09-09

Project Title: An evaluation of the significance of climate forcing on time-varying growth and fecundity of rockfish in the California Current (Year 1 of 2 Progress Report)

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Goals:

The goal of this two-year funded project is to investigate climate effects on rockfish growth and productivity in the California Current. Stock assessments have increasingly begun to include these important effects in estimating abundance and production. In turn, critical metrics used in stock assessments (spawning biomass, spawning output and recruitment) vary as a function of environmental conditions. Our working hypothesis for this study is that poor feeding conditions during warm oceanographic regimes result in trade-offs affecting bioenergetic allocation patterns by females, resulting in reduced growth and reduced fecundity. This hypothesis is being addressed in three ways: (1) by expanding on process studies relating environmental conditions to growth and fecundity; (2) by using these results to modify existing bioenergetics models, investigating mechanisms by which climate may drive changes in energy budgets; and (3) by incorporating findings from these efforts into existing stock assessment models of West Coast groundfish for which time-varying growth (and potentially fecundity) have been identified as key factors.

These refinements should improve future assessments by increasing precision and decreasing uncertainty. The following is a progress report for year one of the project, focusing on chilipepper rockfish, *Sebastes goodei* and yellowtail rockfish, *Sebastes flavidus* in the California Current.

Approach:

Growth analysis

Time-varying growth in relation to changing oceanographic conditions has been identified as a key source of uncertainty in past stock assessments. The most recent chilipepper stock assessment estimated time-varying growth internally (Field 2008), indirectly relating growth to major shifts in the ocean environment as indexed by the Pacific Decadal Oscillation (PDO). To better inform growth curves and offsets relative to environmental factors, our project focuses on additional ageing effort, using archived chilipepper otoliths from historical fishery-independent surveys. Archived chilipepper otoliths are being aged from a variety of NOAA/NMFS rockfish surveys (Table 1). The majority of otoliths were dissected and stored dry in vials or trays. However, some of the archival otoliths were preserved in ethanol and were dried before ageing. All otoliths are prepared for age determination by the "break and burn"method (Figure 1). Whole otoliths are broken through the core by hand and lightly burned over an ethanol flame to aid in visualization of the growth increments. Annual growth increments are counted with knowledge of fish size, sex, capture location and date of capture.

Table 1. A summary of the years of fishery-independent surveys and the number of chilipepper otoliths in each collection used to inform time-varying growth.

Survey	Method	Year	Months	Location	Number of samples
NOAA Northwest Fisheries Science Center's West Coast Groundfish Survey					
	Trawl	1983	Summer	N. CA to S. CA	753
	Trawl	1992	Jul-Aug	N. CA to S. CA	246
	Trawl	1998	Jun-Jul	N. CA to S. CA	441
	Trawl	2001	Summer	N. CA to S. CA	487
	Trawl	2003	Jul-Oct	Central OR to S. CA	705
	Trawl	2005	Jun-Oct	Central OR to S. CA	891
	Trawl	2006	Jun-Oct	Central OR to S. CA	625
	Trawl	2007	Jun-Oct	Central OR to S. CA	611
	Trawl	2008	Jun-Oct	Central OR to S. CA	720
NOAA Southwest Fisheries Science Center (current project)					
	Hook and line	2009-2010	Nov-Mar	N. CA to S. CA	479
				Total	5958

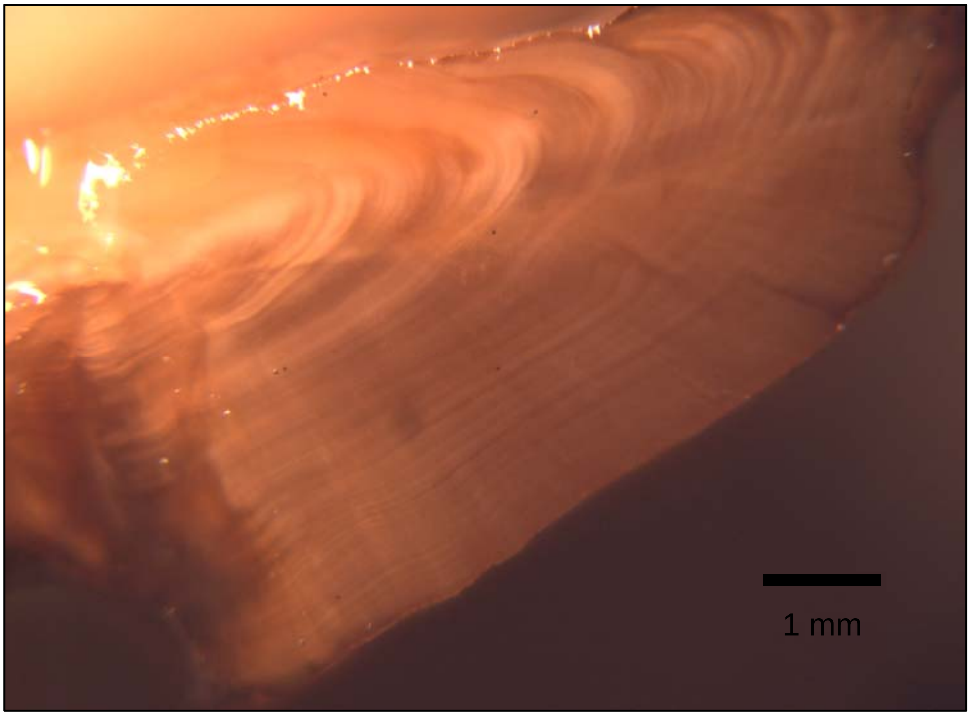

Figure 1. Chilipepper rockfish aged at 17 years by identification of annual growth increments. Otolith prepared by the "break and burn" method.

Bioenergetics modeling

We are evaluating the likely or potential mechanisms driving time-varying growth by simulating climate and growth interactions using an existing bioenergetics model of rockfish

(Harvey 2005, Harvey et al. 2006). This model estimates rockfish energy budgets, allocating energy to somatic growth, gonadal production, and metabolic costs as a function of variables such as body size, temperature, feeding rate and prey quality. The model was used, for example, to evaluate the influence of El Niño conditions on rockfish growth and fecundity (Harvey 2005), and can be reconfigured to evaluate factors that relate to the observed changes in growth suggested in the size-at-age data and the assessment model. The model framework thus provides a direct, mechanistic linkage between climate variability and rockfish growth, and supports improved assessments and better predictions by anticipating varying patterns of chilipepper growth and reproductive capacity under alternate climatic scenarios.

Fecundity analysis

We expect climate effects on reproductive capacity, fish condition and fish health to be primarily driven by large scale oceanographic parameters such as PDO. Several studies have documented a decline in female health or growth during warm ocean periods, but how this effect translates into changes in reproductive capacity is not known. For this study, we are evaluating the impact of environmental effects on fecundity using three approaches. First, we are conducting an ongoing assessment of regional and temporal climate effects on rockfish growth and productivity by sampling fish along the California coast over a two-year period. Rockfish are surveyed by hook-and-line methods from four locations (Figure 2). These sampling locations were chosen to target chilipepper and yellowtail rockfish and include: Eureka in northern California; Cordell Bank, a marine sanctuary located 25 miles off the coast of Bodega Bay; Half Moon Bay in central California; and the Santa Barbara Channel located just south of Pt. Conception.

Figure 2. Map of 2009-2010 rockfish survey locations. Note that fish from Bodega Bay were collected approximately 25 miles offshore in the Cordell Bank National Marine Sanctuary.

Surveys are currently being conducted over the winter months corresponding to the period of larval development and release for both chilipepper and yellowtail rockfish. Data collected from these surveys will be combined with past datasets to provide a current assessment of rockfish age and growth, reproductive capacity and fish condition in the California Current. We also collected a variety of other rockfish species caught incidentally in the survey for which relatively little growth and fecundity data exists. These species included the rosy, speckled, canary, squarespot, bocaccio, olive, bank, brown, half-banded and greenspotted rockfish. Humboldt squid were encountered on many of the surveys and stomach samples were taken for an ongoing diet study at the SWFSC of this rockfish predator

All rockfish were packed in ice and transported to the SWFSC laboratory in Santa Cruz for processing. Any female fish that looked to be pregnant was placed in an individual plastic bag to capture any eggs or larvae extruded during the capture or handling process. In the laboratory, fish length and weight measurements were recorded and the gonads, liver and otoliths dissected. Weighed subsamples of the ovaries were collected from females with either stage 3 fertilized eggs, or stage 4 eyed-larvae for fecundity estimates. To assess fish condition, a Distell fish fatmeter was used to read percent fat in muscle tissue along the lateral line of each side of the fish before dissection. In addition, muscle tissue samples of 2-20g were collected and desiccated to estimate water content of muscle tissue for comparison to fish fatmeter readings.

Hook-and-line rockfish surveys for this project will continue in the fall of 2010 spanning a two-year period of contrasting oceanographic conditions. Moderate warm water El Niño conditions were experienced in the California Current during the winter of 2009 followed by cooler and presumably more productive conditions thus far in the spring and summer of 2010, suggesting that the growth opportunity for rockfish will differ between the two years. All rockfish growth, fecundity and condition data collected in these two years will be examined for interannual differences related to changing environmental conditions.

Our second approach uses laboratory experiments to examine the relationship of fish health with reproductive allocation strategies. Experiments are designed to test the response of female rockfish to low food availability for an extended period prior to parturition. This treatment is intended to simulate poor feeding conditions in the ocean during the pre-reproductive stage. Females held with low rations are compared to females receiving unlimited food, with metrics of fecundity, larval size and quality (lipid reserves), and timing of parturition. These experiments provide direct tests of any shifts in allocation associated with poor foraging success and will be valuable in establishing the relationships of fish health/condition with reproductive performance.

Our third approach is a retrospective analysis of fecundity relationships during contrasting oceanographic conditions. We have available an extensive dataset of fecundities for yellowtail rockfish captured on Cordell Bank in the 1980s (1985-1991), much of which is published (i.e., Eldridge et al. 1991, Eldridge and Jarvis 1994) and E.J. Dick at the SWFSC, has compiled a comprehensive database of published and unpublished fecundity estimates in a broad suite of *Sebastes* species for a phylogenetic analysis of maternal effects. He has not examined interannual differences in fecundity previously and has agreed to collaborate with us on this effort. For comparison, more recently we collected large numbers of yellowtail, chilipepper and widow rockfish from Cordell Bank over a 3 year time period (2005-2008). All fecundity estimates will be examined for relationships with maternal age, length, and weight to derive appropriate adjustments accounting for maternal effects (Boehlert et al. 1982, Bobko and Berkeley 2004, Sogard et al. 2008, Dick 2009). We expect any reduction in annual fecundities to be associated with decreased female condition. Fulton's K (somatic weight * $length^{-3}$) provides a simple index of fish condition. Where data are available on fish length, somatic weight, and fecundity, we will be able to determine any relationships and potentially how they vary with fish size or age. If Fulton's K is correlated with fecundity (after adjusting for fish size and age), it may provide a useful indirect proxy for fecundity.

Work Completed:

Work on our project began in October 2009 with the hiring of a research technician, Sabrina Beyer. The primary duties of the technician in year one were to coordinate rockfish collecting trips along the California coast, conduct laboratory experiments exploring maternal condition effects on rockfish fecundity, synthesize data on rockfish growth, reproduction and condition and various laboratory work. Time in the laboratory was divided between ageing of archival chilipepper otoliths and fecundity analysis of ovary samples from chilipepper and yellowtail rockfish.

Growth analysis

In year one, the technician was trained in ageing techniques of chilipepper rockfish otoliths and completed age work on archived otoliths from the 2003, 2005 and 2006 NWFSC's West Coast Groundfish trawl surveys. Additionally, an evaluation of the ageing method was initiated to explore latitudinal effects on age precision estimates ranging from Oregon to Southern California. There is some indication that fish from southern waters are more difficult to age (greater imprecision) than those from northern waters, perhaps due to the weaker seasonality of upwelling and productivity in the south and greater seasonality of these processes in the north. There is some indication of this phenomena as being a factor related to the difficulties in ageing a co-occurring species, bocaccio (D. Pearson and J. Field, unpublished data), however bocaccio are difficult to age by any reader and thus the significance of this possible process is unclear. Consequently, a statistical comparison of both within- and between-reader error for chilipepper rockfish may help improve our understanding of the relationship between climate and readability for both of these species.

Preliminary ageing efforts showed evidence of a strong 1999 recruitment year-class for chilipepper rockfish along the coasts of Oregon and California (Figure 3). The 1999 year class was strong across all regions, suggesting a general response to large scale oceanographic conditions and correlating to the moderate cool water La Niña conditions experienced in 1999. In contrast, a strong year class in 2004 was evident only in the Central California region, suggesting a more local response.

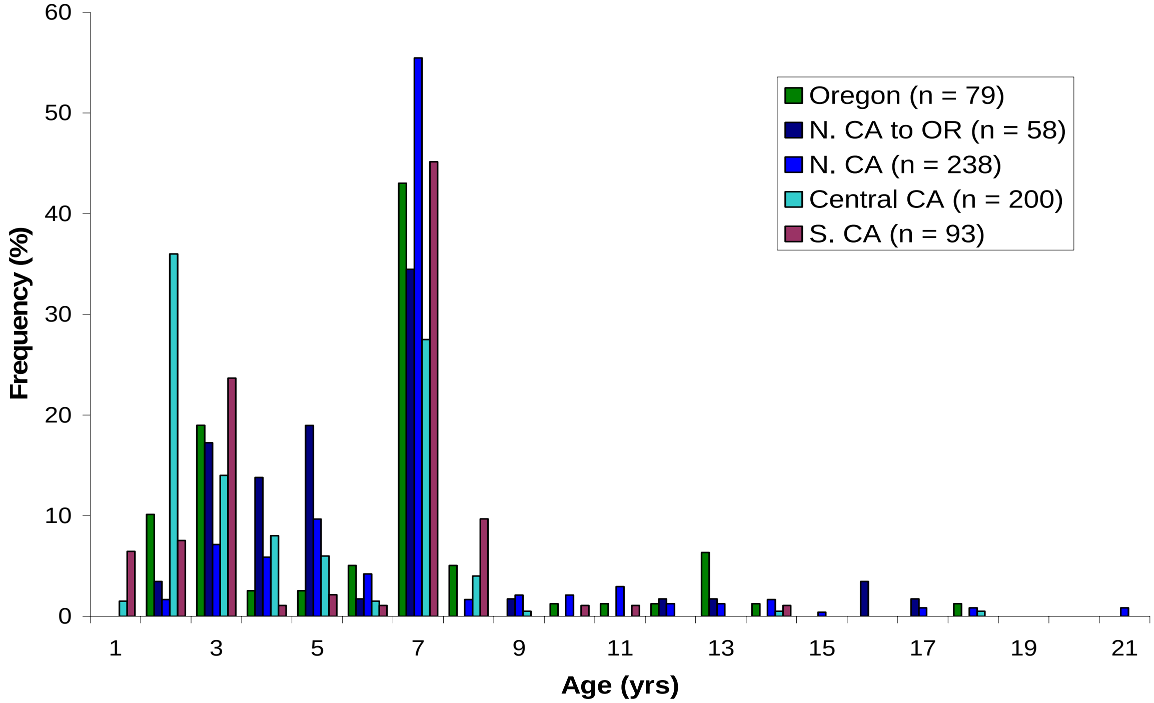

Figure 3 Age-frequency distribution of chilipepper rockfish collected in 2006 along the Oregon and California coast. Note a strong 1999 recruitment year-class across all regions (age 7 fish).

In year two of this study, we will complete ageing work of archival chilipepper otoliths from the 1983, 1992, 1998, 2001, 2007 and 2008 NWFSC rockfish trawl surveys. This fishery-independent size at age data will be critical to re-evaluating the stock assessment model that includes time-varying growth. Additionally, we will initiate analysis of annual growth increment widths in chilipepper otoliths to further explore varying interannual growth as related to oceanographic conditions. All newly acquired age and growth data from the archival fishery-independent chilipepper otoliths will be combined with fishery-dependent data into an updated version of the most recent chilipepper stock assessment to re-examine methods for modeling time-varying growth as influenced by environmental factors.

Bioenergetics modeling

A work-group meeting is scheduled for August 16-19, 2010 at the SWFSC to initiate bioenergetics modeling efforts for chilipepper and yellowtail rockfish. Growth and fecundity data will be incorporated into an existing bioenergetics model of rockfish (Harvey 2005, Harvey et al. 2006) to evaluate the likely or potential mechanisms driving time-varying growth by simulating climate and growth interactions.

Fecundity analysis - current regional comparisons

Monthly rockfish hook-and-line surveys were completed out of four ports along the California coast between November 2009 and March 2010 to assess regional effects on growth and reproduction. All fish were processed at the SWFSC for fecundity, size and condition data. A summary of chilipepper and yellowtail rockfish collected is shown in Table 2.

Table 2. Summary of target species collected in 2009-2010.

Location	Chilipepper Rockfish	Yellowtail Rockfish
Eureka	0	23
Cordell Bank	119	37
Half Moon Bay	140	84
Santa Barbara	220	35
Total	479	179

We completed fecundity analysis of chilipepper and yellowtail rockfish collected in the winter of 2009-2010. Preliminary results from year one collections suggest a strongly positive relationship between fish size and weight-specific fecundity (Figure 4). This pattern highlights the importance of contributions from large, and presumably older, female fish to population production.

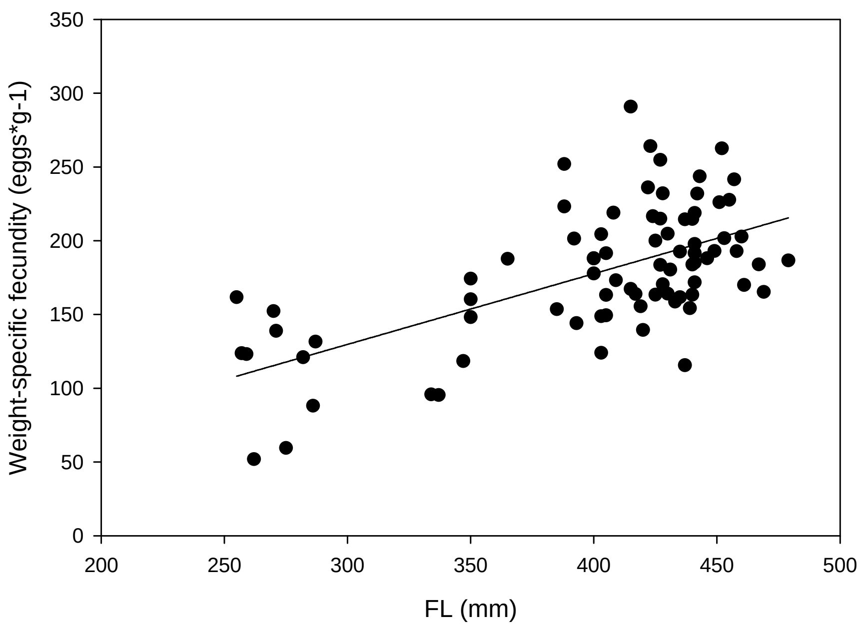

Figure 4 Weight-specific fecundity (eggs*g^{-1}) as a function of fish length for chilipepper rockfish collected along the coast of California in the winter of 2009-2010.

Evidence of multiple broods was apparent for a few of the rockfish collected in 2009-2010 from Southern and Central California (Table 3). Ovaries that contained a small portion of remaining eyed-larvae from a recent parturition as well as developing stage 2 (unfertilized) or stage 3 (fertilized) eggs were considered to have produced multiple broods within the spawning season. This occurrence has been documented for rockfish in Southern California (Love et al. 1990) and has consequences for estimates of the total lifetime and seasonal reproductive capacity.

Table 3. Number of rockfish with evidence of multiple broods out of the total number of mature fish collected by month and by species for 2009-2010.

Location	Species	Dec 2009	Jan 2010	Mar 2010
Santa Barbara (S. CA)	Chilipepper	17 of 42	4 of 50	
	Speckled	4 of 6	2 of 6	1 of 19
Half Moon Bay (Central CA)	Chilipepper		5 of 50	

Fecundity analysis - lab experiments

Brown rockfish were held in laboratory tanks in two treatments on either a high or low ration diet from October 2009 (fall mating period) until June 2010 (time of parturition). Two flow-through seawater tanks (5,870 L) holding fifteen females and five or six males each were set up in October and fish fed chopped squid to satiation three times a week (high ration treatment) or once every 6 weeks (low ration treatment). In January 2010, all rockfish were weighed, measured and moved into two larger (18,300 L) group tanks continuing either a high or low ration diet. Following the move, feeding in the low ration treatment was increased to once every four weeks. In March 2010, after mating had presumably occurred and before assumed timing of parturition, female fish were moved into individual tanks (575 L) to capture larvae and males sacrificed. Rations for females in the low ration treatment were again increased to feeding every two weeks for the duration of the experiment. In addition to experimental fish, sixty brown rockfish were collected near Pt. Reyes in central California by hook and line in April and May 2010 for comparison of fish condition and fecundities to experimental fish (Figure 5).

Males in the high ration treatment ($n = 6$) had noticeably greater amounts of mesenteric fat surrounding the internal organs and large, robust testes still producing milt in March. In comparison, males in the low ration treatment ($n = 5$) did not have the same fat reserves surrounding the internal organs and had visibly smaller testes with no evidence of sperm. Dehydrated muscle tissue samples showed a significant difference in water content of muscle tissue, and presumably lipid content of muscle tissue, between the two treatments for both males (*t*-test, *p*-value <0.0001) and females (*t*-test, *p*-value <0.0001, Figure 5). Remaining females were sacrificed in early June after it was evident that none of the fish would produce live larvae. In the high ration treatment, seven out of the twelve remaining females had experienced full or partial atresia of eggs with pre-parturition release of what appeared to be fertilized but dead or unhealthy eggs. In the low ration treatment, no females released eggs or ever showed external signs of pregnancy.

All fish were dissected at the termination of the experiment in June. In the high ration treatment, macroscopic examination of the ovaries showed eight females had a mix of partial to full fertilization of eggs and four showed no signs of fertilization. Eggs appeared to be dead or unhealthy and in most cases were being reabsorbed by the female. Although not expected, these results suggest that at least some of the females had successfully mated with the males in the laboratory group tanks, but were unsuccessful at bringing larvae to term.

In comparison, only two of the ten remaining females in the low ration treatment showed any signs of mating or fertilization of eggs after macroscopic examination of the ovaries. The ovaries from these two fish had a very small percentage of eggs that were fertilized with the majority of the ovary containing unfertilized eggs in the process of being reabsorbed by the female. An obvious difference in fertilization and condition of both male and female fish subject to either a high or low ration treatment was observed, however we were unable to estimate fecundities for experimental fish in year one.

The majority of experimental fish (n = 33) appeared to be healthy and ate well when fed, however a few fish died (n = 7) after not fully recovering from transportation from the wild or from problems with parasites. Technical problems with maintaining a constant water temperature in experimental tanks due to equipment failure (temperature ranged from 10 ˚C to 14 ˚C) and handling stress are possible explanations for the observed results. Equipment issues and handling protocol will be revised and the experiment repeated in the fall of 2010.

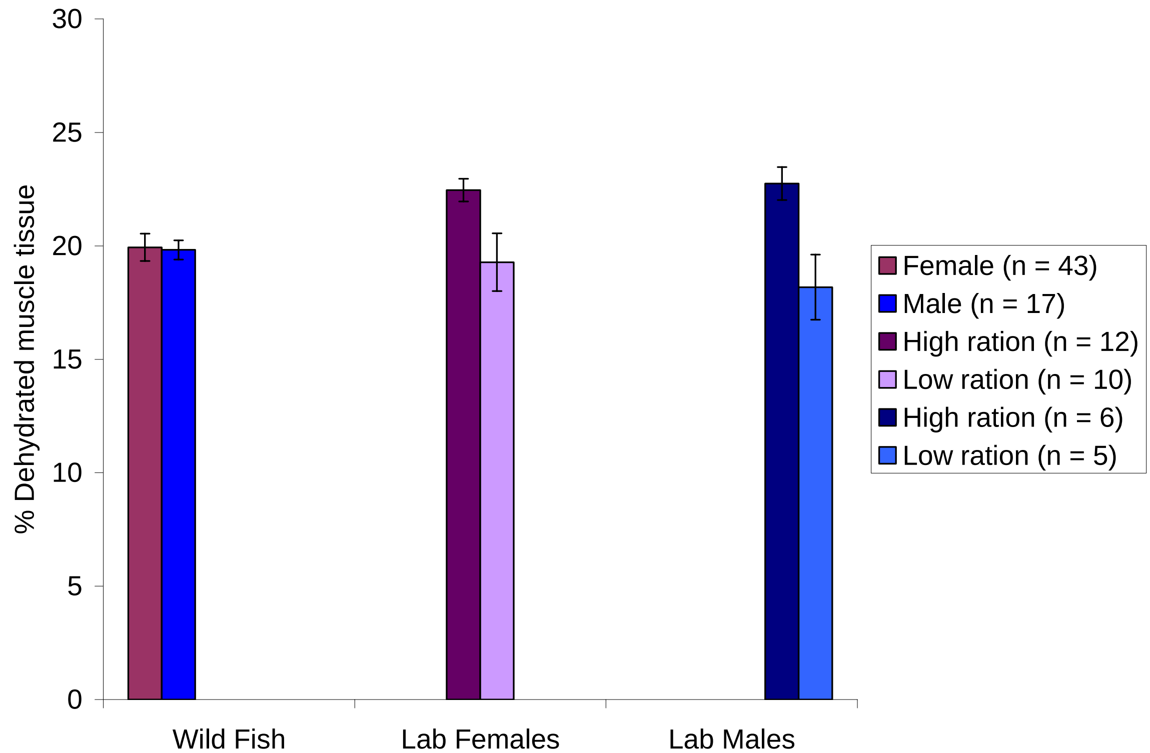

Figure 5. Fish condition comparison of male and female brown rockfish collected in April and May 2010 near Pt. Reyes California and experimental male and female brown rockfish subject to either a high or low ration treatment.

Fecundity analysis - retrospective comparisons

This ongoing portion of the project has resulted in a compilation of datasets on rockfish fecundities (Table 4). All fecundity data will be examined for interannual differences following completion of fecundity analyses of rockfish collected in 2009-2010 in addition to fish that will be collected over the upcoming winter 2010-2011 period of larval development and parturition.

Table 4. Summary of datasets and the number of fecundity estimates available for both chilipepper and yellowtail rockfish.

Year	Location	Chilipepper	Yellowtail	Source
1958	CA	11	11	Phillips 1964
1959	CA	7	2	Phillips 1964
1960	CA	5	-	Phillips 1964
1961	CA	-	2	Phillips 1964
1967	OR	-	2	Snytko and Borets 1973
1985	Cordell Bank/ N. CA	-	30	MacFarlane (unpublished)/ Eldridge et al. 1991
1986	Cordell Bank/ N. CA	-	53	MacFarlane (unpublished)/ Eldridge et al. 1991
1987	Cordell Bank/ N. CA	-	67	MacFarlane (unpublished)/ Eldridge et al. 1991
1988	Cordell Bank/ N. CA	-	25	MacFarlane (unpublished)/ Eldridge et al. 1991
1989	Cordell Bank/ N. CA	-	55	MacFarlane (unpublished)/ Eldridge et al. 1991
1990	Cordell Bank/ N. CA	-	60	MacFarlane (unpublished)/ Eldridge et al. 1991
2005	N. CA	80	7	Sogard et al. 2008
2006	N. CA	32	62	Sogard et al. 2008
TBD	S. CA	39	34	Love et al. 1990
2009-2010	CA	101	14	Current Project
Total		275	424	

Applications:

Reproductive capacity and growth are critical components of stock assessments, and improved understanding of how these factors vary with ocean conditions will be of great utility in incorporating environmental variability into stock assessments and management. As the significance of these factors can easily be evaluated in the existing assessment model of chilipepper rockfish, and potentially in models of widow or yellowtail rockfish currently being developed, methods to incorporate and evaluate the sensitivity of assessment models to these factors are the primary deliverables of this project.

This project capitalizes on a species with clearly recognized variation in growth over time (chilipepper), and for which a recent, relatively data-rich assessment model is available. Existing bioenergetics models will be evaluated simultaneously to explore the potential role of climate-related mechanisms behind this growth. Additionally, reproductive capacity is a critical component of stock assessment, and improved understanding of how fecundity varies with the environment will be of great utility in incorporating oceanographic factors into stock assessments and management advice. Furthermore, we intend to evaluate whether insights gained from such (relatively) data-rich species could translate into insights for more data-poor species, such as blue or bocaccio rockfish (Key et al. 2008; Field et al. 2009), as both of these assessments (and associated reviews) identify time-varying growth as a factor in urgent need of additional analysis. Our results will also provide a base model from which time-varying growth and fecundity can be explored in other species. Additional insights into the consequences of variable reproductive capacity will also address another key uncertainty in stock assessments, regarding the utility of larval abundance data (primarily from the CalCOFI sampling program).

Publications/Presentations/Webpages:

Sogard, S., Field, J., Harvey, C., Beyer S., 2010. An evaluation of the significance of climate forcing on time-varying growth and fecundity of rockfish in the California Current. Fisheries and the Environment (FATE) annual meeting, Woods Hole, Massachusetts, June 21-22, 2010.

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