SPATIAL AND TEMPORAL COMPARISONS OF GOPHER ROCKFISH
(*SEBASTES CARNATUS*) LIFE HISTORY AND CONDITION IN
SOUTH CENTRAL CALIFORNIA

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by
Natasha Leigh Meyers-Cherry

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COMMITTEE MEMBERSHIP

TITLE: Spatial and temporal comparisons of gopher rockfish (*Sebastes carnatus*) life history and condition in south central California

AUTHOR: Natasha Leigh Meyers-Cherry

DATE SUBMITTED: December 4, 2014

COMMITTEE CHAIR: Royden Nakamura, PhD
Professor of Biological Sciences

COMMITTEE MEMBER: Dean Wendt, PhD
Professor of Biological Sciences

COMMITTEE MEMBER: Benjamin Ruttenberg, PhD
Assistant Professor of Biological Sciences

ABSTRACT

Spatial and temporal comparisons of gopher rockfish (*Sebastes carnatus*) life history and condition in south central California

Natasha Leigh Meyers-Cherry

Recent studies have shown environmental factors influence life history traits in fishes. Understanding intraspecific variability of life history characteristics and condition 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 and condition of this species. Our study locally defines growth parameters, size (age) at reproductive maturity, and condition for gopher rockfish in south central California. The growth parameter values of gopher rockfish from our study are similar to previously published research. However, our data also indicate that the current local gopher rockfish stock in south central California reaches reproductive maturity at a larger size and an older age when compared to gopher rockfish sampled throughout central California (primarily in Monterey) between 1977-1982. Furthermore, we examined spatial and temporal differences of life history information, within and outside of two south central California Marine Protected Areas (MPAs) established in 2007, between two time periods. Our data show that the size and longevity of fish has increased after the establishment of MPAs.

Keywords: Life history, *Sebastes carnatus*, Marine Protected Areas

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I. 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 (Reznick et al. 1990; Ruttenberg et al. 2005; Hamilton et al. 2007; Caselle et al. 2011). Furthermore, anthropogenic factors like fishing (Rijnsdorp 1993; Rochet 1998; Law 2000; Conover 2007) can also alter these characteristics. Understanding regional variation in life history characteristics and fish condition due to multifarious environmental influences among geographically distinct locations can improve current fisheries management strategies.

Life history traits including growth parameters and maturity calculations are critical to determine appropriate fisheries management efforts; they can be used as indicators to predict species and population-level vulnerability (Adams 1980; Roff 1984; Stokes et al. 1993; 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. Using this knowledge, Target Reference Points (TRP) can be set for local populations that aptly promote the long-term sustainable exploitation of stocks. This kind of information is especially valuable for long-lived, slow growing species that maximize reproductive output at larger sizes (older ages) that may be vulnerable to overharvesting (Adams 1980).

Understanding life history growth parameters (L_{∞} and T_{max}) and determining the size (age) at which individuals and populations attain reproductive maturity 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. 2004, Palumbi 2004, O’Farrell and Botsford 2005, Sogard et al. 2008). Therefore, allowing fish to reach larger maximum sizes and older ages amplifies their reproductive output. For this reason, preserving old growth fish is essential to the stability and future productivity of fisheries systems (Hixon et al. 2013). Understanding regional variability of growth parameters as well as size (age) at sexual maturity allows management strategies to account for intraspecific differences among local populations.

In addition to life history information, assessing variability in fish condition over time and space can also be useful to inform fisheries management. Hepatosomatic index (HSI) is often utilized to represent indirect measures of energy reserves in fish, and can be used to assess the overall health of fish populations (Bolger and Connolly 1989). Larger hepatosomatic indices often indicate healthier fish in better energetic condition (Bolger and Connolly 1989). Past research indicates that fish with lower measures of condition are less productive (Rätz and Lloret. 2003).

Rockfish 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, have episodically irregular recruitment patterns, and possess small home ranges (Love et al. 2002).

Furthermore, commercial fishing efforts have reduced populations (Karpov et al. 1995; Love et al. 1998; Mason 1998), and several management strategies have been implemented for *Sebastes* species (Leaman 1991; Parker et al. 2000; Love et al. 2002). For this study, gopher rockfish *Sebastes carnatus* (Jordan and Gilbert 1880) was chosen to ascertain regional ecological and fisheries variability.

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 estimated shallow nearshore recreational rockfish catch in California (Key et al. 2005); however, limited data exist concerning spatial and temporal variability in key life history characteristics or condition 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) assumes analogous life history information for all populations of this species, north of Point Conception (in “northern” California) and does not discuss any other distinctions at smaller spatial scales or over time. By making this assumption, some localized populations may be overfished while other populations are being under-utilized. Understanding how life history traits vary across geographical locations accounts for the possibility that populations of fish occupy distinct regions and may require different management strategies.

Defining regional life history characteristics allow management of local populations at a more appropriate ecological scale.

This study primarily aims to locally define growth parameter values (estimated maximum sizes and ages), size (age) at reproductive maturity, and condition values (hepatosomatic index (HSI)) of gopher rockfish in south central California to be compared among broader geographic regions. This study was conducted inside and outside of two south central California Marine Protected Areas (MPAs), thus life history traits and condition were compared between MPAs and adjacent fishable waters, as well as between the study areas (Point Buchon and Piedras Blancas). Regional variability in life history information will be better understood by comparing life history parameters of gopher rockfish over time and across geographic locations. Overall, this study compares life history traits and condition of gopher rockfish temporally and spatially in south central California.

II. METHODS

I EXPERIMENTAL METHODS

Figure 1. Map of south central California, USA including Point Buchon and Piedras Blancas State Marine Protected Areas (MPAs) established in 2007, as well as adjacent reference sites (REFs). Data collected mid-July through mid-September from 2007-2009 and mid-July through mid-November from 2012-

2013. The Point Buchon and Piedras Blancas MPAs were designed to include shallow rocky reef environments that provide habitats to many nearshore species, including gopher rockfish. Also pictured are key geographical landmarks, including cities for reference. Red marks indicate cells monitored by the CCFRP in the Point Buchon and Piedras Blancas MPAs, while blue marks indicate cells monitored by the CCFRP in the Point Buchon and Piedras Blancas REFs.

1.1 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 the CCFRP, Point Buchon and Piedras Blancas are two large State MPAs, established in 2007 along the south central coast of California. We used standardized hook-and-line fishing with baited and unbaited shrimp flies (hooks) and jigs (weighted lures) (Wendt and Starr 2009) to obtain fish within the Point Buchon and Piedras Blancas MPAs as well as in adjacent reference sites (REFs) in south central California, USA (Figure 1). In 2012, we collected fish mid-September through mid-November in the Point Buchon MPA/REF sites, 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. Furthermore, we collected some samples from licensed recreational fishers on Commercial Passenger Fishing Vessel (CPFV) trips. We recorded individual length to the nearest whole centimeter was; and fish were weighed to the nearest gram.

1.2 Aging: otolith analysis

To estimate the age of fish, we removed sagittal otoliths from sacrificed fish. We weighed and then stored otoliths dry in labeled envelopes. We analyzed additional otoliths collected from a previous study (Loury 2011) between the years 2007-2009.

We aged otoliths using the break-and-burn technique (Chilton and Beamish 1982). To remain consistent through processing, we chose the right otolith from the pair (if available). We snapped otoliths in half along their center (length wise) by placing them sulcus side up between the thumb and forefinger of both hands and carefully applying pressure until fragmented. 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 postrostrom 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. A pair of prominent translucent (now browned) and opaque zones was counted as one year of growth in the fish (Lea et al. 1999). We read otoliths blind twice, with at least a week between each reading by a single reader. If there was disagreement in years (a difference of a year or greater), we read samples a 3rd time as per established protocol.

1.3 Assigning maturity stage

We removed and weighed gonads to the nearest 0.001g. We initially did developmental staging macroscopically. We assigned macroscopic and histological maturity stages for ovaries and testes based on previously published scales (Echeverria 1987, Chilton 2007, and TenBrink and Spencer 2013). Macroscopically, ovaries were determined to be immature if they appeared thin, thread-like, small, translucent, round in shape, and yellow-pink in color. The presence of individual eggs, eyed larvae, or black blotches indicated mature ovaries. We determined testes to be macroscopically immature if they appeared thin, thread-like, small, translucent, and slightly triangular in shape. Mature testes were large, firm, triangular in shape, and white in color. After initial staging, we preserved organs 10% formalin and had them histologically processed by the Central Coast Pathology lab. One to two gram ovarian and testicular cross sections were embedded in paraffin, thin-sectioned to 4µm using a rotary microtome, mounted on slides, stained with hematoxylin and eosin, and read under a compound microscope. In each sample, 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”, postovulatory follicles, atretic oocytes, or residual larvae all signified that ovaries were mature. We designated testes to be 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.

1.4 Calculating condition

We removed and weighed livers to the nearest 0.1 mg. We used hepatosomatic indices (HSI), ratio of liver weight to total body weight, to assess the general conditions of sampled individuals as liver size is relative to the nutritional state of fish (Lambert and Dutil 1997).

2 ANALYSES

We used size and age data from the years 2007-2009 and 2012-2013 in analyses. We used 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) individuals were able to grow indefinitely, K is the growth coefficient which 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 on the sex of individuals collected from years 2007-2009, we combined sexes for all analyses. For all models, t_0 was fixed at the value -0.5 (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 is calculated by finding the mean of the upper 25% of individuals in a given population, based on highest annuli readings (Beverton 1992). Two-sample t-tests using 95% confidence intervals were used to compare two means, and comparisons were done to see if area, site, or time period is associated with (T_{max}). We used Bonferroni corrections when making multiple comparisons.

We modeled size (age) at maturity by using a logistic regression to fit sigmoid curves using the expression $P = Pr (Maturity|x_1) = (\frac{e^{(b_0+b_1x_1)}}{1+e^{(b_0+b_1x_1)}})$. P is the probability an individual is mature at length or age (x_1), and the constants b_0 and b_1 are parameters that were estimated after fitting the curve. Predicted size (age) at 50% maturity, the size at which 50% of fish attain sexual maturity, were estimated with the equation $L (or A)_{50} = -b_0/b_1$ using previously estimated constants. We compared 95% confidence intervals to see if area or site is associated with size (age) at reproductive maturity.

We calculated hepatosomatic index (%) as $HSI = (\frac{LW}{W}) \times 100$, where LW is the wet total liver weight (g) of the fish and W is the wet total body weight (g) of the fish. We utilized two-way ANOVAs to test whether the independent variables area or site are associated with (HSI).

We completed statistical analyses using JMP Pro 11 (SAS Institute Inc., Cary, NC). We confirmed normal distributions using Shapiro-Wilk test for Goodness of fit. Parameters for all models are listed as means $\pm$ SE in text and figures, and were reported using 95% confidence intervals.

III. RESULTS

1 GROWTH PARAMETER ESTIMATES

When data from all areas (Point Buchon and Piedras Blancas), sites (MPA and REF), and time periods (2007-2009 and 2012-2013) were combined for gopher rockfish in south central California, the growth parameter L_{∞} (maximum length) was found to be 34.80 ± 0.57 ; K was 0.18 ± 0.01 ; and T_{max} (maximum age) was $9.58 \text{ years} \pm 0.16$.

The estimated growth parameters for fish from the Point Buchon MPA sampled between the years 2012-2013 showed increased maximum length (L_{∞}) ($p = 0.01$) and increased T_{max} ($p < 0.0001$) when compared to individuals sampled in 2007-2009 (Table 1; Figure 2; Figure 3). 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 2012-2013 when compared to fish sampled in 2007-2009. The parameter T_{max} was significantly higher in the Point Buchon MPA compared to the REF site ($p < 0.0001$) in 2012-2013 (Table 1). Temporal differences in growth parameters were found when data from the Point Buchon MPA and REF sites were combined in years 2007-2009, and then compared to years 2012-2013 (Table 1; Figure 2; Figure 3). Individuals from both sites in years 2012-2013 had significantly higher L_{∞} ($p = 0.002$) and T_{max} ($p < 0.0001$) than individuals from 2007-2009.

These 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; Figure 4; Figure 5) and T_{max} ($p < 0.0001$) (Table 1) when years 2008-

2009 were compared to years 2012-2013. Increased T_{max} ($p = 0.0003$) was also observed over time from fish sampled in the Piedras Blancas REF site in 2012-2013 when compared to fish sampled in 2007-2009. In addition, the T_{max} parameter increased ($p < 0.0001$) for fish sampled from the Piedras Blancas MPA in 2008-2009 and compared to the years 2012-2013 (Table 1).

The growth coefficient (K) was identical between area, site, and year (Table 1). No other significant differences were observed in von Bertalanffy growth parameters between areas, sites, or over time ($p > 0.05$).

Table 1. Growth parameters L_{∞} , K , and T_{max} estimated for all areas (Point Buchon: PB and Piedras Blancas: BL), sites (MPA: M and REF: R), and years. Estimates given in mean $\pm$ standard error (SE).

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

Figure 2. von Bertalanffy growth curve for gopher rockfish sampled in the Point Buchon MPA and REF sites during the 2007-2009 field seasons ($n = 136$). The average L_{∞} value was $31.27 \text{ cm} \pm 0.60$, and the average K value was 0.27 ± 0.01 . The value for t_0 was fixed at -0.5 (Lea et al. 1999). Circles represent data points from the MPA site, and plus symbols represent data points from the REF site.

Figure 3. von Bertalanffy growth curve for gopher rockfish sampled in the Point Buchon MPA and REF sites during the 2012-2013 field seasons ($n = 108$). The average L_{∞} value was $34.65 \text{ cm} \pm 0.88$, and the average K value was 0.21 ± 0.01 . The value for t_0 was fixed at -0.5 (Lea et al. 1999). Circles represent data points from the MPA site, and plus symbols represent data points from the REF site.

Figure 4. von Bertalanffy growth curve for gopher rockfish sampled in the Piedras Blancas MPA and REF sites during the 2008-2009 field seasons ($n = 121$). The average L_{∞} value was $32.50 \text{ cm} \pm 0.95$, and the average K value was 0.22 ± 0.02 . The value for t_0 was fixed at -0.5 (Lea et al. 1999). Circles represent data points from the MPA site, and plus symbols represent data points from the REF site.

Figure 5. von Bertalanffy growth curve for gopher rockfish sampled in the Piedras Blancas MPA and REF sites during the 2012-2013 field seasons ($n = 86$). The average L_{∞} value was $35.96 \text{ cm} \pm 1.37$, and the average K value was 0.18 ± 0.01 . The value for t_0 was fixed at -0.5 (Lea et al. 1999). Circles represent data points from the MPA site, and plus symbols represent data points from the REF site.

2 MATURITY

Based on our data, size at 50% maturity (L_{50}), the length at which 50% of gopher rockfish from south central California attain sexual maturity, for individuals sampled 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 sampled from all areas and sites was 6.01 years with an approximate 95% confidence interval from 5.72 to 6.29 years ($n = 194$; $R^2 = 0.60$; $p < 0.0001$). By comparing 95% confidence intervals for the mean size (age) at reproductive maturity between area or site, we found no significant differences. The youngest and smallest mature female recorded was four years old and measured 22 cm. The youngest and smallest mature male recorded 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.

3 CONDITION

The mean hepatosomatic index for gopher rockfish in south central California was 2.28 ± 0.06 . Analysis using a two-way ANOVA comparing mean hepatosomatic indices between areas and sites indicate geographic variation between the Piedras Blancas and Point Buchon areas ($p < 0.0001$). Furthermore, mean hepatosomatic index was significantly greater in the Piedras Blancas MPA in comparison to the Point Buchon MPA ($p < 0.0001$). However the mean hepatosomatic indices of fish between sites (MPA and REF) were not significantly different ($p > 0.05$).

IV. DISCUSSION

1 GROWTH PARAMETER ESTIMATES

We were able to locally define growth parameter values (maximum size and maximum age), size (age) at reproductive maturity, and a measure of condition of gopher rockfish in south central California, which can serve as the basis for comparisons on broader geographic scales and times. Furthermore, we found temporal increases in growth parameters after the establishment of MPAs.

Lea et al. (1999) examined life history traits of nearshore rockfishes, including gopher rockfish, in central California during the 1980's. The majority of samples were collected near Monterey, however the study region spanned from Monterey Bay to Morro Bay. The following growth parameters were estimated for gopher rockfish in central California (sexes combined) for Lea's study: $L_{\infty} = 34.1$, $K = 0.23$, and $t_0 = -0.5$. The K and L_{∞} values from this study are relatively comparable to K and L_{∞} values from our research.

After addressing our research goal that compared data inside and outside of MPAs, between study areas, as well as between time periods, we found differences in growth parameter values (maximum size and age), likely caused by natural and anthropogenic factors. Differences in growth parameter values imply that MPAs may have influenced the longevity and size of gopher rockfish in both Piedras Blancas and Point Buchon. Our data showed, over time, increases in L_{∞} and T_{max} in the Point Buchon MPA compared to the REF sites. When the data from both the MPA and REF sites were combined in Point Buchon, temporal increases in L_{∞} and T_{max} were also observed. Relatively recent pre-MPA baseline

data from the south central coast region show that recreational fishing effort was not as intense in the Piedras Blancas area (MPA and REF sites) when compared to the Point Buchon area (MPA and REF sites) prior to the implementation of MPAs (Ivens-Duran et al. *submitted*). Past fishing effort in 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. Furthermore, there were no differences found between L_{∞} estimates for individuals from the Point Buchon MPA and REF sites within separate year classes for a given area. This may be due to fish reaching maximum (asymptotic) lengths, however continuing to age. In addition to this, adult gopher rockfish that normally occupy MPAs may have traveled outside of reserve boundaries (or vice versa) during our sample seasons and were captured during hook-and-line surveys. In the Piedras Blancas MPA, temporal increases in T_{max} were observed; however, no differences existed between estimates of L_{∞} over time. Yet when MPA and REF were combined, both T_{max} and L_{∞} increased over time. The Piedras Blancas MPA and REF were sampled a year less than the Point Buchon MPA and REF, and perhaps missing data from 2007 is the reason we did not detect temporal differences in estimated L_{∞} from the MPA site. It has also been shown that a regional shift in fishing effort away from the Piedras Blancas area occurred with the implementation of MPAs in 2007 (Ivens-Duran et al. *submitted*). This pattern may explain why no differences were observed in either L_{∞} or T_{max} between MPA and REF sites. 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.

Data from gopher rockfish sampled in the Point Buchon and Piedras Blancas areas suggest that six years may be long enough to observe changes in growth parameters of gopher rockfish, due to the removal of fishing pressure. In the 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). Temporal increases in L_{∞} and T_{max} present in both the Point Buchon and Piedras Blancas areas, as well as differences in T_{max} between the Point Buchon MPA and REF sites suggests that past fishing pressure and the implementation of marine reserves may allow fish to attain maximum ages and sizes. In general, our data suggest that there has been increased longevity and maximum length after the establishment of MPAs. Size selective harvest from fishing can cause size (age)-truncations in populations where the oldest and largest individuals are being preferentially removed from populations (Rochet 1998). The elimination of fishing pressure in the Point Buchon and Piedras Blancas MPAs may explain these differences in life history traits, although environmental factors may also be influencing growth parameters. Comparing our data among broader geographic scales and over a longer time frame may provide insight into more suitable management strategies. 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.

2 MATURITY

Comparing size (age) at maturity from our research to a past study reveals differences in values. Echeverria 1987 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 17cm, respectively (Echeverria 1987). Because our data showed gopher rockfish were maturing two years later and over five centimeters larger sizes, this suggests either a change in maturity over time, between regions, from additional sources (like fishing pressure), or a combination of factors. Delayed maturity and increased lifespans may result from excessive mortality (fishing) of individuals prior to them reaching maturity (Giesel 1976). Furthermore, fishing adults in excess may decrease size and age at maturity (Giesel 1976), which has been shown in Atlantic cod (Beacham 1983; Olsen et al. 2004), Northeast Arctic cod (Jørgenson 1990), plaice (Rijnsdorp 1993), and grayling (Haugen and Vøllestad 2001). While we cannot determine what factor has predominantly contributed to these differences, future management should apply this regional knowledge. Past management decisions that were based on information from the stock assessment may be inappropriate for south central California gopher rockfish, therefore future strategies should reflect current trends. Harvest rates should be calculated based off of this local maturity information. Without running harvest models, delayed maturity can translate to delayed recruitment; therefore, a fish reaching maturity at larger sizes and older ages could indicate a more conservative estimate of reproductive output. If this is

the case, fish with delayed maturity may require more conservative harvest rates than previously determined from the past stock assessment. It would be beneficial to collect regional data over longer time periods to establish appropriate localized management for this species. Because life history characteristics can vary over time and space, it is essential to utilize accurate regional data for local populations; doing so enables management on a more ecosystem-based spatial scale.

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.

3 *CONDITION*

Spatial variation existed in the hepatosomatic indices of fish collected from Piedras Blancas compared to Point Buchon, which can likely be attributed to multiple environmental factors. The relative abundance of predators and predation pressure may impact the condition of prey species. Energy spent avoiding predation may decrease energy reserves (Walsh et al. 2012); likely translating to decreases in hepatosomatic indices. Lingcod, *Ophiodon elongatus*, is a predatory teleost that often preys on gopher rockfish (Love 2011). Lingcod abundance measured in catch-per-unit-effort (CPUE) is significantly greater ($p < 0.0001$) in the Point Buchon MPA in years 2012-2013 than in the Piedras Blancas MPA in years 2012-2013 (California Collaborative Fisheries Research Program (CCFRP) Annual Report, 2014), which may explain spatial differences in HSI between areas. More lingcod in the Point Buchon MPA could mean greater predation

pressure, which may alter energy reserves in prey species like gopher rockfish. In addition, food quality and quantity may influence fish condition. Dietary digestible lipid is known to increase hepatosomatic indices in juvenile Korean rockfish, *Sebastes schlegeli* (Lee et al. 2002). A gut content study by Lounsbury (2011) showed differences in gopher rockfish diet between Piedras Blancas and Point Buchon. Data regarding gopher rockfish diet trends during our study years do not exist; at present it is unknown how temporally stable these patterns in diet are. While the difference in hepatosomatic indices between our study areas is likely due to various environmental factors, it is difficult to interpret our results at this time.

4 CONCLUSIONS

Our data suggest that both natural and anthropogenic factors, including the removal of fishing pressure, may explain some spatial and temporal differences in life history traits and condition of gopher rockfish from south central California. The elimination of fishing, after the implementation of the Point Buchon and Piedras Blancas MPAs, may have resulted in increased longevity and maximum sizes of individuals in these reserves. In order to determine if these patterns are temporally stable, this study should be conducted over a longer period of time. Future research should focus on the long-term effects of eliminating fishing on gopher rockfish life history characteristics. While it will be difficult to determine if potential life history changes are due to plastic or adaptive responses, determining the lasting effects of MPA implementation on these parameters is a topic worth further investigating. Moreover, factors like predation pressure and

diet are possible explanations for variation in fish condition between study areas. Environmental information should be monitored to verify influences on body condition. Localized life history information expanding over the full range of this species could theoretically help policymakers better manage gopher rockfish stocks at smaller regional levels. Overall, it is essential to gather current life history and condition data to understand spatial and temporal differences of an economically valuable species in order to manage stocks sustainably for the future.

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