Brody-Bertalanffy Growth Curves from Tag and Recapture Studies on Cabezon (*Scorpaenichthys marmoratus*) and Gopher Rockfish (*Sebastes carnatus*) of the Central Coast

A Senior Project

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Table of Contents

List of Tables

List of Figures

Introduction

The Central Coast of California is home to diverse species of commercially and recreationally valuable, shallow water demersal fish; such as Cabezon, rockfish, and various flat fishes. The California Marine Life Management Act was established in 1998 to protect these resources. At the federal level, the Magnuson-Stevens Act, reestablished in 1996, created lower catch limits utilizing a data poor, precautionary approach to management of nearshore species with an overall goal of long-term stock rebuilding (Leet et al. 2001). Cabezon and rockfish were not targeted heavily at a commercial level until the establishment of a live fish fishery in the early 1990's in which live fish could be sold at higher prices to primarily Asian American markets (Leet et al. 2001, Mireles 2005). In addition to state and federal protection acts, a moratorium on permits for nearshore fisheries was established in response to fears over the scope of these new fish markets.

The catch limits on these species are often based on inadequate life history data and corresponding parameters (Lea et al. 2001). In addition, management practices are often based on the assumptions of stable baselines and do not take into consideration seasonal or regional variation in populations (Leet et al. 2001). Several studies have suggested that populations are variable on regional and temporal scales. For example, El Nino events are thought to severely reduce the spawning biomass of many rockfish species (Lenarz et al. 1995). Genetics work has shown that there are at least three distinct populations of Cabezon along the central coast (Nakamura and Villablanca 2007). With the revelation of population structure, finer scale management strategies may be necessary to account for distinct population parameters and stresses. In this paper, an effort is made to define and compare growth parameters for two

nearshore species, *Scorpaenichthys marmoratus* (cabezon) and *Sebastes carnatus* (gopher rockfish), on a regional population level.

Cabezon are large cottids found from Pt. Abrejos, Baja California to Sitka, Alaska (Miller and Lea 1972). Cabezon reach a maximum length of 990mm and a weight of 11.4 kg (Feder et al. 1974). They are sexually dimorphic, with females being larger than males of the same age (Grebel 2003, Lauth 1987). Males are polygynous nest guarders and both sexes have typically small home ranges and high site specificity (Lauth 1987, Mireles 2005). There have been three studies attempting to establish growth curves for cabezon; O'Connell's 1953 study in California, Joanna Grebel's 2003 study done in a broad area of California coastline, and Robert Lauth's 1987 study done in Puget sound. All three studies utilize otolith readings to determine age. As far as we know, there are no tag and recapture studies on cabezon that have looked at growth curves.

Gopher rockfish are found from San Roque, Baja California to Eureka, California (Miller and Lea 1972). They are known to grow up to 15.6 inches in length and live to depths of 80 meters, although they are typically found in much shallower water from 9 to 37 meters depth (Love 1996, Eschmeyer et al. 1983). Gopher rockfish are primarily caught with line and hook in both recreational and commercial fisheries and although they are among the most commonly captured rockfish species, they are not managed on an individual species basis. (Key et al. 2005, Wilson et al. 2008). Only one attempt has been made at establishing a growth curve, which was done utilizing surface aging techniques.

To examine growth parameters of gopher rockfish and cabezon of the south central coast, we used available mark-and-recapture data to form Brody-Bertalanffy growth curves, modified Ford-Walford plots, and length vs. weight relationship curves. Existing data on these species were compared with the parameters defined in this study to look at disparities based on methods,

fishery history, population status, or natural population differences. The information provided through tag and recapture studies adds to the overall understandings of life histories for these species.

Methods

Data Acquisition

Data from tag and recapture studies as well as otolith derived studies on cabezon were reviewed to estimate Brody-Bertalanffy growth curves for the species using Growth II software by Pisces Conservation. The first set of data, the Estero study, came from work done by Carlos Mireles, which sampled Cabezon using standard traps with otter rings from Killers Reef in Cayucos to Leffingwell Landing in Cambria, California (2005; Fig. 1). The study began in August of 2004 and continued into December of 2004 with a total of 10 sampling days and 1239 fish tagged (Mireles 2005). The second set of Cabezon data, the Big Creek study, came from a recapture study done in Big Creek, California in July 2006 using similar methods to the Mireles study (Fig. 1). Big Creek is located in Big Sur, just north of Lopez Point. A third study done by Joanna Grebel, was based on otolith analysis and conducted throughout California. Length, weight, and time at large for the cabezon in these studies were used to estimate parameters of growth rate (K), theoretical maximum length (L_∞), and theoretical time at zero length (t_0).

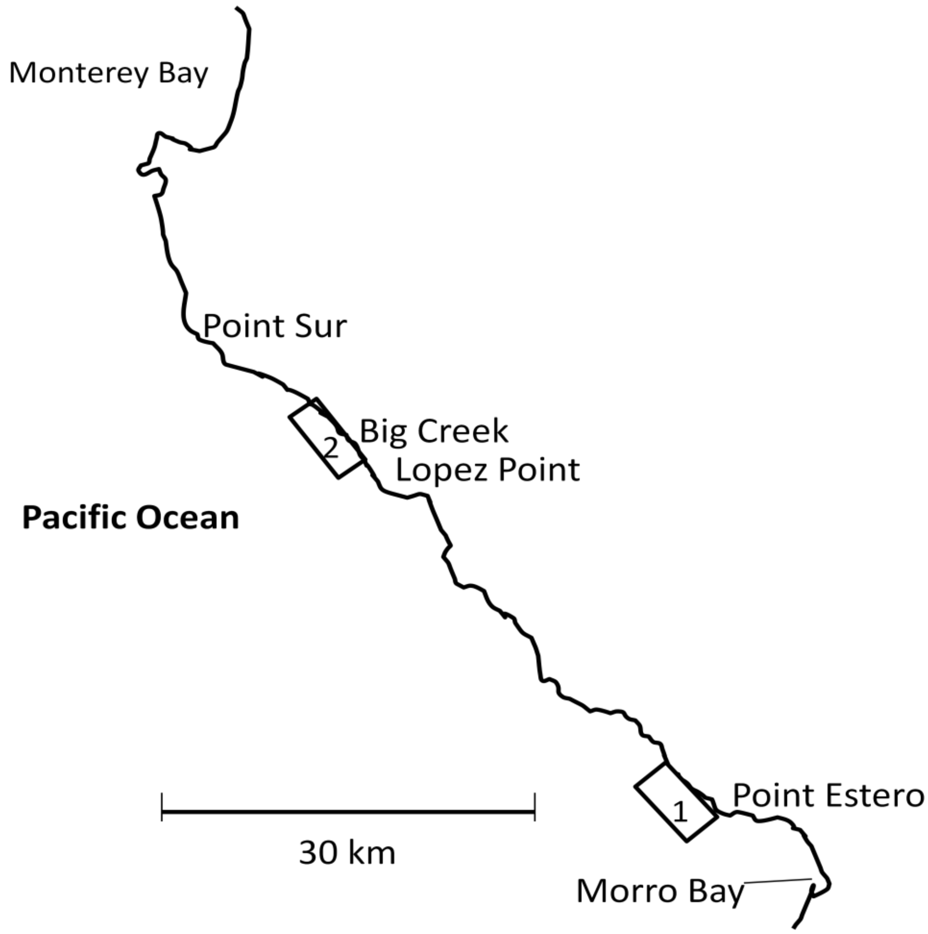

Figure 1. Map of sampling sites for tag and recapture studies on cabezon. Site one occurs on Estero reef, which is a heavily fished zone where Mireles collected his data. Site two occurs in the marine reserve near Big Creek in Big Sur. Sampling of gopher rockfish occurred throughout the central coast.

Brody-Bertalanffy and von Bertalanffy Growth Curves

Data on length at capture, length at recapture, and time at large were used to create Brody-Bertalanffy curves, which are a slight variation of von Bertalanffy curves:

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

in which l_t represents the length at time t after t_0. The von Bertalanffy equation is an integration of the equation:

$$^{d_l}/_{d_t} = K(L_\infty - l)$$

which is an assumption that the growth rate (K) gradually decreases as the size (l) of an organism approaches a theoretical maximum (L_∞) (Henderson 2006). An equivalent equation, the Brody-Bertalanffy curve:

$$l_t = L_\infty(1 - be^{-Kt})$$

in which b is equal to e^{kt} and l_t, L_∞, and K are the same as in the von-Bertalanffy curve; utilizes length changes over periods of time (Faben 1965). Growth II software uses the Brody-Bertalanffy curve for tag and recapture studies (incremental data), whereas von Bertalanffy curves are used for otolith reading studies in which all samples are sacrificed upon capture for known age information (classed data) (Henderson 2006).

Ford-Walford Linear Growth Relationship

A modified version of a Ford-Walford plot was used to independently estimate L_∞, K, and the instantaneous growth rate (e^{-k}). A traditional Ford-Walford plot shows length at capture versus length after 1 year at large for each fish in the study, which gives a linear estimation of growth parameters. However, for the data analyzed in this paper, calculating the length at one year accurately from the available data proved impossible, so recapture length was used regardless of time at large for each recapture. The L_∞ obtained from the Ford-Walford plots

differed from that obtained from the Brody-Bertalanffy curve because Growth II software could not accommodate data points in which fish were recaptured on the same day.

Weight and Length Plots

The natural logs of weight and length for each fish were plotted against each other to construct a linear regression. The slope of the linear regression should be roughly equal to 3.00 (Hempel 1982).

Paired Comparisons of Growth Parameters

The growth data from Estero Reef and Big Creek studies for cabezon contained no information on sex of the individuals, which means that the growth curves represent an unknown combination of male and female cabezon. Growth parameters available from the other three studies on cabezon were split into male and female categories. To make the present study comparable to the others, the parameters needed to be combined into one mixed sex term. Since the raw data from Lauth's Puget Sound study was included in his paper, Growth II was used to recalculate a single von Bertalanffy curve that included both sexes (Fig. 2). Grebel's otolith paper only included parameter mid-points and confidence intervals, so after consultation with the Cal Poly Statistics Department, it was decided that the parameters of the growth equation could be combined into mixed sex terms through a weighted average of the parameters (L_∞ and K) and variances (V) (Karen McGaughey, personal comm.). In the example equation:

$$\frac{L_{\infty 1}n_1 + L_{\infty 2}n_2}{n_1 + n_2} \pm \left(\sqrt{\left(\frac{1}{n_1 + n_2}\right)^2 \left[n_1{}^2 V_{L_{\infty 1}} + n_2{}^2 V_{L_{\infty 2}}\right]} \right)(Z_{95\%}) \quad = \quad L_\infty \pm MoE$$

two L_∞ parameters (male and female) and their respective standard errors are combined into a single average and margin of error (MoE). Multiplication of the standard error by the Z-value for 95% confidence ($Z_{95\%}$) gives MoE. The equation assumes that the two parameters are

independent of each other. The same equation was used to combine growth rate values. Since Grebel had recalculated O'Connell's growth parameters which had a miscalculation in the original paper, the same method was used to convert Grebel's corrected version of O'Connell's parameters into single, mixed sex parameters (Table 1).

After the parameters for other available cabezon growth data were converted to mixed sex numbers, the standard error and mean for each parameter were compared using a difference of means confidence interval:

$$(L_{\infty 1} - L_{\infty 2}) \pm Z_{95\%}\sqrt{SE_1{}^2 + SE_2{}^2} = (c, d)$$

in which L_∞ represents the midpoint in the 95% confidence interval for maximum length in each sampling, $Z_{95\%}$ is the Z-value for 95% confindence, *SE* is the standard error for each respective L_∞, and *(c,d)* is the resulting 95% confidence interval of midpoint difference. Our null hypothesis stated that no difference exists between paired comparisons of growth equation parameters. Intervals of midpoint difference that include zero would fail to reject the null hypothesis that there is no difference between the growth parameter (L_∞ or *K*) of the two populations. All possible comparisons between populations were made.

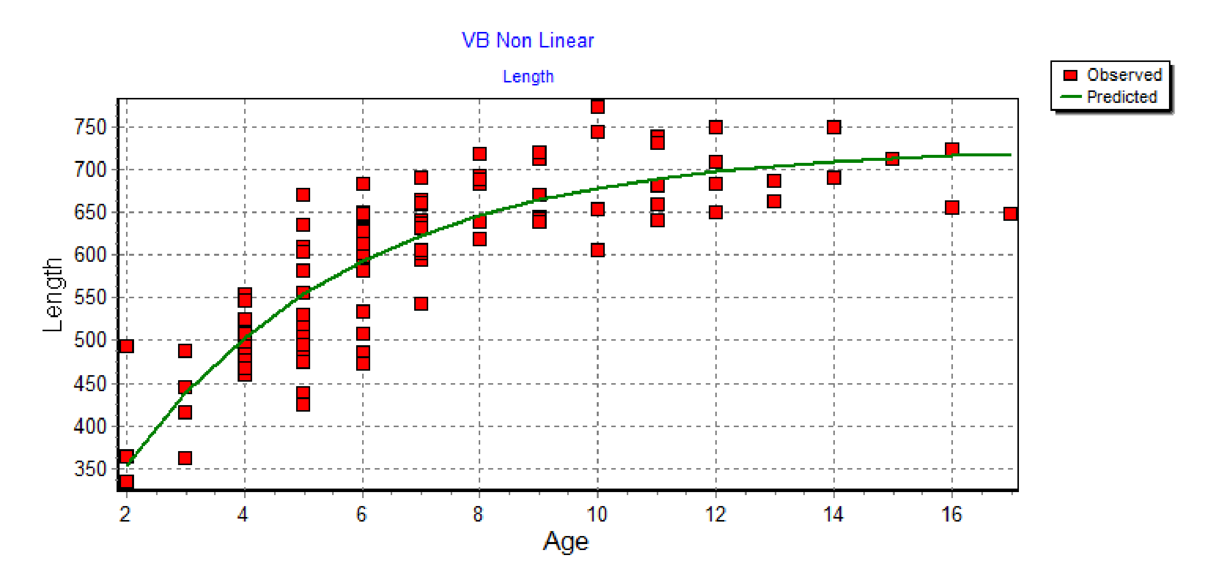

Figure 2. Lauth's 1983 Puget Sound cabezon growth curve for sex combined data. $L\infty$ = 726.70 ± 0.37 mm, K= 0.257 ± 0.001, and t_0 = -0.60 years. Length is in millimeters and age is in years.

Gopher Rockfish

A set of gopher rockfish tag and recapture data collected from various locations on the central coast of California was used to create a modified Ford-Walford plot and Brody-Bertalanffy growth curve using the same techniques as described for cabezon (Longabach 2010). No weight data as collected on these samples. No comparisons were made because there are no available data or parameters with confidence intervals provided.

Results

Cabezon Age and Growth: Present Study

Cabezon from the 2004 Estero Reef tag and recapture study showed a log transformed length versus weight relationship with a slope of 2.78 (Fig. 3), which was acceptably close to the expected slope of 3.00 for populations with logistic growth. A Ford-Walford plot, modified to show only recapture length (not length at one year), gave an L_∞ of 49.5 cm and a K of 0.1667 (Fig. 4). The theoretical maximum length given by the modified Ford-Walford plot differs from the one calculated from the Brody-Bertalanffy curve, which was estimated at 44.61 cm (Fig. 5, Table 1).

The Big Creek tag and recapture study of Cabezon was much more data poor with recapture rates greatly reduced when compared with those of the Estero Reef study site. Nonetheless, the log transformed weight versus length plot showed a 2.96 slope (Fig. 6). The modified Ford-Walford plot estimated L_∞ to be 47.00 cm, and e^{-k} to be 0.59. K was estimated at 0.524 (Fig. 7). The Brody-Bertalanffy plot for the Big Creek data was largely inadequate for estimating growth parameters other than L_∞ (Fig. 8). The sample size of cabezon recaptures was too small (n=16) for an accurate Brody-Bertalanffy curve to be established through Growth II software (Table 1).

Cabezon Growth Study Comparisons

Pairwise comparisons for L_∞ were generated between Lauth's Puget Sound study, Grebel's otolith study, O'Connell's otolith study, and the present studies near Estero Reef and Big Creek (Fig. 9). We are 95% confident that none of the pairwise comparison intervals for L_∞ contained zero, so we have evidence to reject the null hypothesis that no differences exist among the maximum lengths for the populations in each study. We found that Lauth's Puget Sound study had the largest L_∞, followed by O'Connel's study in California, Grebel's study in California, the present study at Big Creek, and, lastly, the present study at Estero Reef.

With the omission of Big Creek (K = 8.35), which had an obviously inaccurate growth rate, all possible K comparisons were made between studies (Fig. 10). At a 95% confidence level, all the intervals contained zero; therefore, we have no evidence to reject the null hypothesis that no differences exist among the growth rates for populations in each study.

Table 1. Growth parameters for known studies on cabezon, organized by location, method of data collection, and by date. Studies by other authors have parameters that have been recalculated by various methods to combine both sexes.

Author: Method, study site, and year	L_∞ **(cm)**	***K***	t_0 **(years)**	***n***
O'Connell : Otolith, California, 1953	Male: 53.58 ± 3.65	0.46 ± 0.23	-0.23 ± 0.98	35
	Female: 67.83 ± 5.88	0.23 ± 0.08	-1.40 ± 1.05	70
	Both Sexes: 63.08 ± 4.10	0.30 ± 0.09	*not calculated	105
Lauth: Ototlith, Puget Sound, 1987	Male: 69.025	0.241	-1.23	50
	Female: 74.087	0.354	0.84	45
	Both Sexes: 72.67 ± 0.38	0.25 ± 0.00	*not calculated	95
Grebel: Otolith, Northern to Central California, 2003	Male: 44.07 ± 1.93	0.35 ± 0.09	-1.50 ± 0.63	239
	Female: 64.72 ± 4.6	0.17 ± 0.03	-1.7 ± 0.48	377
	Both Sexes: 56.31 ± 2.91	0.23 ± 0.04	*not calculated	616
Present study: Tag and Recapture, Estero Reef, California, 2004	Both Sexes: 44.61 ± 2.41	0.41 ± 0.17	0.68	259
Present study: Tag and Recapture, Big Creek, California, 2006	Both Sexes: 47.87 ± 1.63	8.34 ± 53.05	3.01×10^6	16

Gopher Rockfish Age and Growth

The modified Ford-Walford plot for the gopher rockfish data gave an estimated L_∞ of 28.29 cm and k of 1.33 (Fig. 11). The instantaneous growth rate was calculated to be 0.27. The Brody-Bertalanffy curve gave an estimated L_∞ of 28.11 ± 0.77 cm, *k* of 1.29 ± 0.94, and t_0 of 21.32 years (Fig. 12).

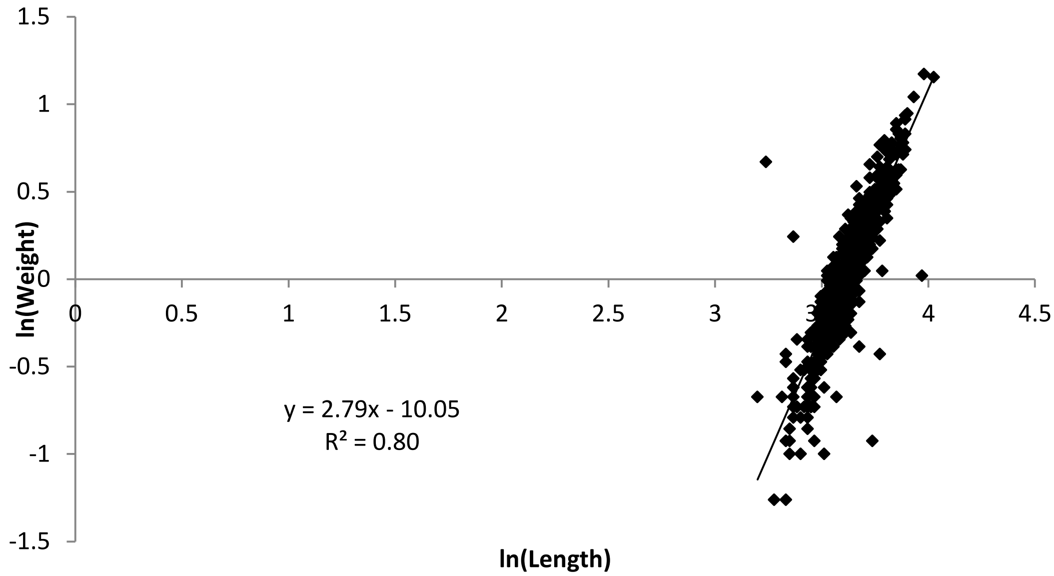

Figure 3. The log-transformed length versus weight data for all cabezon (captures and recaptures) for which data existed from the tagging study done in Point Estero, California. n=800.

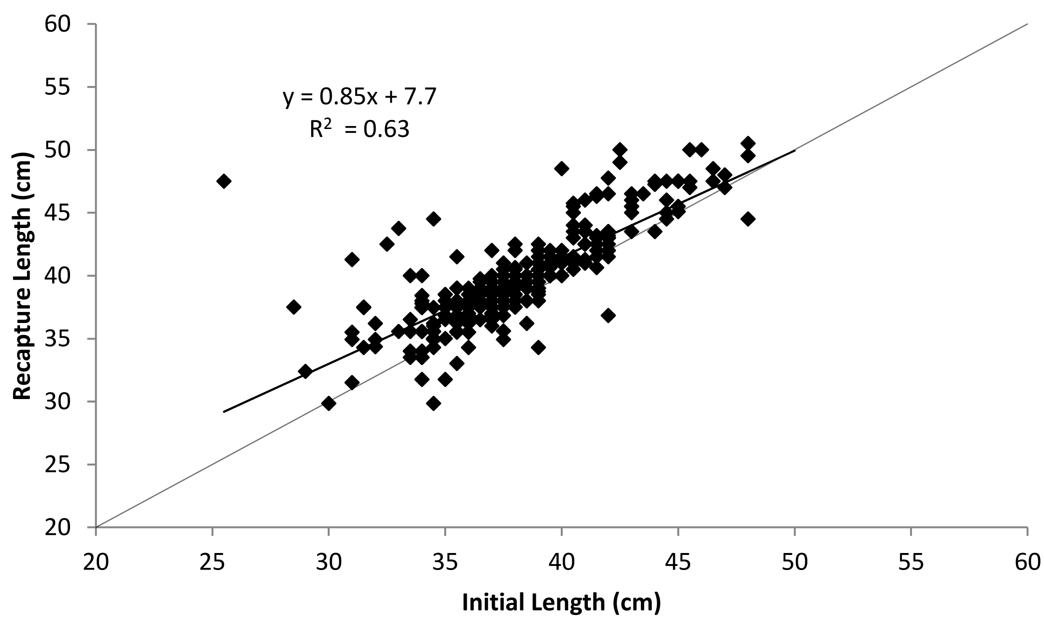

Figure 4. Ford-Walford plot of initial lengths and first recapture lengths of cabezon at Point Estero, California. The theoretical maximum length of the Point Estero cabezon was found to be 49.5 cm. n=285. The instantaneous growth rate (e^{-k}) is given by the slope and the growth coefficient (K) was calculated to be 0.17.

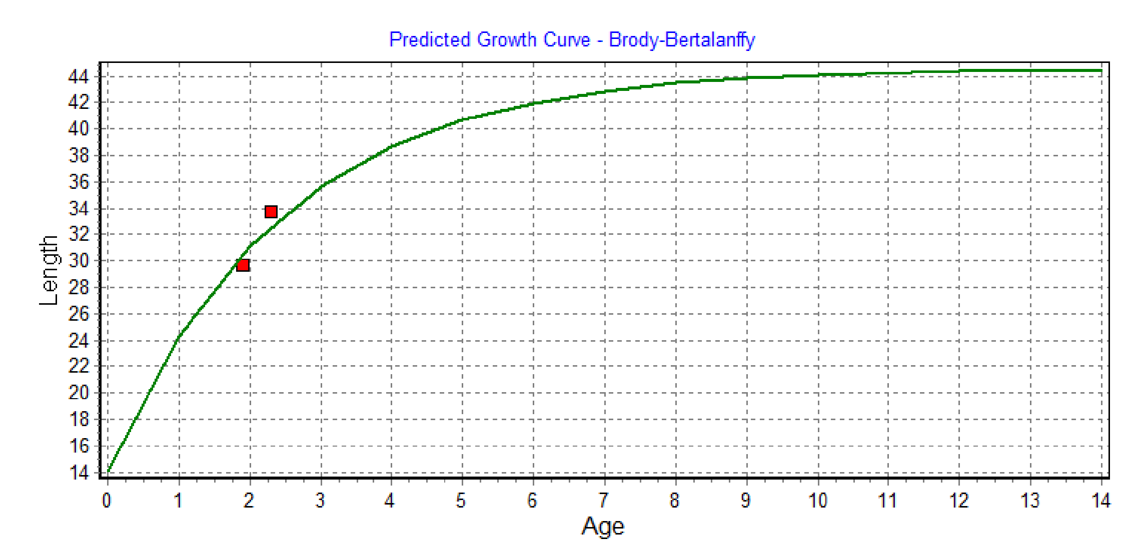

Figure 5. Brody-Bertalanffy growth curve for cabezon tagged and recaptured off of Point Estero, California. Length is in centimeters and age is in years. The red data points represent known age and length of two Cabezon measured with otolith data retrieved by Joana Grebel. L_∞ = 44.61±2.41 cm and K = 0.41 ± 0.17 at 95% confidence.t_0 was calculated at 0.68 years. n=259.

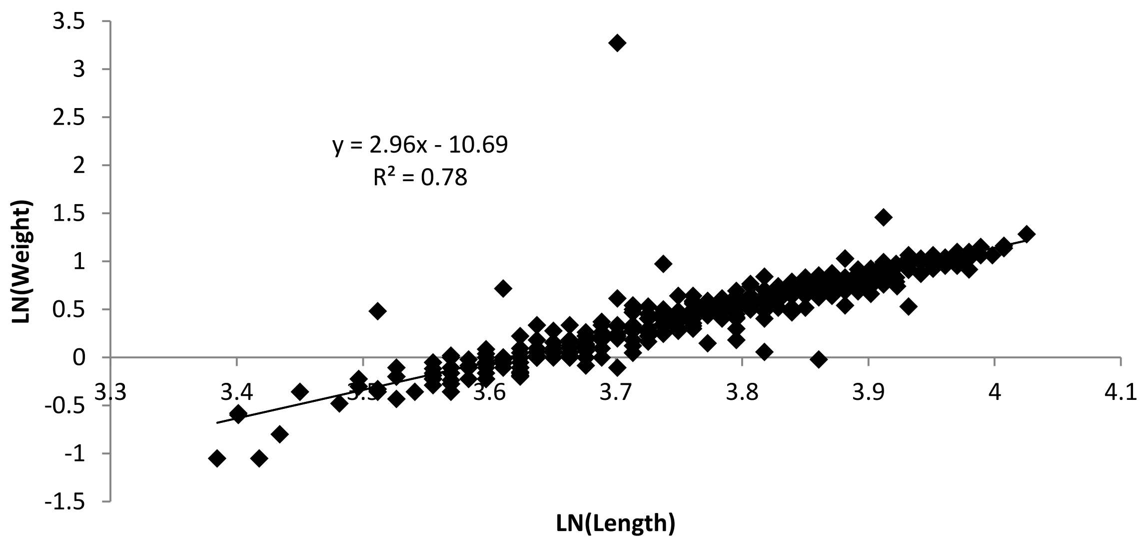

Figure 6. Log transformed relationship between length and weight of all cabezon, both captures and recaptures, for the Big Creek study site in both 2006 and 2008. n=501.

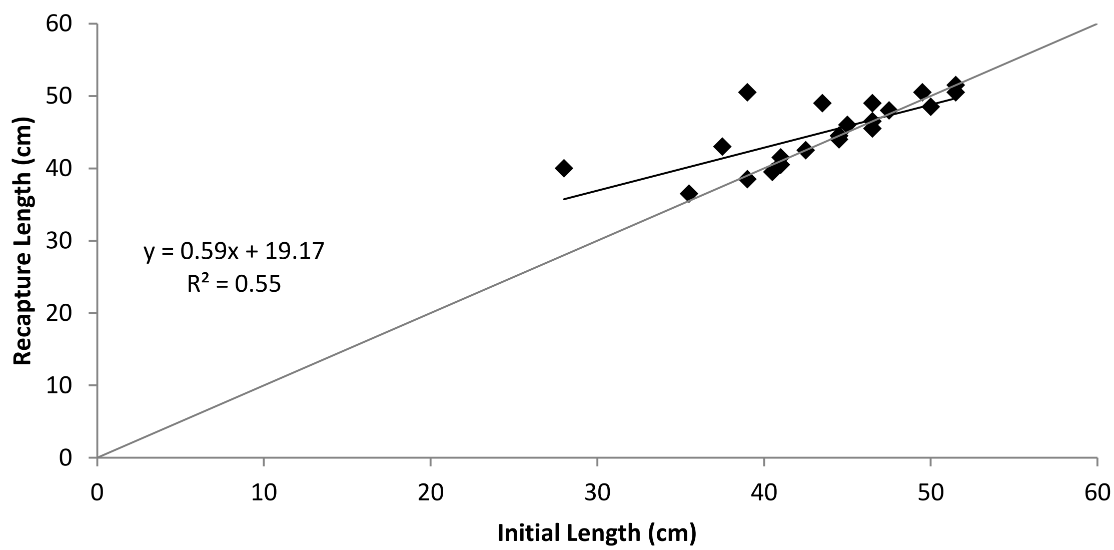

Figure 7. Ford-Walford plot for initial lengths and first recapture lengths of cabezon caught in Big Creek in July 2006. L_∞ was estimated to be 47.00 cm. The instantaneous growth rate (e^{-k}) was estimated to be 0.59 and K was found to be 0.59. n=16.

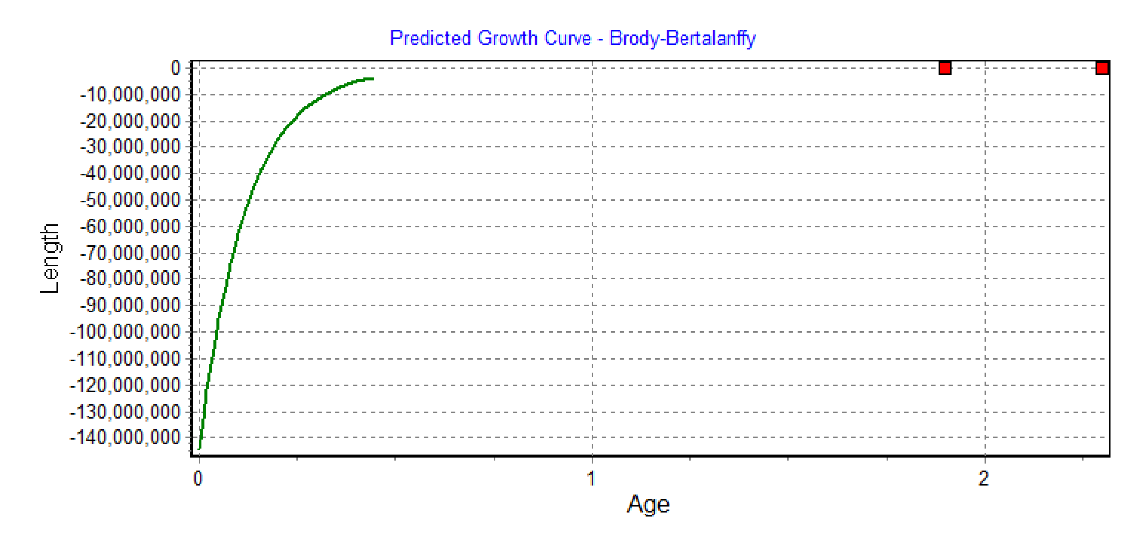

Figure 8. Brody-Bertalanffy growth curve for cabezon tagged and recaptured near Big Creek located in Big Sur, California. Length is in centimeters and age is in years. n=16. L_{∞} = 47.87 ± 1.63 cm and K = 8.35 ± 53.05 at 95% confidence. With this particular data set, Growth II software was largely inadequate for determining population parameters, particularly t_0, which, as shown by the length axis on the graph, was not calculable.

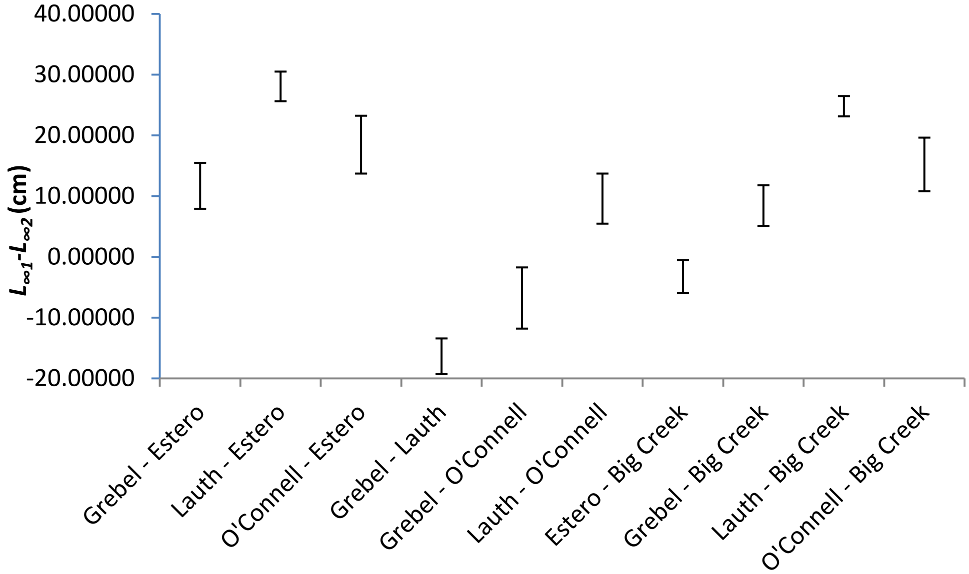

Figure 9. Paired comparison intervals at 95% confidence for differences in L_{∞} (cm) across studies. None of the intervals contain zero, suggesting that each comparison is significantly different from the null hypothesis and that evidence exists for distinct theoretical maximum lengths across studies.

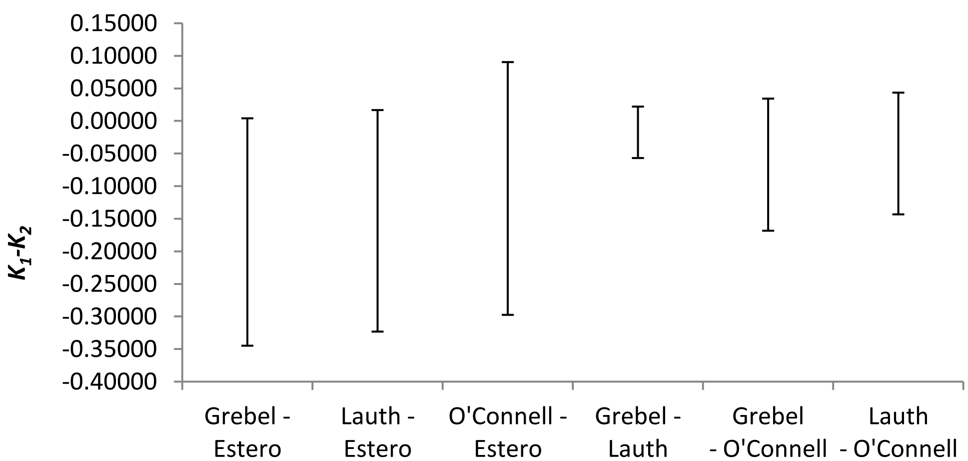

Figure 10. Paired comparison intervals at 95% confidence for differences in growth rates (*K*) between studies. Big Creek growth rate comparisons are not included. All of the intervals contain zero, suggesting that there is no evidence to reject the null hypothesis and the growth rates across studies are not significantly different.

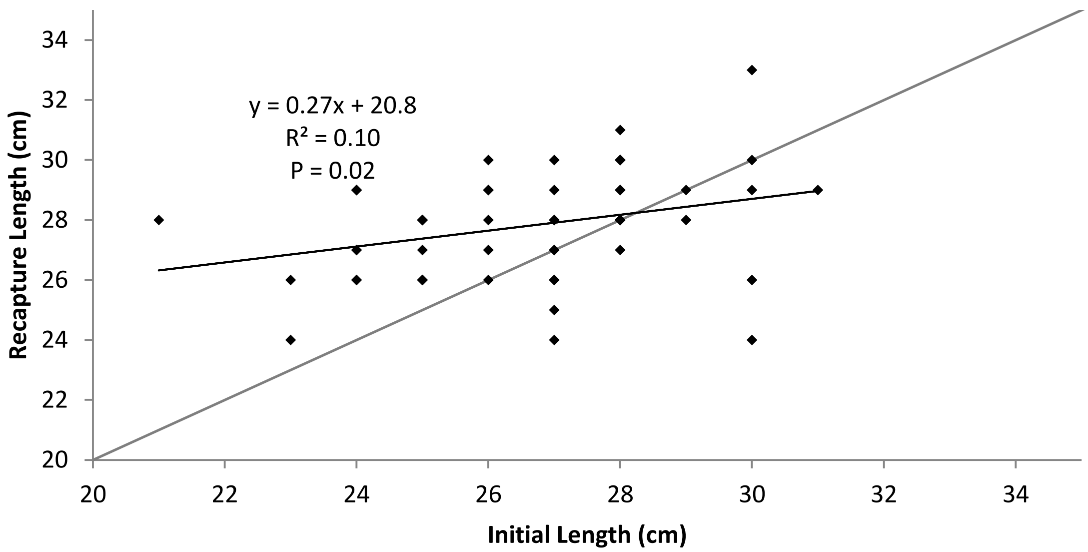

Figure11. Modified Ford-Walford plot of initial and recapture lengths of Gopher rockfish. n=52. L_∞ was calculated at 28.29 cm and K was calculated at 1.33. The instantaneous growth rate was calculated to be 0.27.

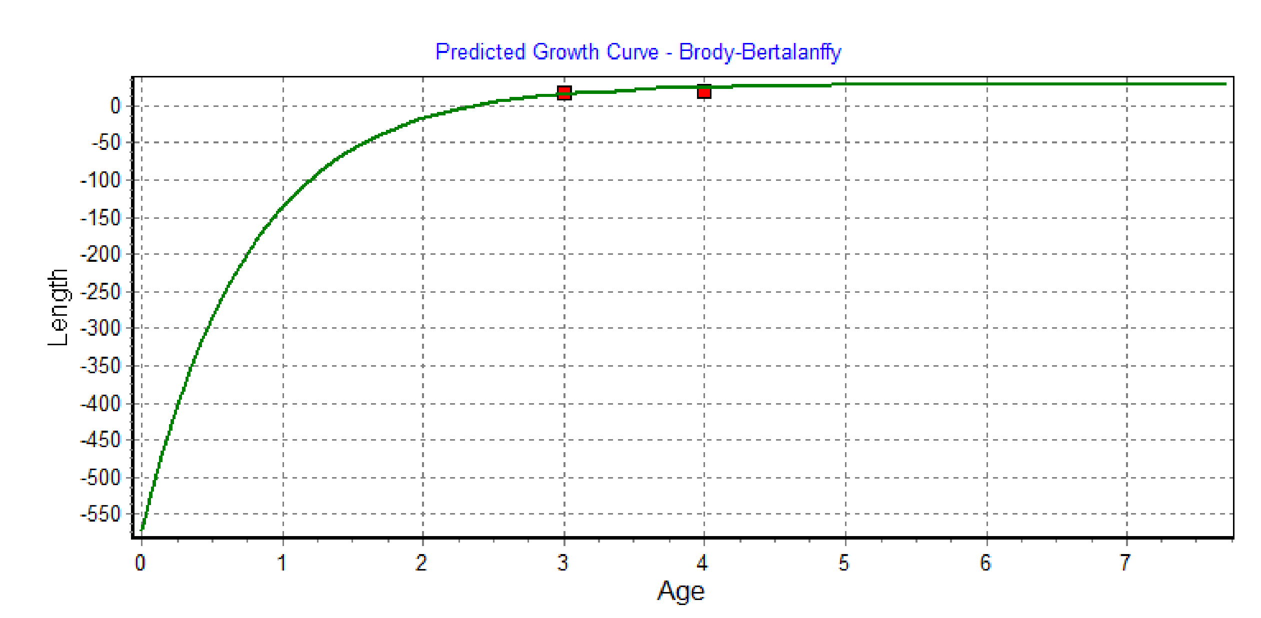

Figure 12. Brody-Bertalanffy curve for gopher rockfish caught in 2007 and 2008. Length is in centimeters and age is in years. L_∞ =28.11 ± 0.77 cm, K = 1.29 ± 0.94, and t_0 = 21.32 years. n=52.

Discussion

One of the main purposes of this study was to compare growth data on Cabezon from other known sources. The primary goals of the comparisons were to reveal potential geographical, temporal, or method differences. The main sources of Cabezon growth were Grebel's 2003 otolith study in California, Lauth's 1987 study in Puget Sound, Washington, and a study done by O'Connel in 1953 in California (table 1). All cabezon growth studies prior to the present one utilized otolith data for establishing age relationships, so there were considerable method differences, which makes the studies much more difficult to compare on an ecologically meaningful basis.

The significant differences found among all theoretical maximum length comparisons, while intriguing, could not be generalized to any one cause. The lack of real comparability reflects the ongoing changes towards standardized sampling methods with respect to fishing gear, baits, and quadrat selection. When focusing on fishing methods alone, there are multiple biases that could have formed across studies. For example, the traps used in the present study had five inch diameter otter exclusion rings that potentially excluded larger fish. O'connell, Lauth, and Grebel used a combination of spear fishing and hook and line catches, which tended to create a bias for larger fish since divers and fishermen typically prize large catches (1953, 1988, 2003). If methods were standardized, then comparisons could be made based on variable fishing pressures between sites, latitudinal species differences, and/or population changes over time. If sampling were standardized, we would, as seen in this study, predict that larger fish would be missing in heavily fished areas and that fish would be larger at higher latitudes.

The pairwise comparisons for *K* were not significant for any of the comparisons made, suggesting that growth rates across all populations within the species are highly variable. Grebel and Lauth's studies showed that growth rates for male and female cabezon are

significantly different, so it is possible that the combined sex data are not sensitive enough to reveal differences in populations. Also, while there were relatively robust data on cabezon from Big Creek, there were few recaptures, which made the data insufficient for calculating growth rates with Growth II software. The Ford-Walford plot for big creek had a K of 0.59, which is within a reasonable level for cabezon.

Growth II software appeared to have highly unstable calculations of t_0, which is why we will not discuss t_0 relative to other studies. Addition or subtraction of one or more known age and length sample drastically affected t_0 without having much of an affect on either L_∞ or K. Without more samples of known age and length or more samples that are relatively small, accurate t_0 values may be difficult to estimate.

The largest recaptured gopher rockfish in our study was 31cm. The L_∞ of 28.11 cm for gopher rockfish was relatively small for this species, which can be seen be seen easily on the Ford-Walford plot showing that many of the fish caught were above the intersection point for L_∞ (fig. 11). The relationship between recapture and initial length for the gopher rockfish data set was weak and the range of sizes was small, which caused L_∞ to be smaller than the actual maximum length for the population. One growth curve has been estimated for gopher rockfish utilizing surface readings of the operculum to determine age (Lea et al. 1999). In the Lea et al. study, L_∞ was found to be 34.1 cm and K was 0.2256 in a sample of 557 fish. Both parameters are much different from our calculated values. Since there were no confidence intervals for the Lea et al. study, no attempts at comparison were made (1999).

Growth II software appears not to work well with small sample sizes, such as with Big Creek cabezon data and the gopher rockfish data. Unless high recapture rates can be attained for a target species, the best method for determining growth curves would be otolith or some other

hard structure aging method. In addition, all previous otolith studies have suggested that sexes within populations have distinct growth curves. With many species, sex may be difficult to determine in a tag and recapture study unless all recaptures are sacrificed. Nonetheless, if adequate recapture data is attainable, having independent growth data for a species is invaluable when accounting for the inherent biases for each method. Overall, it appears that both large sample sizes and a wide range of ages for a population are needed to calculate accurate growth curves using Growth II software. Only the Estero Reef data for cabezon met these requirements fully.

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I would like to thank Royden Nakamura, my advisor, for trusting so much in my abilities and guiding me through this project from start to finish. I thank Karen McGaughey, faculty of the Cal Poly Statistics consultant, who provided much needed advice on handling studies with no raw data. I would also like to thank Carlos Mireles and Nathan Hall for access to their data on cabezon and gopher rockfish for this paper, which was funded by a grant from the Resource Legacy Foundation in cooperation with the Marine Interest Group (D. Wendt).

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