FATE (FY2014) proposal. Development of a fishery-independent time series of rockfish (*Sebastes* spp.) abundances under varying environmental and management conditions to improve stock and ecosystem assessments

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Background

Rockfishes (*Sebastes* spp.) are important components of the West Coast commercial and recreational fisheries [1] as well as the coastal marine and terrestrial ecosystems [2]. Over the past half century fishing pressure, coupled with varying oceanographic conditions, led to dramatic declines in catch per unit effort of many of the larger species such as cowcod [3], bocaccio [4,5], and blackgill rockfishes [6]. Stock assessments formalized the collapse of several populations which led to the establishment of multiple rockfish conservation areas (RCAs) along the west coast of the United States. Although many of these RCAs have now been in place for more than a decade there is little information on rockfish population trends, thus hindering the capacity of stock and ecosystem assessments to characterize rockfish and ecosystem status and our ability to evaluate reserve efficacy. **Our proposal seeks to develop and incorporate into stock assessments and Integrated Ecosystem Assessments (IEA) a new fishery-independent data set on rockfish dynamics in southern California and test the influence of RCAs and oceanographic conditions on stock and ecosystem status.**

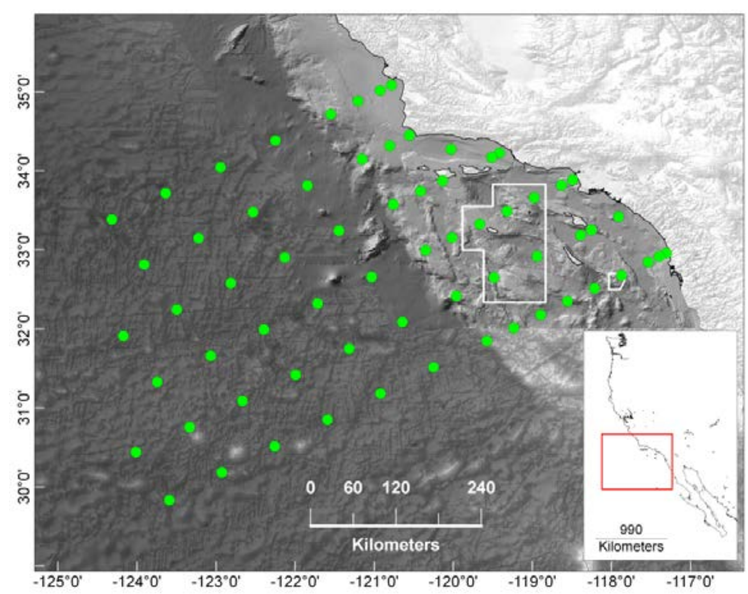

Figure 1. Location of CalCOFI stations from which ethanol-preserved samples were consistently collected. White polygons outline the CCAs.

RCAs present unique challenges for monitoring rockfish dynamics [7]. Whereas stock and IE assessments typically utilize fishery-dependent (e.g., landings, demographic characteristics of the catch, catch per unit effort) and fishery-independent (e.g., hook and line or trawl surveys) data**, this information can no longer be collected within the bounds of many RCA**s. For example, within the Cowcod Conservation Areas (CCAs), two large RCAs in the Southern California Bight (Figure 1), fishing is prohibited at depths greater than 36 m, thus effectively eliminating collection of fishery-dependent data. Moreover, fishery-independent trawl and hook and line surveys cannot be conducted within the CCAs to minimize take of cowcod. **This lack of data seriously compromises our ability to evaluate rockfish population trends and ecosystem status in southern California.** Consequently, a unifying theme of recent stock assessments is that an additional source of fishery-independent trend data that samples throughout southern California is needed to resolve uncertainty in estimates of stock dynamics [6,8-10]. In addition, this data gap compromises the ability of the California Current IEA (CCIEA) to evaluate ecosystem status in southern California. The one exception to the lack of systematic, temporal data on rockfishes in this region are the ichthyoplankton samples that have been collected by the California Cooperative Oceanic Fisheries Investigations (CalCOFI) program. If funded, **we will utilize existing CalCOFI samples to develop an 18 year (1997-2014) time series of larval rockfish abundances in southern California, integrate it into stock and ecosystem assessments, and model the influence of environmental conditions and presence of reserves on rockfish dynamics**.

CalCOFI has monitored larval fishes (ichthyoplankton) from fixed locations off the coast of North America for more than 60 years (Figure 1; [11]). Unfortunately, larvae of most rockfishes are morphologically indistinguishable and, except for seven species, have been identified only to genus. Beginning in 1997, however, CalCOFI ichthyoplankton samples have been stored in ethanol, which preserves DNA and allows larvae to be identified with genetic techniques (as opposed to the traditional technique of preservation in DNA-degrading formalin). For the first part of this study, we **will use genetic methods to identify CalCOFI rockfishes to species.**

The second part of this project will integrate the time series into stock assessments and the CCIEA and attempt to identify factors that affect the fluctuation of multiple rockfish species. Many **studies show that larval data can provide an accurate index of the relative abundance of female groundfish spawning** [3,12-14], and CalCOFI larval indices are currently being used in stock assessments for rockfish species with morphologically identifiable larvae that are (cowcod: [9] and bocaccio: [10]) and are not (shortbelly: [15]) targeted by fishers. Preliminary genetic analysis of rockfish larvae collected within and around the CCAs in the winters of 2005 (Thompson *in prep*) and 1999 [16] show that rockfishes that are currently being formally assessed (blackgill and greenspotted) or under consideration for future assessment (bank) are found in southern California plankton samples (Table 1). Because larval abundances of these species are comparable to those of cowcod and boaccio we believe there is a high probability that these data will be robust enough to effectively augment stock assessments of rockfishes that live in southern California.

The rockfish time series should also be a valuable addition to the CCIEA [17]). Two ecosystem goals considered within the CCIEA are groundfish and ecosystem integrity, and much effort has been devoted to the identification of appropriate and reliable indicators to track the status of each [18-20]. However, very few of the indicators highlighted in the CCIEA are robust enough to be considered long-term indicators of groundfish or ecosystem integrity status. Furthermore, relatively few of the CCIEA indicators of ecosystem integrity extend into southern California. The CalCOFI larval rockfish data set has the potential to fill this gap because it was collected over a relatively long period of time, and the rockfishes are subjected to varying degrees of fishing pressure, utilize a range of habitat types, have short to long generation times, and occupy multiple trophic levels (Table 1). As such, the

Table 1. Genetically identified Sebastes spp. larvae from a subset of the stations sampled during three cruises in the SCB (Taylor et al. 2004, Thompson et al. *in prep*). Fishing pressure is our estimate of fishing intesntiy over the past three decades in Southern California based on catch records and species accounts

Species name	Common name	Common depth of adults (m)	Maximum size (cm)	Fishing pressure
atrovirens	Kelp	1-25	42	moderate
aurora	Aurora	300-500	41	moderate
carnatus	Gopher	12-80	42	high
caurinus	Copper	1-90	66	high
chlorostictus	Greenspotted	60-240	47	high
crocotulus (*miniatus type 1*)	Vermillion	> 100	76	high
constellatus	Starry	60-150	46	high
diploproa	Splitnose	215-350	46	moderate
elongatus	Greenstriped	100-250	43	moderate
ensifer	Swordpine	60-200	25	low
entomelas	Widow	140-240	59	high
flavidus	Yellowtail	90-180	66	high
gilli	Bronzespotted	75-413	71	low
goodei	Chillipepper	75-325	59	high
helvomaculatus	Rosethorn	100-350	41	moderate
hopkinsi	Squarespot	30-150	29	low
jordani	Shortbelly	150-200+	35	low
levis	Cowcod	>150	94	high
macdonaldi	Mexican	76-238	66	low
melanostomus	Blackgill	250-600	61	high
miniatus	Vermillion	< 100	76	high
moseri	Whitespeckled	50-220	21	none
mystinus	Blue	1-90	53	high
ovalis	Speckled	60-150	56	high
paucispinis	Bocaccio	50-250	91	high
phillipsi	Chameleon	174-274	52	low
rastrelliger	Grass	1-46	56	high
rosaceus	Rosy	40-150	36	low
rosenblatti	Greenblotched	55-200	48	moderate
ruberrimus	Yelloweye	91-180	91	high
rubrivinctus	Flag	60-200	44	moderate
rufinanus	Dwarf-red	70-180+	17	none
rufus	Bank	90-360	55	high
saxicola N	Spinetail	100-200	41	low
semicinctus	Halfbanded	60-150	25	low
serranoides	Olive	1-120	61	moderate
simulator	Pinknose	>150	42	low
umbrosus	Honeycomb	45-60	29	moderate
wilsoni	Pygmy	60-150	23	none

CalCOFI rockfish data set should provide insights into how the ecosystem has responded both to fishing pressure (or cessation of fishing pressure within the CCAs) and oceanographic variability (see below). By directly linking ecosystem indicators to natural and anthropogenic pressures, this type of analysis will allow us to conduct one of the first quantitative, empirical risk assessments in the CCIEA. As with stock assessments, there is precedent for using CalCOFI ichthyoplankton data in IEAs as larval abundances are currently being used to track the status of coastal pelagic species and ecosystem diversity, an indicator of ecosystem integrity in the CCIEA [17].

A major goal of this study is to elucidate the causes of rockfish variability in southern California over the last 17 years. Specifically, we will attempt to evaluate whether the presence of the CCAs and environmental variation explain dynamics of rockfishes with differing life-history traits (e.g., targeted versus untargeted species, deep versus shallow habitats). Because samples were collected both within and outside of the reserves (Figure 1), we will compare population trajectories of species in the two regions with the expectation that population sizes of fished species are increasing within but not outside of the reserves and that the dynamics of unfished species are unaffected by reserves. A potential problem with using larvae to evaluate reserve effects is that individuals may drift from natal habitat. To remove the potentially confounding effect of advection on evaluation of larval origin, we will measure the size of each larva and focus on the smaller individuals that are known to associate with natal habitat [16,21]. Because environmental conditions can influence rockfish spawning biomass [22,23] independent of fishing pressure, we will evaluate additive and multiplicative effects of potentially important oceanographic parameters on spatial and temporal larval variability. For example, there is concern that shoaling of the oxygen minimum layer [24] is affecting the viability of deep-living rockfishes such as blackgill, bocaccio and cowcod [25-27]. Fortunately, the CalCOFI samples were collected in concert with detailed, depth-specific oceanographic measurements. In addition, these oceanographic measurements were taken in the same locations four times per year. As such, we will test whether oceanographic conditions experienced by adults during copulation and internal brooding, as well as conditions measured when larvae were captured, correlate with larval abundance. If we find that particular environmental parameters and/or that whether larvae spawned within or outside of the CCAs impact temporal trends, then this will suggest that these key variables should be included into rockfish stock assessments and IEA.

Approach

The primary goals of this project are to **develop a fishery-independent data set of species-specific larval rockfish abundance trends, incorporate this data into stock and ecosystem assessments, and evaluate potential impacts of environmental fluctuation and presence of marine reserves (i.e., CCAs) on the dynamics of fished and unfished species**. The project is comprised of two main phases: 1) sorting, measuring, and genetically identifying larvae; and 2) analysis.

Sorting will be conducted by a FATE-funded technician and a University of San Diego (USD) graduate student under the supervision of Thompson and Watson. Sorting will constitute the removal and measurement of larvae from winter (the peak rockfish spawning season [22]) CalCOFI samples [28]. At present, rockfish larvae have been sorted from nine (1997-1999, 2001-2005, and 2011) of the 18 ethanol-preserved winter cruises. Thus, ~280 samples collected from the 35 CalCOFI stations on the continental shelf (Figure 1) will be sorted for this project. We project it will take 6 months to complete the sorting.

Hyde and Thompson will supervise the genetic component of the project which involves sequencing ~700 base pairs of the mitochondrial cytochrome *b* gene from each rockfish larva. This gene discriminates with certainty the identity of all rockfishes from southern California [29]. Preliminary genetic analysis from a subsampling of stations from two research cruises identified 39 rockfishes of a variety of sizes, habitat preferences and fishing histories in southern California (Table 1). It should take approximately 5 months to finish the genetics work. Thus, all lab work should be completed after 11 months.

Once genetic identification is completed, the analysis phase will commence. Analysis can be categorized into three nonexclusive sections that will be spearheaded by particular PIs.

First, we will incorporate the time series into rockfish stock assessments. This portion of the project will be led by Field who, together with a FATE-funded postdoctoral researcher, will utilize techniques for inclusion of larval data into stock assessments for species such as shortbelly and bocaccio rockfishes. For these assessments, relative abundance indices of spawning biomass were developed using a delta-GLM approach, which combines a binomial model for presence/absence information with a model of catch per unit effort for positive observations [30,31]. Akaike's Information Criterion (AIC) was used to determine the appropriate error distributions and to assess the most parsimonious model with respect to the number of covariates [32]. Year effects are independently estimated covariates which reflect a relative index of abundance for each year (month and line-station effects are also estimated), and error estimates for these parameters are developed with a jackknife routine. These time series have proven invaluable for the assessment of several *Sebastes* species, and upon processing of the ichthyoplankton data, the first step will be to develop comparable indices for blackgill and greenspotted rockfish (recently assessed species that are predominately found in the Southern California Bight), evaluate how the data might improve or inform the assessments, and contrast the suggested trends with other sources of information such as indices of abundance based on trawl or hook and line surveys. Indices will also be developed for other exploited rockfishes. For example, bank rockfish are strong candidates for formal assessment in the near future. Data on the larval dynamics of bank rockfish will likely augment assessment efforts for this species because it resides in southern California and preliminary genetic analyses indicate that its larvae are relatively common in CalCOFI samples (Thompson *in prep*).

Second, Samhouri and a FATE-funded research technician will lead the drive to test the capacity of larval rockfishes to serve as an indicator of ecosystem integrity. The ecosystem integrity section of the CCIEA currently reports on several indicators, including diversity for a variety of taxa. The CalCOFI larval data will be evaluated according to standard criteria [17], and will likely augment the ecosystem integrity portion of the CCIEA substantially, as it will should allow reporting of status and trends in rockfish diversity in a way that was previously impossible. The larval rockfish diversity indicator, and others derived from the CalCOFI data, will be compared to and used in combination with other indices, such as those based on the groundfish trawl survey. The goal of these analyses will be to determine the value added by including information about rockfish larvae in assessments of groundfish and ecosystem integrity status. In addition, we will test for relationships between individual larval rockfish species and natural (oceanographic) and anthropogenic (fishing) pressures. This analysis will serve as a springboard for a quantitative risk assessment, aimed at identifying nonlinearities and (previously unexamined) related thresholds in ecosystem pressure-state relationships [19,33]

Finally, Thompson and the USD graduate student will seek to explain the causes of species-specific larval rockfish fluctuation between 1997 and 2014. We envision using a model-selection approach [34] based on generalized linear mixed models [35] to explain how well various categorical and continuous variables explain fluctuations of rockfishes with different life history traits. The plausibility of a set of *a priori* candidate models that include fixed (are stations inside or outside of the CCAs), random (station), continuous (e.g., year and ENSO index) and nested continuous [station-specific measurements such as bottom depth and oceanographic CTD measures (e.g., temperature and depth of the OMZ from CTD casts)] effects will be assessed based on AIC values for each species. Depending on the abundance of particular species, we will use binomial (presence-absence), poisson, or negative binomial distributions with appropriate link functions for the models. We will then compare model results for species that are and are not fished and that live in deep versus shallow habitats (Table 1). To evaluate reserve effects, we will initially focus on smaller larvae that are known to be collected close to natal habitat [16,21]. If environmental factors explain a large proportion of the variation in larval variability, this will help guide incorporation of particular environmental parameters into stock or IE assessments [36,37].

Benefits

Results should benefit stock and IE assessments, and our understanding of factors affecting the population dynamics of rockfishes in southern California. To benefit stock assessments, **we will provide an index of female spawning biomass for rockfishes that are grossly undersampled in southern California**. We are confident that these data will be useful for stock assessments as larval indices are already used in stock assessments of cowcod, bocaccio, and shortbelly rockfishes (which have morphologically distinct larvae). Our preliminary genetic results show that several fished species (e.g., bank, blackgill, blue, chillipepper, copper, cowcod, speckled,) had larval abundances that were similar to boacaccio and cowcod in 2005. This suggests that sample sizes will be high enough to produce meaningful time series for these species.

In an **IEA context, these results will bolster evaluations of indicators for the groundfish and ecosystem integrity goals in the California Current**, and potentially add to corresponding assessments of status and trends. In addition, **risk assessments are to date perhaps the least developed of the CCIEA sections [38], and the analysis of relationships between larval rockfish abundances or diversity and ecosystem pressures will help to fill this void**. Moreover, such analyses may reveal previously unknown nonlinearities and related thresholds for individual species and/or for rockfish diversity more broadly.

This study also has the potential to **discern whether oceanographic condition and protection from fishing have influenced rockfish** dynamics since 1997. Preliminary results of trends in bocaccio larvae suggest that populations were stable or increasing within the CCAs but declining outside of these reserves. This may be a consequence of the concentration of fishing mortality in the open areas, where there may be localized depletion, while abundance within the closed areas is likely to be increasing. Resolution of this highly important issue has been repeatedly identified as one of the most important factors to evaluate in future assessments [6,10], and effort to begin to explore the spatial dynamics of larval distributions within and outside of the CCAs will be initiated as a part of this proposal. If we can identify important factors that are affecting larval abundances of specific rockfishes, then these variables could be used in assessments to more accurately forecast rockfish recruitment and stock sizes [36] and ecosystem integrity.

Deliverables

- New larval abundance data for over 30 rockfish species will be available through links on both the CalCOFI and Southwest Fisheries Science Center websites.
- Report detailing the efficacy of the new rockfish time-series indices in stock assessments.
- New indicators will included in the groundfish and ecosystem health sections of the CCIEA.
- Results will be disseminated through peer-reviewed scientific journals.
- Results will be presented at scientific meetings such as the CalCOFI conference
- Results will be used for a masters project by a USD graduate student

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