IMPORTANCE OF FAR-OFFSHORE SAMPLING IN EVALUATING THE ICHTHYOPLANKTON COMMUNITY IN THE NORTHERN CALIFORNIA CURRENT

TOBY D. AUTH
Cooperative Institute for Marine Resources Studies
Oregon State University, Hatfield Marine Science Center
2030 Marine Science Drive
Newport, Oregon 97365, USA
toby.auth@noaa.gov

ABSTRACT

The distribution and concentration of ichthyoplankton were examined from stations extending 2–364 km offshore at 7–53 km intervals along the Newport Hydrographic (NH) and Crescent City (CC) (July 2008 only) lines in the northern California Current (NCC) during March, April, and October 2007, and March, June, and July 2008. A total of 2372 fish larvae representing 36 taxa from 22 families were collected in 72 bongo samples from 30 stations: 15 stations were "shelf" (<2000 m depth), 15 were "far-offshore" (>2000 m depth). Four dominant taxa accounted for 90% of the total larval fish concentration: *Stenobrachius leucopsarus* (47%), *Sebastes* spp. (25%), *Engraulis mordax* (12%), and *Tarletonbeania crenularis* (6%). Mean study-wide concentrations of the dominant taxa were significantly greater in the far-offshore region than in the shelf region. Weighted mean length was significantly greater only for larval *Sebastes* spp. collected at the far-offshore compared with the shelf stations, while *E. mordax* larvae were only collected at far-offshore stations in June and July 2008. Larval distributions and concentrations were also examined in relation to variable local environmental factors (i.e. temperature, salinity, dissolved oxygen, fluorescence, and east-west Ekman transport) and basin-scale indices (i.e. MEI and PDO). Historic and ongoing survey designs used to characterize the plankton community in the NCC have usually incorporated only coastal and shelf (<~100 km offshore) stations extending out to the continental slope (~2000 m depth). Increased sampling effort at far-offshore stations will be required to adequately characterize the ichthyoplankton community of the NCC in the future.

INTRODUCTION

Ichthyoplankton surveys have long been recognized as cost-effective proxies to identify spawning locations, success, environmental requirements, essential fish habitat, and recruitment potential of marine fish stocks (Hunter et al. 1993; Houde 1997; Lyczkowski-Shultz 2006), as well as providing ecosystem indicators of environmental change (Brodeur et al. 2008) and an understanding of trophic interactions between zooplankton and important piscivores (Hunter and Kimbrell 1980). However, by focusing their sampling efforts almost exclusively on near-shore and shelf waters while neglecting to sample far-offshore waters beyond the continental slope, these surveys may not adequately sample the entire, or even primary, cross-shelf range of the dominant larval taxa of interest.

During the past 40 years, most ichthyoplankton studies conducted in the northern California Current (NCC) have focused on fish eggs and larvae collected inshore of the continental slope (Richardson and Pearcy 1977; Richardson et al. 1980; Mundy 1984; Boehlert et al. 1985; Brodeur et al. 1985; Auth and Brodeur 2006; Auth et al. 2007; Auth 2008; Brodeur et al. 2008; Parnel et al. 2008). Only three NCC studies have hitherto incorporated far-offshore ichthyoplankton samples: Waldron 1972, Richardson 1973, and Doyle 1992. However, Waldron 1972 only sampled during two months (April and May) in 1967, whereas Richardson 1973 only sampled from May to October in 1969 and only differentiated sampling effort between near-shore (<37 km from shore, ~150 m in depth) and broadly-defined offshore (37–425 km from shore, ~150–3000 m in depth) stations. Doyle 1992 reported on general ichthyoplankton densities from the NCC in 1980–87, but did not conduct any testable statistical analyses of cross-shelf distributions and concentrations.

During the two decades since the completion of Doyle's 1992 work, the NCC has experienced extreme and variable climate-induced environmental fluctuations, including multiple shifts between warm and cold regimes, El Niño and La Niña events, variability in seasonal upwelling intensity, and change in biological communities (Schwing and Moore 2000; Peterson and Schwing 2003; Brodeur et al. 2006; Hooff and Peterson 2006) that may have altered the cross-shelf distribution of the ichthyoplankton community in the region. However, all studies during that time, including the on-going National Marine Fisheries Service (NMFS) Stock Assessment Improvement Plan (SAIP), U.S. Global Ocean Ecosystem Dynamics Program (GLOBEC), and Pacific Coast Ocean Observing System (PaCOOS) monitoring projects, have focused on collecting plankton samples primarily from coastal and shelf stations, largely neglecting far-offshore waters beyond the continental slope.

The present study is the first in 20 years to examine the cross-shelf variability in distribution and concentration of ichthyoplankton collected in the NCC at regular spatial intervals from near-shore out to far beyond the continental slope during multiple seasons in two consecutive years, and the first to date to do so using testable statistical techniques. Through this, I hope to (1) compare the ichthyoplankton concentrations in the heavily-sampled coastal and shelf region to those in the under-sampled far-offshore region in the NCC; (2) relate these concentration data to local (i.e. temperature, salinity, dissolved oxygen [DO], fluorescence, and eastward Ekman transport [EET]) and basin-scale (i.e. Multivariate El Niño-Southern Oscillation Index [MEI] and Pacific Decadal Oscillation [PDO]) environmental variables and indices; (3) compare and contrast these results to those of previous studies; and (4) provide a recommendation of the extent of cross-shelf sampling that is needed to adequately characterize the ichthyoplankton community of the NCC in ongoing and future sampling efforts.

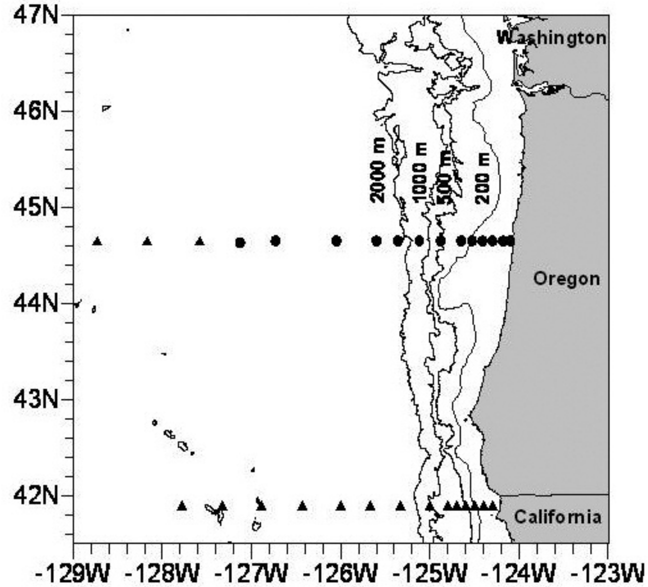

Figure 1. Locations of stations sampled in March, April, and October 2007, and March, June, and July 2008 (circles). Not all stations were sampled during each cruise. Stations indicated by triangles were only sampled during July 2008. Depth contours of 200, 500, 1000, and 2000 m (continental slope) are shown. The 2000 m isobath represents the separation between normally-sampled coastal and shelf stations and normally-unsampled slope and open ocean stations.

METHODS

Sampling procedures

A total of 72 ichthyoplankton samples were collected during the study. Samples (n = 8–9 per cruise) were collected from 13 stations extending 2–238 km offshore at 7–53 km intervals along the NH line (44.65°N) off the central Oregon coast in the NCC during March, April, and October 2007, and March, June, and July 2008 (fig. 1). Not all stations were sampled during all cruises. An additional 17 stations were sampled in July 2008 extending 274–364 km offshore along the NH line (n = 3) and 7–276 km offshore along the Crescent City (CC) line (41.9°N) (n = 14) off the northern California coast at 7–46 km intervals (fig. 1). Stations were sampled at different times during both day (n = 32) and night (n = 40). No significant diel differences in larval concentration were found ($p > 0.05$), therefore all samples were used in theses analyses regardless of time of sampling. Samples were collected using a bongo net with a 70 cm (60 cm in June and July 2008) diameter mouth opening and 335 µm mesh nets. The bongo was fished as a continuous oblique tow from ~45 m to the surface at a retrieval rate of 28 m/min and a ship speed of 1.0–1.5 m/s. In June and July 2008, the bongo was fished from ~100 m (or within 5 m of the bottom at stations <100 m) to the surface at the same retrieval rate and ship speed. A depth recorder and flowmeter were placed in the net during each tow to determine tow depth and volume of water filtered. The mean water-volume filtered was 132.5 m^3 (standard error [SE] = 5.7). Temperature (°C), salinity, DO (ml/L), and fluorescence (volts) (an indicator of primary productivity) were measured throughout the water column using a Seabird SBE 911 (SBE 25 in June 2008) CTD.

Because sampling was conducted as part of multiple unrelated projects, station locations, sampling depth, and mouth opening of the sampling gear were not uniform throughout the study. However, the same relative number of shelf and far-offshore stations were sampled during each cruise, and the sampling depth and gear were identical for all stations within each cruise. Since the study was designed to test for differences in larval fish concentrations between two cross-shelf regions and not between, but within, different months or years, it is not likely that the variability in sampling design over the course of the study biases the results and interpretation of any cross-shelf differences that were found.

Ichthyoplankton samples were preserved at sea in a 10% buffered-formalin seawater solution. Fish larvae from each sample were completely sorted, counted, and identified to the lowest taxonomic level possible in the laboratory using a dissecting microscope. The majority of larval *Citharichthys* spp., Osmeridae, *Sebastes* spp., and *Sebastolobus* spp. collected were not identifiable below the generic or family level based on meristics and pigmentation patterns, so no species-specific inferences are intended for these taxa in this study. However, the majority of those individuals classified as *Citharichthys*

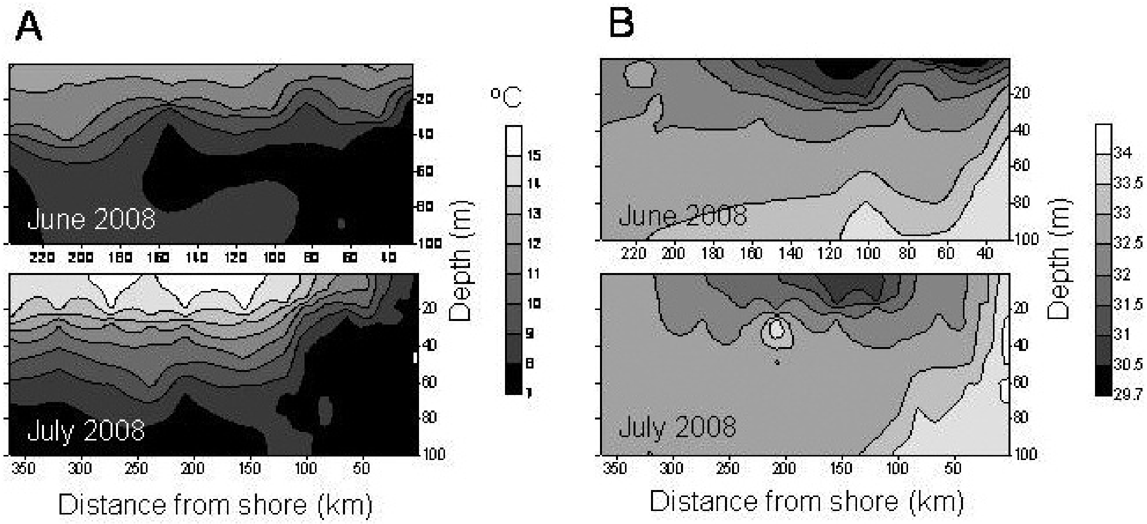

Figure 2. Cross-section of the Newport Hydrographic (NH) line showing (A) temperature (°C) and (B) salinity contours from the surface to 100 m in June and July 2008.

spp. most likely are either *C. sordidus* or *C. stigmaeus* based on the larger, identifiable individuals collected and the dominance of these paralichthyid taxa in the NCC ichthyoplankton (Matarese et al. 1989). The lesser of either all larvae or a random sub-sample of 30 individuals from each taxon in each sample was measured to the nearest 0.1 mm standard length (SL) (or notochord length for preflexon larvae) using UTHSCSA Image Tool Version 3.0 image processing and analysis software (http://ddsdx.uthscsa.edu/dig/itdesc.html 2009).

Data analyses

Along the NH line the continental slope abruptly descends from the shelf (<900 m depth) onto the abyssal plain (~3000 m depth) between 84 and 102 km offshore. To facilitate cross-shelf distributional analyses, stations were classified as either shelf (station depth <900 m) or far-offshore (station depth >2800 m) based on the location and depth of the continental slope. Larval fish concentrations were expressed as the number of individuals per 1000 m^3. An ANOVA and *t*-test were applied to the $\log_e(n + 0.1)$-transformed larval concentration data to test for significant differences between shelf and far-offshore stations. Weighted mean (based on concentration) lengths of the dominant and total larval taxa were also calculated for each station, and were similarly tested for significant differences between cross-shelf classifications.

Pair-wise correlation analyses were also conducted to assess the relationship between concentrations of several dominant taxa (*Engraulis mordax*, *Sebastes* spp., *Stenobrachius leucopsarus*, and *Tarletonbeania crenularis*) and total fish larvae, and the following environmental variables: temperature, salinity, DO, and fluorescence all measured at both 3 m and 20 m depths. The environmental variables from 3 m represent near-surface conditions, while those from 20 m represent conditions near the pycnocline and the depth stratum with the highest *Sebastes* spp., *S. leucopsarus*, and *T. crenularis* larval concentrations as reported by Auth and Brodeur 2006. Prior to inclusion in the analyses, larval concentrations were $\log_e(n + 0.1)$-transformed which normalized the data and homogenized residual variances. Statistical significance was determined at $\alpha = 0.05$. All ANOVA and correlation analyses were performed using the statistical software JMP Version 7 (SAS Institute 2007).

RESULTS

Hydrography

Temperature, salinity, DO, and fluorescence sections (not shown) showed little cross-shelf variability in March, April, and October 2007, and March 2008 (and in June and July 2008 for DO and fluorescence). Near-surface temperatures generally increased and near-surface salinities generally decreased with distance offshore. In June and July 2008, however, pronounced upwelling-induced cross-shelf variability in temperature and salinity was observed, with cold, saline water rising to the surface from depth nearshore (<50 km), while warmer, less-saline water was pushed along the surface offshore (fig. 2). The presence of Columbia River plume waters along the NH line was apparent by a patch of warm, less-saline near-surface water 100–160 km offshore in June (mean 3 m temperature = 12.3°C; mean 3 m salinity = 30.4) and 120–275 km offshore in July (mean 3 m temperature = 15.1°C; mean 3 m salinity = 31.4) 2008. Temperature at 3 m depth along the NH line varied between 9.3°–10.0°C in March, 9.8°–10.8°C in April, and 11.2°–13.6°C in October 2007, and 8.7°–9.1°C in March, 11.5°–13.0°C in June, and 7.5°–15.5°C in July 2008.

TABLE 1

Composition, frequency of occurrence, mean concentration (no./1000 m^3), and percent of total concentration for all larval fish collected off the Oregon coast at stations along the Newport Hydrographic (NH) line (44.65°N) in March, April, and October 2007, and March, June, and July 2008, as well as off the northern California coast at stations along the Crescent City (CC) line (41.9°N) in July 2008.

	Common name	Frequency occurrence	Mean concentration (no./1000 m^3)	Total concentration (%)
Clupeidae				
Sardinops sagax	Pacific sardine	0.01	0.07	0.03
Engraulidae				
Engraulis mordax	Northern anchovy	0.10	29.97	12.24
Bathylagidae				
Bathylagus pacificus	Pacific blacksmelt	0.01	0.10	0.04
Lipolagus ochotensis	Eared blacksmelt	0.08	1.48	0.60
Osmeridae				
Undetermined spp.	Smelts	0.03	1.30	0.53
Stomiidae				
Chauliodus macouni	Pacific viperfish	0.03	0.19	0.08
Tactostoma macropus	Longfin dragonfish	0.01	0.14	0.06
Paralepididae				
Lestidiops ringens	Slender barracudina	0.01	0.16	0.07
Myctophidae				
Protomyctophum crockeri	California flashlightfish	0.06	0.40	0.16
Protomyctophum thompsoni	Bigeye lanternfish	0.04	0.34	0.14
Tarletonbeania crenularis	Blue lanternfish	0.49	13.80	5.64
Nannobrachium regale	Pinpoint lampfish	0.21	2.39	0.98
Stenobrachius leucopsarus	Northern lampfish	0.68	113.91	46.53
Diaphus theta	California headlightfish	0.04	0.62	0.25
Gadidae				
Microgadus proximus	Pacific tomcod	0.01	1.73	0.71
Bythitidae				
Cataetyx rubrirostris	Rubynose brotula	0.01	0.09	0.04
Trachipteridae				
Trachipterus altivelis	King-of-the-salmon	0.01	0.09	0.04
Scorpaenidae				
Sebastes spp.	Rockfishes	0.63	61.80	25.25
Sebastolobus spp.	Thornyheads	0.13	2.04	0.83
Anoplopomatidae				
Anoplopoma fimbria	Sablefish	0.01	0.18	0.08
Cottidae				
Artedius fenestralis	Padded sculpin	0.01	0.19	0.08
Agonidae				
Bathyagonus pentacanthus	Bigeye poacher	0.01	0.06	0.03
Liparidae				
Liparis fucensis	Slipskin snailfish	0.06	0.70	0.29
Liparis mucosus	Slimy snailfish	0.01	0.34	0.14
Cryptacanthodidae				
Cryptacanthodes aleutensis	Dwarf wrymouth	0.01	0.18	0.07
Icosteidae				
Icosteus aenigmaticus	Ragfish	0.04	0.42	0.17
Ammodytidae				
Ammodytes hexapterus	Pacific sand lance	0.01	0.19	0.08
Centrolophidae				
Icichthys lockingtoni	Medusafish	0.07	0.37	0.15
Tetragonuridae				
Tetragonurus cuvieri	Smalleye squaretail	0.03	0.20	0.08
Paralichthyidae				
Citharichthys sordidus or *stigmaeus*	Pacific or speckled sanddab	0.04	0.65	0.27
Pleuronectidae				
Embassichthys bathybius	Deepsea sole	0.01	0.11	0.04
Glyptocephalus zachirus	Rex sole	0.11	2.45	1.00
Isopsetta isolepis	Butter sole	0.03	0.84	0.34
Lyopsetta exilis	Slender sole	0.18	3.04	1.24
Microstomus pacificus	Dover sole	0.08	1.21	0.49
Parophrys vetulus	English sole	0.06	2.65	1.08
Undetermined		0.01	0.14	0.06

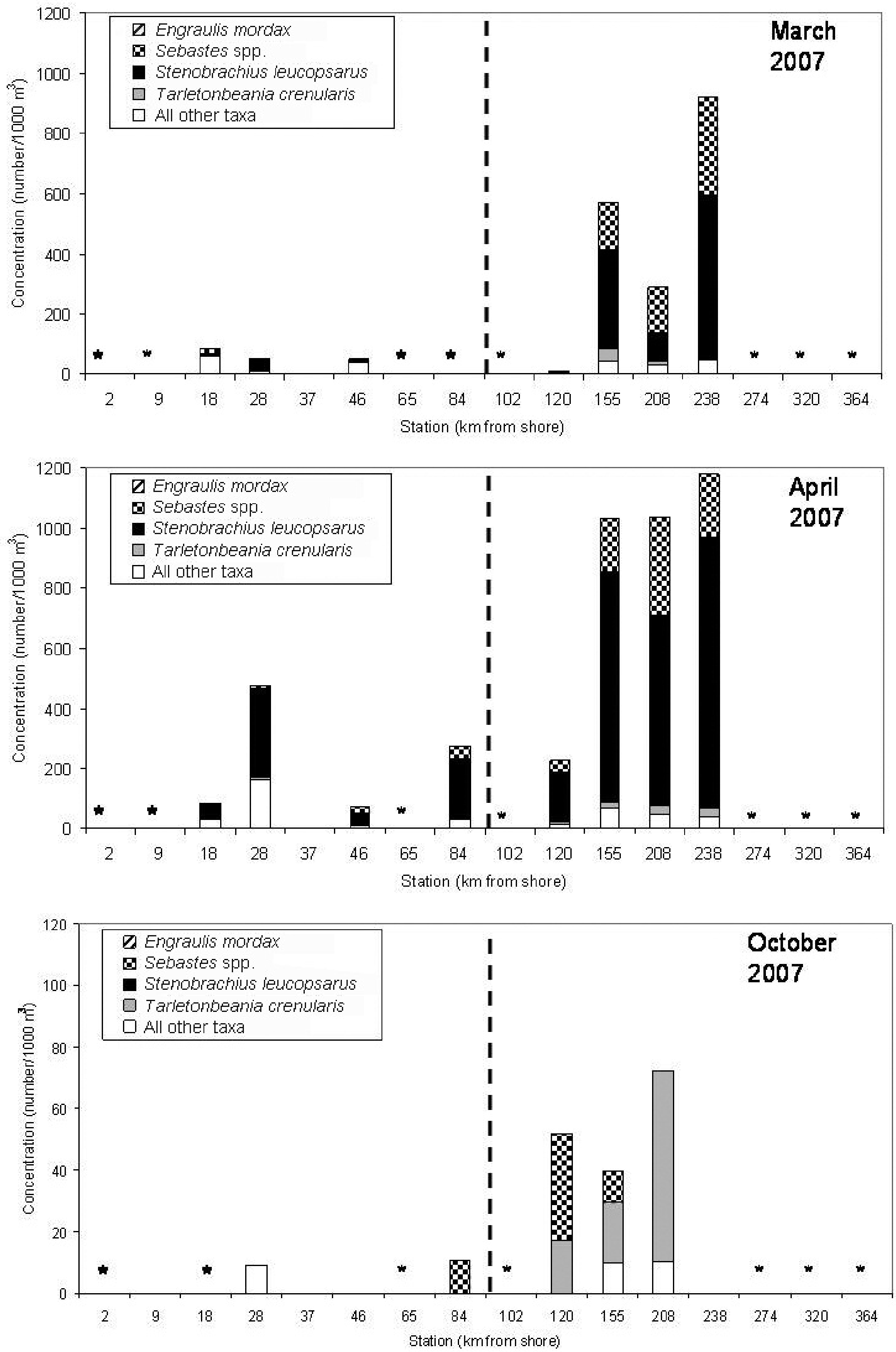

Figure 3. Cross-shelf concentrations (number/1000 m³) of the dominant larval fish taxa collected off the Oregon coast at stations along the Newport Hydrographic (NH) line (44.65˚N) in March, April, and October 2007, and March, June, and July 2008, as well as off the northern California coast at stations along the Crescent City (CC) line (41.9˚N) in July 2008. Vertical dotted lines indicate the separation between normally-sampled coastal and shelf stations and normally-unsampled far-offshore stations. * = station not sampled.

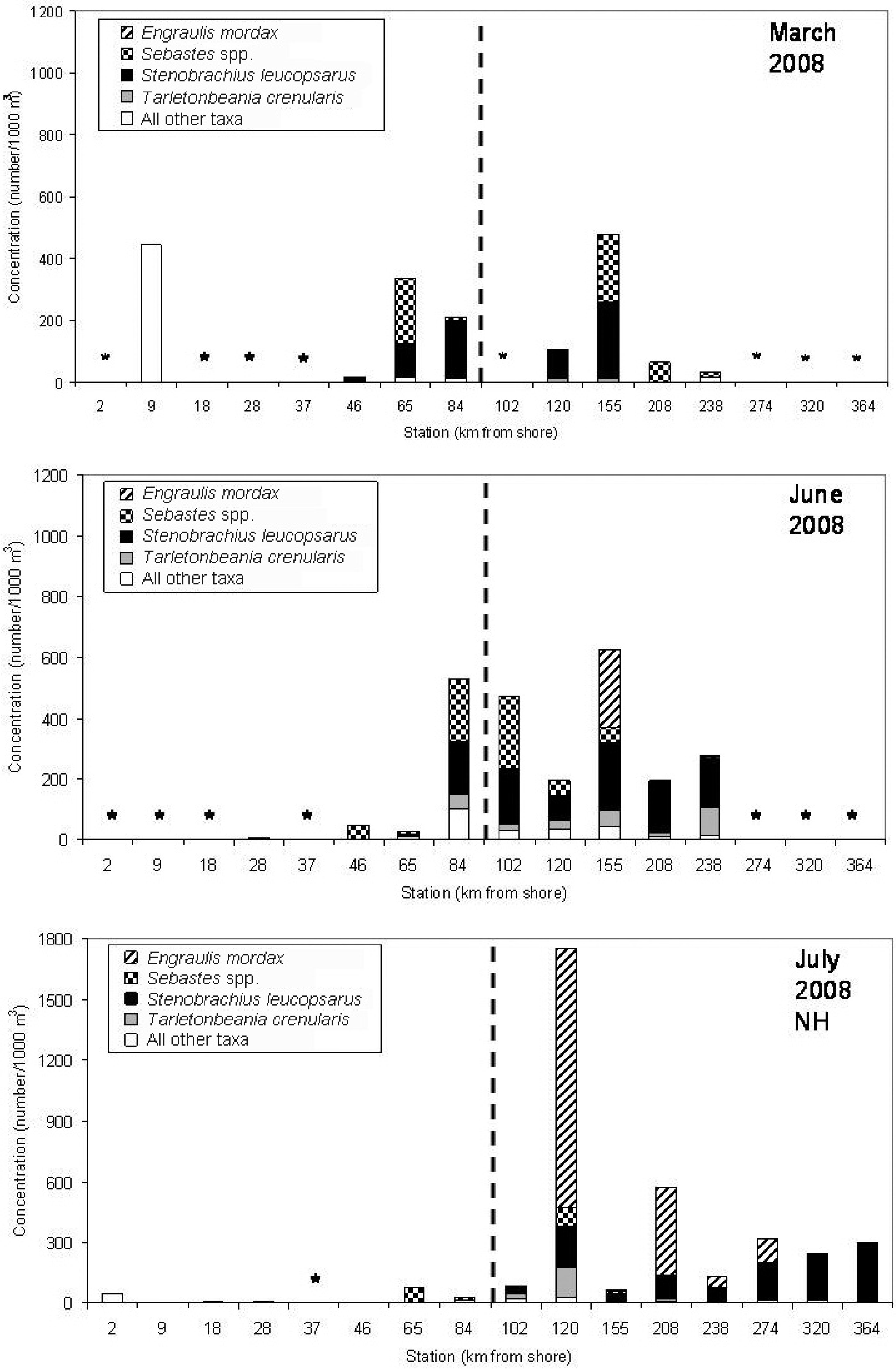

Figure 3 (continued). Cross-shelf concentrations (number/1000 m³) of the dominant larval fish taxa collected off the Oregon coast at stations along the Newport Hydrographic (NH) line (44.65°N) in March, April, and October 2007, and March, June, and July 2008, as well as off the northern California coast at stations along the Crescent City (CC) line (41.9°N) in July 2008. Vertical dotted lines indicate the separation between normally-sampled coastal and shelf stations and normally-unsampled far-offshore stations. * = station not sampled.

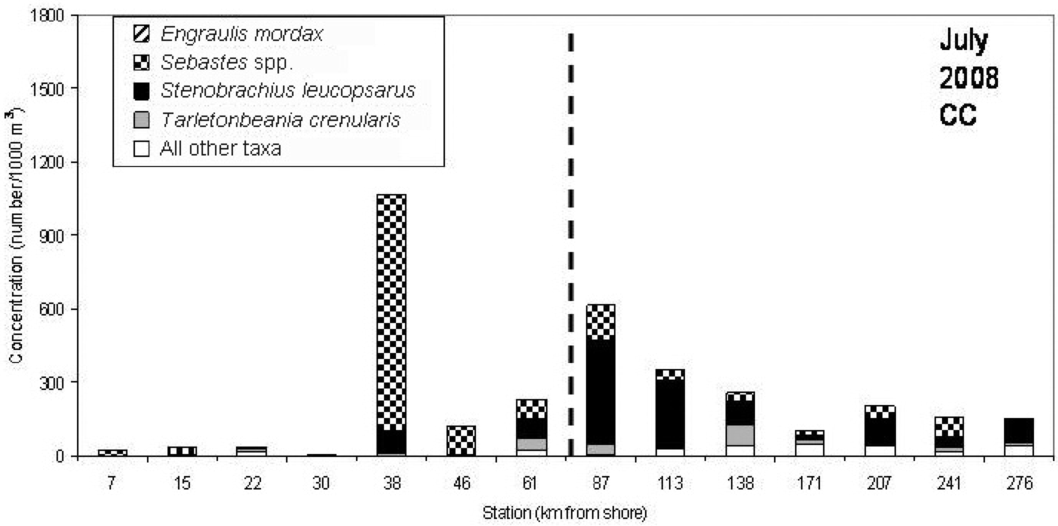

Figure 3 (continued). Cross-shelf concentrations (number/1000 m^3) of the dominant larval fish taxa collected off the Oregon coast at stations along the Newport Hydrographic (NH) line (44.65°N) in March, April, and October 2007, and March, June, and July 2008, as well as off the northern California coast at stations along the Crescent City (CC) line (41.9°N) in July 2008. Vertical dotted lines indicate the separation between normally-sampled coastal and shelf stations and normally-unsampled far-offshore stations. * = station not sampled.

Larval concentrations and distributions

A total of 2372 fish larvae representing 36 taxa from 22 families were collected throughout the study (tab. 1). Four dominant taxa accounted for 90% of the total larval concentration: *S. leucopsarus* (47%), *Sebastes* spp. (25%), *E. mordax* (12%), and *T. crenularis* (6%). Several other taxa occurred at relatively high frequencies (>0.10) but at lower mean concentrations: *Nannobrachium regale, Lyopsetta exilis*, *Sebastolobus* spp., and *Glyptocephalus zachirus*.

Mean study-wide concentrations of all dominant taxa (excluding an anomalously high *Sebastes* spp. value at the 38 km station on the CC line in July 2008) and total larvae were significantly higher in the normally-unsampled far-offshore region than the normally-sampled coastal and shelf region (fig. 3). This was particularly true for *E. mordax* larvae, which were exclusively found in the warmer Columbia River plume waters in the far-offshore region in June and July 2008. Mean study-wide concentration of *Sebastes* spp. larvae was 2.6 times higher at far-offshore than at shelf stations, with a monthly maximum of 33 times higher in March 2007. Larval *S. leucopsarus* were five times more concentrated overall at far-offshore than shelf stations, and as much as 15 times more in March 2007. *Tarletonbeania crenularis* larvae were six times more concentrated throughout the study at far-offshore than shelf stations, and were exclusively collected at far-offshore stations in half of the months sampled (March and October 2007, and March 2008). A high concentration (442.4/1000 m^3) of diverse, nearshore, non-dominant larval taxa (i.e. *Ammodytes hexapterus*, *Artedius fenestralis*, *Citharichthys* spp., *Isopsetta isolepis*, *Liparis fucensis*, *Microgadus proximus*, Osmeridae, and *Parophrys vetulus*) were also collected along the NH line in March 2008 at a station 9 km from shore, and comprised 25% of all non-dominant larvae collected throughout the study.

Study-wide weighted mean length was significantly greater for larval *Sebastes* spp. collected at far-offshore (mean = 6.1 mm, SE = 0.2) than at shelf (mean = 4.3 mm, SE = 0.2) stations ($p < 0.0001$). However, no significant cross-shelf differences in weighted mean lengths were found for either *S. leucopsarus* or *T. crenularis* larvae.

Environmental relationships

Pair-wise correlation analyses revealed that larval fish concentrations were generally positively correlated with temperature and negatively correlated with salinity (tab. 2). Concentration of larval *E. mordax* was significantly positively correlated with 3 and 20 m temperature, and negatively correlated with 3 m salinity and 3 m and 20 m fluorescence ($p < 0.05$). *S. leucopsarus* larvae were significantly positively correlated with 3 m and 20 m temperature and 20 m DO, and negatively correlated with 3 m and 20 m salinity ($p < 0.05$). *T. crenularis* larval concentration was significantly positively correlated with 3 m and 20 m temperature, and negatively correlated with 20 m salinity ($p < 0.05$). However, there were no significant correlations between any of the measured environmental variables and larval *Sebastes* spp. concentration ($p > 0.05$).

DISCUSSION

The four dominant larval taxa found in this study were among the dominant taxa reported by other cross-shelf studies conducted in the last 40 years in the NCC during spring and summer (Waldron 1972; Richardson

TABLE 2
Correlation coefficients for 13 variables sampled off the Oregon coast at stations along the Newport Hydrographic (NH) line (44.65°N) in March, April, and October 2007, and March, June, and July 2008, as well as off the northern California coast at stations along the Crescent City (CC) line (41.9°N) in July 2008: 3 m and 20 m temperature (°C) (n = 67), salinity (n = 67), dissolved oxygen (DO) (ml/L) (n = 67), fluorescence (n = 54), and $\log_e(n + 0.1)$-transformed concentrations (no. 1000 m^3) of *Engraulis mordax*, *Sebastes* spp., *Stenobrachius leucopsarus*, *Tarletonbeania crenularis*, and total larvae. * = $p < 0.05$.

	Engraulis mordax	*Sebastes* spp.	*Stenobrachius leucopsarus*	*Tarletonbeania crenularis*	Total larvae
Temperature 3 m	0.50*	−0.06	0.30*	0.40*	0.20
Salinity 3 m	−0.31*	−0.17	−0.26*	−0.19	−0.22
DO 3 m	0.11	0.01	−0.09	0.13	−0.02
Fluorescence 3 m	−0.29*	−0.04	−0.09	−0.18	−0.09
Temperature 20 m	0.47*	−0.11	0.34*	0.39*	0.20
Salinity 20 m	−0.22	−0.12	−0.33*	−0.31*	−0.28*
DO 20 m	−0.02	0.20	0.31*	0.24	0.25*
Fluorescence 20 m	−0.29*	−0.03	−0.07	−0.15	−0.14

1973; Richardson and Pearcy 1977; Richardson et al. 1980; Brodeur et al. 1985; Doyle 1992; Auth and Brodeur 2006; Auth et al. 2007; Auth 2008). A single *Sardinops sagax* larva (4.3 mm notochord length) was also collected at a station 320 km offshore along the NH line in July 2008, while several *S. sagax* eggs were collected at the furthest offshore stations (320 and 364 km offshore) along the NH line and the furthest offshore station (276 km offshore) along the CC line in July 2008. This species has only been known to spawn in the study area since the mid-1990s after an absence of nearly 40 years (Emmett et al. 2005), and would not have been detected during this study under a normal shelf-sampling-only regime.

The cross-shelf distributions of the dominant larval taxa found in this study differed in some cases from those reported by previous studies conducted in the California Current region. *Engraulis mordax* larvae were found in high concentrations and exclusively in the warm, offshore Columbia River plume waters as reported previously (Richardson 1973; Shenker 1988; Auth and Brodeur 2006). However, because the Columbia River plume was located far offshore during June and July (when peak *E. mordax* spawning occurs) 2008, these larvae would not have been detected along this transect had sampling only occurred at normally-sampled coastal and shelf stations. The myctophid larvae were much more prevalent at far-offshore than shelf stations during the present study. In the NCC region, Waldron 1972 reported more zero catches of *S. leucopsarus* and *T. crenularis* larvae in shelf than far-offshore waters, while Doyle's 1992 mean-distribution maps for 1980–87 showed marginally higher concentrations of these two taxa offshore of the continental slope. In the southern California Current (SCC) region, the 1951–98 California Cooperative Oceanic Fisheries Investigation (CalCOFI) surveys showed that *S. leucopsarus* larvae were distributed in higher concentrations inshore of the continental slope than farther offshore, while *T. crenularis* larvae were more evenly distributed (Moser et al. 2001).

Previous studies also identified variable cross-shelf distributions of *Sebastes* spp. larvae. In the NCC region, Waldron 1972 found higher concentrations of larval *Sebastes* spp. inshore of the continental slope, and Richardson 1973 reported a similar distribution between stations inshore and offshore of 37 km, while Doyle 1992 reported the highest concentrations along the continental slope. In the SCC region, the CalCOFI surveys showed that *Sebastes* spp. larvae were almost exclusively distributed inshore of the continental slope (Moser et al. 2001). Although mean concentrations of larval *Sebastes* spp. in the present study were higher in the far-offshore than the shelf region, these larvae were distributed on both sides of the slope. In fact, an anomalously high number of *Sebastes* spp. larvae (n = 164), around four times greater than the number found at any other station during the study, were collected at a mid-shelf station located 38 km offshore along the CC line in July 2008. However, since all of those larvae were relatively small and similar in size (mean = 4.2 mm, standard deviation [SD] = 0.6), this was determined to be an outlier resulting from small-scale spatial patchiness which can be a common confounding factor in any large-scale ichthyoplankton survey (Gray 1996).

Variations in local and basin-scale environmental factors and indices did not appear to explain the consistently higher concentrations of the dominant larval fish taxa in far-offshore than shelf and coastal waters during this study. Although *E. mordax*, *S. leucopsarus*, and *T. crenularis* larval concentrations were positively correlated with temperature and negatively correlated with salinity as previously reported (Auth and Brodeur 2006), the magnitude and direction of cross-shelf variability in these environmental factors were not consistent between the different months in which sampling occurred. In addition, MEI, PDO, and EET index values all varied between positive, neutral, and negative during the different sampling periods (fig. 4), while mean concentrations of the dominant and total larval fish taxa remained consis-

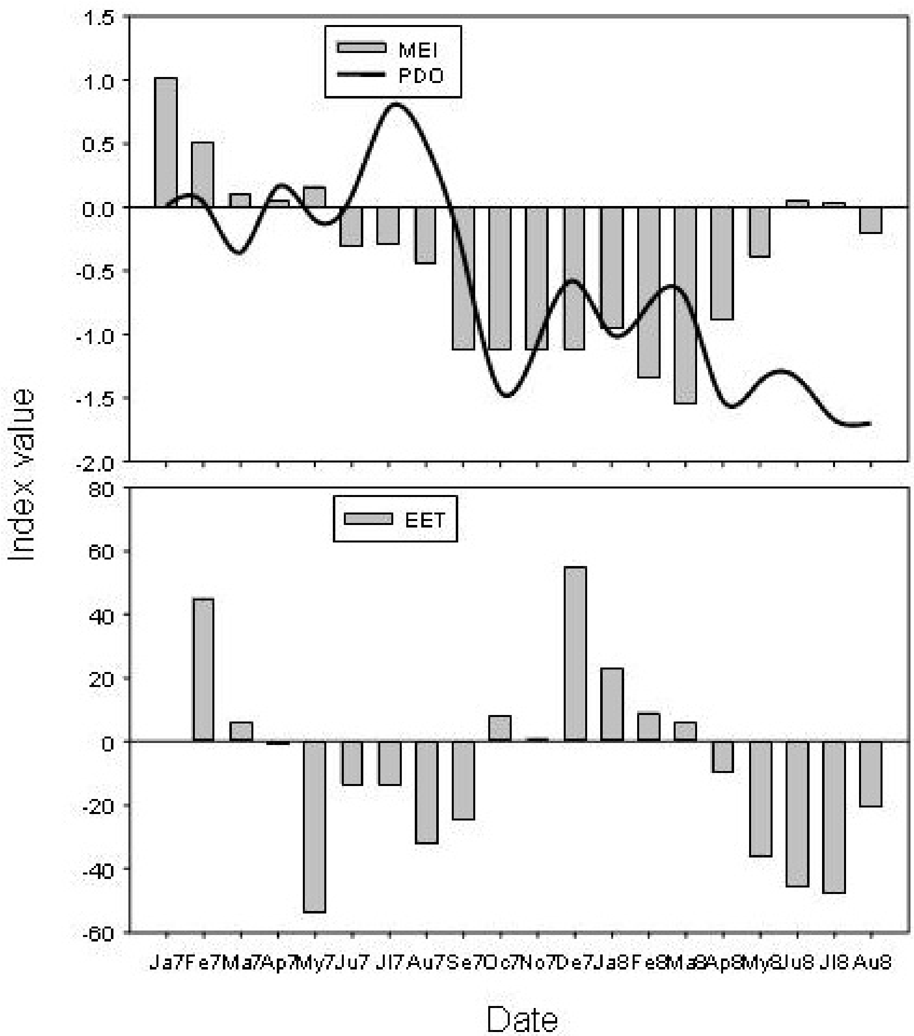

Figure 4. Monthly-averaged multivariate El Niño-southern oscillation index (MEI), Pacific decadal oscillation (PDO), and eastward Ekman transport (EET) (kg/m) from 45°N, 125°W.

tently higher at far-offshore than more-nearshore stations. Variations in seasonal or annual cross-shelf zooplankton prey concentrations and assemblages may help explain the high far-offshore larval fish concentrations observed in this study, which will be examined in a future study (W. Peterson[1]).

It is important to note that the four dominant taxa found in this study are all commercially or ecologically significant to the northeast Pacific Ocean fishery and ecosystem. Adult *Sebastes* spp. and *E. mordax* are widely harvested throughout the NCC region (Brodeur et al. 2003), while myctophids such as *S. leucopsarus* and *T. crenularis* are the dominant component of the micronekton community and represent a vital trophic link between zooplankton and piscivorous organisms in the north Pacific Ocean (Beamish et al. 1999; Brodeur and Yamamura 2005; Suntsov and Brodeur 2008, Phillips et al. 2009). With such high concentrations of the larvae of these dominant taxa being found far offshore beyond the continental slope, it would be unreasonable to assume that these individuals are lost from the system or will not recruit to the more nearshore adult community. Active or passive advection of far-offshore larvae back onto the shelf may occur as a result of larvae and juveniles regulating their position in the water column through diel vertical migrations to take advantage of selective Ekman transport and varying tidal currents (Norcross and Shaw 1984; Auth et al. 2007). If such advection does occur, then the numerous larvae found far offshore may substantially contribute to the overall recruitment of more inshore stocks, and must be considered as part of any stock assessment program incorporating an ichthyoplankton component.

Stock assessments for many of the ~40 species of *Sebastes* occurring in the NCC region are regularly con-

[1]W. Peterson. Pers. commun. Hatfield Marine Science Center, Newport, OR 97365.

ducted as part of the fisheries management plans for the important commercial stocks within this genus. Although *Sebastes* spp. larvae could not be identified to species in this study based on meristic and pigmentation patterns, future studies may result in identification of specimens to species using molecular genetics techniques (Gray et al. 2006). This could eventually lead to the incorporation of larval abundance data in stock assessments. Variability in cross-shelf location and seasonal timing of spawning may occur for different species of *Sebastes* within the NCC region (Love et al. 2002). This may contribute to the cross-shelf and seasonal variability in concentration and length of *Sebastes* spp. larvae found in this study. The more numerous, larger larvae found far offshore may be different species than the less numerous, smaller larvae collected over the shelf, or could represent an advection of recently-spawned larvae of similar species composition from more-nearshore to farther-offshore waters through ontogeny. If the species composition and spawning time is similar in the two cross-shelf regions, then the larger size of the far-offshore larvae could be due to an increased growth rate resulting from increased prey quantity and/or quality in the far-offshore region. In any case, with a pelagic larval-stage duration of one to two months and a juvenile stage lasting weeks to months before demersal settlement (Love et al. 2002; Matarese et al. 2003), early-life stages of *Sebastes* spp. could accomplish cross-shelf migrations in search of optimal environmental conditions and prey availability before finally settling in coastal and shelf waters.

Evidence for *Sebastes* spp. surviving into the juvenile stage in far-offshore waters was found in June 2008, when the highest concentration (4.4/1000 m^3) of *Sebastes* spp. juveniles (mean SL = 23.9 mm, SD = 2.4) ever recorded out of all 176 mid-water trawl samples containing at least one *Sebastes* spp. individual from the 2004–08 SAIP survey was collected at a station 208 km offshore along the NH line[2]. This was the only mid-water trawl conducted at such a far-offshore station in the five years of the SAIP survey, and represents a concentration almost three times higher than that found for *Sebastes* spp. juveniles at any other station to date. Not only does this suggest that early-life stages of *Sebastes* spp. can survive in far-offshore waters through ontogeny, but also brings into question the effectiveness of marine protected areas for this genus designated solely in coastal and shelf waters if adults are spawning in farther-offshore waters.

The results from the present study showed that not only are the dominant fish larvae in the NCC region, comprising commercially and ecologically important taxa found in normally-unsampled far-offshore waters beyond the continental slope, but that they exist in higher concentrations in this area than in the normally-sampled coastal and shelf waters. Ongoing and future sampling designs should incorporate far-offshore stations at least 100 km beyond the continental slope if they are to truly capture the entire community structure of ichthyoplankton in the NCC. This could be accomplished with little or no additional resources of ship and personnel time by reducing the fine-scale latitudinal spacing of stations in favor of a broader and more complete cross-shelf coverage as previously suggested by Auth 2008.

[2]T. Britt and A. J. Phillips. Unpub. data. Hatfield Marine Science Center, Newport, OR 97365.

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