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Linking Early Fish Growth and Transport to Circulation Using Otolith Microstructure and Microchemistry

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Authors

Love, Milton S.
Warner, Robert R.
Washburn, Libe

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FINAL TECHNICAL NARRATIVE

PROJECT: R/CZ-178

PROJECT LEADERS:

Milton Love, Marine Science Institute, University of California Santa Barbara (UCSB)

Robert Warner, Department of Evolution, Ecology, and Marine Biology, UCSB

Libe Washburn, Department of Geography, UCSB

ASSOCIATED STAFF:

Mary M. Nishimoto, Marine Science Institute, UCSB

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Linking Early Fish Growth and Transport to Circulation Using Otolith Microstructure and Microchemistry

SUMMARY

An estimate of the degree of connectivity among local populations through larval dispersal can help to define the appropriate geographic scale of resource management (e.g., spatial extent of fishery closures, placement of marine reserves). The aim of our research is to reconstruct larval transport pathways in relation to dynamic coastal circulation. In this study, we used a novel approach incorporating microchemistry data from time-keeping otoliths and remotely-sensed sea surface current mapping. In 1998, we linked late-larval stage and pelagic juvenile fish abundance patterns to cyclonic eddy circulation in the channel (Nishimoto and Washburn, 2002). In the present study, laser-ablation inductively coupled plasma mass

spectrometry (LA-ICPMS) data was collected from otoliths of shortbelly rockfish (*Sebastes jordani*) sampled within the eddy feature and outlying areas. LA-ICPMS measures the concentration of selected elements at discrete locations within the calcium carbonate structure of an otolith (e.g., its edge and core). We show that otolith microchemistry and microstructure (i.e., ageing) can be used to evaluate persistent cyclonic circulation as a mechanism of retention. Our work indicates that early pelagic stages of fish collected from geographic areas with distinguishable water mass properties possess unique trace element signatures in their otoliths. Furthermore, the association of early larval signatures with areas where the fish were captured at a later date was related to the timing of the evolution of eddy circulation in the channel and the conditions of limited dispersal. Our results suggest that transport pathways of cohorts differ. Thus, the degree of connectivity among local populations may depend on the relative recruitment success of cohorts within a year.

STRONG LINK BETWEEN CIRCULATION AND THE DISTRIBUTION OF PELAGIC JUVENILE FISH

A cyclonic eddy persisted in the Santa Barbara Channel during Spring 1998. In Figure 1, the feature is evident in the satellite sea surface temperature image and the vector map of sea surface currents derived from coastal-based high frequency radar observations from June 1-14, 1998 during a midwater trawling survey. The counter-clockwise turning eddy was about 30 km (19 mi.) wide with surface current speeds as fast as 0.4 m/s (21.4 mi/day). Fish abundance (red bars represent the mean number of late-stage larval and pelagic juvenile rockfishes in midwater trawl samples from different areas) was extraordinarily high in the center of the eddy (Nishimoto and Washburn, 2002).

USING THE FISH EAR BONE AS A TIME-KEEPING ENVIRONMENTAL RECORDER

Increments visible as bands on the otolith form on a daily basis and commonly are used to estimate the age of an individual fish (Fig. 2). The calcium carbonate material that is added onto the otolith structure each day has an elemental signature that reflects the conditions of the water environment that the fish resides in at the time the growth increment is formed. The objective of this study was to determine if otoliths as environmental loggers can be used along with oceanography to reconstruct the coastal transport histories of fish. In this study, we examined otoliths from 56 pelagic juvenile shortbelly rockfish (*Sebastes jordani*) collected from six areas during June 1998 when a persistent eddy was observed in the channel (Fig 3). Laser-ablation inductively coupled plasma mass spectrometry (LA-ICPMS) was used to measure the amount of calcium and other elements in a series of samples across each otolith. The chemical signature of each sample was defined by seven element ratios: Mg/Ca, Mn/Ca, Fe/Ca, Zn/Ca, Sr/Ca, Ba/Ca, and Pb/Ca.

The discrete samples appear as dark pits across the sagittal plane of the cross-sectioned otolith in Figure 2. The estimated age of fish used in this study ranged from 37-102 days. Age estimates were based on otolith increment counts. Ethanol-preserved fish size ranged from 12.9-47.2 SL. Rockfish are viviparous, and the core of the otolith represents larval development within the female. The outermost increments correspond with the most recent growth near the time of collection.

NATURAL TAGS AT THE EDGE OF OTOLITHS REFLECT THE OBSERVED CIRCULATION PATTERNS NEAR THE TIME OF CAPTURE

The elemental signature from the edge of the otolith of fish collected off Purisima (north of the Channel) grouped together and were distinct from those collected in the Channel and off Pt. Mugu (east of the Channel) (Fig. 4). (See Fig. 3 map for locations of midwater trawling stations where specimens used in this study were collected.) The spatial separation of the unique natural tags at the edge of the otolith corresponds with the circulation patterns observed at the time the fish were collected in June 1998. The Purisima samples were collected in the water mass north of Point Conception that was oceanographically separated from waters in the channel by upwelling at the headland. (See plume of cold water extending across the west entrance of the Channel in Fig 1.)

THE ASSOCIATION OF EARLY LARVAL SIGNATURES WITH AREAS WHERE FISH WERE CAPTURED AT A LATER DATE WAS RELATED TO EVOLVING CIRCULATION PATTERNS

The persistence of circulation patterns from the early larval period through the time of capture was reflected in the consistent grouping of elemental signatures. Fig 5A and 5B show distinct clustering of early larval signatures. A high proportion, 74%, of the early larval signatures of the youngest age group (Cohort 1 comprised of individuals with birthdates: April 22-May 2, 1998) could be correctly assigned to the area where the fish were collected at least one month later in June based on canonical discriminant analysis (Fig 5A). Similarly, 93% of the early larval signatures of Cohort 2 (birthdates April 12-21, 1998) could be correctly assigned to a collection area (Fig 5B). Time series of surface current data from remote-sensing radar

indicate that the eddy circulation had persisted since at least late April (data not shown). This correspondence of otolith and oceanographic data suggests that groups of individuals had been separated by persistent circulation patterns from the time of early larval development through the time of capture.

In contrast, the early larval period of the oldest age group (Cohort 3 birthdates March 8-April 11, 1998) proceeded the period of eddy circulation in the Channel. Correspondingly, the predictability in assigning the early larval signatures of the older fish to areas where they were collected was poorer than that for younger fish. Only 57% of the early larval signatures of the oldest cohort could be correctly assigned to areas where the individuals were collected about 2 months later (Fig 5C). Prior to late April, a strong coastal jet flowed along the central California coast, passed Point Conception, and entered the Channel. Figure 6 is an example of surface current pattern in late March showing the strong exchange from north of Point Conception into the Channel before the evolution of persistent eddy circulation in the Channel. These findings suggest that the poor predictability in grouping the early larval signatures of the oldest larvae with the areas where the fish were collected reflects mixing within the population prior to conditions that limited larval dispersal within the study region.

CONCLUSIONS

The results from this study demonstrate the utility of using otolith microchemistry and microstructure to evaluate persistent cyclonic circulation as a mechanism of retention. Natural chemical tags at the edge of otoliths reflected the spatial distribution of fish and the predominant circulation pattern. The association of early larval signatures with areas where the fish were captured at a later date was related to the timing of the evolution of eddy circulation in the

channel and the conditions of limited dispersal. Our results suggest that transport pathways of cohorts differ. Thus, the degree of connectivity among local populations may depend on the relative recruitment success of cohorts within a year.

The results from this study contribute to a better understanding of transport processes and are a significant step toward reconstructing larval transport pathways in relation to coastal circulation. The timeliness of research of this kind is exemplified by recent activities by state and federal agencies and the California legislature. In particular, the need for larval transport estimates is acknowledged in the site planning of marine reserves. Our results indicate that otolith microchemistry has a promising potential as a tool along with oceanographic analyses to work toward estimating what proportion of larvae released from a spawning site arrive as successful recruits to the same site and to other distant or not-so-distant areas. Ultimately, predictions of larval exchange may be modeled and be invaluable to interested parties with diverse concerns that include the spread of exotic marine pests, emergency oil spill response, alteration of coastal zones, and fisheries response to climate change.

We are continuing to work toward refining our interpretation of the transport histories of the individuals collected in the Channel region in 1998. Larval and juvenile samples from central and southern California collected in 1998 by NMFS SWFSC-Santa Cruz and CalCOFI, respectively, will serve as source area identities that will be compared with the Santa Barbara Channel samples in the microchemistry analysis. Furthermore, growth data will be examined in relation to circulation patterns in the channel. We will also examine the contribution of the various elements among the different signatures in relation to otolith growth history, age grouping, and place of capture.

ACKNOWLEDGEMENTS

Results from this project were presented at the ASLO Summer Meeting in June 2002 in Victoria, British Columbia and at the World Oceans Conference in October 2002 in Santa Barbara, CA. California Artificial Reef Enhancement (CARE) foundation and David and Lucille Packard Foundation provided matching funds. Department of Geography and PISCO operated and equipped the microchemistry facilities at UCSB. Institute for Computational Earth System Science (ICESS), UCSB provided the remotely-sensed sea surface current observations and SST imagery. Other resources included the Biological Resources Division, USGS; Center for Coastal Studies, UCSD; and CalCOFI. NMFS SWFSC-Santa Cruz and Cooperative Oceanic Fisheries Investigations (CalCOFI) provided fish samples that will be used as work continues.

REFERENCES

Nishimoto, M. M. and L. Washburn. 2002. Patterns of coastal eddy circulation and abundance of pelagic juvenile fish in the Santa Barbara, Channel, California, USA. *Marine Ecology Progress Series* 241:183-199.

FIGURES

Figure 1. Strong link between eddy circulation and the distribution of pelagic young-of-year rockfishes.

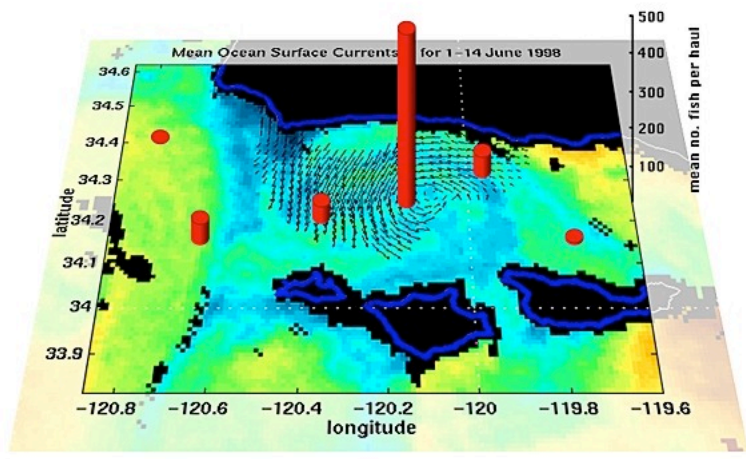
Figure 2. Example of a shortbelly rockfish otolith that was sampled for elemental data using LA-ICPMS.

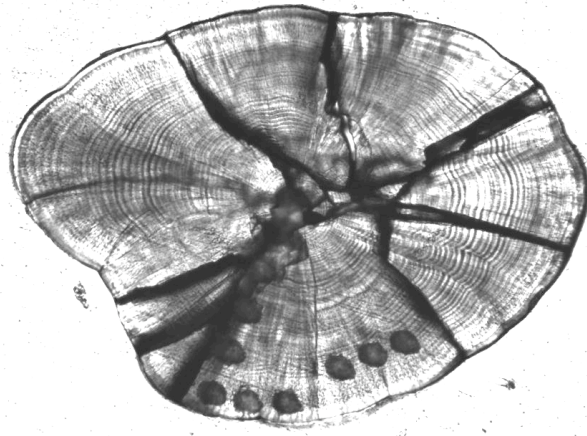
Figure 3. Map of midwater trawling stations where specimens were collected and overlay of dynamic height (m, 1/200 dbar) contour showing cyclonic eddy (center of feature shaded gray) at time of sampling, 1-14 June 1998.

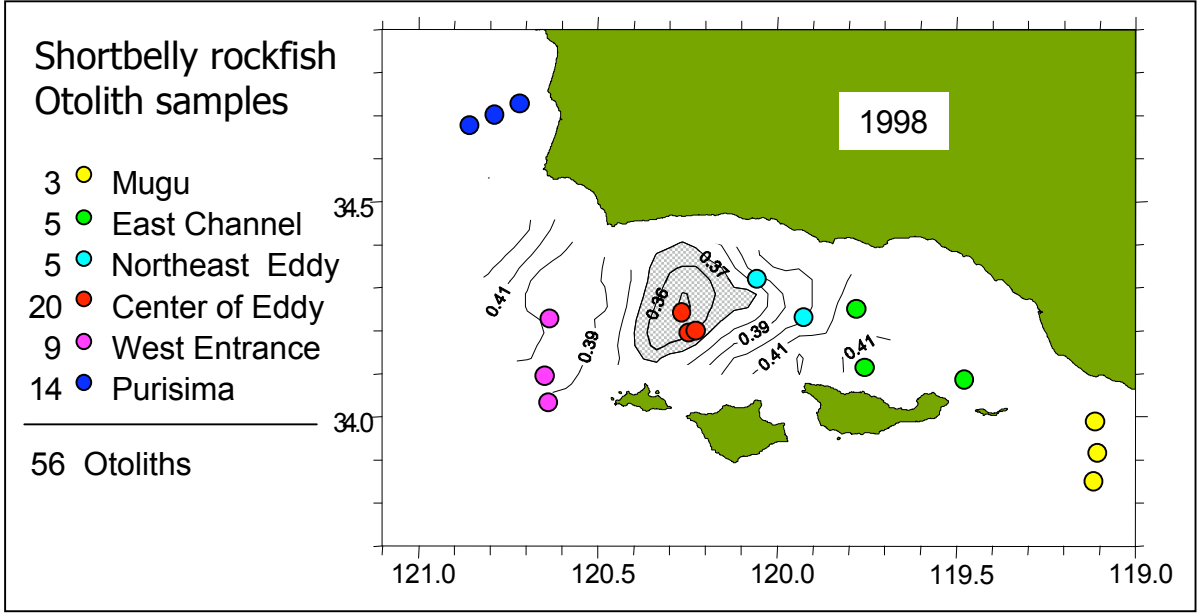
Figure 4. Canonical discriminant analysis shows that unique elemental signatures from the edge of the otolith indicate geographic separation of water masses near the time that fish were collected.

Figure 5. Canonical discriminant analysis shows that discrimination of collection areas by early larval elemental signatures was better for the two younger cohorts (A, B) than for the oldest age grouping (C).

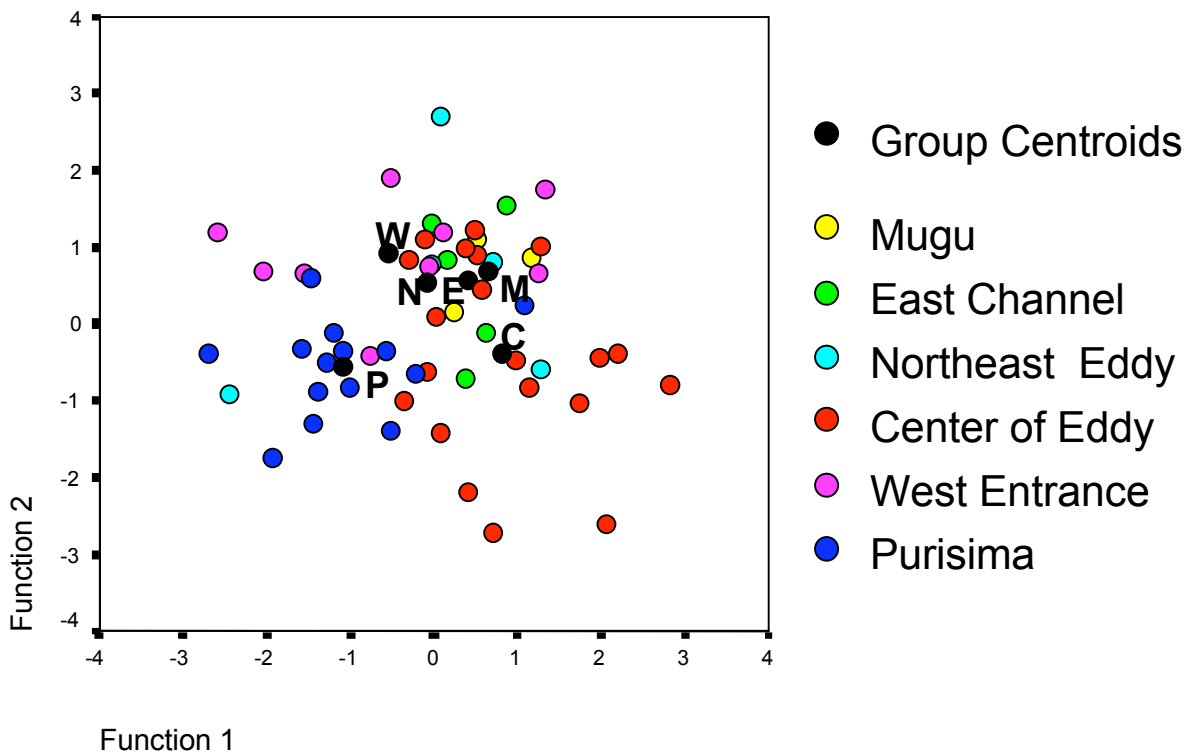
Figure 6. Conditions prior to late April 1998 were conducive to dispersal as exemplified by this map of sea surface currents derived from hourly coastal-based high frequency radar observations.





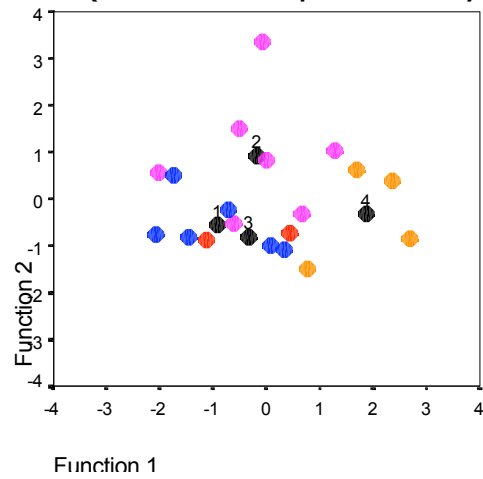


Edge (near the time of collection)

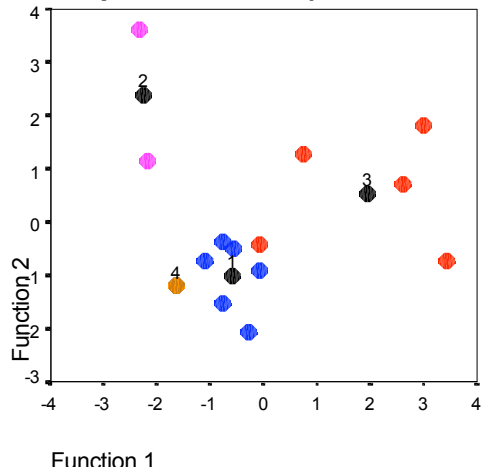


Early larval period (adjacent to core)

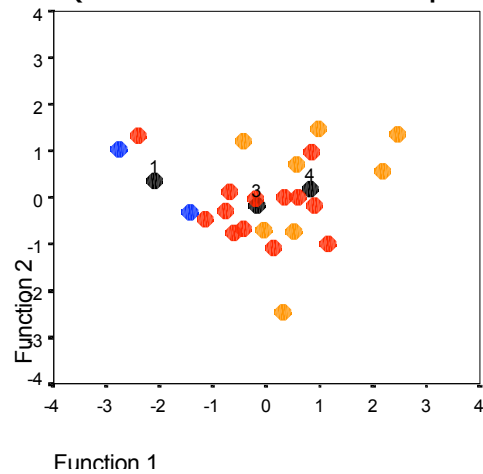
A. Cohort 1 (Birthdates April 22-May 2, 1998)



B. Cohort 2 (Birthdates April 12-21, 1998)

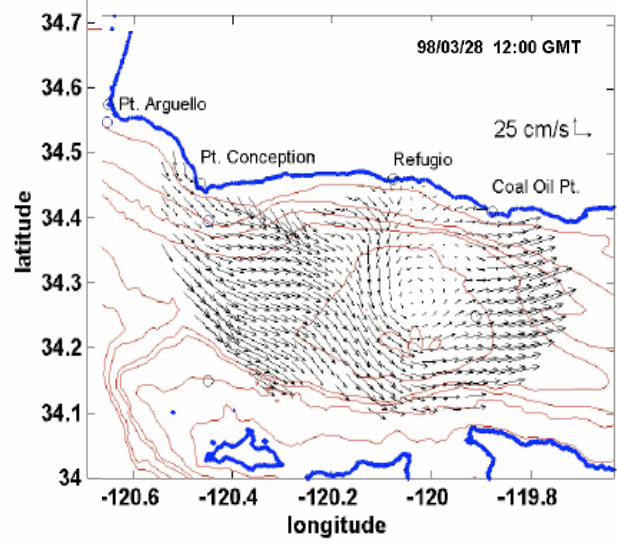


C. Cohort 3 (Birthdates March 8-April 11, 1998)



Specimen collection areas

- 4. NE Eddy, E Ch, Mugu
- 3. Center of Eddy
- 2. West Entrance
- 1. Purisima
- Group Centroids



Presentation:

Nishimoto, M. M. and L. Washburn. Can otoliths link early fish growth and transport to mesoscale coastal circulation patterns off California? American Society of Limnology and Oceanography 2002 Summer Meeting, June 9-14, 2002, Victoria, British Columbia, Canada

Poster:

Nishimoto, M. M., M. Love, R. Warner, and L. Washburn. Linking connectivity pathways to chemical markers in pelagic juvenile rockfish otoliths. Poster at 2002 California and the World Ocean Conference, October 27-30, 2002, Santa Barbara, California