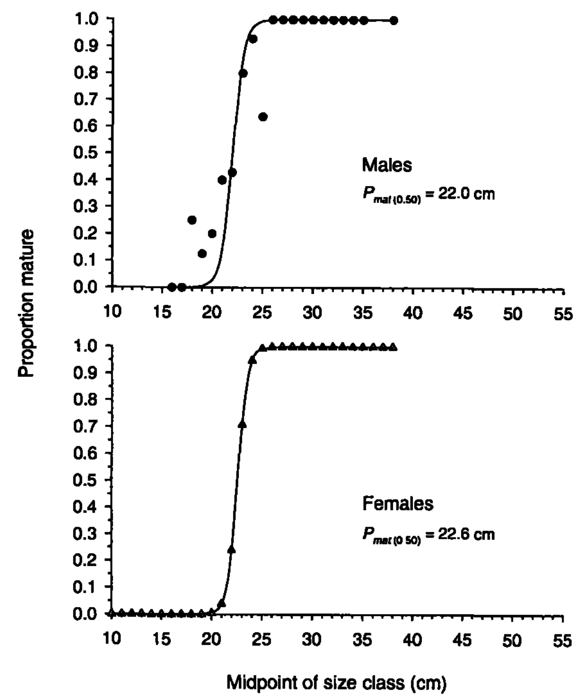

Figure 6

Length-maturity relationships for male (n=68) and female (n=84) kelp bass (*Paralabrax clathratus*) taken in the southern California Bight, including estimated lengths at which 50% of the bass were mature. Solid line represents predicted relationship.

just one set of parameters. A nonsignificant F-value ($F_{3,397}$=0.60, P>0.05) indicated that no significant additional variation was explained by assuming different values for the three von Bertalanffy parameters for each species.

In their early years, both species grew fairly quickly, a few reaching 20 cm TL in their first year (Fig. 5). Growth rates declined at around age 5. The von Bertalanffy parameters for all kelp bass (with standard errors in parentheses) were l_∞=69.8 (3.76), k=0.06 (0.008), t_0=–3.50 (0.48); those for all barred sand bass were l_∞=66.2 (5.08), k=0.08 (0.014), t_0=2.63 (0.63). The oldest kelp bass aged was 33 yr, and the oldest barred sand bass was 24 yr; however, most fish sampled were less than 15 yr old.

Length and age at first maturity

Both male and female kelp bass matured within a relatively narrow length range and at about the same age (Figs. 6 and 7). While a few males and females matured at 18 cm, 50% of males matured at 22.0 cm and 50% of females at 22.6 cm. All males were mature by 26 cm, all females by 27 cm. Males matured between the ages of 2 and 4 years; females between 2 and 5 years.

The smallest mature male barred sand bass that we found were 19 cm, the smallest females were 21 cm (Figs. 8 and 9; Table 2). All males were mature by 26 cm, all females by 27 cm. Length at 50% maturity was 21.9 cm for males and 23.9 cm for females. As with kelp bass, male barred sand bass matured between the ages of 2 and 4 years, and females between 2 and 5 years.

Discussion

Recruitment and annual abundance

In the annual recruitment pattern, kelp bass is a late spring to early fall spawner. Because this species has a pelagic larval phase lasting at least one month (Butler et al., 1982), most of this recruitment pattern would be expected. The peak of recruitment seen in December may represent an artifact of slower win-

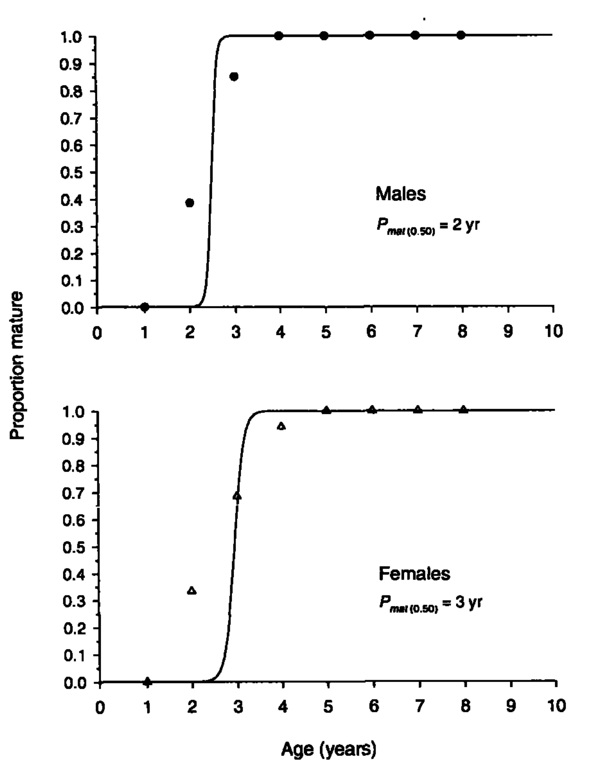

Figure 7

Age-maturity relationships for male (n=68) and female (n=84) kelp bass (*Paralabrax clathratus*) taken in the southern California Bight, including estimated ages at which 50% of the bass were mature. Solid line represents predicted relationship.

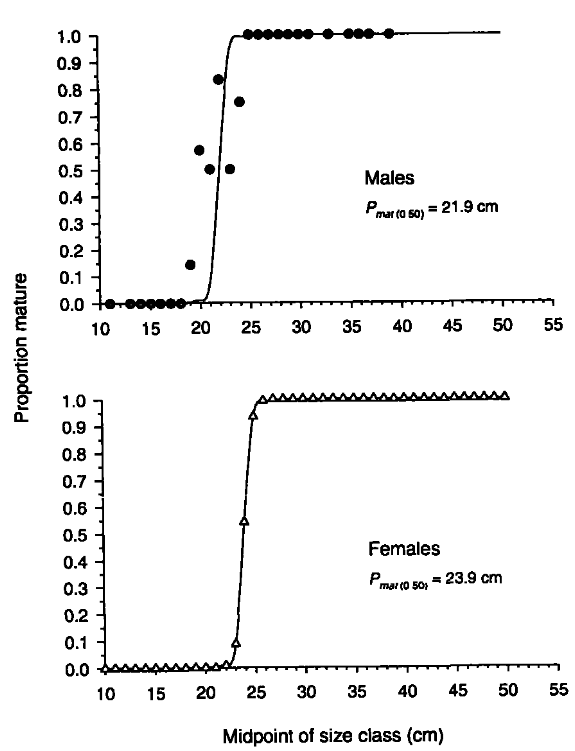

Figure 8

Length-maturity relationships for male (n=66) and female (n=85) barred sand bass (*Paralabrax nebulifer*) taken in the southern California Bight, including estimated lengths at which 50% of the bass were mature. Solid line represents predicted relationship.

ter growth rates. A fish recruited in October may not grow appreciably and, with only length as a criterion, would appear to be a new recruit in December. Barred sand bass recruitment in King Harbor was low throughout the 1980's; the large increase in numbers of older fish was probably due to immigration from outside the harbor.

We believe that the increase in abundance of kelp bass and barred sand bass in King Harbor during the late 1970's and 1980's may be related to a general warming trend of southern California waters during the period (Stephens et al., 1994). A significant increase in catches of both kelp and barred sand bass occurred then throughout the southern California Bight (Love et al.[2]). In fact, the increase in bass populations may have been part of a general alteration of nearshore fish populations, resulting from warming ocean waters. During this period, colder-water species (such as rockfishes) declined in abundance, whereas populations of warm-temperate and subtropical species (including labrids and pomacentrids) increased (Stephens et al., 1986). This trend has also been noted among nearshore pelagic species, such as chub mackerel (*Scomber japonicus*) and Pacific sardine (*Sardinops sagax*) (Barnes et al., 1992).

Age and growth

Although no other study of barred sand bass growth rates is available, some age-length data derived from scales, for kelp bass, have been reported in Young (1963). We compared our age-at-length estimates (from the von Bertalanffy equation) with the mean length at age calculated by Young (Table 3). Except for the very youngest and the very oldest fish, our data sets are similar, particularly at ages 4–7.

The results of our comparison of growth rates of the two species suggest that there is little difference between kelp bass and barred sand bass. We were unable to reject our "combined species" model by fitting the age and length data for both species to one growth curve in favor of our "separate" model which fits the three growth parameters separately for each species.

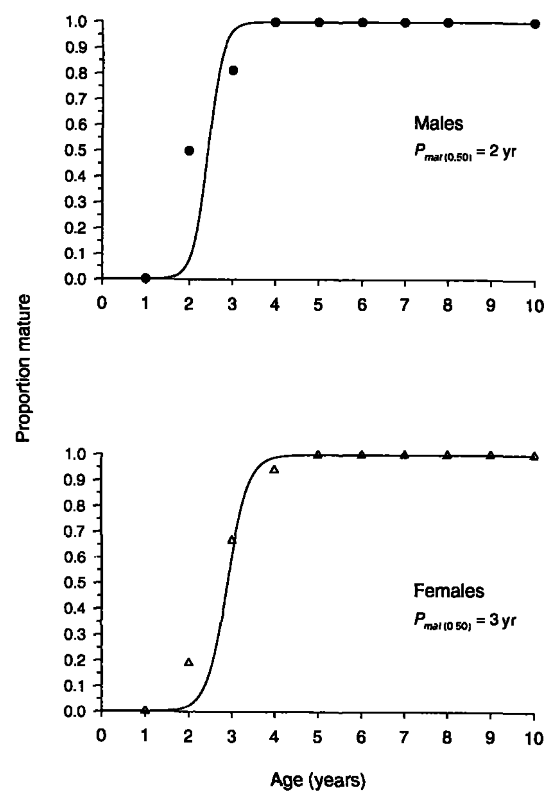

Figure 9

Age-maturity relationships for male (n=66) and female (n=85) barred sand bass (*Paralabrax nebulifer*) taken in the southern California Bight, including estimated lengths at which 50% of the bass were mature. Solid line represents predicted relationship.

Table 2

Maximum-likelihood estimates for the parameters of the logistic equation relating proportion mature to lengths and ages of kelp bass (*Paralabrax clathratus*) and barred sand bass (*P. nebulifer*). Predictive length ($l_{0.50}$) and age ($age_{0.50}$) at 50% maturity and correlation coefficients (r^2) are also presented.

	Length			
Kelp bass	a	b	$l_{0.50}$(cm)	r^2
Males	−1.77	38.88	22.0	0.65
Females	−2.04	46.03	22.6	0.59
	Age			
	a	b	$Age_{0.50}$	r^2
Males	−18.18	45.14	2.0	0.92
Females	−9.56	28.10	3.0	0.86
	Length			
Barred sand bass	a	b	$l_{0.50}$(cm)	r^2
Males	−2.48	54.49	21.9	0.67
Females	−2.50	59.82	23.9	0.68
	Age			
	a	b	$Age_{0.50}$(cm)	r^2
Males	−5.67	13.81	2.0	0.94
Females	−4.11	11.91	3.0	0.91

Table 3

A comparison of kelp bass (*Paralabrax clathratus*) age at length (to the nearest centimeter) up to age 9 in Young's study (1963) with age at length in the current study. Young's data are based on mean length at age for each year in inches and are converted to the nearest centimeter.

Age (yr)	Length (cm) Young's study (1963)	Length (cm) Current study
1	10	16
2	15	20
3	22	24
4	25	26
5	29	29
6	31	31
7	34	32
8	36	34
9	42	36

Since individuals of both species appear to be adequately described by a common age-length relationship, a comparison of size records for each species may provide some insight into their relative longevities. Eschmeyer et al. (1983) reported maximum lengths of 72 cm and 65 cm for kelp bass and barred sand bass, respectively. These lengths suggest that kelp bass may be the longer lived of the two species. Indeed, the oldest kelp bass we found was 33 yr (a new record), the oldest barred sand bass was 24 yr.

Length and age at first maturity

Clark (1933) reported on length at first maturity for kelp bass and barred sand bass taken in the commercial catch and landed at San Pedro. In that study, all kelp bass <25 cm were immature (note that she used fork length [FL]), and she assumed that the "average size at first maturity" was about 26 cm FL. We also found that there was little difference in length at first maturity for the two species. However, if we take "average size at first maturity" to mean length at which 50% of the individuals are mature, our results are somewhat different. On average, our fish were two to four centimeters (depending on sex and species) shorter at maturity. Our results for kelp bass are very similar to those reported by Collyer and Young (1953). Clark also speculated from only a few fish that barred sand bass matured at about the same length as kelp bass.

Kelp bass and barred sand bass matured over an almost identical size and age range. In both species, sexual maturity was reached at a young age and small size, particularly when compared to many of the other large reef species in California. In the eastern Pacific Ocean, kelp and barred sand bass are the most northerly occurring Serranidae, which are typically tropical. In general, tropical fishes tend to mature at a fairly young age and these two subtropical-warm temperate species follow this pattern. The differences between these basses and some other co-occurring species, for instance the many rockfishes (Scorpaenidae) that share habitats with the two basses, is particularly pronounced. Rockfishes are typically cold-temperate species and tend to mature when older and larger, relative to maximum body length. For instance, olive rockfish (*Sebastes serranoides*), which superficially resembles kelp bass and co-occurs with it in the northern part of the southern California Bight, matures between 29 and 39 cm and between 3 and 8 years (Love and Westphal, 1981).

Conversely, the two species exhibit a typically temperate-fish growth pattern (Beverton, 1986); a relatively slow growth rate and fairly long life span. Research on a sympatric congener, the spotted sand bass, *P. maculatofasciatus*, implies that not all *Paralabrax* exhibit this pattern (Allen et al., 1995). Spotted sand bass inhabit backwaters from southern California into the Gulf of California and, compared with kelp bass and barred sand bass, exhibit a typically tropical-species pattern, with a faster growth rate and short (about 12 years) life span.

One possible explanation is that growth rate is more plastic in response to environmental conditions than is reproduction. This would lead to fishes growing more slowly, because of colder conditions in the southern California Bight, but conserving their tropically-derived reproductive schedule.

Acknowledgments

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Larry Allen provided many of the specimens for this study and both he and Chuck Valle critically reviewed drafts of the manuscript. We would like to thank the crew of the RV *Yellowfin*, Jim Cvitanovich, Paul Irving, and Danny Warren, for their good-humored assistance. Michael Franklin, Tom Grothues, Tim Hovey, Ron Klaver, Loretta Roberson, Bob Scott, and Carrie Wolfe collected, prepared, and analyzed many of the fish.

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