Otolith microchemistry of pelagic juvenile rockfish as an indicator of upwelling exposure within the open coastal system of central California

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Introduction

Coastal upwelling is an oceanographic condition known to be an important determinant of recruitment for marine demersal fish[1-6]. However the magnitude of its importance is unknown because there is no means of distinguishing between individuals who did or did not experience upwelled water. There is a need to develop a tool to identify these individuals, and subsequently sort out the role upwelling exposure plays in larval recruitment, growth and larval condition. A promising approach that may allow us to identify these individuals is the use of otolith microchemistry. Otoliths are the ear stones of fish. These structures have been shown to record water chemistry[7], and therefore may be a means of making this distinction between fish who spent time in upwelled water masses, and those that did not.

Here we evaluate whether or not otolith microchemistry may be used as an indicator of upwelling exposure. Both water and pelagic juvenile rockfish (*Sebastes jordani & Sebastes entomelas*) otoliths were collected from water masses with varying degrees of upwelling intensity off the coast of Central California in the summers of 2007 and 2008. A standardized set of transects was used at a spatial resolution designed to capture meso-scale oceanographic features. The different water masses are defined using satellite sea surface temperature imagery along with CTD profiles. Identifying the chemical signature linked to upwelling exposure would allow for retrospective analysis of adult fish otoliths and give insight into any effects this oceanographic process may have on recruitment, growth and survival beyond recruitment.

Widow Rockfish
(*Sebastes entomelas*)

Shortbelly Rockfish
(*Sebastes jordani*)

Hypotheses

The goal of this study is to address the following hypotheses:

I. There is an identifiable chemical difference between upwelled and non-upwelled water masses along central California.

II. There are chemical differences between otoliths collected from fish within upwelling versus non-upwelling water masses.

III. There is a spatial relationship between water mass and otolith chemistry due to changing water masses and the movement of fish (i.e. a lag due to southern transport).

Elements of Interest

Barium is thought to be an indicator of upwelled water as it follows a nutrient profile, meaning it is in higher concentrations at depth than it is at the surface[8]. Barium will only be present in surface waters at high concentrations when it is brought up by active upwelling.

Strontium is known to relate to salinity[9] and may indicate water collected from around the San Francisco Bay. The amount of Sr uptake by the otolith has also been linked to ambient temperature and may show differences between very cold upwelled water and that of non-upwelled water.

Magnesium will also be measured as it has been previously used to differentiate rockfish otoliths from water masses on a larger scale (northern vs. southern California)[10]. However the mechanisms behind Mg uptake are poorly understood and thought to be under osmoregulatory control.

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Methods

Sampling occurred in 2007 and 2008 as part of the NMFS annual pelagic juvenile rockfish survey aboard R/V David Starr Jordan (Fig.1).This survey occurs from May through mid-June, which captures the time at which juvenile rockfish are most abundant in the pelagic environment. This also coincides with the upwelling season. NMFS' 83 core stations (Fig.1) between Monterey (36°35'N latitude) and Point Reyes (38°10'N latitude) were used as collection stations for both sea water and juvenile rockfish. Three passes were made through these core stations over the course of the cruise.

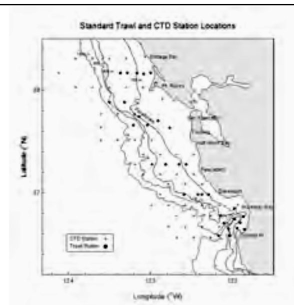


Figure 1. NMFS standard trawl and CTD locations for central California. Figure courtesy of Keith Sakuma.

Seawater

Samples were collected using a 1080 General Oceanics "GOFLO" sampler (Fig.2) at 25m depth. Water samples were removed, filtered, and preserved under HEPA filtered laminar flow hood conditions. Samples were kept frozen until they could be analyzed using Inductively Coupled Plasma Mass Spectrometry (ICP-MS). The element to Calcium ratios for Ba, Sr, and Mg.

2007: 44 upwelled samples, 129 non-upwelled

2008: 43 upwelled samples, 37 non-upwelled

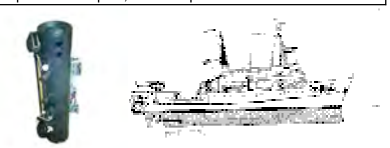


Figure 2. GOFLO water sampler (left) and research vessel David Starr Jordan (right)

Rockfish

Juvenile shortbelly and widow rockfish were collected by mid-water trawl. Trawls were conducted at night for 15 minutes each at a target headrope depth range of 25-30m[11]. Rockfish were stored at -80 °C.

The rockfish were later thawed, and their sagittal otoliths removed. An otolith, from each pair, was chosen at random to be cleaned and mounted. The otolith was then polished to a flat plane, exposing the outer edge (Fig. 3).

Element to Calcium ratios for Barium, Strontium, Magnesium and Manganese were quantified using Laser Ablation ICP-MS. The laser ablation transects targeted the outer five days of growth (~15μm) (Fig. 3).

2007: 42 otoliths from upwelling, 83 from non-upwelling

2008: 15 otoliths from upwelling, 54 from non-upwelling

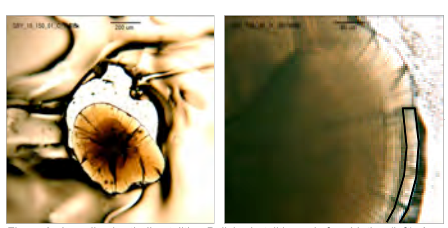


Figure 3. Juvenile shortbelly otoliths. Polished otolith ready for ablation (left). An ablated otolith with ~5day ablation outlined in black (right).

Acknowledgements

Mark Carr - Thesis Advisor, Ecology and Evolution, UCSC	**NMFS SWFSC Fisheries Ecology Division**
Rob Franks - UCSC Marine Analytical Lab	R. Bruce MacFarlane, Keith Sakuma, Ken Baltz, Tom Laidig, Andrew Pike, and others
Jeremy Hourigan - Earth Sciences, UCSC	**Project Volunteers**: Megan Gunvalson, Gabriel Singer, Kevin Stierhoff, Gina Archer
Robyn Hannigan and Eric Freeburg - U. of Mass., Boston	**Raimondi-Carr Lab**
C. Brock Woodson - Environmental Fluid Mechanics, Stanford	**Officers and Crew of the R/V David Starr Jordan**
Margaret McManus - Department of Oceanography, UH, Honolulu	Funding Support Provided by **NMFS Fisheries Ecology Division**

Results

I. In both 2007 and 2008 higher Barium to Calcium ratios in the water were significantly correlated with low sea surface temperature (Mantel p=0.0027, p=0.0412 respectively). This suggests Barium is indeed a strong indicator of cold upwelled water. Basic ANOVAs run between upwelled and non-upwelled water were significant for Ba/Ca (p=0.035, r^2=0.02) in 2007, with Barium being higher on average in upwelled water. Mg/Ca was significantly higher in upwelled water in 2008 (p=0.027, r^2=0.049).

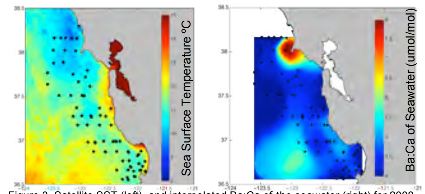


Figure 3. Satellite SST (left), and interpolated Ba:Ca of the seawater (right) for 2008.

II. Based on ANOVAs, Ba/Ca and Mg/Ca in the otoliths were significantly different (p=0.011, r^2=0.044. p=0.028, r^2=0.031) between upwelled and non-upwelled water, but only in 2007 (Fig. 4). Sr/Ca had a significant negative correlation with temperature (p<<0.001, r^2=0.182) in 2008, and Mg/Ca had a positive correlation with salinity (p=0.014, r^2=0.074). A discriminate function analysis (DFA) using all three elements, was significant (p=0.001) for 2007 with overall classification success of 65%. 68% for upwelling alone.

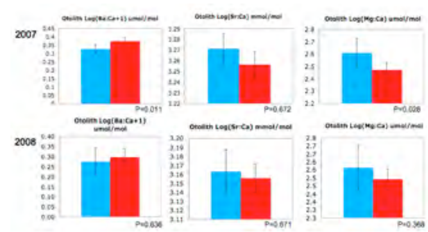


Figure 4. Average element to calcium ratios found in the otoliths for both 2007 and 2008. Blue bars (left) represent fish caught in upwelled water, and red bars (right) represent fish from non-upwelled water. Error bars represent 95% confidence intervals.

III. There was a strong spatial relationship between Ba/Ca in the water and in the otoliths in 2008. Analysis of spatial cross-covariance indicated otoliths were most highly correlated to water samples between 20 and 60kms to the north of where they were collected.

Spatial Cross Covariance of Barium in 2008

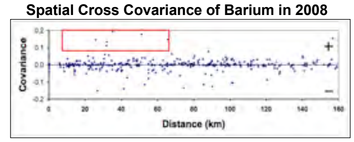
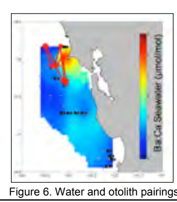


Figure 5. Cross covariance cloud for Ba:Ca in the water and the otolith. Each data point represents a water to otolith pairing and their covariance at the distance they are apart. Red box encompasses the strongest and most positive covariations out to ~60km.



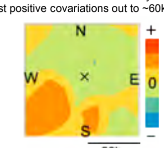


Figure 7. Polar contour plot shows relationships between every sample (out to 60kms). Most positive covariance occurs in the southwest direction between 20 and 60kms.

Figure 6. Water and otolith pairings selected from red box (fig.5).

Discussion

Based on the results of the Mantel and ANOVA tests we conclude that Ba/Ca is indeed an indicator of cold upwelled water and possibly Mg/Ca which was significant only in 2008. There was no significant relationship found between Sr/Ca and SST. Sr and Mg uptake are thought to be regulated more so by hydrography, and strong differences in water chemistry based on these elements was not expected.

Differences in otolith chemistry between upwelled and non-upwelled water were not as strong as expected, however the trends are consistent over time. The inverse relationship seen between Ba/Ca of the seawater and otoliths is likely driven by the movement of fish over the five days sampled on the otolith. Spatial cross covariance results for Ba in 2008 support this by suggesting southern transport. The significant DFA result for 2007 is promising especially considering the variability in our data. This result keeps otolith microchemistry on the table with regards to distinguishing between individuals who did or did not experience recent upwelling.

There is still more work to be done on this front. Our analyses would be greatly improved with larger sample sizes, which we are fortunate to have for 2009, and have yet to analyze. These preliminary results suggest that an "upwelling tag" on the otolith may exist, but its strength is likely dependent on interannual variation in upwelling. To recover them may require more precise methods of otolith sampling, and knowledge of how fish move within this open system.