THE RESPONSE OF A PREDATORY FISH, *OPHIODON ELONGATUS*, TO A MARINE PROTECTED AREA: VARIATION IN DIET, CATCH RATES, AND SIZE COMPOSITION

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TITLE: The Response of a Predatory Fish, *Ophiodon elongatus*, to a Marine Protected Area: Variation in Diet, Catch Rates, and Size Composition.

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ABSTRACT

The Response of a Predatory Fish, *Ophiodon elongatus*, to a Marine Protected Area: Variation in Diet, Catch Rates, and Size Composition.

Eric Shufeldt Anderson

Marine Protected Areas (MPAs) are a management tool used to protect and sustain many ecologically and economically important fish species from overexploitation by recreational and commercial fishing. Lingcod (*Ophiodon elongatus*) and some of its prey species, such as rockfish (*Sebastes* spp.), are species that are protected from fishing in some California MPAs. Lingcod is an apex predator that consumes a variety of fish and invertebrate species. In this study, I sought to assess the effect of an MPA on the abundance, size and diet of Lingcod. I hypothesized that Lingcod in a no-take MPA would be more abundant and larger than Lingcod in an adjacent reference site (REF) that was open to fishing. Furthermore, I hypothesized that diet would differ between Lingcod in caught the MPA and Lingcod in the REF. I collected Lingcod from the Point Buchon State Marine Reserve (MPA) and an adjacent REF site that was open to fishing. I measured, weighed, sexed, and collected stomach contents from Lingcod using the gastric lavage (stomach pumping) technique. Then, I identified prey items from Lingcod stomach contents down to the lowest taxonomic level possible and quantified diet composition by percent by occurrence, percent by number, and percent by mass. Lingcod in the MPA consumed more fish prey items than Lingcod in the REF site. Lingcod in the REF consumed more cephalopod prey items than Lingcod in the MPA. I analyzed the four most common prey items (rockfish, anchovies, flatfish, and octopus) for nutritional content. My data suggest that Lingcod increased in size and abundance in a no-take MPA because they do not suffer from fishing mortality. However, a more nutritious diet could also contribute to a biologically significant advantage for Lingcod in the MPA. To address this would require further research focused on calculating the net energy (gross energy extracted from the prey item minus the energetic costs of handling and digesting the prey item) obtained by Lingcod from consuming different fish and cephalopod prey items. MPAs can be an effective management tool for protecting fish stocks, although, it is important to understand the interspecific interactions between predator and prey species to adaptively mange MPAs and the species that reside within them.

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INTRODUCTION

Marine Protected Areas

No-take Marine Protected areas (MPAs) can an effective management tool for protecting many commercially and recreationally harvested fish species from overexploitation (Fox et al. 2012, Marinesque et al. 2012). In general, MPAs can increase the density, biomass, and size of fish within reserves (Halpern 2003, Halpern and Warner 2002, Lester et al. 2009). There is also evidence that no-take MPAs have positive impacts on populations of nearshore temperate reef fish with small home ranges, such as rockfish (*Sebastes* spp.) and Lingcod (*Ophiodon elongatus*) (Hamilton et al. 2010, Martell et al. 2000, Paddack and Estes 2000, Starr et al. 2004, Starr et al. 2015).

California's MPA Monitoring and Fisheries Management

California has a statewide network of MPAs with various levels of protection and the Marine Life Protection Act requires that selected MPAs are monitored to facilitate the adaptive management of this network of MPAs (CDFG 2008, Kirlin et al. 2013). In accordance to this requirement, four MPAs along the central coast of California have been continuously monitored since their implementation in 2007 by researchers at California Polytechnic State University (Cal Poly), San Luis Obispo and Moss Landing Marine Laboratories as part of the California Collaborative Fisheries Research Program (CCFRP; Starr et al. 2015, Wendt and Starr 2009, Yochum et al. 2012). The CCFRP collects data on the species composition, catch rates, and biomass of nearshore groundfish populations inside and outside of MPAs (Starr et al. 2015, Wendt and Starr 2009, Yochum et al. 2012).

Lingcod and rockfish are ecologically important and economically valuable to both the sport and commercial fisheries on the central coast of California (Hamel et al. 2009, Jagielo and Wallace 2005, Lenarz 1986, Lynn 2010). Yet despite the ecological and economic importance of these fisheries, the management of rockfish species and Lingcod in California is largely reliant of fisheries dependent data and some species still lack a continuous long-term data set to inform management decisions (Leet et al. 2001, Lynn 2010, Wendt and Starr 2009). However, as Wendt and Starr (2009) describe, the data from the CCFRP monitoring can be utilized for both traditional and data limited stock assessments and for evaluations of MPA performance. In this study, I use these data to ask novel questions about the effect of an MPA on the abundance, size, and diet of Lingcod along the central coast of California.

Potential Effects of MPAs on Lingcod and Prey Species

The release of fishing pressure caused by marine reserves can increase Lingcod density, length, and biomass (Martell et al. 2000). However, the removal of mortality due to fishing may not be the only factor responsible for these increases. Lingcod are primarily piscivorous (Simenstad et al. 1979, Beaudreau and Essington 2007) and the implementation of a no-take MPA may also result in more fish at lower trophic levels (Halpern 2003) available for Lingcod consumption. If there is an increase in prey availability, then the optimal foraging theory states that a predator will consume the amount, size, and type of prey closer to their optimal diet (Ringler 1979, Townsend and Winfield 1985, Werner and Hall 1974). Thus, if there is more prey available to Lingcod in MPAs, then they may need to spend less time foraging for prey than Lingcod that

forage outside of MPAs. Additionally, if there is a high abundance of all prey items, then the predator should almost exclusively consume the prey items that provide the greatest net energy, or the gross energy extracted from the prey item minus the energetic costs of handling and digesting the prey item (Ringler 1979, Townsend and Winfield 1985, Werner and Hall 1974). Therefore, if an MPA increases the amount of all prey items with in its boundary, then Lingcod should consume a disproportionate amount of the prey items that provide the greatest net energy and have a less diverse diet than Lingcod that are foraging in areas with a lower abundance of prey items.

Lingcod consume a wide variety of prey species, but two of their most common prey items are fish and cephalopods (Beaudreau and Essington 2007, Tinus 2008). As prey items, fish generally contain a greater percentage of fats than cephalopods (Goodman-Lowe et al. 1999, Goodman-Lowe et al. 2000, Iverson et al. 2002) and cephalopods generally contain a greater percentage of proteins than fish (Goodman-Lowe et al. 1999, Goodman-Lowe et al. 2000). Furthermore, cephalopods contain a greater percentage of water (moisture) than fish (Goodman-Lowe et al. 1999, Goodman-Lowe et al. 2000), and therefore have less digestible energy per gram than fish. Because fish can obtain more calories from a gram of fat than they can from a gram of protein (Phillips and Brockway 1959), fish prey items should be more energetically dense than cephalopod prey items. Thus, Lingcod should receive a more energetically rich diet by consuming fish as opposed to cephalopods.

Compared to most of the rockfish that inhabit the nearshore rocky reef habitat, Lingcod are fast growing and mature quickly (Cass et al. 1990, Leaman 1991, Love et al. 1990, Lynn 2010, Starr et al. 2015). Slow-growing rockfish may take longer to respond

to the release of fishing pressure and become larger and more abundant in MPAs. Starr et al. (2015) suggest that perhaps 20 years are needed for most rockfish species. However, the predator-prey interactions between Lingcod and rockfish may add complexity to this response. For instance, Lingcod as top predators might consume enough rockfish to cause the recovery of certain rockfish populations to happen even more slowly. Indeed, no-take marine reserves have been shown to benefit top predator species and reduce the density of prey species (Graham et al. 2003, Takashina et al. 2012). Tinus (2008) showed that Lingcod prefer shrimp, sand lances, and other transient and pelagic fishes over rockfish. However, rockfish consumption by Lingcod has been estimated to be 3–10 times greater in marine reserves than in nonreserves (Beaudreau and Essington 2007, Beaudreau and Essington 2009). Therefore, understanding how marine reserves will affect the size and abundance of individual species requires knowledge of the trophic interactions that occur within the reserve.

The objectives of this study are to examine the effect of a no-take MPA on the (1) abundance and size of Lingcod, (2) the composition of Lingcod diet, and (3) the energetic value of prey consumed by Lingcod. I hypothesize that: (1) Lingcod will be more abundant and larger in the no-take MPA than the reference site, (2) the diet of Lingcod in these two sites will be different and that Lingcod will consume more fish in the MPA as opposed to the reference site, and (3) there will be differences in energy densities of the various prey items that Lingcod consume. This study aims to improve the understanding of the influence MPAs have on the abundance, size, and diet of a top predator in the nearshore rocky reef community and provide information that can be used to better manage our nearshore fisheries.

METHODS

Study Site

I conducted this study off the central coast of California, USA. I collected Lingcod from two sites: the Point Buchon State Marine Reserve (MPA) and an adjacent reference site that is open to fishing (REF; Figure 1).

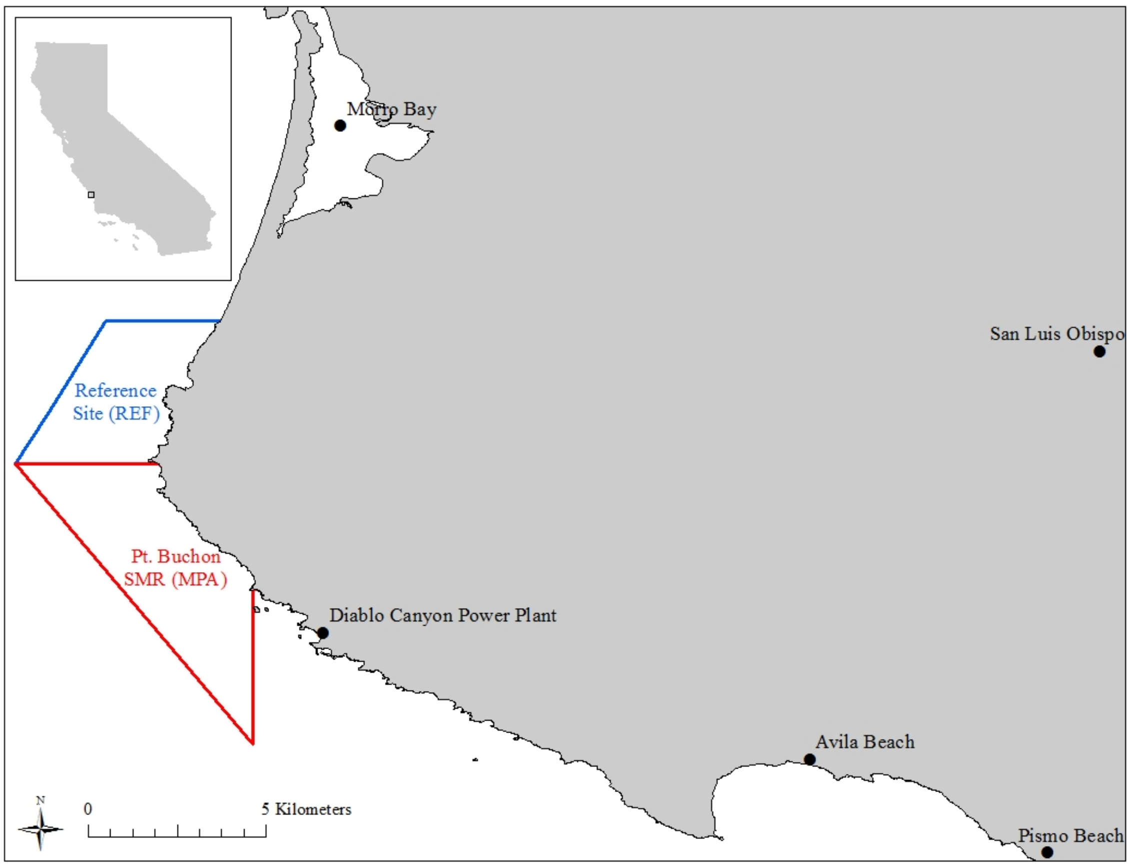

Figure 1. A map of the Point Buchon State Marine Reserve (MPA, red border) and the adjacent reference site (REF, blue border) where Lingcod were collected.

Data Collection

Lingcod Abundance

The California Collaborative Fishing Research Program (CCFRP) has collected data on the abundance and size of fish caught in the MPA and REF site since 2007, when the Point Buchon State Marine Reserve was established (Starr et al. 2015, Wendt and Starr 2009, Yochum et al. 2012). These two sites were each sampled four days per year, from July to September. On each sampling day, four 500 m x 500 m grid cells within the MPA or REF were selected for sampling using standardized recreational hook-and-line fishing methods (shrimp flies with squid bait, shrimp flies without bait, and weighted jigs; Starr et al. 2015). Lingcod were measured (total length) to the nearest centimeter, sexed, tagged, and released. The number of anglers and time-spent fishing was recorded so that effort could be calculated in angler hours. From 2007 to 2014, 537 Lingcod were caught and processed in the Pt. Buchon MPA and REF sites as part of this project. For full details of the CCFRP sampling protocols, see Starr et al. (2015).

Lingcod Length, Weight, and Stomach Contents Collection

CCFRP technicians at Cal Poly sampled Lingcod in the MPA and REF sites and collected stomach contents between July 2013 and October 2014 in conjunction with CCFRP trips using the same standardized recreational hook-and-line fishing methods. Additional sampling was conducted on non-CCFRP trips aboard Cal Poly research vessels. We collected stomach contents from 106 Lingcod in the MPA and 49 in the REF site, for a total of 155 Lingcod. Prior to obtaining stomach contents, Lingcod were

measured (total length) to the nearest centimeter, sexed, tagged, and weighed to the nearest 0.01 kilogram using a digital hanging scale.

We obtained stomach contents form Lingcod either by using lethal (sacrifice and dissection) or non-lethal (gastric lavage) techniques. The gastric lavage, or stomach flushing, method is the most effective non-lethal way to obtain stomach contents from Lingcod (Kamler and Pope 2001, Beaudreau and Essington 2007). We used the methods for gastric lavage described by Beaudreau and Essington (2007), with the exception that the Lingcod were not anesthetized in this study. We used a hand powered garden sprayer to spray water down the esophagus of a Lingcod and expel its stomach contents, which were collected in a metal sieve.

We preserved the Lingcod stomach contents in a 10% formalin solution to prevent further digestion. In the laboratory, we identified and measured prey items using the methods described by Beaudreau and Essington (2007). We identified prey items to the lowest taxonomic level possible using dichotomous keys (Miller and Lea 1972). Then, we removed excess water with paper towels and weighed each prey item to the nearest 0.01 gram using a digital scale. Finally, we assigned a code to each prey item that corresponded to how much of the prey item had been digested using the standards set by the Alaska Fisheries Science Center. (AFSC 2010).

Data Analysis

Lingcod Abundance

I analyzed lingcod abundance in the MPA and REF sites using CCFRP data from 2007 to 2014 (Starr et al. 2015). I used a fixed effects generalized linear model with a

Poisson distribution, where year as a categorical variable, site (MPA or REF), the interaction between year and site, grid cell, and effort (measured in angler hours) were predictors of Lingcod catch. Next, I set up a contrast to compare the MPA and REF sites for the year of 2008, which was the first year of MPA enforcement. Then, I specified another contrast between MPA and REF sites for the subsequent years (2009–2014). I specified a third contrast to see if Lingcod catch changed in the MPA from 2010 to 2011. Finally, I used a logistic regression model to determine if there was a difference in the number of Lingcod longer than 55 cm (minimum size for recreational take since 2011) caught in the MPA and REF site from 2012 to 2014. This model included year as a categorical variable, site, and the interaction of year and site as predictor variables of Lingcod size (shorter or longer than 55 cm).

Lingcod Length and Weight

I used the CCFRP dataset (Starr et al. 2015) to determine if Lingcod were changing in size in the MPA and REF sites over time. To explore the possibility of a recruitment event that happened prior to 2009, I created a subset of the data set that only included data from the years 2008 and 2009. Using this data subset, I created a two-way ANOVA model with year as categorical variable, site, and the interaction of year and site as predictors of Lingcod length. Then, I used a linear regression model to see if Lingcod were changing in length from 2009 to 2014. The linear regression model included year as a continuous variable and site as predictors of mean Lingcod length.

I used data from the 155 Lingcod that I lavaged in 2013 and 2014 to see if Lingcod length and weight varied across year and/or site. I used a log transformation

improve the normality of the Lingcod length and weight response variables. I created two separate ANOVA models to examine the response variables of Lingcod length and weight. The models had year as a categorical variable, site, and the interaction between year and site as predictors of Lingcod length or weight. If any of the predictor variables were significant ($\alpha = 0.05$), then I compared the pairwise means with a Tukey's Honest Significant Difference (HSD) test.

Diet Analysis

For the Lingcod that contained prey items in their stomach, first, I described prey items using three broad taxonomic groups: fish, cephalopods, and shrimp. Then, I classified them into more specific groups at the lowest taxonomic level possible. Finally, I quantified each prey item's contribution to Lingcod diet by calculating the percent of occurrence (%O), percent by number (%N), and percent by mass (%M) for Lingcod caught in the MPA and REF sites.

I used logistic regression analyses to examine the occurrence of prey items (%O) in Lingcod stomachs. Year as a categorical variable, site, the interaction of year and site, and Lingcod length were predictor variables of prey item occurrence. If any of the models had any significant predictor variables ($\alpha = 0.05$), then odds ratios were calculated to quantify the difference in prey item occurrence. Odds ratios represent the probability that a prey item will occur in a Lingcod stomach given a particular value of the predictor variable compared to the probability that a prey item will occur in a Lingcod stomach given the other value(s) of that variable. For example, an odds ratio could represent the probability that a certain prey item will be present in a Lingcod that was

caught in the MPA compared to the probability that the prey item will be present in a Lingcod that was caught the REF site.

I also attempted to analyze the %M and %N of prey items found in Lingcod stomachs using beta regression models. But because the distributions were very non-normal and most the responses were either zero or one, I was unable to effectively model the %M and %N data.

Nutritional Analysis of Prey Items

I examined the nutritional content of the four most common prey items observed in Lingcod stomachs (Scorpaenidae, Engraulidae, Octopodidae, and the flatfishes). I chose one species to represent each taxonomic group by choosing the most common species observed for each of these four taxonomic groups. Blue Rockfish (*Sebastes mystinus*) represented family Scorpaenidae, Pacific Sanddab (*Citharichthys sordidus*) represented the flatfishes, Northern Anchovy (*Engraulis mordax*) represented family Engraulidae, and East Pacific Red Octopus (*Octopus rubescens*) represented family Octopodidae. Specimens from the central California area were collected by trawl, purse seine, or by spear or hand while on SCUBA.

I used five Blue Rockfish, five Pacific Sanddabs, 40 Northern Anchovies, and ten East Pacific Red Octopuses for this analysis. All of the individuals of each species were frozen, chopped into smaller chunks with a meat cleaver, and then homogenized using the Dr. Tech 3HP Commercial Blender. Two subsamples of both the Blue Rockfish and Northern Anchovy homogenates and one subsample of both the Pacific Sanddab and East Pacific Red Octopus homogenates (there was not enough material to send two samples)

were analyzed for their nutritional content at the Merieux NutriSciences laboratory in Cypress, California. The specific nutritional components analyzed were energy density (measured in Joules/gram), percent fat, percent protein, percent carbohydrates, percent moisture, and percent ash. I used these values to determine the nutritional value of each prey item.

RESULTS

Lingcod Abundance

There was no significant difference in Lingcod catch between the MPA and REF sites in 2008 ($p = 0.65$; Figure 2). However, Lingcod catch in the MPA was significantly greater than in the REF site during the subsequent years from 2009 to 2014 ($p < 0.001$; Figure 2). Additionally, Lingcod catch in the MPA was significantly greater in 2011 than it was in 2010 ($p < 0.001$; Figure 2). Finally, since 2012, there were significantly more Lingcod longer than 55 cm (minimum size for recreational take since 2011) caught in the MPA than the REF site ($\chi^2 = 10.19$, df =1, $p = 0.001$; Figure 2). Only 46.8% of Lingcod caught in the REF site were above the minimum size for recreational take. However, during this same period, 73.4% of Lingcod caught in the MPA were larger the minimum size limit.

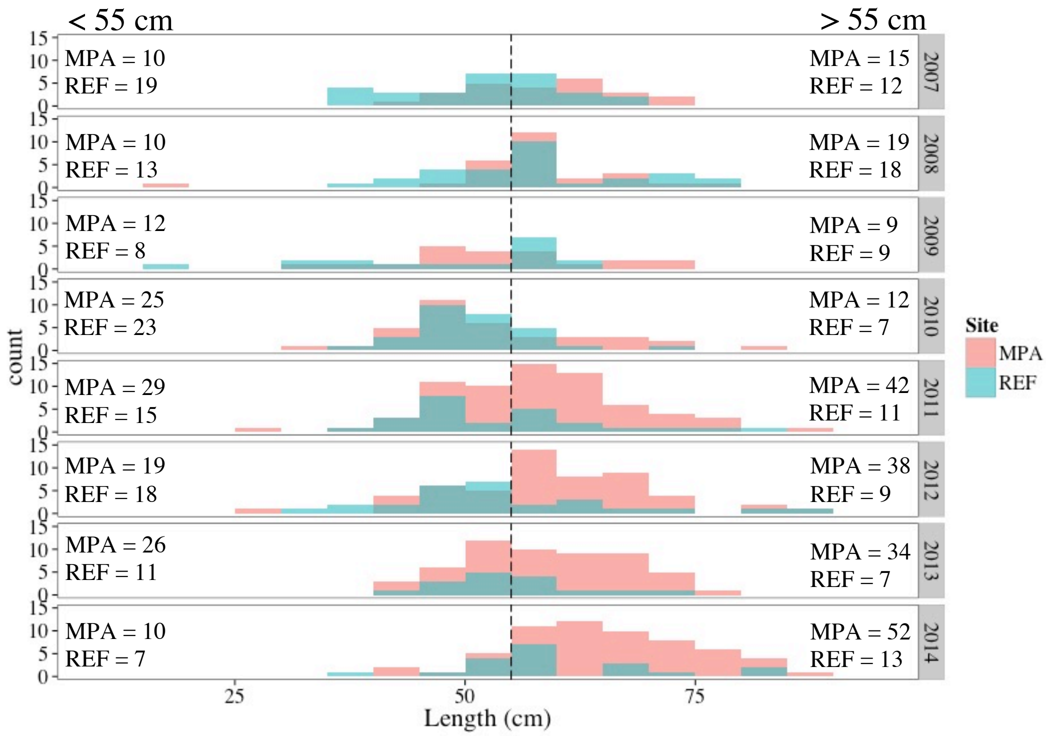

Figure 2. Histogram of the length of Lingcod collected by the CCFRP from 2007 to 2014. Lingcod length is defined by 5 cm bins. The black dashed line represents the minimum size (55 cm) for the recreational take of Lingcod from 2011 to 2014. Sample sizes for Lingcod less than and greater than 55 cm are shown on the left and right side of the figure, respectively.

Lingcod Length and Weight

A two-way ANOVA model showed that Lingcod in both the MPA and REF sites were significantly longer in 2008 than 2009 ($F_{1, 90} = 6.61$, $p = 0.01$). Additionally, a linear regression model showed that from 2009 to 2014, the mean length of Lingcod in both the MPA and REF sites significantly increased over time ($F_{1, 8} = 26.17$, $p < 0.001$).

The results from a two-way ANOVA model showed that in 2013 and 2014, year ($F_{1, 151} = 7.24$, $p = 0.008$), site ($F_{1, 151} = 8.45$, $p = 0.004$), and the interaction between year and site ($F_{1, 151} = 4.44$, $p = 0.037$) were significant predictors of Lingcod length. The

post-hoc Tukey's HSD test showed that Lingcod caught in the MPA in 2014 were significantly longer than (1) Lingcod caught in the MPA in 2013 ($p < 0.001$), (2) Lingcod caught in the REF site in 2013 ($p = 0.003$), and (3) Lingcod caught in the REF site in 2014 ($p < 0.001$; Figure 3). The results from a second two-way ANOVA model showed that in 2013 and 2014, year ($F_{1, 149} = 7.23$, $p = 0.008$), site ($F_{1, 149} = 6.90$, $p = 0.010$), and the interaction between year and site ($F_{1, 149} = 4.20$, $p = 0.042$) were significant predictors of Lingcod weight. The post-hoc Tukey's HSD test showed that Lingcod caught in the MPA in 2014 were significantly heavier than (1) Lingcod caught in the MPA in 2013 ($p < 0.001$), (2) Lingcod caught in the REF site in 2013 ($p = 0.005$), and (3) Lingcod caught in the REF site in 2014 ($p < 0.001$; Figure 4).

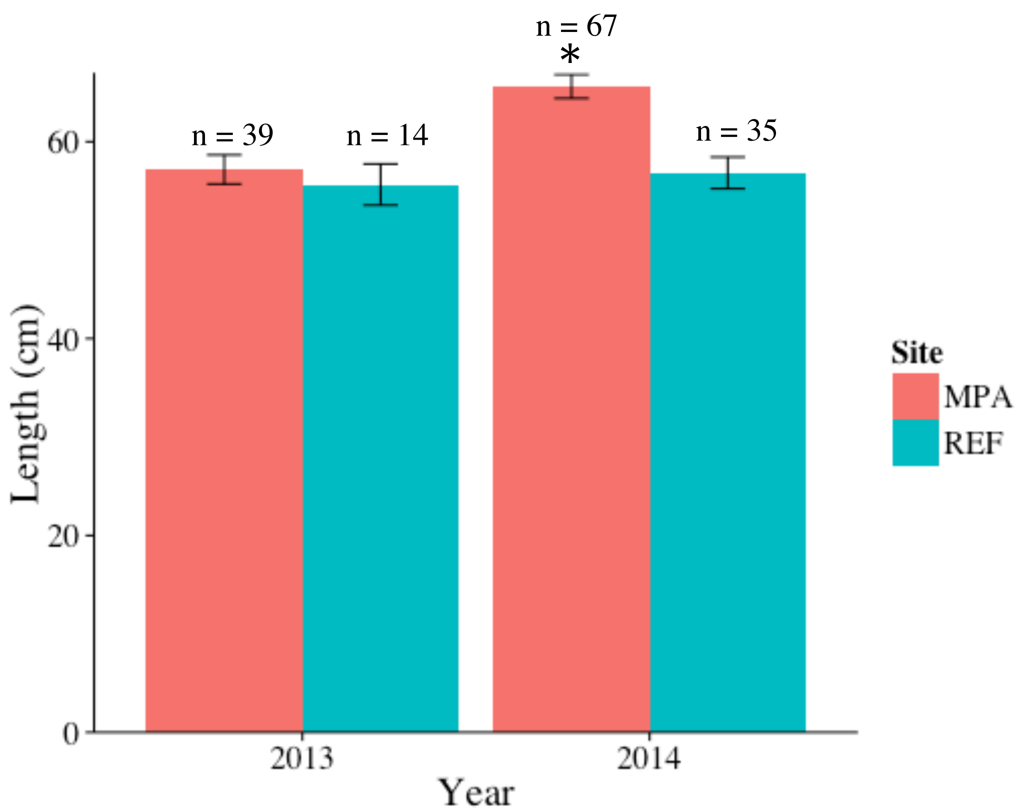

Figure 3. The mean lengths of Lingcod caught in the MPA and REF site for 2013 and 2014. Error bars represent the standard error of the means. Bars that are marked with an * are significantly different (Tukey's HSD).

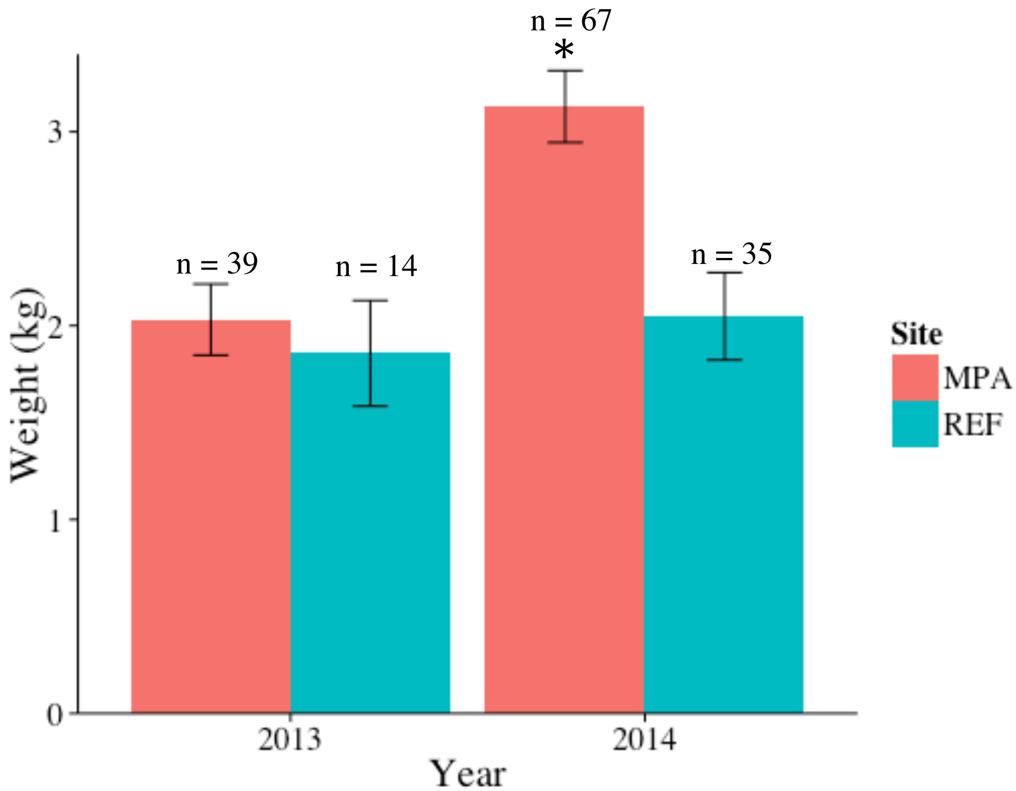

Figure 4. The mean weights of Lingcod caught in the MPA and REF site for 2013 and 2014. Error bars represent the standard error of the means. Bars that are marked with an * are significantly different (Tukey's HSD).

Diet Analysis

Frequency of Prey Items in Stomachs

For the 106 Lingcod caught in the MPA, 86 contained at least one prey item in their stomach. For the 49 Lingcod caught in the REF site, 42 contained at least one prey item in their stomach. None of the predictor variables (year, site, the interaction of year and site, and Lingcod length) were significant predictors of the frequency of having at least one prey item in a Lingcod stomach.

Diet Composition

In the MPA, fish prey items made up the majority of Lingcod diet composition by number, mass, and occurrence (Table 1). In the REF site, cephalopods (octopus and squid) made up the majority of Lingcod diet composition by number, mass, and occurrence (Table 1). Lingcod in the MPA also consumed shrimp prey items (families Natantia and Pandalidae), but they only made up 0.68% and 0.55% of their diet by number and mass, respectively (Table 1).

We examined 13 logistic regression models to predict the occurrence of a specific prey item in the stomach of a Lingcod, but only the model that predicted the occurrence of any fish prey item and the model that predicted the occurrence of any cephalopod prey item, had any significant predictor variables. In both cases, site (MPA or REF), was a significant predictor for the occurrence of a fish ($\chi^2 = 6.27$, df = 1, p = 0.012) or a cephalopod ($\chi^2 = 3.95$, df = 1, p = 0.047) prey item in a Lingcod stomach. Lingcod caught in the MPA were 2.91 times more likely to consume a fish prey item than Lingcod in the REF site. Lingcod caught in the REF site were 2.63 times more likely to contain a cephalopod prey item in their stomach than Lingcod in the MPA.

When prey items were grouped into more specific taxonomic levels, Scorpaenidae (rockfishes), Engraulidae (anchovies), and flatfishes were the most common identifiable fish prey items and Octopodidae (octopus) was the most common cephalopod prey item (Table 1).

Table 1. Diet composition by site (MPA or REF) for Lingcod caught in 2013 and 2014. Prey items were quantified by percent number, mass, and occurrence. The number of Lingcod that contained at least one prey item was 86 in the MPA and 42 in the REF.

	% Number		% Mass		% Occurrence	
Prey Items	**MPA**	**REF**	**MPA**	**REF**	**MPA**	**REF**
Fish	53.72	33.36	58.33	38.91	72.09	45.24
Cottidae	1.36	0	2.12	0	2.33	0
Embiotocidae	0	0.79	0	1.47	0	2.38
Engraulidae	9.78	12.57	9.06	12.05	13.95	16.67
Hexagrammidae	1.16	5.56	1.16	7.14	1.16	7.14
Flatfishes	6.55	0	7.12	0	9.3	0
Scorpaenidae	13.29	12	18.67	15.58	24.42	19.05
Stichaeidae	0.58	0	0.69	0	1.16	0
Synodontidae	0.58	0	0.47	0	1.16	0
Unidentified Fish	20.41	2.45	19.03	2.67	32.56	7.14
Cephalopods	45.61	66.64	41.11	61.09	61.63	80.95
Octopodidae	22.73	41.75	31.62	48.92	38.37	57.14
Loliginidae	2.1	3.06	2.38	4.29	3.49	7.14
Unidentified Ceph.	1.04	0.95	2.15	0.19	3.49	2.38
Cephalopod Beak	19.73	20.88	4.96	7.70	31.40	33.33
Shrimp	0.68	0	0.55	0	2.33	0

Nutritional Analysis of Prey Items

Northern Anchovies (representing Engraulidae) contained more than twice the energy density and six times the percent fat than the other of the four most common prey items (Table 2). Out of the other three common prey items (Scorpaenidae, flatfishes, and Octopodidae), Blue Rockfish (representing Scorpaenidae) contained the second greatest energy density and had the greatest percent protein (Table 2). Furthermore, the energy density of Blue Rockfish was 10% greater than the energy density of East Pacific Red Octopus (representing Octopodidae; Table 2). Pacific Sanddabs (representing the flatfishes) contained the lowest energy density of all other prey items (Table 2). However, because of the small sample sizes for these analyses, these trends may not be

completely representative of the actual differences in nutritional value and should be interpreted cautiously.

Table 2. The nutritional values of the four most common prey items found in Lingcod stomachs. Sample sizes are shown in parentheses next to prey item. ww = wet weight.

Prey Item	Energy Density (J/g ww)	% Fat (ww)	% Protein (ww)	% Carb. (ww)	% Moisture (ww)	% Ash (ww)
S. mystinus (2)	3682	1.945	18.625	<0.1	75.08	5.35
E. mordax (2)	7406	12.1	18.035	<0.1	67.825	2.985
C. sordidus (1)	3180	1.32	16.7	<0.1	79.24	3.31
O. rubescens (1)	3347	2.17	14.19	1.01	80.49	3.31

DISCUSSION

I found that Lingcod abundance was greater in the MPA from 2009 to 2014 than it was in the REF site (Figure 2). Lingcod length increased in both the MPA and REF sites from 2009 to 2014. Additionally, there were differences in diet between Lingcod in the MPA and REF in 2013 and 2014; Lingcod in the MPA consumed more fish (Table 1) and Lingcod in the REF consumed more cephalopods, specifically octopus (Table 1).

The increase in Lingcod abundance in the MPA could be due to a possible large recruitment event, which I suspect occurred prior to 2009, coupled with the absence of fishing pressure. The decrease in Lingcod length from 2008 to 2009 in both the MPA and REF sites shows evidence for a possible recruitment event, as smaller Lingcod from this possible recruitment event were sampled by CCFRP in 2009 (Figure 2). Additionally, there was a large increase in Lingcod abundance in the MPA from 2010 to 2011, which could be attributed to the Lingcod from this recruitment event growing to a size that is more likely to be selected by our fishing gear. Lingcod length increased in both the MPA and REF sites from 2009 to 2014. However, after 2012 there were significantly more legal sized (greater than 55 cm) Lingcod caught in the MPA than REF site (Figure 2). This suggests that fishing pressure is contributing to the removal of large Lingcod in the REF site, which is open to fishing. Taken together, these data support evidence for an MPA effect on Lingcod abundance and size at Point Buchon.

Adult Lingcod are top-order predators in the rocky-reef habitat along the west coast of North America and consume both fish and invertebrates (Cass et al. 1990, Beaudreau and Essington 2007, Beaudreau and Essington 2009, Jagielo and Wallace 2005, Tinus 2008). Due to the fact that there were more and larger Lingcod in the MPA

relative to the REF site, we would expect that there are higher rates of predation on species at lower trophic levels inside the MPA. Consequently, species at lower trophic levels may not increase in number and size because of a greater predation rate inside the MPA (Graham et al. 2003, Takashina et al. 2012). That said, if the magnitude of mortality from Lingcod predation is less than the magnitude of mortality from fishing, then protection from fishing would provide some refuge for recreationally and commercially targeted fish species that are at lower trophic levels. As such, the benefits of an MPA for top-order predators like Lingcod could be twofold: 1) they may benefit from the lack of fishing mortality, and, 2) they may benefit from being able to prey upon more abundant fishes at lower trophic levels.

I observed clear differences in diet between Lingcod caught in the MPA and REF sites. Lingcod in the MPA consumed more fish compared to Lingcod in the REF site and Lingcod in the REF site consumed more cephalopod prey items as compared to Lingcod in the MPA (Table 1). It is possible that octopus and other cephalopods are more abundant in the REF site because of habitat differences between the two sites. Although no data exist on the abundance of octopus for the two sites, there are some habitat differences between the MPA and REF sites (Figure 5). I compared the rugosity of the rocky habitat in MPA and REF grid cells (Figure 5) with a t-test using data acquired, processed, archived, and distributed by the Seafloor Mapping Lab at California State University, Monterey Bay. The result of the t-test shows that the seafloor of the MPA has significantly greater rugosity than the seafloor of the REF site ($t = 2.49$, $df = 18.28$, $p = 0.022$). Ambrose (2008) found that octopus shelters were most frequently located in bedrock and boulder substrates that contained crevices and holes. The difference in

habitat between the MPA and REF sites (Figure 5) and the patterns of where Ambrose (2008) observed octopus shelters suggest that the MPA could contain more suitable habitat for octopus, as well as fish species, than the REF site. A better understanding of octopus abundance in the MPA and REF sites would allow us to ask some interesting questions on Lingcod prey preference based on what we know about differences in Lingcod diet between the MPA and REF sites (Table 1).

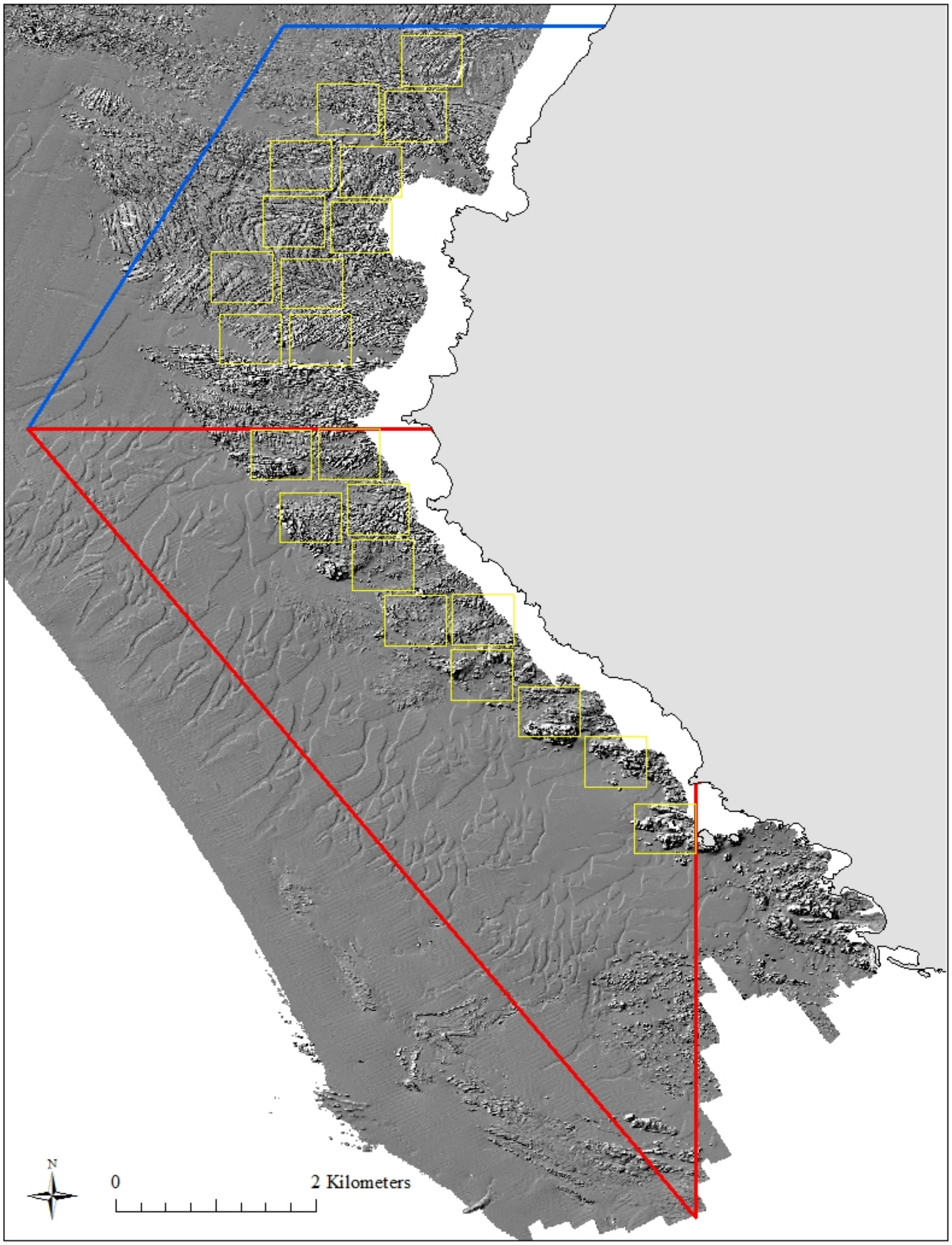

Figure 5. A map of the bathymetry of the Point Buchon SMR (MPA, red border) and the adjacent reference site (REF, blue border). 500 m x 500 m gird cells are outlined in yellow. White area nearshore was covered by kelp and could not be accessed for the habitat surveys. Two-meter resolution bathymetry data was acquired, processed, archived, and distributed by the Seafloor Mapping Lab of California State University Monterey Bay (http://seafloor.otterlabs.org).

While we have limited knowledge on the abundance of octopus in the two sites, there is more concrete evidence that there are more rockfish prey items in the MPA than in the REF site. The CCFRP collects data on the abundance of rockfish species (Starr et al. 2015, Wendt and Starr 2009, Yochum et al. 2012), which serve as potential prey items for Lingcod. Gopher Rockfish (*S. carnatus*), Blue Rockfish (*S. mystinus*) and Black Rockfish (*S. melanops*) were the three most common rockfish species caught by the CCFRP in the Point Buchon MPA and REF sites during the 2013 and 2014 sampling seasons (unpublished data from Starr et al. 2015). Therefore, they are the most abundant potential prey items for Lingcod and are also targeted by CCFRP sampling gear. The Catch Per Unit Effort (CPUE) of Gopher, Blue, and Black Rockfish combined was significantly greater in the MPA than the REF site in 2013 and 2014 ($F_{1, 187} = 7.44$, $p = 0.007$; Figure 6). This suggests that there are more rockfish prey items available to Lingcod in the MPA than Lingcod the REF site.

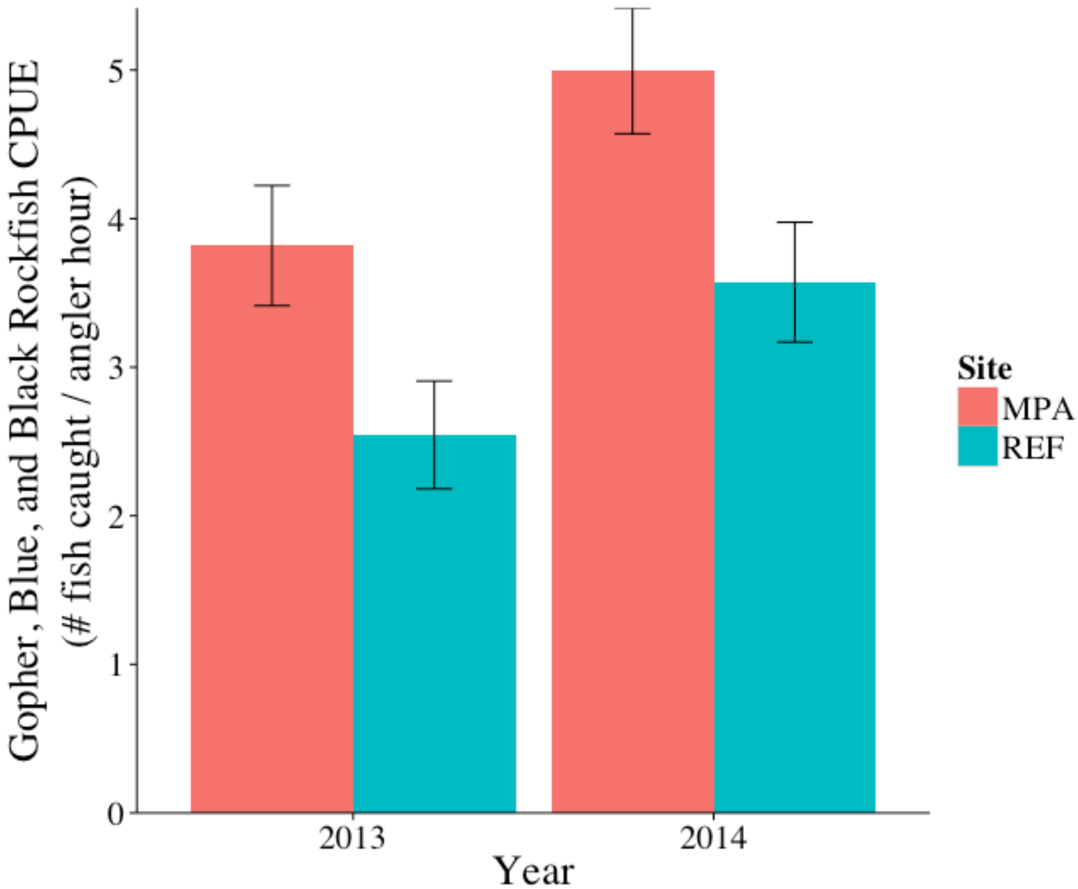

Figure 6. Catch Per Unit Effort (CPUE) by year for Gopher, Blue, and Black Rockfish combined in the Point Buchon SMR (MPA) and adjacent reference site (REF). Error bars represent the standard error of the means. Data is from the CCFRP data set described in Starr et al. 2015.

Regardless of the reasons why the diet of Lingcod differs between the MPA and REF sites, it is clear that Lingcod in the MPA consume more fish prey items and Lingcod in the REF consume more cephalopod prey items (Table 1). Fish prey items generally have a greater energy density compared to cephalopod prey items (Table 2). While octopus (family Octopodidae) actually consisted of a greater percentage of fat than rockfish (family Scorpaenidae) and sanddabs (flatfishes) and a lower percentage of protein than rockfish, anchovies (family Engraulidae), and sanddabs (Table 2), they still

contained a lower overall energy density than both rockfish and anchovies, due to their high percentage of moisture content (Table 2). Not surprisingly, anchovies contained the greatest energy density, due to their high percentage of fat and relatively low percentage of moisture (Table 2). Although anchovies seem to be the most nutritious prey item for a Lingcod, their availability as prey items is sporadic due to their extensive movement (Haugen et al. 1969, Messersmith et al. 1969), relative to Lingcod (Starr et al. 2004). Additionally, their expansive movement should allow them to be equally available to Lingcod in both the MPA and REF sites. In contrast, our data show that rockfish species are more consistently available as prey for Lingcod, which is consistent with their small home ranges and strong site fidelity (Freiwald 2012, Starr et al. 2015).

In order to determine if differences in diet between Lingcod caught in the MPA and REF sites could contribute to a biologically significant advantage for Lingcod that reside in an MPA, we would require some additional information on Lingcod digestion and foraging behavior. First, the handling time, or energy it takes to capture prey item, for fish and cephalopods is unknown and could be very different. If it takes more energy for a Lingcod to capture a cephalopod than a fish prey item, then this may contribute to fish prey items providing a Lingcod with a greater net energy value than cephalopod prey items. Similarly, the energy spent digesting a cephalopod could be different than the energy spent digesting a fish prey item. Finally, the amount of digestible energy that a Lingcod can extract from a prey item is likely different for fish and cephalopod prey items. While there have been studies that have calculated the digestion and foraging costs of piscivorous fish (Beaudreau and Essington 2009, Brett and Groves 1979, Johnston and Battram 1993, Pandian and Vivekanandan 1985), these values could be

different for a predator that consumes a large proportion of cephalopod prey items in its diet. Calculating the energy costs for the digestion and foraging for cephalopod prey items would be the next step for determining if the difference in diet between Lingcod in the MPA and REF sites are contributing to a biologically significant nutritional advantage for Lingcod that reside in the MPA.

If there is a biologically significant nutritional advantage to foraging in the MPA, then we could make some predictions on Lingcod diet based on the optimal foraging theory. First, we would expect that Lingcod would prefer to consume the prey items that provide it with the greatest net energy. Then, if we assume that an MPA increases the abundance of all prey items, we would predict that Lingcod that forage inside the MPA would consume a disproportionate amount of the prey items that provide the greatest net energy. Therefore, we would expect that Lingcod foraging in the MPA are going to have a less diverse diet than Lingcod foraging outside of the MPA.

If Lingcod in the MPA are consuming a disproportionate amount of the highest quality prey items and thus, receiving a diet of greater nutritional value than Lingcod in the REF site, then they could grow faster and reach reproductive maturity sooner than Lingcod in the REF site. Over time, this could add a small contribution to Lingcod in the MPA increasing in both abundance and size. However, the presence of fishing in the REF site is likely a more important explaining the difference between the MPA and REF sites. Fishing pressure selectively removes the largest individuals from a population (Birkeland and Dayton 2005), and could have greater effect on the abundance and size structure of the Lingcod population than the nutritional value of the prey they consume.

This effect is shown by the size distribution of Lingcod in the MPA and REF sites, as there are far fewer legal sized Lingcod caught in the REF site than the MPA (Figure 2).

The description of Lingcod abundance, size, and diet inside and outside the Point Buchon State Marine Reserve offers insight on potential effects of the establishment of an MPA. Most studies suggest that the establishment of an MPA will lead to an increase in fish abundance and size, regardless of trophic level, due to the removal of fishing mortality (Halpern 2003, Halpern and Warner 2002, Hamilton et al. 2010, Lester et al. 2009, Martell et al. 2000, Paddack and Estes 2000, Starr et al. 2004, Starr et al. 2015). However, the removal of fishing mortality may have differential impacts on fish species. For example, top predators, like Lingcod, could also benefit from MPA protection if they have access to a greater abundance of their preferred prey items. In contrast, there are cases where the benefits to species at lower trophic levels may not be realized if the abundance of large predators increases too dramatically (Graham et al. 2003, Takashina et al. 2012). To properly manage all MPAs it is essential to understand how MPAs affect the interactions between predator and prey species. Understanding these interactions and consequences will be critical to adaptively managing the MPAs as mandated in Califonia's Marine Life Protection Act (CDFG 2008, Kirlin et al. 2013).

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