GOPHER ROCKFISH (*SEBASTES CARNATUS*) LIFE HISTORY IN SOUTH-CENTRAL CALIFORNIA

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ABSTRACT

Understanding intraspecific variability of life history characteristics is necessary to determine local fisheries management strategies. Gopher rockfish, *Sebastes carnatus*, comprise 50% of the estimated shallow nearshore recreational rockfish catch in California, yet insufficient local data exist regarding life history traits of this species. We defined growth parameters and size and age at reproductive maturity for gopher rockfish in south-central California. The growth parameter values of fish from this study are similar to previously published research from California; however, results from this study also indicate that these fish reach reproductive maturity at a larger size and an older age when compared to gopher rockfish sampled throughout central California between 1977–82. Furthermore, results from this study show that the size and longevity of gopher rockfish has increased after the establishment of two south-central California marine protected areas.

INTRODUCTION

It is well understood that natural and anthropogenic factors affect the physiological condition of individuals and hence the populations they compose. Naturally occurring environmental factors may influence life history traits in fishes (Ruttenberg et al. 2005; Hamilton et al. 2007; Caselle et al. 2011). Furthermore, anthropogenic factors like fishing can also alter these characteristics (Rijnsdorp 1993; Law 2000; Conover 2007). Understanding regional variation in life history characteristics due to multiple environmental influences among geographically distinct locations can improve fisheries management strategies.

Life history growth parameters (L_∞, T_{max}, and K) and size (age) at reproductive maturity can be used as indicators to predict species and population-level vulnerability (Adams 1980; Roff 1984; Reynolds et al. 2005) and to determine localized management strategies (Caselle et al. 2011) in the form of harvest restrictions for economically valuable species. Allowable harvest rates should be calculated based on life history data from local populations so that biological reference points (BRP) for stock biomass, growth, maturity, recruitment, and mortality are regionally accurate and target reference points (TRP) can be set for local populations that aptly promote the long-term sustainable exploitation of stocks. This information is especially valuable for long-lived, slow-growing species that may be vulnerable to overharvesting (Adams 1980). Identifying regional variability of growth parameters as well as size and age at sexual maturity allows management strategies to account for intraspecific differences among local populations.

Moreover, understanding life history traits is relevant to fisheries management because of the reproductive implications of having larger (older) fishes in populations. "The Big Old Fat Fecund Female Fish" (BOFFFF) hypothesis states that larger fish are more fecund and may produce higher quality offspring than smaller individuals in certain species (Berkeley et al. 2004a; Palumbi 2004; O'Farrell and Botsford 2005). Therefore, allowing fishes to reach larger sizes and older ages amplifies their reproductive output. For this reason, preserving larger and older fishes is essential to the stability and future productivity of fisheries systems (Hixon et al. 2013). Marine protected areas (MPAs) are a form of spatial management, in which specific areas of the ocean are protected from various types of human disturbance (Kelleher and Kenchington 1992; Gubbay 1995; Gaines et al. 2010), and may allow fishes to maximize reproductive output (Berkeley et al. 2004b). Point Buchon and Piedras Blancas State Marine Reserves are two large, previously "data-poor" MPAs, established in 2007 along the south-central coast of California as part of the statewide network of MPAs in California, USA. Ideally, these MPAs should allow fishes to attain maximum sizes and ages within their boundaries.

Rockfishes belong to the genus *Sebastes* and are an economically valuable group of fishes that primarily exist in the Northeast Pacific (Love et al. 2002). They are long-lived, slow growing, late maturing, and have small home ranges (Love et al. 2002). Several rockfish management strategies have been implemented (Leaman 1991; Parker et al. 2000; Love et al. 2002) as fishing has reduced populations (Karpov et al. 1995; Love et al. 1998; Mason 1998).

For this study, we chose gopher rockfish, *Sebastes carnatus* (Jordan and Gilbert 1880) to ascertain regional fisheries variability in populations. Gopher rockfish range from Oregon to Baja California (Love 2011) and are a shallow-water species often targeted by recreational anglers (Chen et al. 2012). They comprise 50% of the estimated shallow nearshore recreational rockfishes catch in California (Key et al. 2005). California recreational groundfish regulations maintain a daily bag limit of ten rockfishes per angler; however, there are no length restrictions on gopher rockfish (California Department of Fish and Wildlife 2014a). Commercial anglers also target gopher rockfish in California and there is a 25.4 cm minimum size limit (unless obtained in trawl nets or landed dead) as well as regional monthly quotas allocated to these fishers (California Department of Fish and Wildlife 2014b). Despite the popularity of gopher rockfish, limited data exists concerning life history characteristics of this species. The first and only stock assessment for gopher rockfish in 2005 by Key et al. (California Department of Fish and Wildlife and the National Marine Fisheries Service) assumed analogous life history information for all populations of gopher rockfish north of Point Conception (in "northern" California). By making this assumption, some populations may be at risk of overexploitation while others may be underutilized. Defining regional life history characteristics allows management of local populations at a more appropriate ecological scale.

We aimed to define growth parameter values and size and age at reproductive maturity of gopher rockfish in south-central California for comparison with broader geographic regions and time periods. We compared life history data from fish between MPAs and adjacent fishable waters, the study areas Point Buchon and Piedras Blancas, and growth data between two time frames. With this knowledge, resource managers can more accurately manage regional stocks.

METHODS

Experimental methods

Sampling protocols We collected gopher rockfish opportunistically during the California Collaborative Fisheries Research Program (CCFRP) field seasons from mid-July through mid-September of 2012 and 2013. Among the areas surveyed by CCFRP, we collected data from the Point Buchon and Piedras Blancas MPAs as well as adjacent reference sites (REFs) in south-central California (fig. 1). We utilized standardized hook and line fishing with baited and unbaited shrimp flies (hooks) and jigs (weighted lures) to obtain fish (Wendt and Starr 2009). In 2012, we collected fish mid-September through mid-November in Point Buchon due to an extended sampling season. We collected additional fish in 2013 from mid-September to mid-November on scuba diving surveys in the Point Buchon MPA/REF sites. We also collected fish from licensed recreational anglers on commercial passenger fishing vessel (CPFV) trips. We recorded individual total length to the nearest whole centimeter and total weight to the nearest gram.

Ageing: otolith analysis To estimate the age of fish, we removed sagittal otoliths from sacrificed fish. We weighed otoliths and then stored them dry in labeled envelopes. We also utilized additional otoliths that were collected from a previous study (Loury 2011) between the years 2007–09.

We aged otoliths using the break-and-burn technique (Chilton and Beamish 1982). For consistent processing, we chose the right otolith from the pair (if available). We snapped otoliths in half along their center (lengthwise) by placing them sulcus side up between the thumb and forefinger of both hands and carefully applying pressure until fragmented. Then, we toasted the broken surface of the postrostrom half of the otolith (when available) next to a direct flame using fine tip forceps until it turned dark brown in color. Caution was taken to burn both sides of the otolith. After cooling on the table, we embedded the unbroken end of the postrostum in adhesive putty and mounted it on a slide. Then, we brushed vegetable oil onto the broken surface to enhance growth rings and placed it under a dissecting microscope to count visible annuli. We counted a pair of prominent translucent (now browned) and opaque zones as one year of growth in the fish (Lea et al. 1999). We read otoliths twice with at least a week between each reading by a single reader without knowledge of fish size or location and year collected. If there was disagreement in years (a difference of a year or greater), we read samples a third time as per established protocol (D. Pearson, National Marine Fisheries Service, Santa Cruz, California, personal communication 2012).

Assigning maturity stage We removed and weighed gonads to the nearest 0.001 g. We assigned macroscopic and histological maturity stages for ovaries and testes based on previously published parameters (Echeverria 1987; Chilton 2007; and TenBrink and Spencer 2013). Macroscopically, we determined ovaries to be immature if they appeared thin, threadlike, small, translucent, round in shape, and yellow-pink in color. The presence of individual eggs,

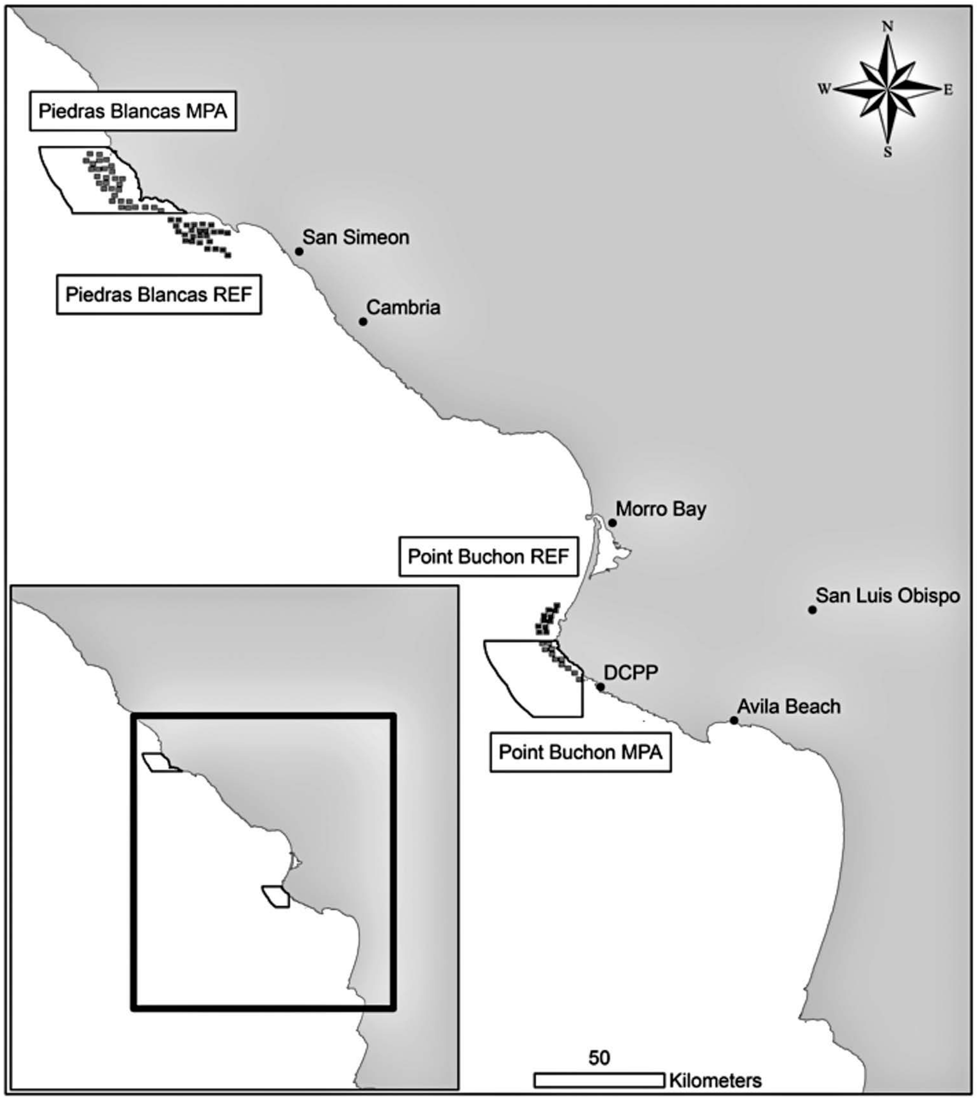

Figure 1. Map of south-central California, USA including Point Buchon and Piedras Blancas State Marine Reserves (MPAs) and adjacent reference sites (REFs). MPAs were designed to include shallow rocky reef environments that provide habitats to many nearshore species, including gopher rockfish. Square marks indicate cells monitored by CCFRP in the MPA and REF sites.

eyed larvae, or black blotches indicated mature ovaries. We determined testes to be macroscopically immature if they appeared thin, threadlike, small, translucent, and slightly triangular in shape. Mature testes were large, firm, triangular in shape, and white in color.

We microscopically staged gonadal tissues to increase accuracy of methods for fishes that were not within their reproductive seasons, but were developmentally mature (Echeverria 1987). After initial staging, we preserved organs in 10% formalin and sent them to be histologically processed by the Central Coast Pathology Lab. One to two gram ovarian and testicular cross sections were embedded in paraffin, thin-sectioned to 4 μm using a rotary microtome, mounted on slides, stained with hematoxilyn and eosin, and read under a compound microscope. We assessed ovary maturity status by defining the most advanced oocyte stage present. We determined ovaries to be immature if ooginal nests and unyolked oocytes were present. Occasionally, initial yolk accumulation in oocytes with very small yolk globules would also indicate immaturity. The presence of tertiary yolk globules and initial oil vesicles, embryonic "eyed larvae," post-ovulatory follicles, atretic oocytes, or residual larvae all signified that ovaries were mature. We designated testes as immature with the presence of germ cells, undifferentiated gonocytes, early to intermediate stages of lumen development, or primary to secondary spermatogonia. The existence of developed lumina filled with spermatozoa, sperm ducts filled with spermatozoa, and clustered organizations of spermatocysts indicated mature testes.

ANALYSES

We used size and age data from years 2007–09 and 2012–13 in the following analyses. We utilized non-linear regression models to fit size (total length) at a specific age (years) using the von Bertalanffy growth equation: $L_t = L_\infty\ (1 - e^{-K(t - t_0)})$ where L_t is the length of an individual at age t, L_∞ is the theoretical maximum length (asymptotic) if individuals were able to grow indefinitely, K is the growth coefficient that is proportional to rate at which L_∞ is reached, t_0 is the theoretical age at $L = 0$ (often negative or zero), and t represents the age of an individual (von Bertalanffy 1934). Since no information existed for the sex of fish collected from years 2007–09, we combined sexes for all analyses. For all models, we fixed t_0 at the value –0.5 because data for smaller and younger classes was limited, and to compare growth data to data from Lea et al. (1999). We related the model parameters K and L_∞ across area, site, and over time by calculating z-scores from means and SE (standard error) to obtain p-values using two-tailed t tests with 95% confidence intervals. The estimated maximum life span of individuals is represented by T_{max}, and we calculated this by finding the mean of the upper 25% of individuals in a given population, based on highest annuli readings (Beverton 1992). We used two-sample t tests with 95% confidence intervals to compare two means, and we made comparisons to see if area, site, or time period was associated with (T_{max}). We used Bonferroni corrections when making multiple comparisons.

We modeled size (age) at maturity using a logistic regression to fit sigmoid curves utilizing the expression

$$P = Pr\ (Maturity\,|\,x_1) = \left(\frac{e(b_0 + b_1 x_1)}{1 + e(b_0 + b_1 x_1)}\right).$$

P is the probability an individual is mature at length or age (x_1), and the constants b_0 and b_1 are parameters estimated after fitting the curve. Predicted size (age) at 50% maturity, size (age) at which 50% of fish attain sexual maturity, was estimated with the equation $L\ (or\ A)_{50} = -b_0/b_1$ using previously estimated constants. We used 95% confidence intervals to see if area or site was associated with maturity.

We completed statistics using JMP Pro 11 (SAS Institute Inc., Cary, NC). We confirmed normal distributions using Shapiro-Wilk test for goodness of fit. Parameters for models are listed as mean ± SE in text and figures, and were reported using 95% confidence intervals.

RESULTS

Growth parameter estimates

When data from all areas (Point Buchon and Piedras Blancas), sites (MPA and REF), and time periods (2007–09 and 2012–13) were combined for gopher rockfish in south-central California, the growth parameter L_∞ (maximum length) was found to be 34.80 ± 0.57; K (growth coefficient) was 0.18 ± 0.01; and T_{max} (maximum age) was 9.58 years ±0.16.

The estimated growth parameters for fish from the Point Buchon MPA sampled between the years 2012–13 showed increased L_∞ (p = 0.01) and increased T_{max} (p < 0.0001) when compared to individuals sampled in 2007–09 (table 1; fig. 2). Increases in L_∞ (p = 0.01) and T_{max} (p = 0.001) were also seen over time from fish sampled in the Point Buchon REF site in 2012–13 when compared to fish sampled in 2007–09. The parameter T_{max} was significantly higher in the Point Buchon MPA compared to the REF site (p < 0.0001) in 2012–13 (table 1). Temporal differences in growth parameters were found when data from the Point Buchon MPA and REF sites were combined in years 2007–09, and then compared to years 2012–13 (table 1; fig. 2). Individuals from both sites in years 2012–13 had significantly higher L_∞ (p = 0.002) and T_{max} (p < 0.0001) than individuals from 2007–09.

Temporal differences were also observed in Piedras Blancas when the MPA and REF sites were combined. There was an increase in L_∞ (p = 0.038) (table 1; fig. 2) and T_{max} (p < 0.0001) (table 1) when years 2008–09 were compared to years 2012–13. Increased T_{max} (p = 0.0003) was observed over time from fish sampled in the Piedras

TABLE 1
L_∞, K, and T_{max} estimated for gopher rockfish, *Sebastes carnatus*, in all areas (Point Buchon: PB and Piedras Blancas: BL), sites (MPA: M and REF: R), and years. Estimates given in mean ± standard error (*SE*).

Area	Site	Years	Mean L_∞(*length*) ± *SE*	Mean K ± *SE*	Mean T_{max} (years) ± *SE*	*N*
BL	M	08–09	31.06 ± 1.22	0.24 ± 0.02	8.07 ± 0.23	61
BL	R	08–09	33.05 ± 1.25	0.22 ± 0.02	8.80 ± 0.23	60
BL	M	12–13	34.86 ± 1.88	0.18 ± 0.02	9.92 ± 0.25	46
BL	R	12–13	37.19 ± 1.95	0.17 ± 0.02	10.10 ± 0.28	40
PB	M	07–09	31.81 ± 0.72	0.25 ± 0.01	8.84 ± 0.34	76
PB	R	07–09	29.16 ± 0.87	0.35 ± 0.04	8.07 ± 0.38	61
PB	M	12–13	34.38 ± 0.83	0.22 ± 0.01	12.40 ± 0.38	59
PB	R	12–13	35.43 ± 2.11	0.20 ± 0.03	10.10 ± 0.46	49

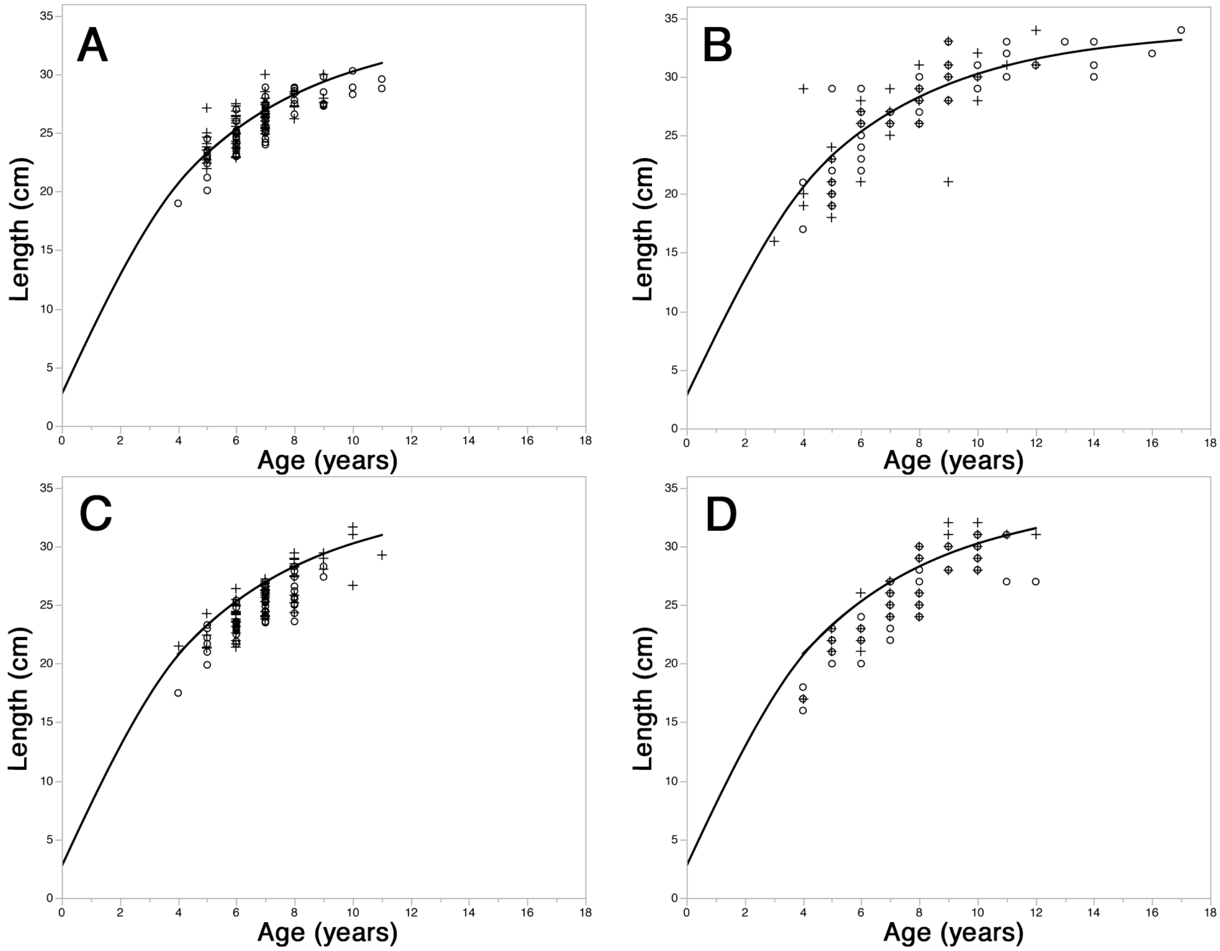

Figure 2. Von Bertalanffy growth curves for gopher rockfish sampled in south-central California. Circles represent data points from the MPA site, and plus symbols represent data points from the REF site. The value for t_0 was fixed at –0.5 (Lea et al. 1999) because data for younger and smaller and younger classes was limited, and to compare growth data to data from Lea et al. (1999). (**a**) Growth curve representing individuals from Point Buchon collected for Loury's 2011 study during the 2007–09 field seasons (n = 136) (Loury 2011). The mean L_∞ value was 31.27 cm ± 0.60, and the mean K value was 0.27 ± 0.01. (**b**) Growth curve representing individuals from Point Buchon during the 2012–13 field seasons (n=108). The mean L_∞ value was 34.65 cm ± 0.88, and the mean K value was 0.21 ± 0.01. (**c**) Growth curve representing individuals from Piedras Blancas collected for Loury's 2011 study during the 2008–09 field seasons (n = 121). The mean L_∞ value was 32.50 cm ± 0.95, and the mean K value was 0.22 ± 0.02. (**d**) Growth curve representing individuals from Piedras Blancas during the 2012–13 field seasons (n = 86). The mean L_∞ value was 35.96 cm ± 1.37, and the mean K value was 0.18 ± 0.01

Blancas REF site in 2012–13 when compared to fish in 2007–09. In addition, T_{max} increased ($p < 0.0001$) for fish from the Piedras Blancas MPA in 2008–09 compared to years 2012–13 (table 1).

Growth coefficient (K) was similar in all areas, sites, and years (table 1). No other significant differences were observed in von Bertalanffy growth parameters between areas, sites, or over time ($p > 0.05$).

Maturity

Size at 50% maturity (L_{50}) for individuals from all areas and sites was 23.61 cm with an approximate 95% confidence interval from 23.04 to 24.15 cm (n = 194; $R^2 = 0.74$; $p < 0.0001$). Age at 50% maturity (A_{50}), for individuals from all areas and sites, was 6.01 years with an approximate 95% confidence interval from 5.72 to 6.29 years (n = 194; $R^2 = 0.60$; $p < 0.0001$). We found no significant differences after comparing 95% confidence intervals for mean size (age) at reproductive maturity between areas or sites. The youngest and smallest mature female was four years old and measured 22 cm. The youngest and smallest mature male was six years old and measured 23 cm. The mean age/length of immature females and males was 5.21 years/20.76 cm and 5.25 years/21.58 cm, respectively. The mean age/length of mature females and males was 8.71 years/28.79 cm and 8.39 years/27.77 cm, correspondingly.

DISCUSSION

Growth parameter estimates

Locally defined growth parameter values from our study were comparable to a study by Lea et al. in 1999. This study examined life history traits of nearshore rockfishes, including gopher rockfish, in central California during the 1980s. The majority of samples were collected near Monterey; however, the study region spanned from Monterey Bay to Morro Bay. The K (0.23) and L_∞ (34.10) values from Lea's study are comparable to the K and L_∞ values from this study.

Overall, our results indicate a general pattern that the maximum size and age of gopher rockfish increased after the establishment of MPAs, likely caused by anthropogenic and natural factors, in addition to possible errors in sampling. According to the BOFFFF hypothesis (Berkeley et al. 2004a; Palumbi 2004; O'Farrell and Botsford 2005) these larger and older gopher rockfish after MPA implementation could potentially be more fecund and producing higher quality offspring than pre-MPA individuals. Past fishing has altered growth in Atlantic salmon (Ricker 1981), Atlantic cod (Swain et al. 2007), plaice (Rijnsdorp 1993), grayling (Haugen and Vøllestad 2001), and Atlantic silverside (Conover and Munch 2002). Furthermore, size-selective harvest from fishing can cause size (age)-truncations in populations where the oldest and largest individuals are being preferentially removed (Rochet 1998). Relatively recent pre-MPA data from the south-central coast region show that the fishing effort of recreational anglers on commercial passenger fishing vessels (CPFV) was not as intense in the Piedras Blancas area when compared to the Point Buchon area prior to the implementation of MPAs (Ivens-Duran 2014). Past fishing effort around Point Buchon may have preferentially selected larger and older individuals from the population. With the elimination of fishing in the Point Buchon MPA, it appears that gopher rockfish were able to reach older ages and larger sizes. It has also been shown that a regional shift in CPFV fishing effort away from the Piedras Blancas area occurred with the implementation of MPAs in 2007 (Ivens-Duran 2014). It may be that a significant decrease in fishing effort in the area allowed for fish to reach larger sizes and older ages in the Piedras Blancas area as a whole. However, a pulse of gopher rockfish recruitment leading to a tight concentration of fishes in certain year classes could also explain these results. Furthermore, closely spaced annuli near otolith margins, as counted by prevailing methods, have not yet been validated by other methods to provide accurate age estimates. Thus, it is possible that sampling error also may have influenced these results. Results from this study suggest past fishing pressure and the implementation of MPAs may have influenced the longevity and size of gopher rockfish in both Piedras Blancas and Point Buchon, although additional environmental factors and possible errors in sampling may have also affected growth parameters.

Maturity

The size and age at maturity values from this study contrast with those from Echeverria (1987). Echeverria studied reproductive aspects of rockfishes from July 1977–July 1982 in northern and central California (between Port San Luis and Crescent City). Gopher rockfish (sexes combined) age and size at 50% maturity were calculated as 4 years and 17 cm, respectively (Echeverria 1987). Because our data showed gopher rockfish matured two years later and at over five centimeters larger, this suggests either a change in maturity over time or between regions, due to environmental conditions or potential sampling error. Because our sampling design limited our collection of smaller and younger fishes, it would be beneficial to repeat this study targeting those size and age classes. This may have influenced our results and future studies should aim to increase collections to a broader size and age range. Although we cannot identify the primary driver of these differences, future management should apply this regional knowledge if these results are repeated in future studies.

Area, site, and sex were not associated with changes in age or size at maturity, suggesting that past fishing pressure and the subsequent elimination of fishing pressure have not elicited plastic responses in fishes sampled.

Conclusions

A continuation of this research would verify if these patterns are temporally stable, and elucidate the long-term effects of eliminating fishing on gopher rockfish life history characteristics. While it will be challenging to determine if potential life history changes are due to plastic or adaptive responses, determining the lasting effects of MPA implementation on these parameters merits further investigation. Moreover, additional environmental information should be monitored to determine influence on life history traits. A next step would be to expand the collection of life history information on gopher rockfish to include the full geographic range of this species. Comparing our data among broader geographic scales and over a longer time frame may provide insight into more suitable management strategies.

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