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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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Zooplankton Night/Day Ratios and the Oxygen Minimum Layer in the Eastern Pacific

Spatial patterns of zooplankton biomass and environmental variables are important for many marine ecosystem and management questions. This document presents methods and results for analyses completed by the first author (Fiedler). The zooplankton N/D ratios were originally analyzed for Färber (Fernández and Färber, 2006; Färber-Lorda and Fiedler, 2007) but have since been updated with additional data and reanalyzed. The analysis of dissolved oxygen data used to describe the oxygen minimum layer (OML) is based on Fiedler and Talley (2006). We conclude with brief comments on the significance of the results, but application to questions concerning eastern Pacific pelagic ecosystems will be published elsewhere.

Methods

CTD dissolved oxygen data (Fig. 1a) were extracted from World Ocean Database 2005 CTDO files (http://www.nodc.noaa.gov/OC5/WOD05/pr_wod05.html). These files were last updated on 10/24/2007. Data were extracted, compiled and exported using Ocean Data View. Then, for each profile with at least 10 samples and to a depth of at least 100m, the sample depth with the minimum dissolved oxygen concentration was found, along with the depths at which concentration first dropped to 1.0 ml l^{-1} (top of the OML) and returned back to 1.0 ml l^{-1} (bottom of the OML).

Zooplankton data files were downloaded from the on-line database NMFS-COPEPOD (Coastal & Oceanic Plankton Ecology, Production & Observation Database, http://www.st.nmfs.gov/plankton/). For vertical or oblique tows with a lower depth between 150 and 250m and a nominal mesh size of 333µm (300-333) or 505µm (500-650), total displacement volume (ml m^{-3}) was extracted from the data record (Table 1, Fig. 1b). The number of 333µm-mesh tows was not sufficient for analysis. For 505µm-mesh tows, samples collected at local times from 0800 to 1600 were considered day tows and those from 2000 to 0400 were considered night tows.

Mean day and night volumes were calculated for 1-degree squares. For squares with at least 1 day and night sample, the night/day ratio was calculated. Sampling density was much higher in the California Current (CCS) than in the eastern tropical Pacific (ETP), so 1-degree means in the CCS are based on 10s to 100s of tows, while most in the ETP are based on 1 or 2 tows. A preliminary analysis using 2-degree means in the ETP did not change the results presented here.

Displacement volume (DV, ml m^{-3}) was converted to zooplankton carbon concentration (C, mg m^{-3}) with the following formula from Wiebe (1988), based on North Atlantic samples:

$$\log(C) = 1.749 + 1.22\log(DV)$$

Night and day oblique tows are almost never done at the same station, and oxygen profiles are rarely collected concurrently with plankton tows. Therefore, night/day ratio means were compared to the depth of the top of the oxygen minimum layer (OML) from the 1-degree gridded field (Fig. 2).

Results

The eastern tropical Pacific has a much more pronounced oxygen minimum layer (OML) than the California Current (Fig. 2). This is not a new result (Fiedler and Talley, 2006, and references therein). Minimum oxygen concentrations are lower and the oxygen minimum later is thicker and centered at a shallower depth. Most important for the vertical distribution of zooplankton and other organisms, the top of the oxygen minimum layer is closer to the surface, at <200m depth except near the equator.

Zooplankton displacement volumes and N/D ratios are presented as one-degree means in Figs. 3 and 5. Contour maps are not shown because the extremely non-uniform distribution of the sample points makes gridding over the entire eastern Pacific region problematic. In general, the maps show higher volumes along the California coast, especially north of Point Conception, and in the eastern tropical Pacific east of 100W, except along a band just north of the equator (the North Equatorial Countercurrent). N/D ratios are variable, but typically >1.

There are no significant differences between means and N/D ratios of zooplankton displacement volume or carbon in the eastern tropical Pacific and California Current (Table 2, Figs. 4 and 6). The nonlinear transformation of zooplankton volume to carbon tends to decrease N/D ratios <1 and increase N/D ratios >1, but not enough to make the difference in regional means significant. Mean N/D ratios are slightly higher in the CCS than in the ETP, but with standard deviations equivalent to factors of 1.5 to 2.3.

Plots of N/D ratio vs. depth of top of the OML (Fig. 7) show no significant relationship, either within regions or within the entire eastern Pacific.

If a lower dissolved oxygen level had been used to define the top of the OML, for example 0.5 or 0.2 ml l^{-1}, the difference between the OMLs in the two regions would be greater, but the N/D ratios would not change.

Conclusion

There is no significant difference between zooplankton 0-200m N/D ratios in the eastern tropical Pacific and California Current, in spite of the more intense and shallow oxygen minimum layer in the ETP. This result does not support hypotheses that a strong regional OML affects zooplankton vertical migration or the availability of prey for planktivores in the surface layer. If low-oxygen water is a barrier to vertically migrating zooplankton, daily migration out of the 0-200m layer should be limited by the shallow OML in the eastern tropical Pacific. However, this is a coarse measure of vertical migratory behavior. Multi-frequency acoustic backscatter data might give more precise information on regional differences.

The NMFS-COPEPOD plankton database contains few zooplankton tow data for the Peru Current that are comparable to the extensive CalCOFI data for the California Current. Comparison of zooplankton biomass, N/D ratios, and the OML in these two eastern boundary current ecosystems could help explain the regional difference in fish production.

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Fernández-Álamo, M. A., and Färber-Lorda, J. (2006). Zooplankton and the oceanography of the eastern tropical Pacific: a review. *Progress in Oceanography*, 69(2-4): 318–359.

Fiedler, P. C., and Talley, L. D. (2006). Hydrography of the eastern tropical Pacific: a review. *Progress in Oceanography*, 69(2-4):143–180.

Wiebe, P. H. (1988). Functional regression equations for zooplankton displacement volume, wet weight, dry weight, and carbon: a correction. *Fishery Bulletin*, 86(4):833-835.

File	333µm		505µm		Project
	Night	Day	Night	Day	
albacore	0	0	5	6	NMFS Cooperative Survey of Albacore, 1959
bcfpofi	75	73	91	67	BCF Pacific Ocean Fisheries Investigations, 1950-1961
calcofi	0	0	4136	3699	California Cooperative Oceanic Fisheries Investigation, 1951-2003
ctzp	0	0	36	27	SIO Coastal Transition Zone Program, 1987
eastropac	501	513	508	502	EAStern TROpical PACific (EASTROPAC) project, 1967-1968
eastropic	0	0	44	47	EAStern TROpical PacifIC (EASTROPIC) project, 1955
equapac	0	7	0	0	Cooperative Survey of the Pacific Equatorial Zone, 1956-1957
fronts88	0	0	88	67	SIO FRONTS-88 project, 1988
gulfofcalif	0	0	1	6	IMECOCAL Gulf of California, 1983
imecocal	0	0	310	306	Investigaciones MExicanas de la COrriente del California, 1997-2001
nmfsswfsc	0	0	471	405	NMFS Southwest Fisheries Science Center survey cruises, 1979-2005
rehoboth67	2	21	0	0	U. Hawaii Rehoboth Cruise 67, 1961
scotexp345	0	0	5	1	Scripps Cooperative Oceanography & Tuna (SCOT), 1958
skipjack	68	87	49	65	NMFS SKIPJACK project, 1970-1973
stor420	0	0	5	6	Scripps Tuna Oceanography Research, 1958-1959
Total	**333**	**300**	**5743**	**5210**	

Table 1. NMFS-COPEPOD data files with vertical or oblique tow zooplankton displacement volume data. Other eastern Pacific files lacked appropriate data: *colombia* (IATTC-Colombia 1965-1966), *costadome* (IATTC/SIO Costa Rica Dome cruise 1959), *cuea* (IDOE Coastal Upwelling Ecosystems Analysis 1976), *ecuador* (IATTC-Ecuador 1962-1964), *iattcisland* (IATTC Island Current Study 1957), *imarpezoo* (Instituto del Mar del Peru 1965, all 300µm surface tows), *mazatlan* (IATTC Mazatlan project 1966-1967), *pioneer66* (UH Pioneer Cruise 66 1961), *scope56* (Scripps Cooperative Oceanic Productivity Expedition 1956), *swansong* (Swan Song expedition 1961), *ursamajor* (SIO Ursa Major expedition 1964), *volcano* (URI Vocano-7 cruise 1988).

	Volume		Carbon	
	Mean	N/D	Mean	N/D
ETP	65.7 (2.05)	1.24 (1.90)	0.307 (2.40)	1.30 (2.19)
CCS	112.3 (2.01)	1.43 (1.51)	0.590 (2.34)	1.54 (1.66)

Table 2. Geometric means (standard deviations) of 1-degree means and mean night/day ratios of zooplankton displacement volume (ml 1000m^{-3}) and zooplankton carbon (mg m^{-3}) concentration in the eastern tropical Pacific and California Current regions. Remember that geometric standard deviations are factors, not ± quantities.

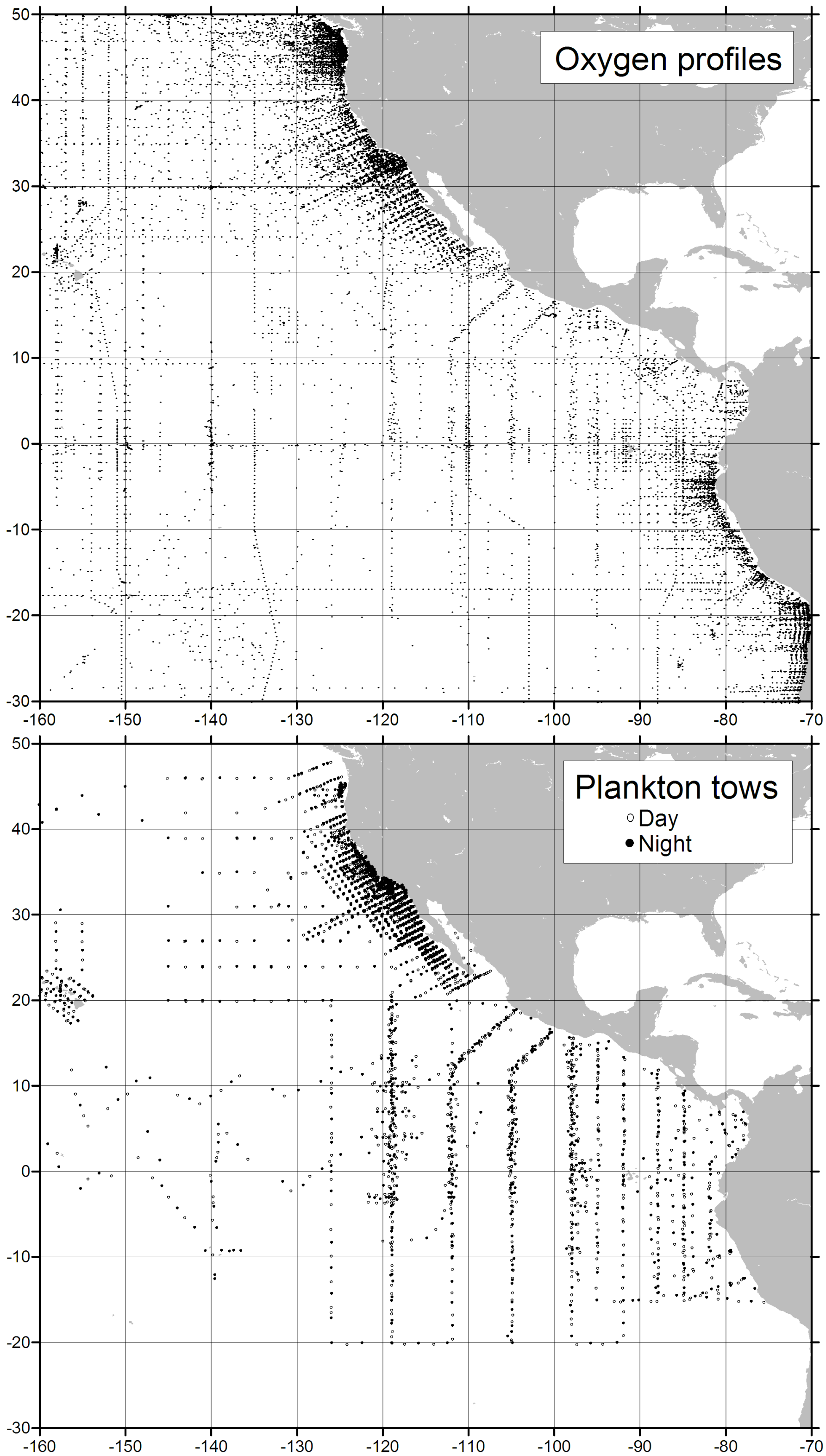

Figure 1. Distribution of NODC Ocean Data Set 2005 CTD oxygen profiles (top) and NMFS-COPEPOD zooplankton tows (bottom, day and night only).

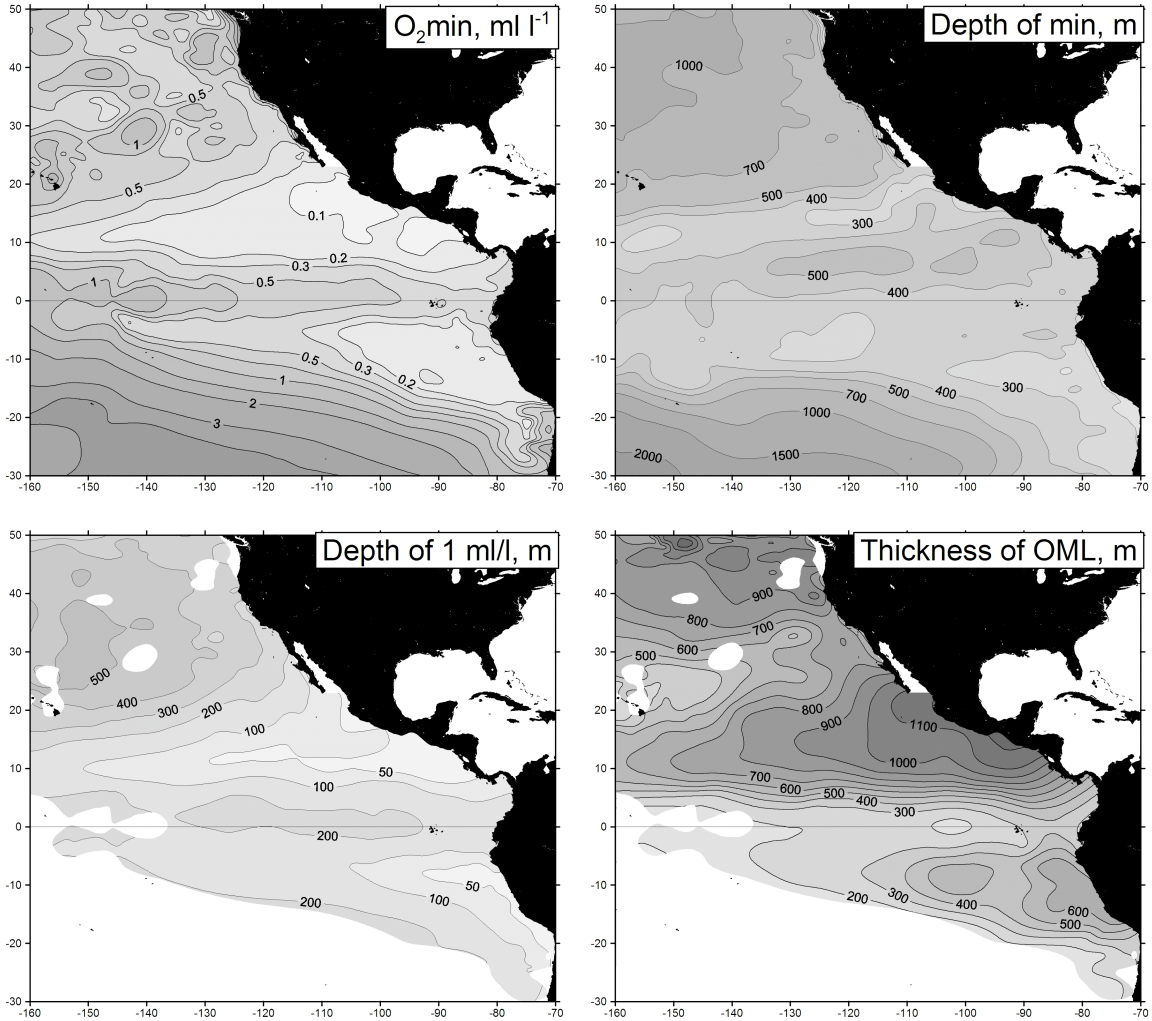

Figure 2. The oxygen minimum layer in the eastern Pacific Ocean, gridded by objective analysis as described in Fiedler and Talley (2006).

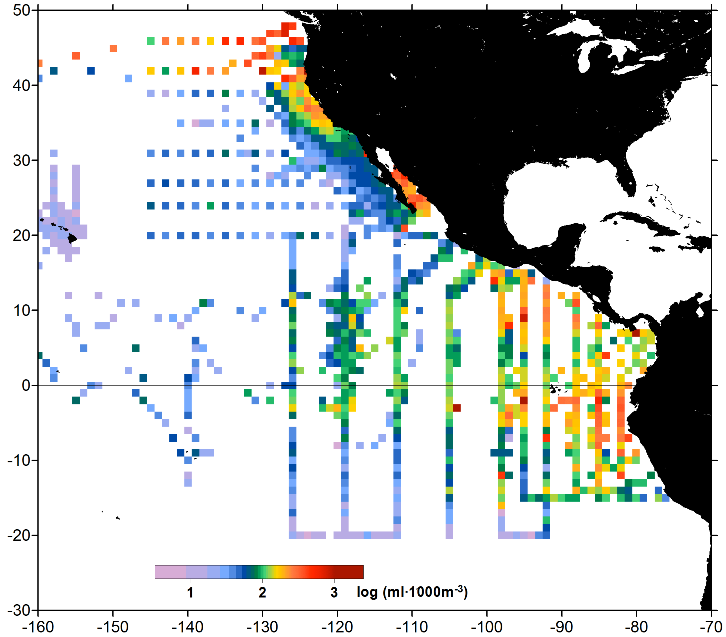

Figure 3. 1-degree mean zooplankton displacement volumes in the eastern Pacific.

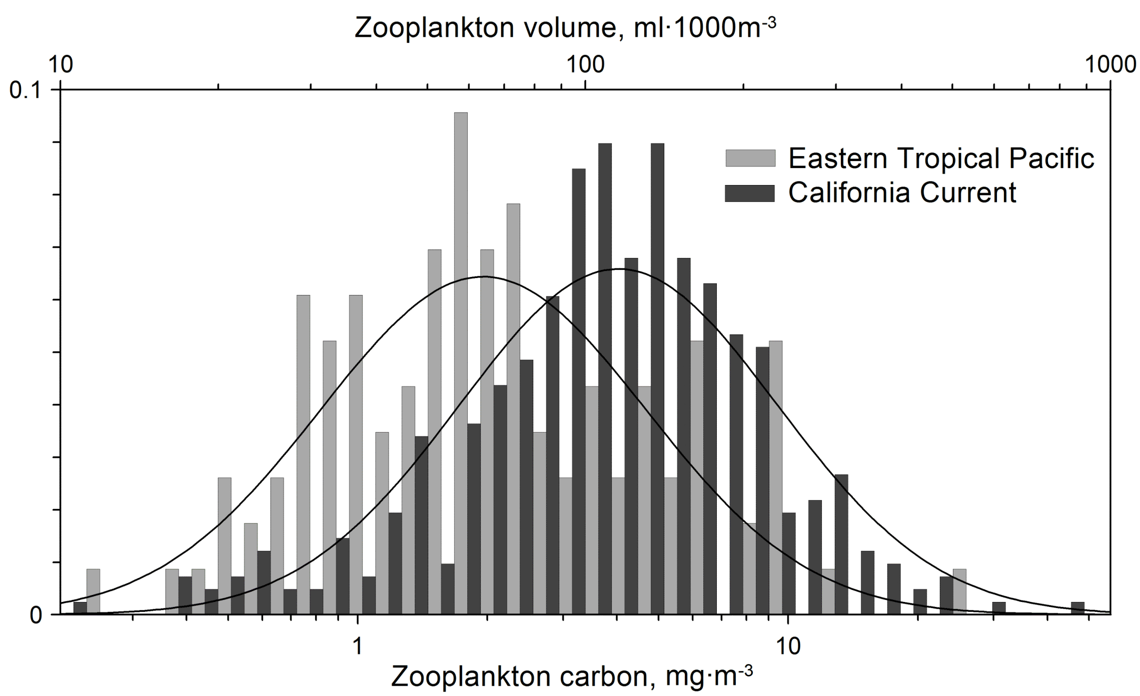

Figure 4. Frequency distributions of 1-degree mean zooplankton displacement volume and carbon in the eastern tropical Pacific and California Current regions. Fitted log-normal distributions are shown. 3 California Current values are >1000 ml m^{-3}.

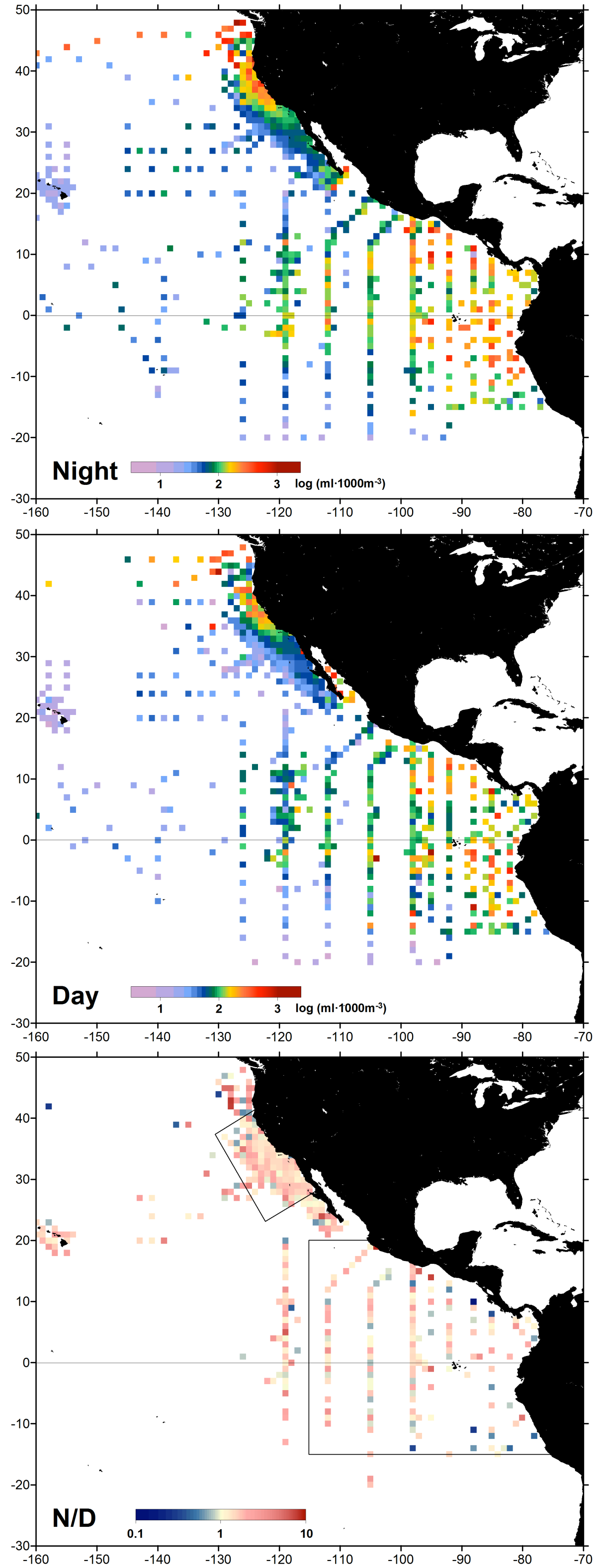

Figure 5. 1-degree mean zooplankton displacement volumes in the eastern Pacific, night (2000-0400) and day (0800-1600), and the N/D ratio (with CCS and ETP region boundaries).

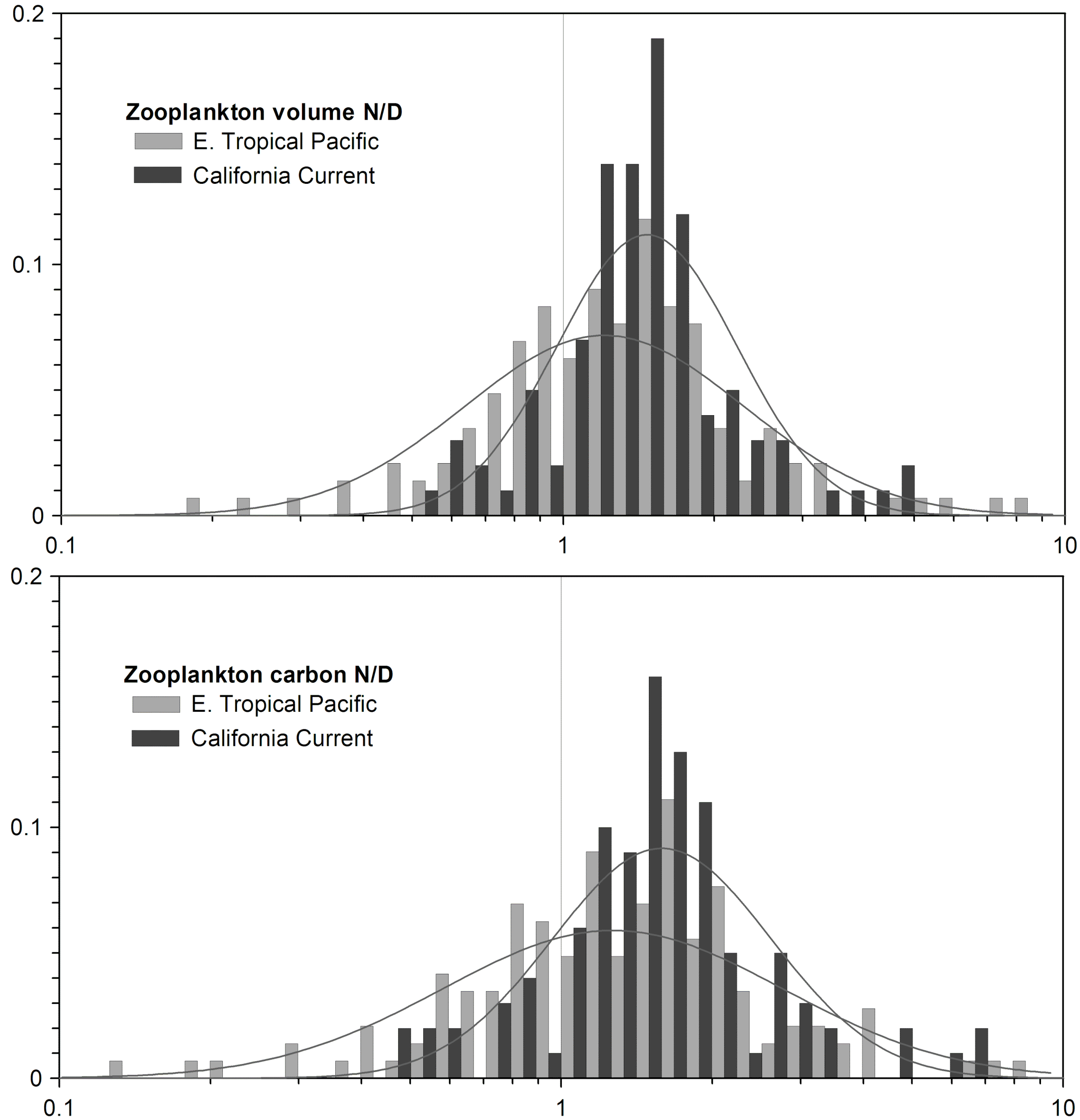

Figure 6. Frequency distributions of 1-degree mean night/day ratios of zooplankton volume and carbon in the eastern tropical Pacific and California Current regions. Fitted log-normal distributions are shown.

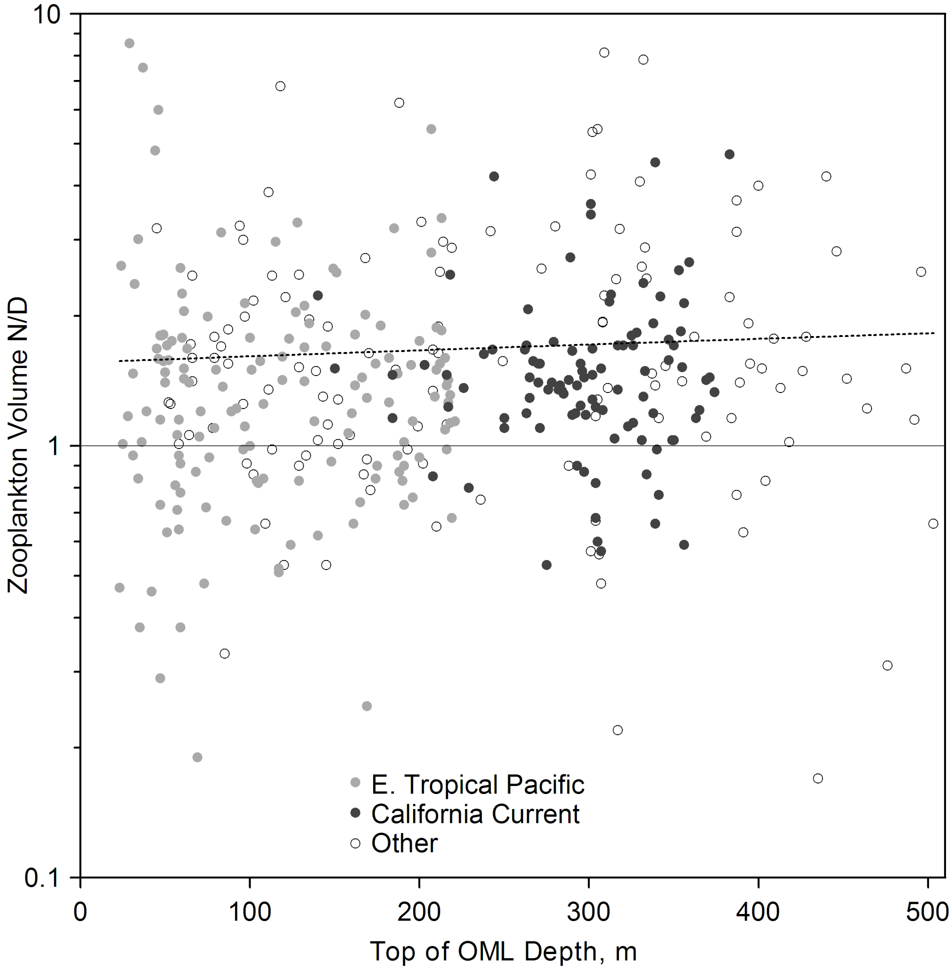

Figure 7. Zooplankton volume mean night/day ratios vs. depth of the top of the oxygen minimum layer (m) in the eastern Pacific. Linear fit (dotted line) is insignificant (r^2 = 0.003).

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