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Age and Growth of Two Herbivorous, Kelp Forest Fishes, the Opaleye (*Girella nigricans*) and Halfmoon (*Medialuna californiensis*)

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Abstract.—Opaleye (*Girella nigricans*) and halfmoon (*Medialuna californiensis*) are herbivorous sea chubs (Perciformes: Kyphosidae) that occupy an ecologically important role in kelp forests off southern and Baja California. This study provides information on length-weight relationships, age, and growth of these two ecologically important species. Opaleye and halfmoon were collected from throughout the Southern California Bight to evaluate these life history characteristics. Length-weight relationships were described by the equations $W = 0.00002L^{3.081}$ for opaleye and $W = 0.000003L^{3.454}$ for halfmoon. Sagittal otoliths were used to age opaleye from ages 3–10 and halfmoon from ages 0–8. In addition, age classes 0-II for opaleye were determined from length frequency analysis of preserved specimens. Von Bertalanffy growth curves were fitted to mean standard length (mm) at age for each species. Opaleye were aged up to 10 years whereas halfmoon was recorded up to eight years of age. Standard length-at-age growth curves were typical of nearshore marine fishes with rapid growth in the first few years, reaching an asymptote quickly thereafter. This study demonstrates opaleye and halfmoon are short-lived, fast growing species, and this information combined with other life history characteristics shows the importance of opaleye and halfmoon and the need for ecosystem-based management in kelp forest communities.

Introduction

Age and growth studies are essential for understanding the life history of fishes (Choat and Robertson 2002, King and McFarlane 2003, Pikitch et al. 2004, Depczynski et al. 2007). Furthermore, knowledge of life history patterns (e.g., age structure, diet, reproduction) is an important facet of fisheries science and should be a fundamental component of management strategies (King and McFarlane 2003). Traditionally, fisheries management has utilized life history information for a single species management approach. However, a major flaw of single species management is the lack of consideration of trophic interactions between target species and the non-target species on which the fishery ultimately depend (Pinnegar et al. 2000). In recent years, fisheries management has begun the slow shift towards utilizing ecosystem-based management (Pikitch et al. 2004). Unfortunately, progress has been hindered by several concerns and impediments that come along with this type of comprehensive management approach (Pinnegar et al. 2000, King and McFarlane 2003). One major obstacle to implementing ecosystem-based management is the lack of basic life history information available on

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non-targeted and/or newly exploited species (King and McFarlane 2003, Pikitch et al. 2004). As knowledge gaps of detailed life history information are filled, managers will be better equipped to implement more holistic fishery management strategies.

Opaleye (*Girella nigricans*) and halfmoon (*Medialuna californiensis*) are two of three herbivorous fishes found in the temperate waters of southern California and as adults, are closely associated with kelp forests (Quast 1968, Allen 1985). Of the three southern California herbivorous species, opaleye and halfmoon are the most abundant; therefore, these two species most likely have the ability to greatly influence the kelp forest community. Opaleye range from San Francisco, California to Baja California, Mexico, whereas halfmoon have a slightly more northern distribution ranging from Vancouver, British Columbia to Gulf of California, Mexico (Miller and Lea 1972). Although herbivorous fishes are rare in temperate waters, opaleye and halfmoon most likely play an essential role in maintaining and contributing to the complexities of the kelp forest food web similar to herbivorous fishes in other marine communities. Through constant grazing, opaleye and halfmoon may help maintain the algal balance in kelp forests by preventing an algal take-over, providing disturbance and potential for competition of other algal species and sessile invertebrates, and increasing nutrient input via excretions (Carpenter 1986, Hixon and Brostoff 1996). Additionally, opaleye and halfmoon contribute largely to the productivity of kelp forests communities. The combined annual production of opaleye and halfmoon within kelp forests at Santa Catalina Island is reported as 13.01 g WWt/m^2/yr (Bredvik 2008, Boerger unpub. data) have the potential to provide a significant amount of energy transfer (via predation) throughout temperate kelp forests and other adjacent nearshore communities. Both opaleye and halfmoon are essential to the functioning of kelp forest ecosystems and contribute indirectly and directly to the commercial and recreational fisheries. However, a thorough examination of opaleye and halfmoon life history patterns needed to be conducted before it would be possible to include either of these abundant fishes in the evaluation and management of nearshore fisheries in southern California. The purpose of this paper is to aid in filling the life history information gap by providing the 1) length-weight relationships, 2) age information, and 3) growth rates for these two ecologically important fishes.

Methods

Field Collection

Juvenile opaleye largely inhabit the rocky intertidal (in tide pools) and shallow subtidal areas and were, therefore, not represented in gill nets samples (see below) which provided freshly extracted and dried otoliths for age determination. Therefore, to determine age for young opaleye, we used preserved specimens taken from tidepools at Palos Verdes and Pin Rock, Catalina Island from 1982 to 1984. Larger opaleye were collected from June 2006 through October 2007 and all halfmoon were collected from February 2005 through May 2007 throughout the Southern California Bight (SCB) at several sampling stations (Figure 1). Fish were collected by a variety of means including spear on snorkel and SCUBA, hook and line, dip nets, and gillnets (Allen et al. 2007). Each fish was measured (head length, standard length, and total length) to the nearest millimeter and weighed with varying degrees of precision depending on the size of the fish. Smaller fish from approximately 20-mm SL to 60-mm SL were weighed in the lab with an analytical scale ($\pm$ 0.0001g) and larger fish with a hand held spring scale aboard ship ($\pm$ 1g).

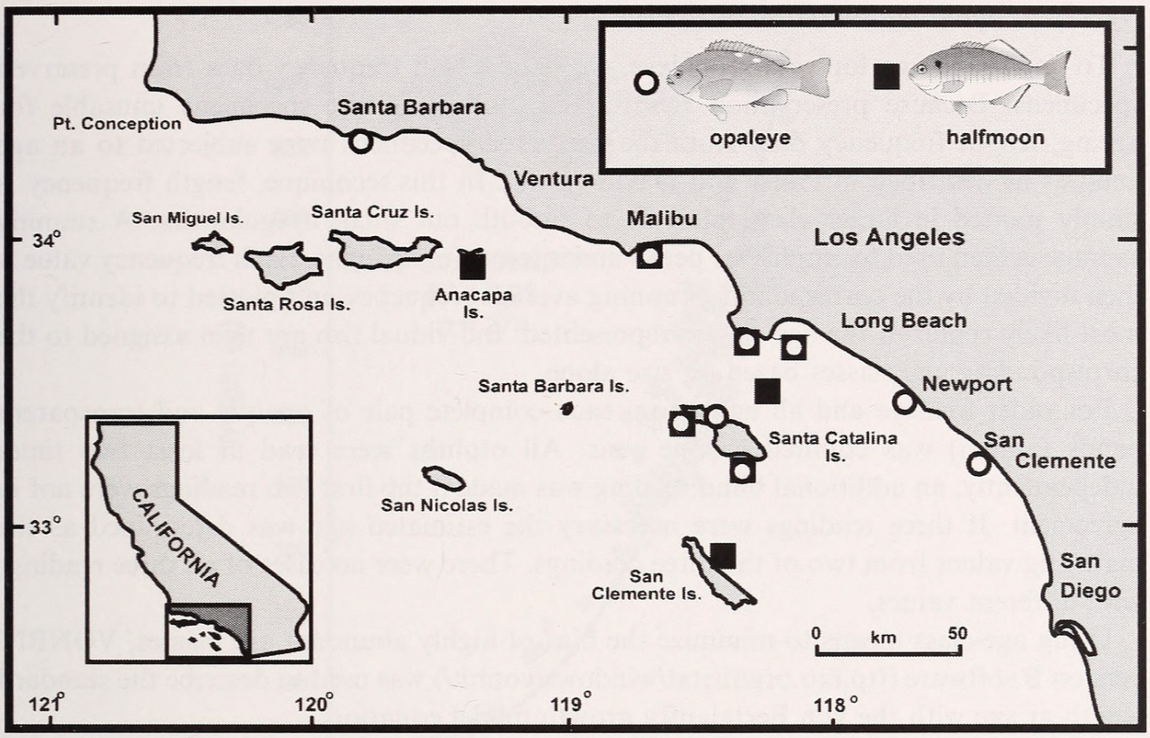

Fig. 1. Map of Southern California Bight indicating locations of field collection sites for opaleye and halfmoon.

Length-Weight Relationships

The length-weight relationships of opaleye and halfmoon were estimated by using the length-weight equation following the method of Ricker (1973) for fitting a nonlinear regression model by least squares. The equation is as follows:

$$W = aL^b$$

where W is total weight (g), L is standard length (mm), and a and b are constants, with values determined by the exponent function subroutine in *Excel* (MS Office 2007).

Otolith Preparation

Following collection of all measurements, sagittal otoliths were extracted, rinsed in distilled water, dried, and stored in small coin envelopes before sectioning. In most cases, the left otolith was used to obtain otolith morphometrics and age unless the left otolith was absent or in poor condition (i.e., broken), in which case the right otolith was used. The length and width of the sagitta was measured (± 0.01 mm) using digital calipers and weighed (± 0.0001 g) using an analytical balance. Each otolith was secured to an individual block of wood (approximately 20 × 10 × 5 mm) using cyanoacrylate glue. After allowing the glue to dry and set (~24 hours) otoliths were sectioned through the focus using a Buehler-Isomet low speed saw. The saw was equipped with two 0.3-mm diamond wafering blades and an acetate spacer which created a 0.75 mm thick transverse otolith section. Otolith sections were removed from the surrounding wood block and ground wet on both sides with 400 grit waterproof sandpaper until sections were approximately 0.5 mm thick, then polished using 600 grit lapping film. Transverse otolith sections were submerged in water in a small watch glass and examined under a dissecting microscope (20–40× magnification) with reflected light on a black background.

Age Determination and Growth Curves

To determine age for young opaleye, we used length frequency data from preserved specimens. Because preservation renders the otoliths of the specimens unusable for ageing, length frequency data from the preserved specimens were subjected to an age analysis as described in Pauly and David (1981). In this technique, length frequency is simply plotted in larger class intervals to smooth out small irregularities. A running average is then used to emphasize peaks and intervening troughs. Each frequency value is then divided by the corresponding running average frequency and plotted to identify the most likely center of the age classes represented. Individual fish are then assigned to the corresponding age classes based on size alone.

For older opaleye and all halfmoon, each complete pair of opaque and transparent bands (annuli) was counted as one year. All otoliths were read at least two times independently, an additional blind reading was made if the first two readings were not in agreement. If three readings were necessary the estimated age was determined as the matching values from two of the three readings. There were no cases of all three readings with different values.

Using age-class means to minimize the bias of highly abundant age classes, VONBIT version B software (ftp.fao.org/fi/stat/windows/vonbit/) was used to describe the standard length at age with the von Bertalanffy growth model equation:

$$L(t) = L_{\infty}\left(1 - e^{-K(t-t_0)}\right)$$

where L(t) is the standard length or weight at age t, L_{∞} is the asymptotic length or weight, K is the growth coefficient, and t_0 is the theoretical age at zero length.

Results

Length-Weight Relationships

The standard length and weight of opaleye and halfmoon collected ranged from 23–310 mm and 20–342 mm, and 0.17–1,147 g and 0.1–2,301 g, respectively. Standard length to total length conversions were TL = 1.221(SL) for opaleye and TL = 1.2366(SL) for halfmoon. The length-weight function for opaleye (n = 279) was calculated as $W = 0.00002L^{3.081}$ ($R^2 = 0.993$) (Figure 2). This relationship for halfmoon (n = 449) was $W = 0.000003L^{3.454}$ ($R^2 = 0.984$) (Figure 3).

Age and Growth

Age classes 0, I, and II were assigned to 216 juvenile opaleye from preserved samples by length frequency analysis (Table 1, Figure 4). Prominent peaks where found centered around the 60–75 mm, 150–180 mm, and 195–210 size intervals representing the Age-0, I, and II classes. Age assignments based on individual lengths yielded sample means of 58 mm SL for Age-0, 150 mm SL for Age-I, and 201 mm SL for Age-II opaleye (Table 1). Overall, 321 opaleye were used to determine age. Opaleye collected throughout the Southern California Bight ranged in age from age-0 (YOY) to a maximum of 10 years. Otolith weight was found to be a significant predictor of opaleye age ($R^2 = 0.69$, $P < 0.001$) and served as an indirect validation of the ageing technique (Choat and Axe 1996, Choat et al. 2009). Individuals used for ageing ranged in length from 24.5–302 mm standard length and in weight from 0.265–1,147 g.

A total of 269 otoliths were readable for the age analysis of halfmoon, yielding eight different size classes ranging from age-0 to eight (no fish were placed in the age-7 class).

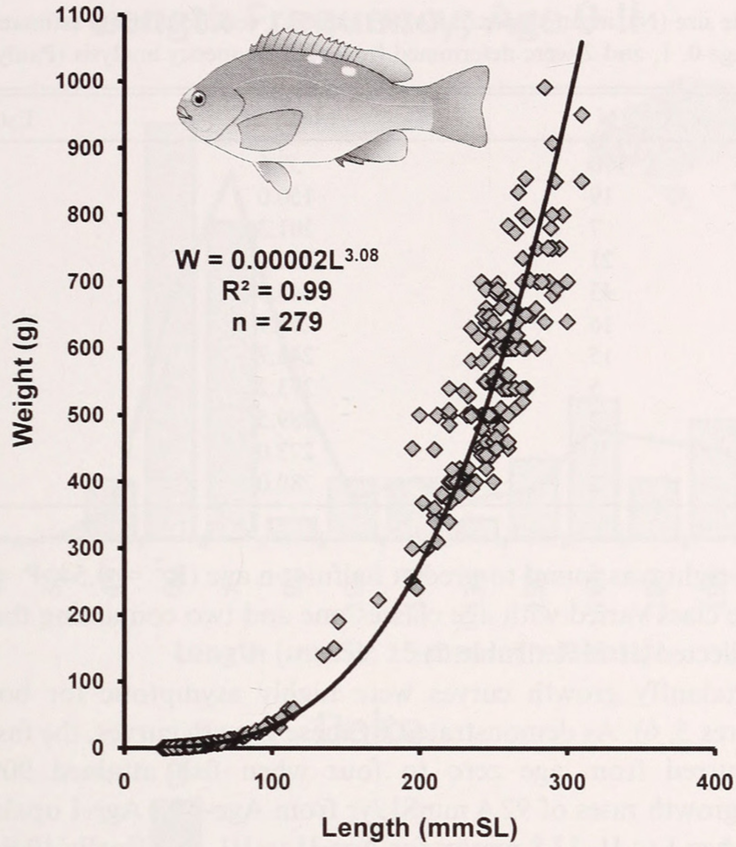

Fig. 2. Length-weight relationship of opaleye (*Girella nigricans*) based on 279 specimens.

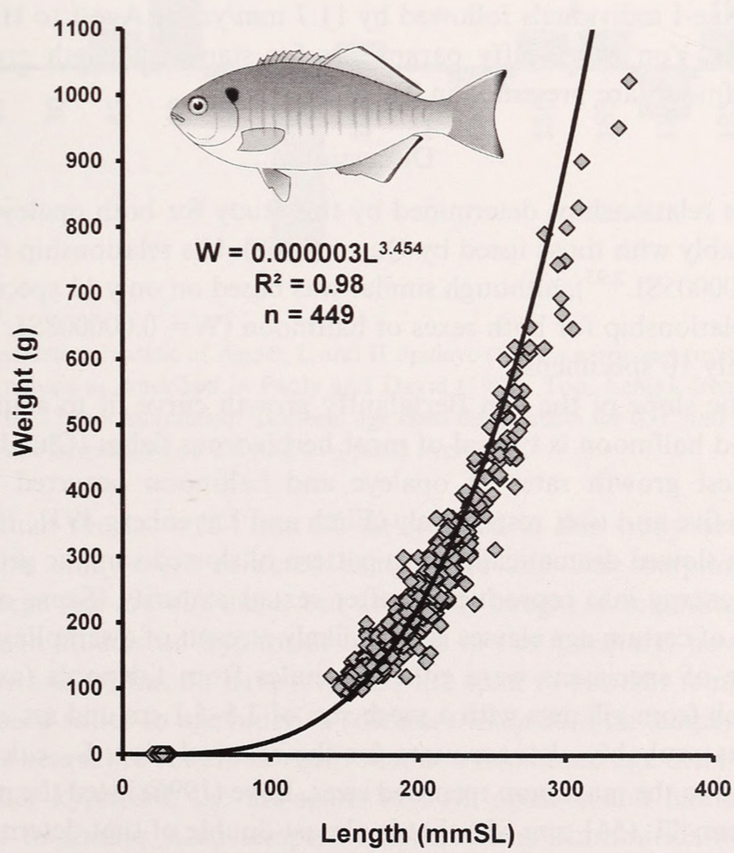

Fig. 3. Length-weight relationship of halfmoon (*Medialuna californiensis*) based on 449 specimens.

Table 1. Sample size (N), mean standard length (mm SL), von Bertalanffy estimate of SL of each age class of opaleye. Age-0, 1, and 2 were determined by length frequency analysis (Pauly and David 1981).

Age Class	N	Mean SL	Estimated SL
0	190	57.6	59.7
1	19	150.0	147.1
2	7	201.3	199.1
3	21	234.1	230.0
4	43	245.0	248.3
5	16	251.1	259.2
6	15	248.7	265.7
7	5	273.2	269.6
8	2	289.5	271.8
9	1	273.0	273.2
10	2	280.0	274.0

Again, otolith weight was found to predict halfmoon age ($R^2 = 0.54$, $P < 0.001$). Sample sizes of each age class varied with age classes one and two containing the largest percent of halfmoon collected at 51% (Table 2).

The von Bertalanffy growth curves were highly asymptotic for both opaleye and halfmoon (Figures 5, 6). As demonstrated by these growth curves, the fastest growth rate of opaleye occurred from age zero to four when fish attained 90% of L_∞. This corresponds to growth rates of 92.4 mmSL/yr from Age-0 to Age-I opaleye, followed by 51.3 mm/yr for Age-I to II, 32.8 mm/yr for Age-II to III, and finally 10.9 mm/yr for Age-III to IV. Likewise, halfmoon grew fastest from age zero to three when fish attained 83% of L_∞ was attained. Corresponding growth rates for young halfmoon were 56.1 mm/yr from Age-0 to Age-I individuals followed by 11.7 mm/yr for Age-I to II, and 5.9 mm/yr for Age-II to III. Von Bertalanffy parameters for standard length growth curves for opaleye and halfmoon are presented in Table 3.

Discussion

Length-weight relationships determined by this study for both opaleye and halfmoon compared favorably with those listed by Quast (1968). His relationship for both sexes of opaleye ($W= 0.00005SL^{2.93}$), although similar was based on only 11 specimens. Likewise, the published relationship for both sexes of halfmoon ($W= 0.000008SL^{3.26}$) was similar, but based on only 10 specimens.

The asymptotic slope of the von Bertalanffy growth curve fit to standard length for both opaleye and halfmoon is typical of most herbivorous fishes (Choat and Robertson 2002). The fastest growth rates of opaleye and halfmoon occurred prior to sexual maturity at ages five and two, respectively (Fitch and Lavenberg 1971, 1975) after which growth in length slowed dramatically. This pattern of slowed somatic growth is common as fish redirect energy into reproduction after sexual maturity (Siems and Sikes 1998). This dominance of certain age classes is most likely a result of a sampling bias where as a large percentage of specimens were either juveniles from tidepools (as in opaleye) or caught as bycatch from gill nets with a mesh size of 2.5–5.1 cm and set at 5–14 m depth. This gill net bias probably also accounts for the relatively low L_∞ calculated for both species compared to the maximum recorded sizes. Love (1996) listed the maximum size of opaleye at 660 mm TL (541 mm SL) that is almost double of that determined herein (L_∞ = 275 mm SL). The maximum size (483 mm TL or 390 mm SL) for halfmoon (Love

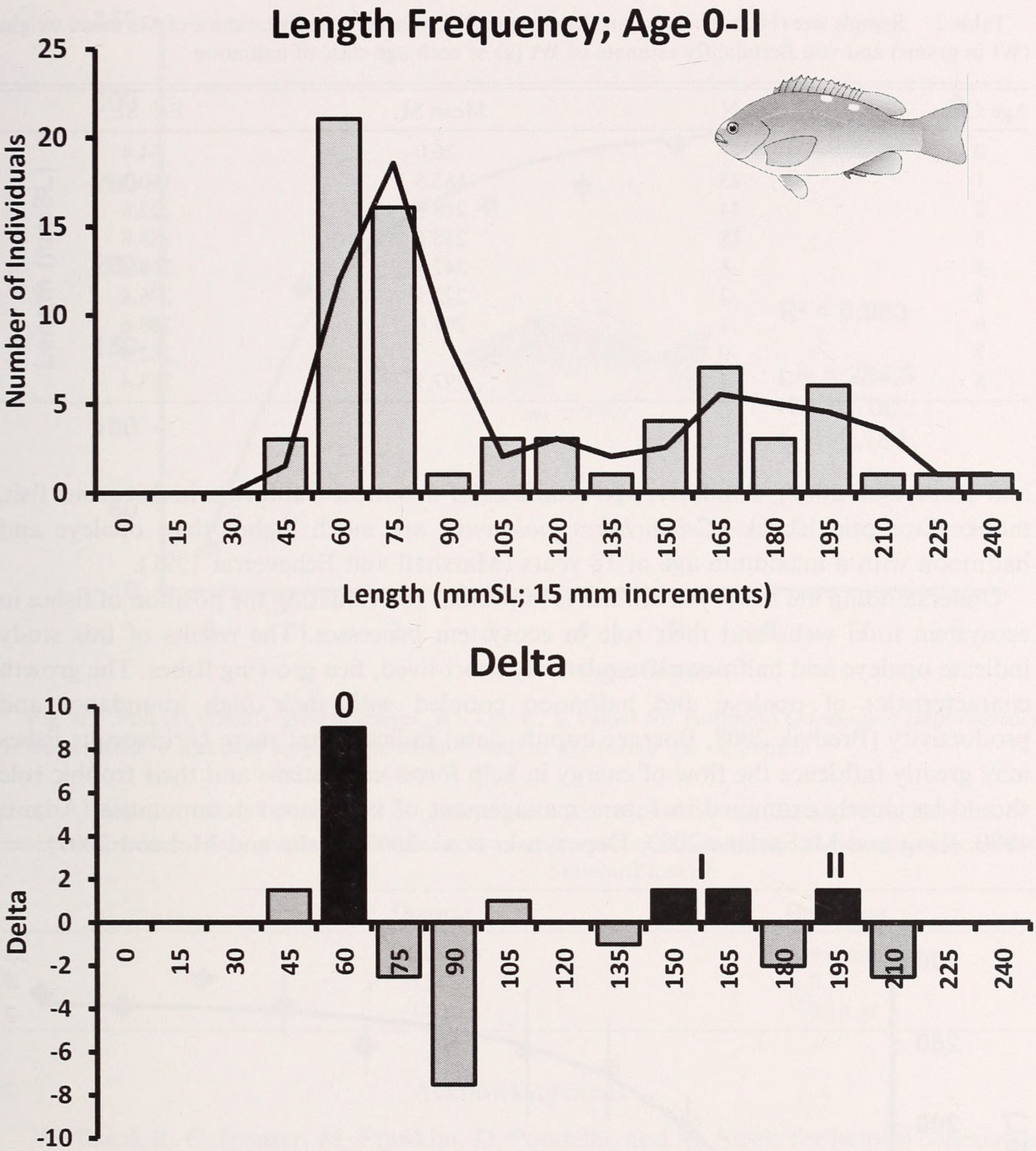

Fig. 4. Age class determination of Age-0, I, and II opaleye (*Girella nigricans*) (mm SL) determined by length frequency analysis as described in Pauly and David (1981). Top: Length frequency and moving, two-point average by 15 mm increments. Bottom: age class designation for 0, I, and II based on highest positive delta between frequency and moving two-point average.

1996) is closer than the L_∞ =284 mm SL determined in this study because the largest halfmoons in this study were collected using hook and line sampling. We can only conclude that large fish are out there, but are rarely caught in scientific gill nets.

Age and growth studies on kyphosids are rare in the literature; however, one study indicates opaleye and halfmoon have a similar life span to another temperate kyphosid. Pollock (1981) used scales to age luderick (*Girella tricsupidata*), a temperate, herbivorous fish found in the nearshore waters of Australia, at a maximum age of 11 years. Although similar to another kyphosid, the life-spans of both opaleye and halfmoon seem short when compared to similar sized temperate herbivorous acanthurids (surgeonfish) and scarids (parrotfish), in which most fishes reached a maximum age of over 20 years (Choat

Table 2. Sample size (N), mean standard length (mmSL), von Bertalanffy estimate of SL, mean weight (Wt in grams) and von Bertalanffy estimate of Wt (g) of each age class of halfmoon.

Age Class	N	Mean SL	Est. SL
0	17	26.0	34.4
1	45	185.5	160.3
2	44	218.8	222.8
3	18	235.6	253.8
4	8	247.9	269.2
5	2	272.5	276.8
6	1	297.0	280.6
7	0	-	282.5
8	2	297.5	283.4

and Robertson 2002). Similarly, age estimates of a central California herbivorous fish, monkeyface prickleback (*Cebidichthys violaceus*), are much higher than opaleye and halfmoon with a maximum age of 18 years (Marshall and Echeverria 1991).

Understanding life history attributes is important to evaluating the position of fishes in ecosystem food webs and their role in ecosystem processes. The results of this study indicate opaleye and halfmoon are relatively short-lived, fast growing fishes. The growth characteristics of opaleye and halfmoon coupled with their high abundance and productivity (Bredvik 2008, Boerger unpub. data) indicate that these herbivorous fishes may greatly influence the flow of energy in kelp forest ecosystems and their trophic role should be closely examined in future management of kelp forest communities (Adams 1980, King and McFarlane 2003, Depczynski et al. 2007, Leslie and McLeod 2007).

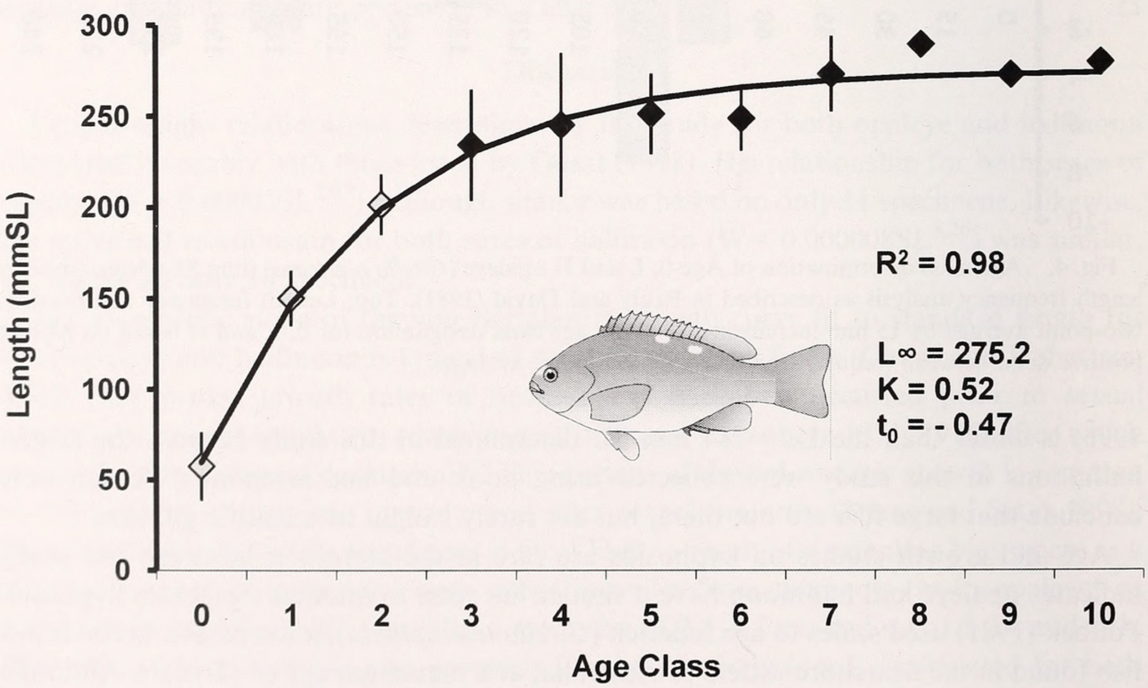

Fig. 5. Von Bertalanffy growth curve , R^2, $L\infty$, K, t_0 values for opaleye (*Girella nigricans*) fitted to standard length (mm, mean ± std) at age for all fish combined. Age-0, I, and II were determined by length frequency analysis (Pauly and David 1981).

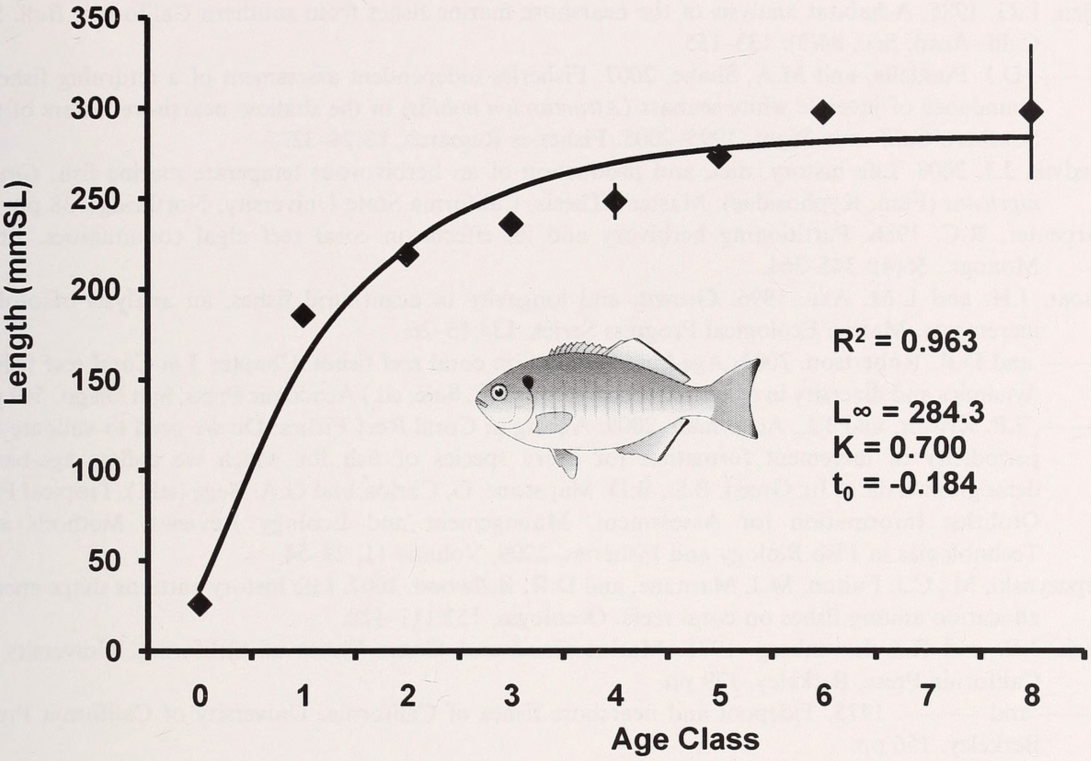

Fig. 6. Von Bertalanffy growth curves, R^2, $L\infty$, K, t_0 values for halfmoon (*Medialuna californiensis*) fitted to fitted to standard length (mm, mean ± std) at age for all fish combined.

Table 3. Growth parameters of opaleye and halfmoon for the von Bertalanffy model.

	Standard Length	
	Opaleye	Halfmoon
L_∞	275.2 mm	284.4 mm
K	0.52	0.70
t_0	−0.47 yr	−0.18 yr

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