

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

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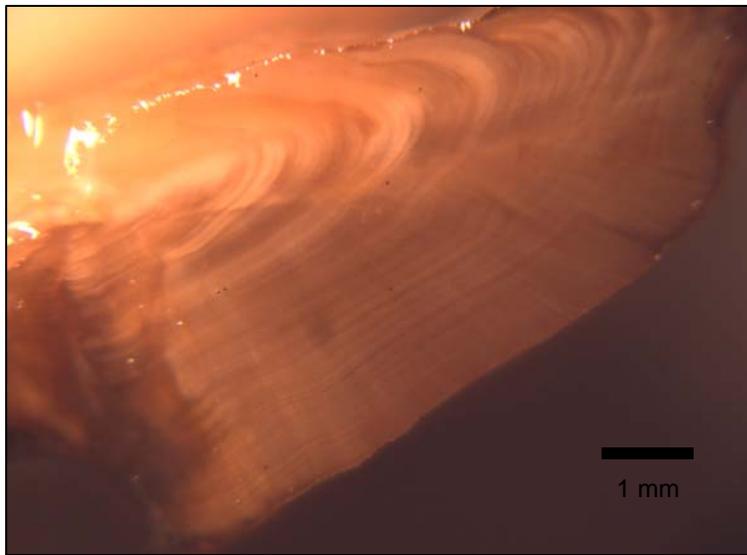
**Goals:**

The primary goal of this project was to investigate climate effects on rockfish growth and productivity in the California Current. Stock assessments have begun to include (and increasingly recognize the need to include) these important effects in estimating abundance and productivity. In turn, critical metrics used in stock assessments (spawning biomass, spawning output and recruitment) often vary as a function of environmental conditions. Our working hypothesis is that poor feeding conditions during warm, low productivity oceanographic regimes result in trade-offs affecting bioenergetic allocation patterns by females, resulting in reduced growth and reduced fecundity. This hypothesis was 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.

**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 (*Sebastes goodei*) 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 focused on additional ageing effort, using archived chilipepper otoliths from historical fishery-independent surveys (Figure 1). Archived chilipepper otoliths were aged from a variety of NOAA/NMFS rockfish surveys (Table 1). In addition, an analysis of yearly growth increment widths was attempted with a subset of chilipepper otoliths. Changes in yearly otolith growth have been correlated with environmental indices such as sea surface temperature and coastal upwelling for the yelloweye rockfish (Black et al. 2008) and bottom temperature for flatfish in the Bering Sea (Matta et al. 2010).



**Figure 1.** Chilepepper rockfish aged at 17 years by identification of annual growth increments. Otolith prepared by “break and burn” method.

**Table 1.** Chilepepper otoliths aged from fishery-independent collections.

Survey	Method	Year	Months	Location	No. Otoliths	Aged
<u>NOAA Alaska Fisheries Science Center Triennial Groundfish Survey</u>						
	Trawl	1983	Jul	Central CA	753	N
	Trawl	1992	Jul-Aug	Central CA to S. CA	246	N
	Trawl	1998	Jun-Jul	Central OR to C CA	441	N
	Trawl	2001	Jun-Jul	Northern CA	487	Y
<u>NOAA Northwest Fisheries Science Center West Coast Groundfish Survey</u>						
	Trawl	2003	Jul-Oct	Central OR to S. CA	706	Y
	Trawl	2005	Jun-Oct	Central OR to S. CA	892	Y
	Trawl	2006	Jun-Oct	Central OR to S. CA	626	Y
	Trawl	2007	Jun-Oct	Central OR to S. CA	596	Y
	Trawl	2008	Jun-Oct	Central OR to S. CA	703	Y
	Trawl	2009	Jun-Oct	Central OR to S. CA	619	Y
	Trawl	2010	Jun-Oct	Central OR to S. CA	806	Y
<u>NOAA Southwest Fisheries Science Center (FATE project)</u>						
	Hook and line	2009-10	Nov-Mar	N. CA to S. CA	478	Y
	Hook and line	2010-11	Nov-Mar	N. CA to S. CA	387	Y
Total					7741	6301

### *Fecundity analysis*

We expected climate effects on reproductive capacity, fish condition and fish health to also 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 (Lenarz and Wyllie-Echeverria 1986, Eldridge and Jarvis 1995), but how this effect translates into changes in reproductive capacity is not well understood for many species. For this study, we evaluated the impact of oceanographic effects on fecundity using three approaches.

First, we conducted an assessment of regional and temporal climate effects on rockfish growth and productivity through field collections along the California coast. Rockfish were collected using hook-and-line methods from four locations (Figure 2).



**Figure 2.** Map of 2009-2011 rockfish hook-and-line survey locations. Note that fish from Bodega Bay were collected approximately 25 miles offshore in the Cordell Bank National Marine Sanctuary.

The 2009/2010 and 2010/2011 surveys were conducted over the winter months during the period of larval development and release for both chilipepper (*S. goodei*) and yellowtail (*S. flavidus*) rockfish. In addition to collecting fecundity data for these target species, we were also able to gather data for other rockfish species caught incidentally in the survey, several for which only minimal information exists on growth and fecundity. These species included the rosy (*S. rosaceus*), speckled (*S. ovalis*), canary (*S. pinniger*), squarespot (*S. hopkinsi*), bocaccio (*S. paucispinis*), olive (*S. serranoides*), bank (*S. rufus*), brown (*S. auriculatus*), half-banded (*S. semicinctus*) and greenspotted (*S. chlorostictus*) rockfish. Humboldt squid (*Dosidicus gigas*) were encountered on many of the surveys in 2009/2010 and stomach samples were collected for an ongoing diet study at the SWFSC of this rockfish predator. No Humboldt squid were encountered in the 2010/2011 survey.

To estimate fish condition and fecundity, rockfish length and weight measurements were recorded and the gonad, liver and otoliths dissected. Weighed subsamples of eggs or larvae from ovaries of gravid females were used to estimate total fecundity. The duration of these collections coincided with two years of contrasting oceanographic conditions. Moderate, warm water El Niño conditions were experienced in the California Current from 2009 through early 2010, followed by cooler, more productive La Niña conditions in the spring and summer of 2010, suggesting that the growth opportunity for adult rockfish differed between the two years.

Our second approach was a retrospective analysis of fecundity relationships during contrasting oceanographic conditions by combining our dataset (2009-2010) with a dataset of yellowtail and chilipepper fecundity from Cordell Bank over a 3 year time period (2005-2008, Sogard et al. 2008). All fecundity estimates were 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 expected any reduction in annual fecundities to be associated with decreased female condition. Fulton's K (somatic weight \* length<sup>-3</sup>) and the hepato-somatic index (HSI, liver weight/somatic weight) was calculated for each fish to provide simple indices of fish condition. The Fulton's K and HSI condition indices were examined as possible indicators for yearly production estimates (after adjusting for fish size).

Our third approach used laboratory experiments to examine the mechanistic link between fish health and reproductive allocation strategies. Experiments were designed to test the response of female rockfish to low food availability for an extended period prior to parturition. This treatment was intended to simulate poor feeding conditions in the ocean during the pre-reproductive stage. Brown rockfish were held in treatments of either a high (ad libitum) or low (below maintenance) ration diet from October (fall mating period) until June (time of parturition) in both 2009 and 2010. For each treatment, approximately 15 females and 5 males were held in 5,870 L flow-through saltwater tanks. In March, after mating had presumably occurred, females were moved into individual 575 L tanks and maintained on their respective treatment rations until the expected time of parturition.

#### *Bioenergetics modeling*

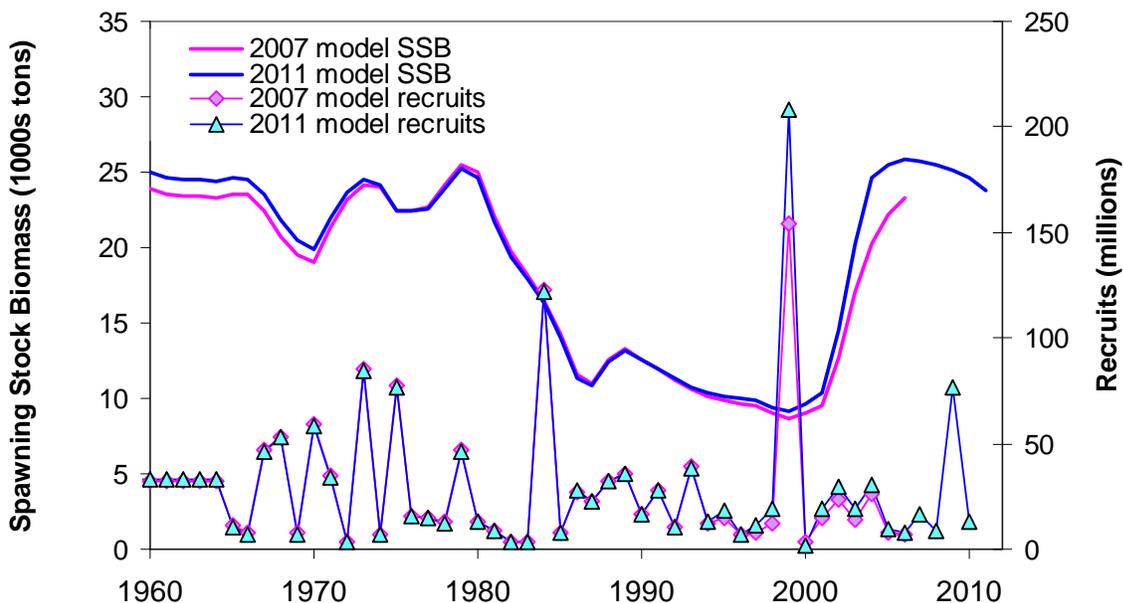
We conducted a series of bioenergetics modeling simulations, using a rockfish bioenergetics model adapted to represent the growth and life history patterns of female chilipepper rockfish from central California waters (Harvey 2005, Harvey et al. 2006). The simulations exposed model rockfish to climate disturbances of different signs ("good" vs. "poor" growing conditions) and durations (1 year, 4 years or 10 years). We also tested different degrees of surplus energy allocation under the different environmental conditions: that is, we varied the amount of surplus energy that was routed to either growth or to reproduction. Our goals were to determine how climate variability affected chilipepper growth, fecundity and life history, and if reallocation of surplus energy during certain climate regimes or anomalies led to a net increase in lifetime reproductive potential. The model framework thus provides a direct, mechanistic linkage between climate variability and rockfish productivity, and supports improved assessments and better predictions by anticipating varying patterns of chilipepper growth and reproductive capacity under alternate climatic scenarios.

## Work Completed:

### *Growth analysis*

We completed ageing of chilipepper rockfish from the majority of the fishery-independent surveys (Table 1) and increment analysis for 29 chilipepper otoliths. The results showed evidence of a strong 1999 recruitment year-class for chilipepper rockfish along the coasts of Oregon and California. For example, chilipepper collected by the 2006 NWFSC trawl survey showed a strong 1999 year class across all regions (age 7 fish), suggesting a general recruitment response to large scale oceanographic conditions (consistent with Field and Ralston 2005 and reported in our year one project update). In contrast, a strong year class in 2004 (age 2 fish) was evident only in the Central California region, suggesting a more localized response.

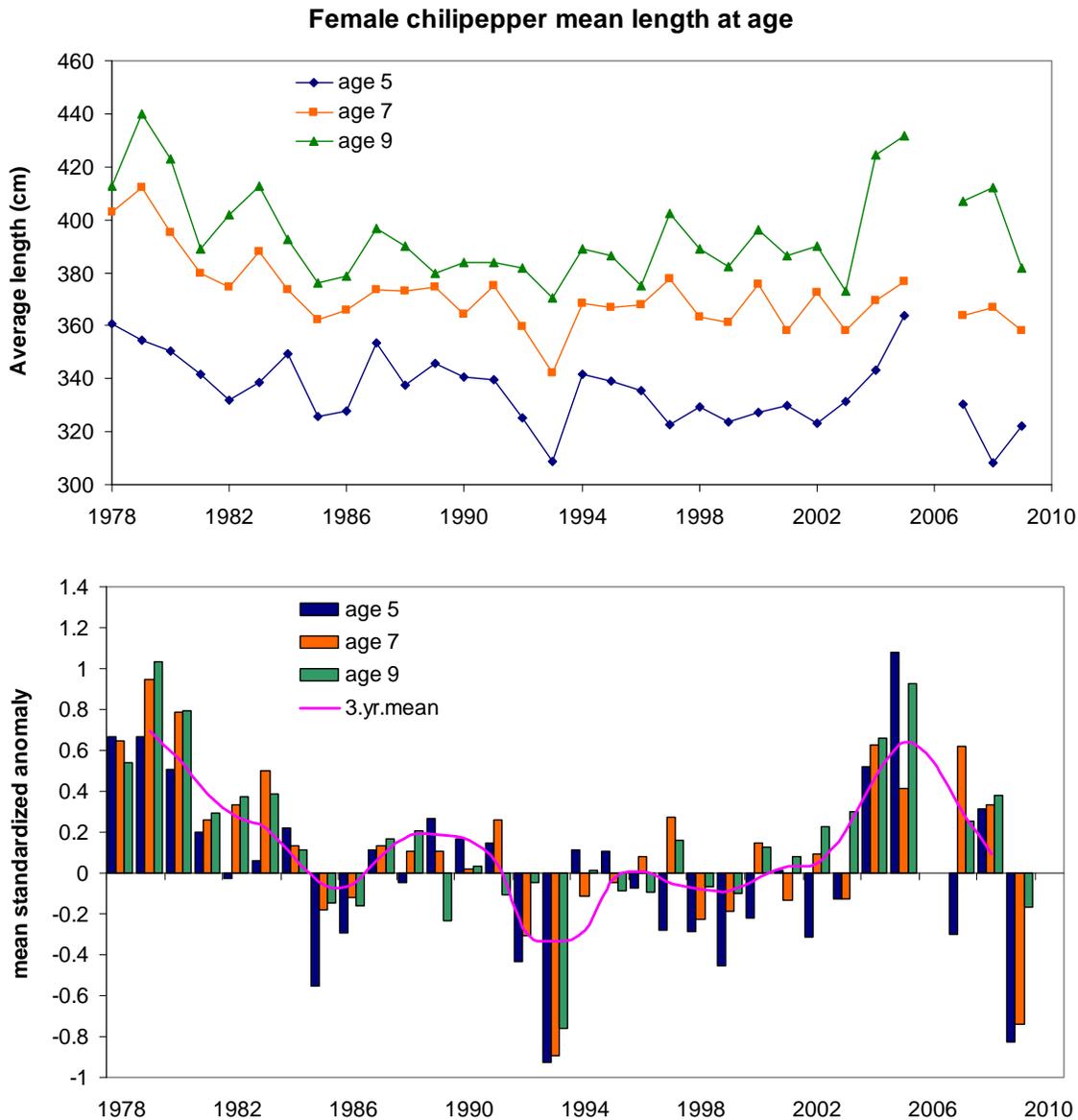
The fishery-independent size-at-age data was critical to re-evaluating the chilipepper stock assessment model that included time-varying growth. All age and growth data from the archival fishery-independent chilipepper otoliths were combined with fishery-dependent data into an updated version of the most recent chilipepper stock assessment to re-examine methods for modeling time-varying growth as influenced by environmental factors. Figure 3 shows the initial and updated assessment models for spawning stock biomass and recruitment. Once again, the strong 1999 recruitment class is evident as well as a moderately strong recruitment in 2009.



**Figure 3.** Updated chilipepper stock assessment model for spawning stock biomass and recruitment, contrasted to the 2007 base model results. Solid lines indicate the spawning stock biomass estimated by the 2007 and 2011 models, respectively, and triangles denote the estimated abundance of recruits.

Mean size-at-age data was updated through 2010 to include both commercial and fishery-independent survey age data, and average annual anomalies from the long term mean (for commercial fish only) were also evaluated as a diagnostic (Figure 4). The results of this analysis are consistent with those described in the proposal, with strong positive anomalies (larger than average fish at age) in the early part of the time series, weakly positive anomalies (slightly larger

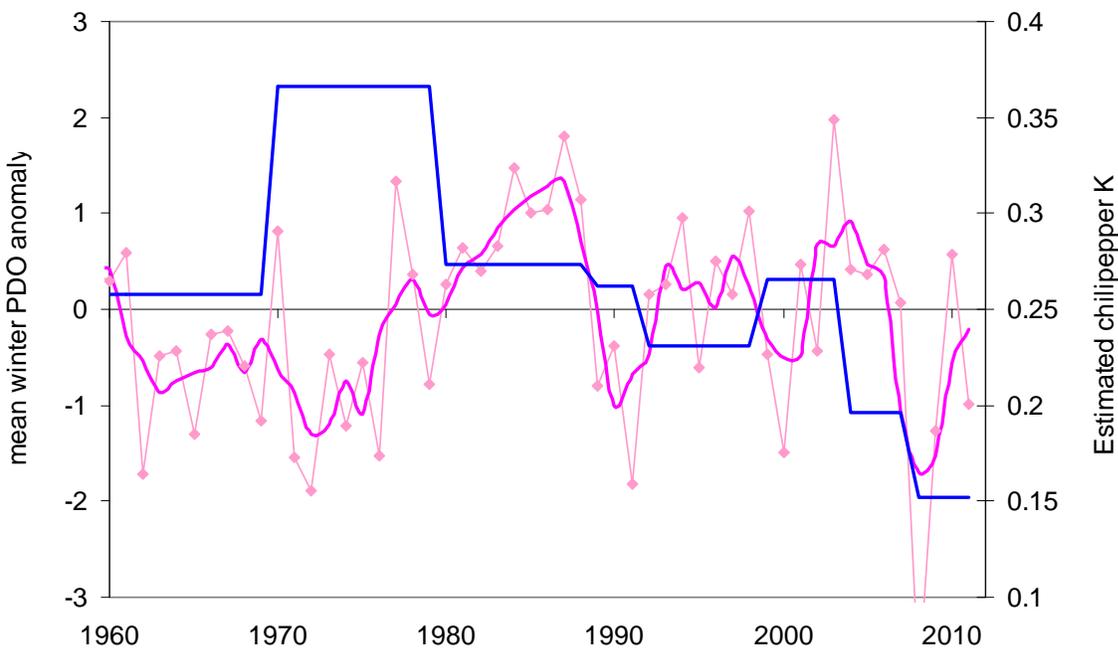
than average fish at age) in the mid to late 1980s, and generally smaller fish throughout most of the 1990s. Interestingly, the positive size at age anomalies observed in the early part of the 2000s appear to have been followed by negative size-at-age anomalies in recent years.



**Figure 4.** Mean size-at-age data by year for age 3, 5 and 9 year-old chilipepper rockfish from 1978 to 2010 (top graph), from commercial fishery samples. Mean size-at-age anomalies by year with a 3 year running mean (bottom graph).

These new age data (and associated length frequency data) were entered into the chilipepper stock assessment, which was updated from the 2007 model (which itself included data only through 2006) to include catches, survey indices and other information through 2010. The approach to estimate time varying growth was replicated, using a similar set of environmental offsets to the von-Bertalanffy growth parameter (K), which were estimated based

on time blocks that were informed by significant changes in the Pacific Decadal Oscillation (PDO) environmental index. Previously, in the 2007 assessment, an increase in the mean K appeared to correlate moderately well with years of negative anomalous PDO conditions, indicative of periods of presumably higher productivity (improved growth conditions) in the California Current. After updating the model from 2006 through 2010, we observed the same unexpected decrease in presumed growth rates as inferred by the raw size-at-age data. We would have a-priori estimated recent years to have been a period of improved growth conditions due to the presumed high productivity and abundant forage base for this species (Figure 5). As a result, the previously weak relationship between the mean winter PDO anomaly for a given time block and the offset to the assessment model growth coefficient parameter (von-Bert. K) has degraded and there is no longer a relationship. This result was unexpected and is not currently fully understood.

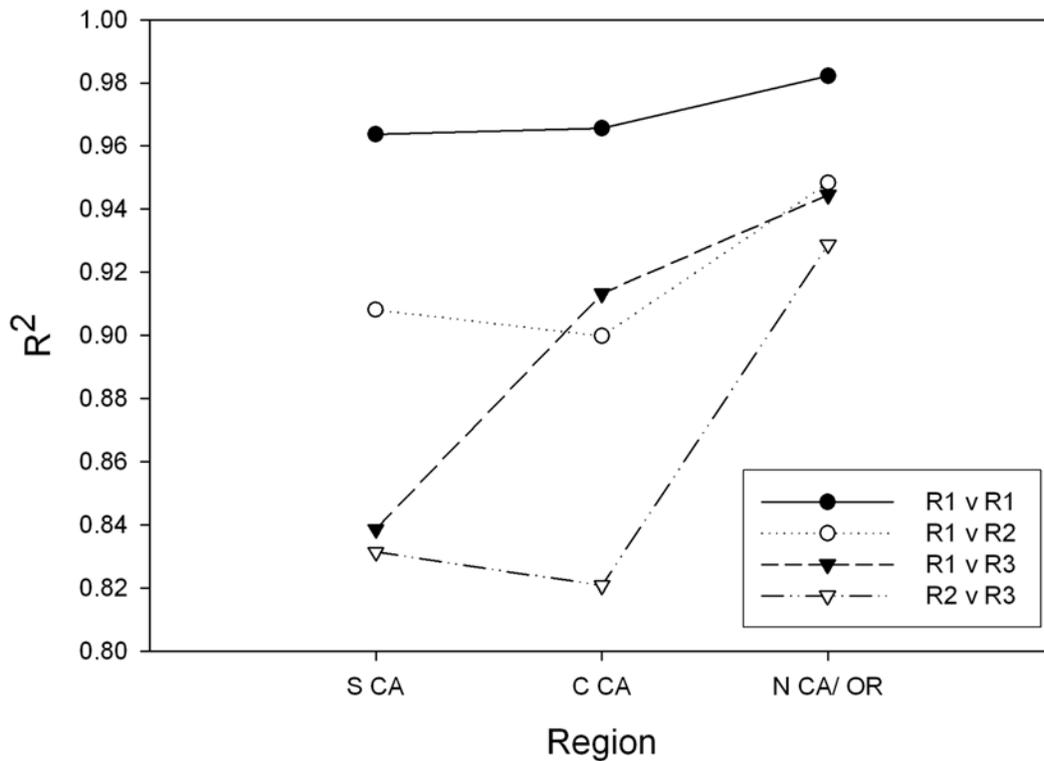


**Figure 5.** Mean winter PDO anomaly (pink symbols), running average of the PDO (pink line) for the years 1960-2010 and estimated von Bertalanffy growth coefficient K (blue line) for chilipepper rockfish.

One explanation for this unexpected result is that the spawning stock biomass for chilipepper is currently at its highest levels since the 1970s and density dependent factors may be influencing growth rates. Another plausible explanation relates to the sources of age data. Since a majority of the chilipepper habitat in central California was closed to fishing over the last decade, the age and growth data from the commercial fishery used to inform the most recent years of the model is comprised mainly of fish from Northern California. Chilipepper from the northern population appear to exhibit slower growth rates than chilipepper in southern and central Californian waters (a trend commonly observed in many rockfish species), and a change in the relative proportion of age samples by region could bias the interpretation of time-varying estimates of K in the model. Further work is needed to parse out the effects of this bias and re-evaluate the correlation between the PDO index and chilipepper rockfish growth rates.

As the chilipepper stock was not assessed as part of the 2011 stock assessment cycle for the Pacific Fishery Management Council (PFMC), the updated assessment has changed little (with the exception of the data developed as part of this project and updated commercial catch and length information), and there was little time to explore alternative hypotheses or model structures. However, this work will be continued in the fall of 2011 and winter of 2012, at which time we will update the model using the most recent version of the assessment model (Stock Synthesis 3), which is more robust at modeling variability in growth rates using age data entered conditionally relative to length. We may also explore the development of models that focus only on the “core” area or habitat for chilipepper rockfish (e.g., central California waters) in order to minimize the potential for latitudinal gradients in growth rates to complicate an understanding of temporal variability. There have also been discussions at the PFMC level of conducting a limited number of stock assessments that explicitly incorporate environmental factors (e.g., climate or trophic interactions) as part of a general movement to adopt a more “ecosystem-based” approach to both management and to the science that supports the current management system. Due to the fact that the chilipepper assessment is one of few West Coast groundfish assessments that currently includes variable growth informed by climate indices, this assessment may be a candidate for future “ecosystem based” assessment (PFMC 2011).

In addition to the comparison of adult growth among years, we conducted an evaluation of latitudinal effects on age precision estimates for chilipepper rockfish ranging from Oregon to Southern California. Specifically, there was 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. A preliminary comparison (simple correlation analysis) of both within- and between-reader age estimates for chilipepper rockfish verified this likely climate-driven effect, demonstrating more variability in age assignments for more southern populations (Figure 6). This effect may help improve our understanding of the relationship between climate and otolith readability for additional difficult to age species, such as bocaccio, and more rigorous analyses of these effects are forthcoming (e.g., quantification of aging error based on Punt et al., 2008).

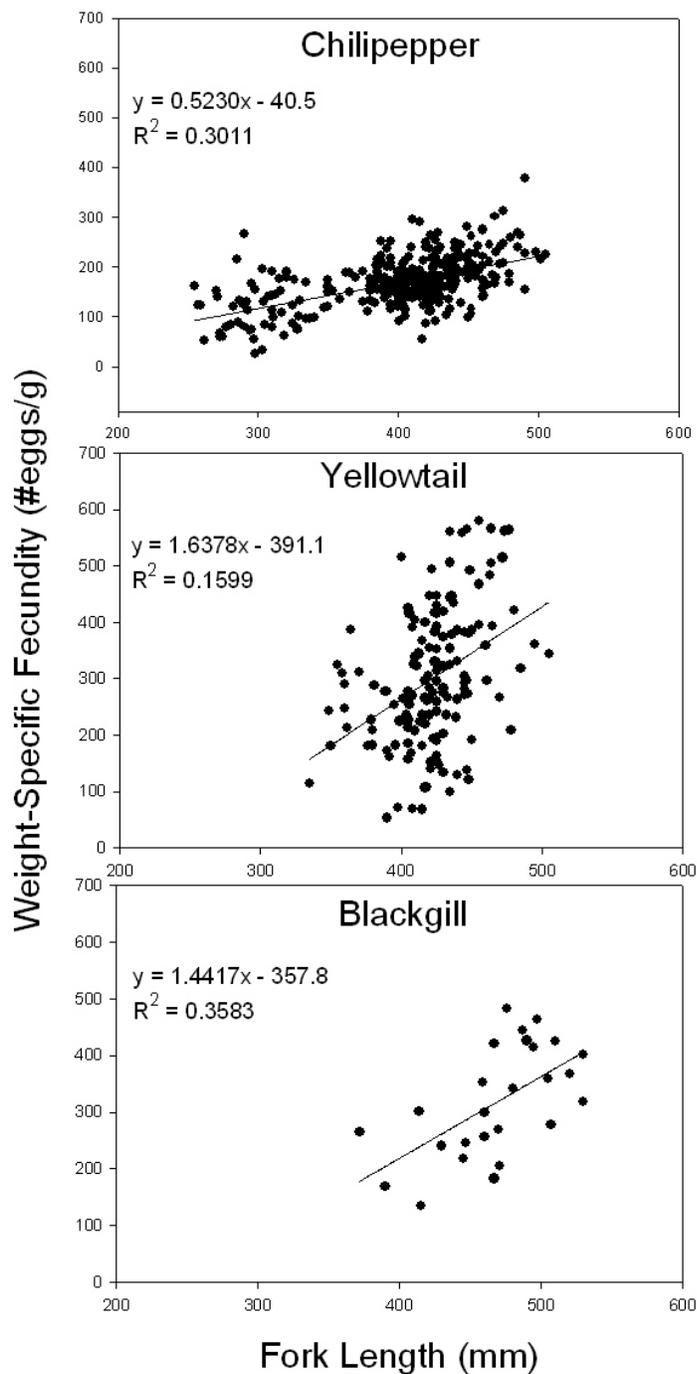


**Figure 6.** A correlation comparison by region for both within- (solid line) and between- (dashed lines) reader age estimates for chilipepper rockfish otoliths (N = 224) for three readers (no double read for readers 2 and 3, R2 and R3).

For the otolith increment analysis, 29 chilipepper otoliths were sectioned through the core with an Isomet low speed saw, lightly burned over an alcohol flame to enhance the contrast of annual growth increments and photographed in the Optimas digital imaging program. Methods followed closely to those in Black et al. (2008) and Matta et al. (2010). Increment analysis was complicated by the fact that chilipepper are a relatively fast-growing, shorter-lived rockfish species and annual increments were not always well defined, especially for fish from southern latitudes (Figure 6). An ongoing continuation of the project will attempt to adapt methods for increment analysis in the literature for chilipepper rockfish otoliths, especially since climate-driven growth patterns such as the 1997-98 El Niño appear visually as a darker increment in many of the otoliths from chilipepper alive during that period.

#### *Fecundity analysis – maternal effects*

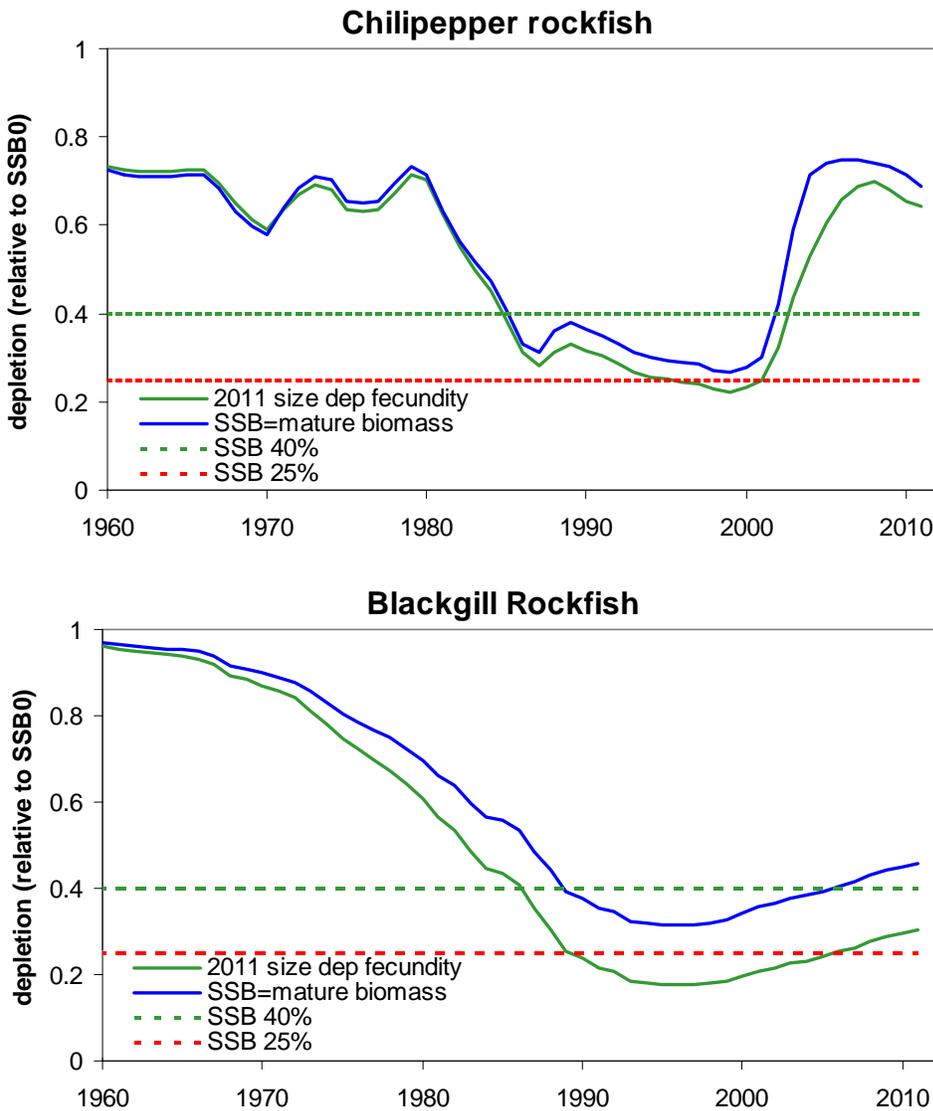
We found a strongly positive relationship between fish size and weight-specific fecundity (eggs or larvae per g of female body weight) for chilipepper, yellowtail and blackgill (*S. melanostomus*) rockfish (Figure 7). This maternal effect was much stronger for yellowtail rockfish, where larger females had as much as twice the number of progeny per gram than smaller females. This pattern highlights the importance of contributions from large, and presumably older, female fish to population production and the importance of accounting for size-specific relative fecundity in regional and interannual comparisons.



**Figure 7.** Relative (weight-specific) fecundity ( $\text{eggs} \cdot \text{g}^{-1}$ ) as a function of fish length for chilipepper, yellowtail and blackgill rockfish collected along the coast of California, all years and sites combined.

The observed changes in relative fecundity with fish size had an effect on the estimation of total population production in both the chilipepper and blackgill rockfish stock assessments. For chilipepper rockfish, the difference was not tremendous, but showed bias toward overestimation of stock status without accounting for size-dependent relative fecundity (Figure

8). Interestingly, the stock would have been classified as “overfished” from around 1996-2001 if size-dependent relative fecundity had been considered in the model. For blackgill rockfish there was a considerably greater effect, with the fecundity relationship contributing to a substantial change in the perception of stock status when the proportionately greater contribution of larger, older females was explicitly modeled. Specifically, when size-dependent relative fecundity is not accounted for, the perception from the stock assessment is that the stock is above target levels and has never been overfished. However, when size-dependent fecundity is included in the model, the current (2011) status is in the precautionary zone and the stock is estimated to have retroactively been in an overfished condition throughout much of the 1990s and early 2000s (based on Field and Pearson, in review).



**Figure 8.** A comparison of the spawning stock biomass (SSB) index with- (green line) and without- (blue line) accounting for size-specific relative fecundity for chilipepper and blackgill rockfish. Management reference points of 40% and 25% SSB depletion are indicated by the green and red dashed lines, respectively.

It is interesting to note that in 2006, when chilipepper rockfish were last formally assessed, only 7 out of 17 *Sebastes* assessments on the West Coast accounted for size-specific relative fecundity. Currently over half of the existing rockfish assessments include this effect, and most of those that do not are assessments for which there were not previously (but are currently) data or analyses to inform such relationships (e.g., Dick 2009, this study). Consequently, most of these stocks (such as chilipepper, yellowtail, canary and others) are likely to include these effects as assessments are updated or redone over time.

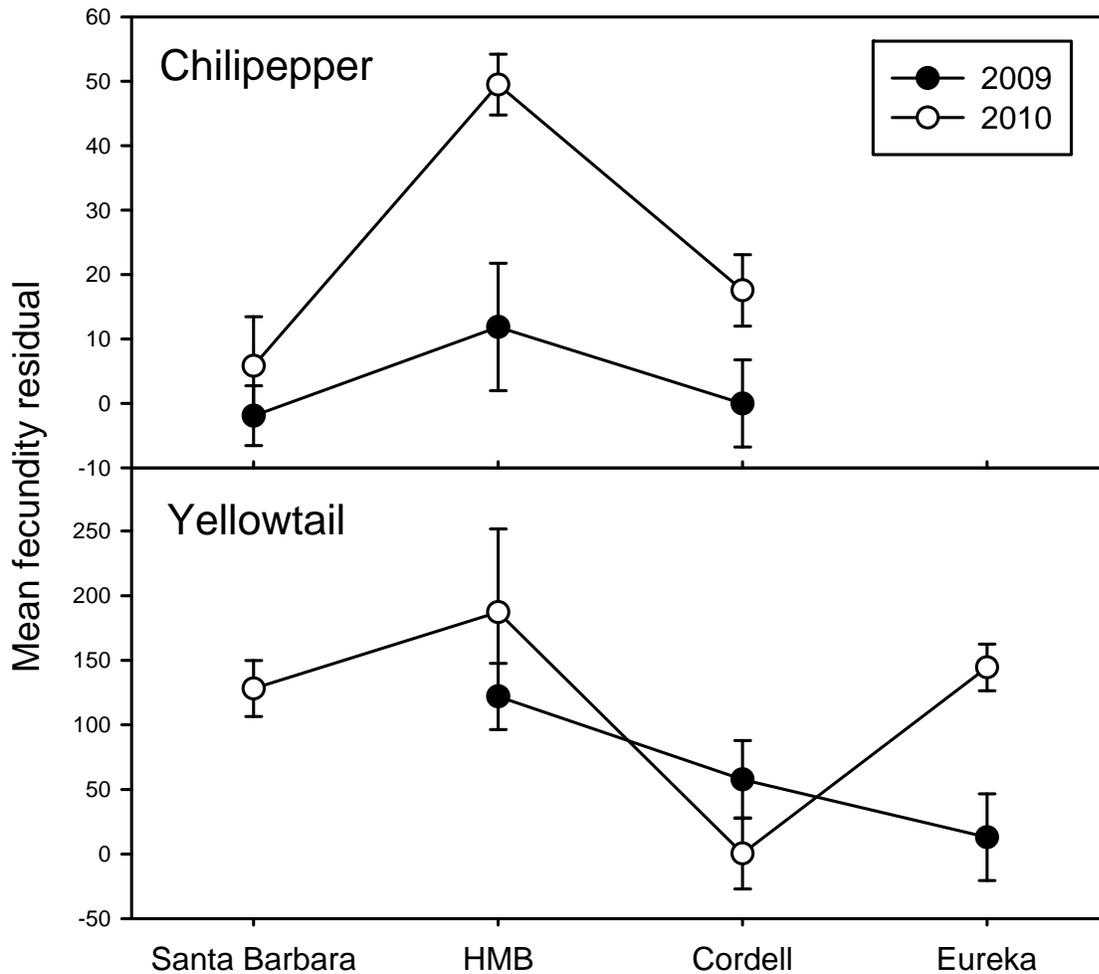
*Fecundity analysis - regional comparisons*

Table 2 summarizes hook-and-line collections completed out of four ports along the California coast in 2009 and 2010. Funding for field collections was provided by the NOAA National Cooperative Research Program. Data from these collections, which specifically targeted gravid females, was incorporated into an overall assessment of time-varying fecundity and correlation with fish condition. For all analyses we used the residual of the relationship between weight-specific fecundity and female length (as shown in Figure 7) to adjust for the maternal effect of size on relative fecundity.

**Table 2.** Summary of rockfish species collected in winters of 2009-2010 and 2010-2011.

Location	2009 Chilipepper	Yellowtail	Other	2010 Chilipepper	Yellowtail	Other
Eureka	0	23	3	0	60	8
Cordell Bank	119	37	24	62	31	95
Half Moon Bay	140	84	16	106	59	56
Santa Barbara	220	35	75	219	137	195
Total	479	179	118	387	287	354

There was some evidence of regional differences in relative fecundity that may be dependent on year and differences in oceanographic conditions among regions (Figure 9). For chilipepper rockfish, in both years fish collected from Half Moon Bay had higher fecundity relative to fish from either Santa Barbara or Cordell Bank (two-way ANOVA;  $F_{2,174}$  for site = 6.12,  $p = 0.003$ ,  $F_{1,174}$  for year = 9.97,  $p = 0.002$ , interaction not significant). For yellowtail rockfish, there was a similar trend of higher fecundity at the Half Moon Bay site, although high variability resulted in no significant difference among sites.



**Figure 9.** Regional comparison (mean  $\pm$  S.E.) of size-adjusted relative fecundity for chilipepper (N=180) and yellowtail (N=39) collected in 2009 and 2010.

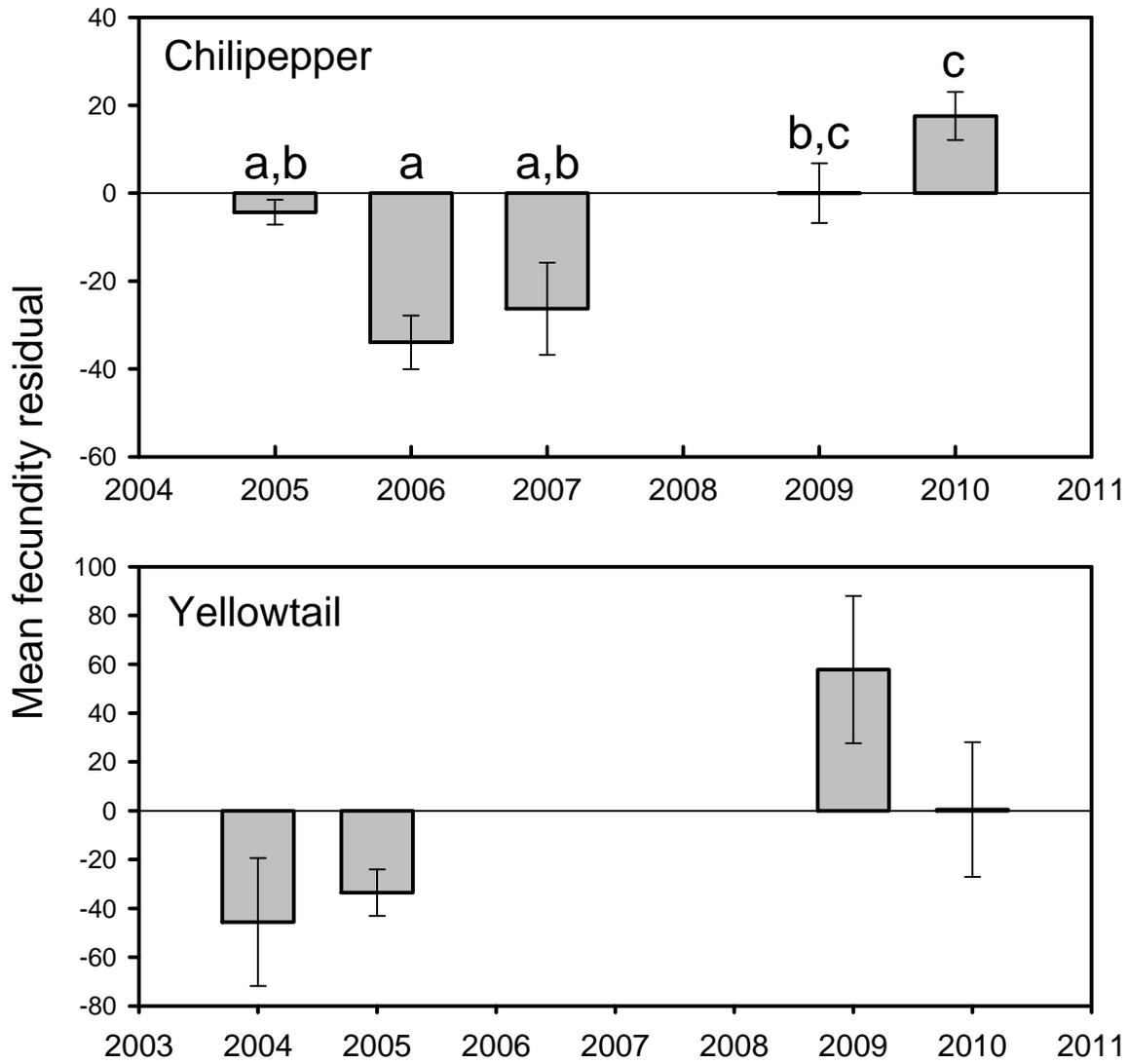
Evidence of multiple broods was apparent for four rockfish species (Table 3). Ovaries that contained a small portion of remaining eyed-larvae from a recent parturition as well as developing stage 2 (unfertilized) or stage 3 (fertilized) eggs were considered to have produced multiple broods within the spawning season. This occurrence has been documented for rockfish in Southern California but is considered rare from central California northward (Love et al. 1990). Females that produce multiple broods will greatly influence estimates of seasonal reproductive capacity as well as lifetime fecundity. All other species examined in this study showed no evidence of multiple broods. Our results are consistent with Love et al. (1990) in that the occurrence of multiple broods is more likely in southern compared to northern populations.

**Table 3.** Number of rockfish with evidence of multiple broods compared with the total number of mature females with developing eggs for 2009-2010. An x indicates no data.

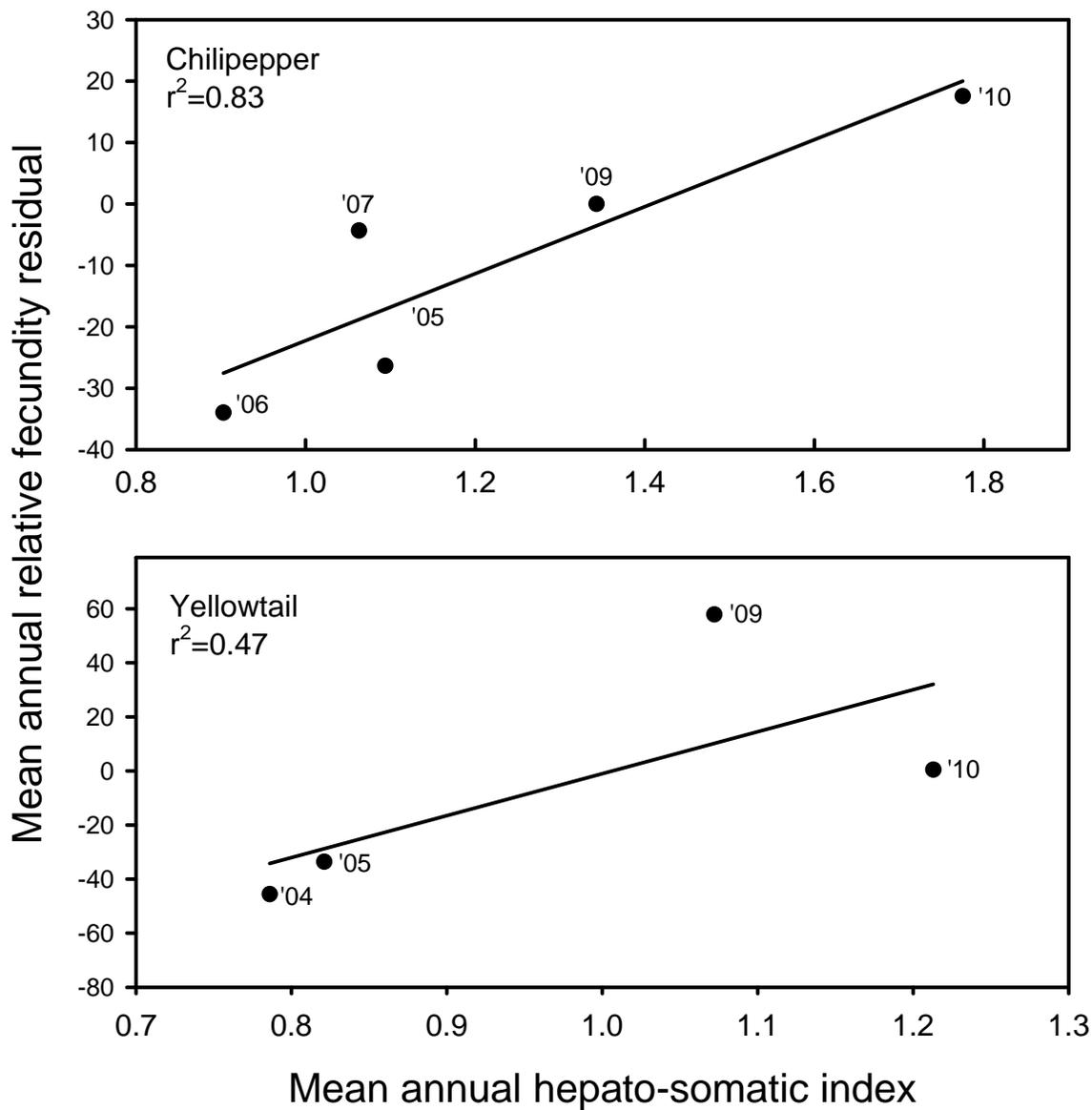
Location	Species	Winter 2009	Winter 2010
Santa Barbara	Chilipepper	30 of 106 (28%)	1 of 67 (1.5%)
	Speckled	10 of 17 (59%)	8 of 15 (53%)
	Rosy	0 of 3 (0%)	1 of 2 (50%)
	Squarespot	4 of 11 (36%)	3 of 6 (50%)
Half Moon Bay	Chilipepper	16 of 84 (19%)	0 of 41 (0%)
	Rosy	x	0 of 1 (0%)
Cordell Bank	Chilipepper	0 of 48 (0%)	0 of 43 (0%)
	Speckled	0 of 3 (0%)	2 of 6 (33%)
	Rosy (Pt Reyes)	1 of 2 (50%)	x
	Squarespot	x	0 of 1 (0%)

*Fecundity analysis- interannual comparisons*

From Cordell Bank we had a time series of fecundity data for both chilipepper and yellowtail rockfish extending from 2004 to 2010 (Figure 10). Because there were substantial differences in fecundity among sites, as noted above, we restricted our analysis of interannual differences to fish collected only from Cordell Bank. Within this time period there was considerable variability in ocean conditions. Female condition differed accordingly, with both species having low condition in 2004-2006, moderate condition in 2009 and high condition in 2010. There were no samples of chilipepper fecundity in 2008, and only a limited number of samples for yellowtail fecundity in 2006 and 2007 (not included in interannual comparison) and no samples for yellowtail in 2008. The variability in female condition, based on the hepatosomatic index (Figure 11) was correlated with variability in weight-specific fecundity during this time period.



**Figure 10.** Time-varying relative fecundity (residual of the relationship between weight-specific fecundity and female length) for both chilipepper and yellowtail rockfish (2004-2010). Data from Cordell Bank collections only. Letters indicate significantly different means ( $P < 0.05$ ) based on Tukey tests following one-way ANOVA; there were no significant differences among years for yellowtail rockfish.

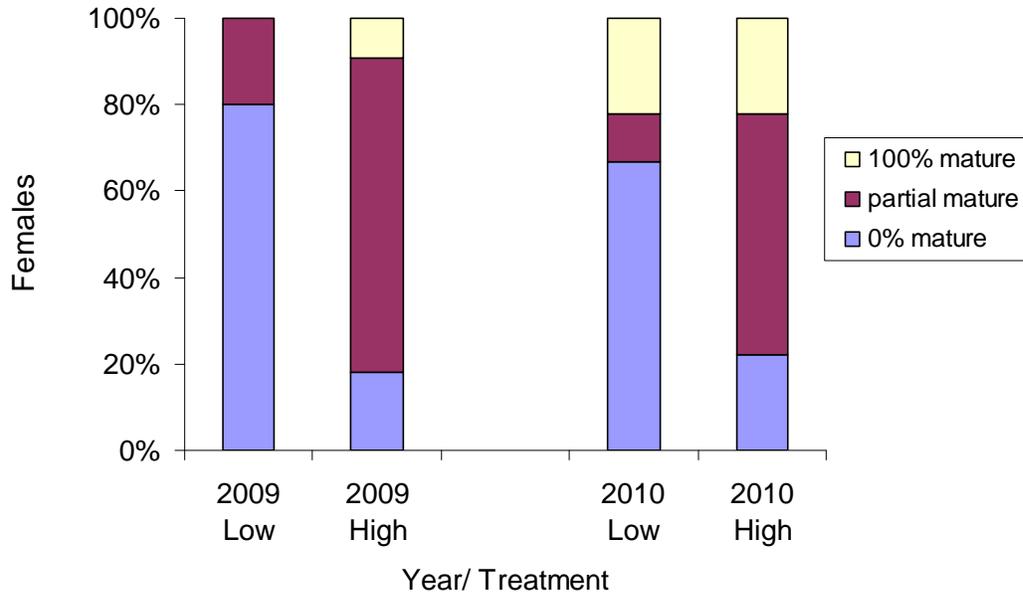


**Figure 11.** Relationship between fish condition (hepato-somatic index) and relative fecundity (residual of the relationship between weight-specific fecundity and female length) for chilipepper and yellowtail rockfish by year. Data from Cordell Bank collections only.

*Fecundity analysis - lab experiments*

The food ration treatments were effective in shifting the condition of brown rockfish females into high and low levels. At the expected time of parturition in May and June, some of the females released eggs that had progressed to a stage presumed to be just prior to fertilization. In July, after parturition should have been completed, all females were dissected and the ovaries examined. There was no evidence of fertilized eggs in any of the females, suggesting that none of them had mated and acquired sperm from the males available in the initial holding tanks.

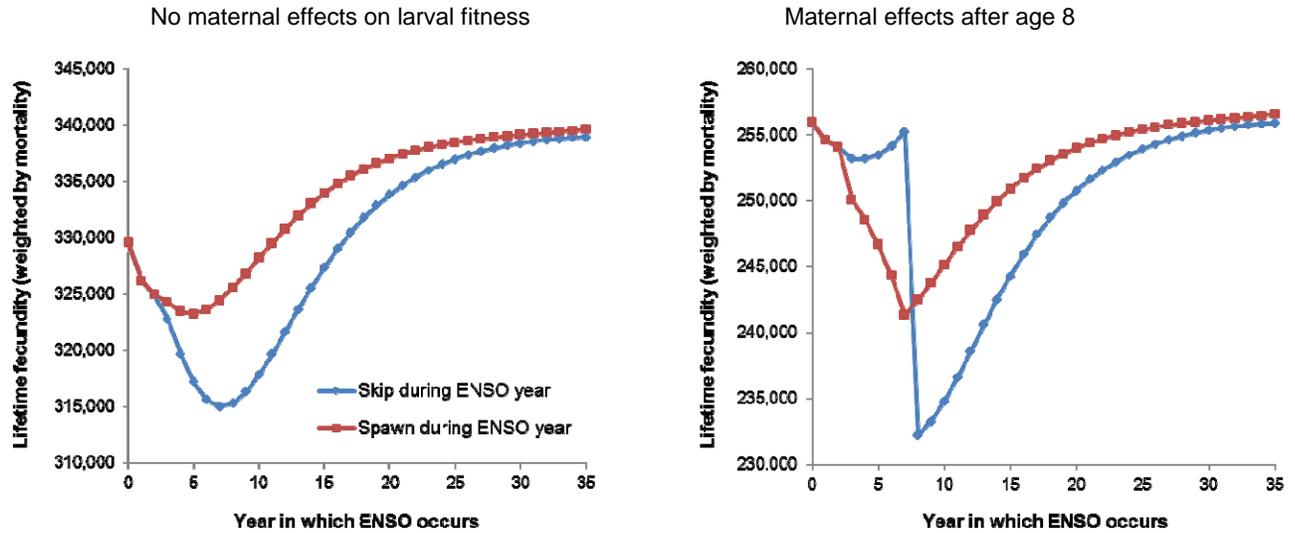
Consequently, fecundity estimates could not be determined. However, we did observe a treatment effect on the proportion of females that proceeded with egg development up to the stage where fertilization would normally occur. In both years, females held on high rations were more likely to initiate egg development than females held on low rations (Figure 12). We interpret this result as an indication that females in poor condition were potentially skipping spawning, whereas females in good condition were undergoing egg development at the appropriate time, but aborted some of them when no sperm were available for fertilization.



**Figure 12.** Final developmental stage of eggs produced by female brown rockfish under conditions of reduced vs. ad libitum rations in laboratory tanks. Egg maturity was defined as a stage of completed vitellogenesis and apparent hydration just prior to fertilization. Bars designate the percentage of females with 0, partial, and 100% of eggs in the mature stage. Treatment was either a low or high ration level.

### *Bioenergetics modeling*

We completed the bioenergetics model analysis and published the study in *Fisheries Research* (Harvey et al. 2011). The central findings of the study were: (1) growth and fecundity responded as expected to climate changes (reduced by “poor” conditions, increased by “good” conditions); and (2) routing surplus energy from reproduction into growth increased population-level fecundity, but only if we assumed that older females produced more viable larvae, *and* if the routing occurred during climate anomalies affecting relatively young females (Figure 13). Our results provide a possible energetic explanation for growth rate variability observed in chilipepper rockfish over the past several decades, and are also consistent with observations of skipped spawning in younger females of two other rockfish species (Pacific ocean perch *S. alutus* and aurora rockfish *S. aurora*, Hannah and Parker 2007, Thompson and Hannah 2010).



**Figure 13.** Modeling results for simulations of lifetime fecundity in female chilipepper rockfish that skip spawning during a year of ENSO conditions vs. females that continue to spawn during all years. Maternal effects, in which older females produce more viable larvae, are incorporated in the right graph but not in the left graph.

### Applications:

Our results demonstrated several new insights regarding fecundity relationships in rockfishes. Our two target species differed in several respects. Both species had a significant effect of maternal size on relative fecundity, but for yellowtail the difference between large and small females was greater than for chilipepper. Yellowtail rockfish had higher weight-specific fecundities than chilipepper rockfish, potentially a function of the smaller size of their larvae at parturition. Yellowtail also exhibited much greater variability in relative fecundity (adjusted for maternal size) both within and among years and sites.

Both target species showed changes in fecundity with changes in the environment. In general, relative fecundities were low from 2004–2007 and high in 2009 and 2010. Relative liver weight appeared to be a good index of fish condition, and was correlated with the residual index of fecundity in both species. Lipid stores in the liver are likely to comprise a major portion of the lipid allocated to developing larvae. Females benefiting from highly productive environments, particularly those evident in 2010, appear to be able to increase their fecundity accordingly. Thus, our results provide further support for the inclusion of climate conditions in stock assessments.

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 is currently being evaluated in the existing assessment model of chilipepper rockfish, and could potentially be explored in models of other species, methods to incorporate and evaluate the sensitivity of assessment models to these factors are important areas

of research to support accurate assessment and evaluation of the productive capabilities of these resources. Preliminary results suggest that the effects of variable growth on the perception of management reference points is modest, while that of size-dependent relative fecundity is considerably greater (and tends to be greater still for relatively long-lived and slow growing species). We have not yet evaluated the effects of time-varying fecundity on the interpretation of reference points, although we hope to explore this factor in future analyses. Although we were unable to fully develop a chilipepper model using the improved capabilities of stock synthesis III in time for this project report, this analysis will be conducted in late 2011 and early 2012. We anticipate that both the empirical analysis and the modeling work that will be conducted over the next six to 12 months will lead to several substantive publications in the peer-reviewed literature, as well as a basis for continuing to include climate-driven growth variability in future assessment models of chilipepper rockfish (and other species) in order to best inform conservation and management measures by the PFM.

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### **Publications/Presentations/Webpages:**

Beyer, S., Sogard, S., Field, J., Harvey, C. 2011. Oceanographic Effects On Rockfish Growth and Productivity In the California Current. American Fisheries Society annual meeting, Seattle, WA.

Sogard, S., Field, J., Harvey, C., Beyer S., 2011. An evaluation of the significance of climate forcing on time-varying growth and fecundity of rockfish in the California Current (Year 2 update). Fisheries and the Environment (FATE) annual meeting, Portland, OR.

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