Distribution in relation to phytoplankton, and potential grazing impact, of microzooplankton in the California Current System

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Abstract: We are analyzing the distribution of microzooplankton (ciliates and heterotrophic dinoflagellates) in the California Current System (CCS) during 2001-2003 as part of the Long Term Observation Program (LTOP) off the Oregon and Northern Californian coasts. In addition, we are also evaluating, via flow cytometry, the abundance distributions of large phytoplankton (diatoms and autotrophic dinoflagellates) and of small phytoplankton (coccoid cyanobacteria, and pico- to nano-eukaryotic algae) in the CCS. This data set should allow us to test the idea that microzoo-plankton, and particularly ciliates, tend to feed on, and thus be associated with, smaller-sized prey cells. In the 2001 field year, we found that ciliate abundance and biomass was high both in inshore regions with high diatom abundance (but low abundance of smaller phytoplankton), and in offshore regions where the phytoplankton assemblage was dominated by small phytoplankton. This does not support the hypothesis of ciliates mainly feeding on small-sized phytoplankton. Along the Newport Hydroline, ciliate abundance was lower at slope stations, even in the presence of high abundances of small phytoplankton; we speculate that top-down control of microzooplankton by mesozooplankton accounts for this observation. Dinoflagellate abundance tended to be more uniformly distributed in the CCS. Estimates of potential grazing impact of microzooplankton, based on our data for cell abundances and literature values for cell-specific grazing rates, indicated that microzooplankton could clear phytoplankton from, on average, 67% of the water column per day during summer in regions dominated by smaller-sized cells.

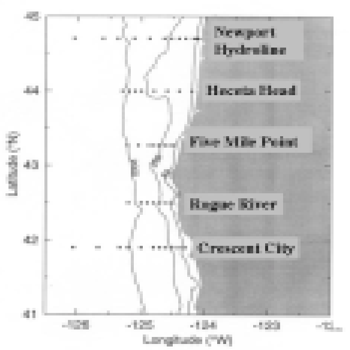


Figure 1. LTOP sampling transects in the CCS. The Newport Hydroline is sampled 5 times a year, the other transects only during the summer.

Figure 2. Sample flow cytometer cytogram plotting cells based on red fluorescence (chl-a), versus orange fluorescence (phycobiliproteins), showing 'clouds' of coccoid cyanobacteria, nano-phytoplankton (mainly phytoflagellates), and larger-sized phytoplankton (mainly diatoms).

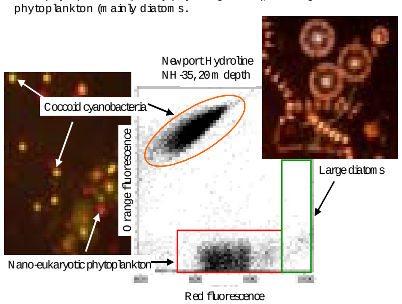
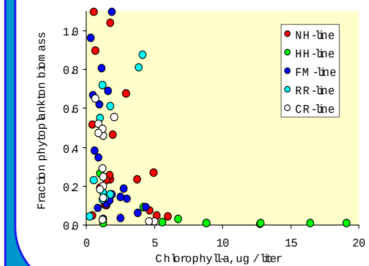


Figure 3. Fraction of phytoplankton biomass due to Σ coccoid cyanobacteria + nano-eukaryotic cell biomass in relation to total phytoplankton stock (chlorophyll-a concentration), September 2001. Colored dots denote individual transect lines.



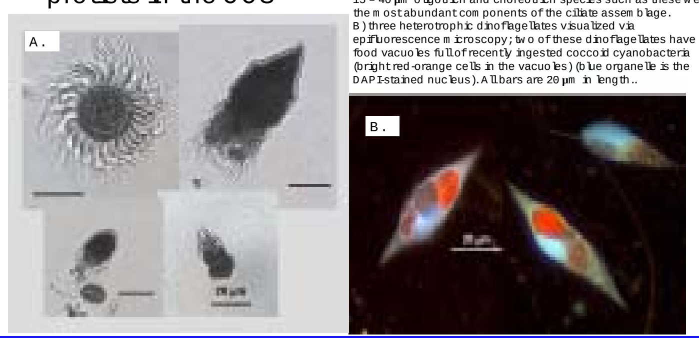
Methods: Water samples were collected from 6 depths in the upper 100 m of the water column at stations along 5 transects (Figure 1) during LTOP cruises.

Ciliates: samples were preserved with 10% final concentration of acid Lugol solution for settling and enumeration/sizing via inverted light microscopy. Heterotrophic dinoflagellates and other flagellates: samples were preserved with formalin, stained with DAPI, and settled onto 3.0 µm black-stained filters for enumeration via epifluorescence microscopy. We enumerated cells larger than about 10 µm in size. Carbon biomass of protists was determined from biovolume estimation of each cell counted, using algorithms for carbon:biovolume ratios (Menden-Deuer and Lessard, 2000).

Phytoplankton: 3 ml samples were preserved with paraformal-dehyde, quick-frozen and stored in liquid nitrogen until thawed and analysed using a Becton-Dickinson FACSCalibur flow cytometer. Coccoid cyanobacteria (Synechococcus) and eukaryotic phytoplankton in two size ranges were enumerated based on orange and red fluorescence, respectively (Figure 2).). Distributions of cells were compared to sigma-t (as a proxy for upwelling) and to in situ fluorescence (as a proxy for phytoplankton biomass) from LTOP CTD data collected on each cruise. We also compared carbon biomass of Synechococcus (100 fg C/cell) and of nano-eukaryotic phytoplankton (1.5 pg C/cell) to total phytoplankton biomass (chlorophyll-a x 40 µg C/ug chl-a) (Zubkov et al. 2000).

Microzooplanktonic protists in the CCS

Figure 4. Examples of microzooplankton protists observed in the CCS: A) four pelagic ciliates visualized via inverted microscopy; 15 – 40 µm oligotrich and choreotrich species such as these were the most abundant components of the ciliate assemblage. B) three heterotrophic dinoflagellates visualized via epifluorescence microscopy; two of these dinoflagellates have food vacuoles full of recently ingested coccoid cyanobacteria (bright red-orange cells in the vacuoles) (blue organelle is the DAPI-stained nucleus). All bars are 20 µm in length..



Results:

1) We found a distinctive pattern of distribution of smaller-sized versus larger-sized phytoplankton during the 2001 GLOBEC LTOP cruises. Larger-sized phytoplankton, mainly diatoms, tended to be most abundant in inshore regions of upwelling. In contrast, highest abundances of both coccoid cyanobacteria (Synechococcus) (1 to 5 x 10^5 cells/ml) and of nano-sized eukaryotic phytoplankton (1 to 7 x 10^4 cells/ml) were often found in slope waters, usually in the region of the offshore upwelling front, based on sigma-t surfaces. Smaller-sized phytoplankton also showed peaks in abundance at the outermost stations of the transects.

2) The fraction of total phytoplankton carbon biomass due to Σcoccoid cyanobacterial biomass + nano-eukaryotic phytoplankton biomass was highly variable, but in general was > 0.1 where chl-a was < 5 ug/liter (Figure 3).

3) Both ciliates and heterotrophic dinoflagellates were common components of the microzooplankton community in the upper water column of the CCS (Figure 4-A & -B). In epifluorescence preparations, ciliates and dinoflagellates were often observed with coccoid cyanobacteria and small eukaryotic phytoplankton in food vacuoles. In the euphotic zone, ciliate abundances ranged from 1 – 14 per ml, and the assemblage was dominated by choreotrichs and oligotrichs with an average cell size of about 20 µm ESD.

4) Distribution of ciliates across individual transects showed variable patterns. For the Newport Hydroline, September 2001, ciliate biomass was high both inshore and offshore, but low at slope stations where pico- and nano-phyto-plankton biomass was highest (Figure 5). In contrast, for the Five Mile Hydroline, high ciliate abundance was confined to the upper 10 m at the slope station, where there was a locally intense bloom of small phytoplankton (Figure 6).

5) For the September 2001 GLOBEC cruise, we were able to compare distribution patterns of the 0-50 m integrated biomass of coccoid cyanobacteria- and nano-eukaryotic phytoplankton (Figure 7-A), and of the integrated abundance of ciliates (Figure 7-B) with respect to surface CTD fluorescence.

6) We used the full data set for microzooplankton (abundance and biomass) for the July 2001 Newport Hydroline to compare biomass, relative size, and potential grazing impact of three components of the microzooplankton: ciliates (Lugols samples), heterotrophic dinoflagellates, and other flagellates > ~ 10 ESD in size (Table 1). To estimate grazing impact, we used literature values for clearance rates of ciliates, dinoflagellates, and other flagellates (Neuer & Cowles 1995, Hansen et al. 1997). We calculated that, based on our cell abundances and assumed clearance rates, the microzooplankton community could clear on average about 2/3 of the water column per day, and at times could clear > 100% of the water column per day. These estimates compare favorably to the grazing rates that Neuer & Cowles (1994) empirically determined for microzooplankton in the Oregon upwelling system: 16 – 121 % of phytoplankton production grazed per day. We also found, as did Neuer & Cowles (1994, 1995), that both ciliates and heterotrophic dinoflagellates were important in terms of phytoplankton grazing (Table 1).

Figure 5. Newport Hydroline, September, 2001: Depth distribution of of A) chlorophyll-a (color) compared to sigma-t surfaces (contour lines); B) coccoid cyanobacteria plus nano-eukaryotic biomass (color) compared to in situ fluorescence (contour lines); and C) ciliates (blue color) compared to in situ fluorescence (contour lines).

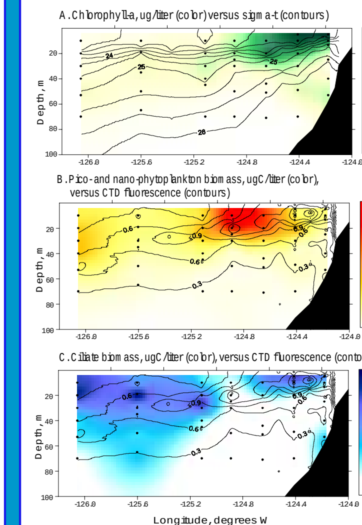


Figure 6. Five Mile Line, September, 2001: Depth distribution of cell abundances of A) coccoid cyanobacteria plus nano-eukaryotic biomass (color) compared to sigma-t surfaces (contour lines); B) ciliates (blue color) compared to in situ fluorescence (contour lines).

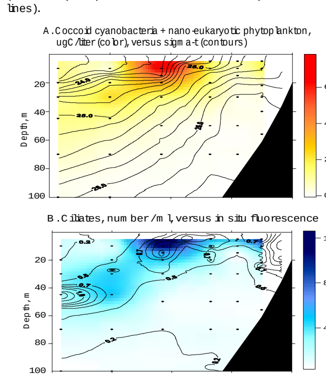


Figure 7. September 2001 GLOBEC LTOP survey: A) 0-50 m integrated biomass (gC/m² of coccoid cyano-bacteria- and nano-eukaryotic phytoplankton, and B) 0-50 m integrated abundance of ciliates, 10^6 per m² (colors), with respect to surface (0-5 m) CTD fluorescence (contours).

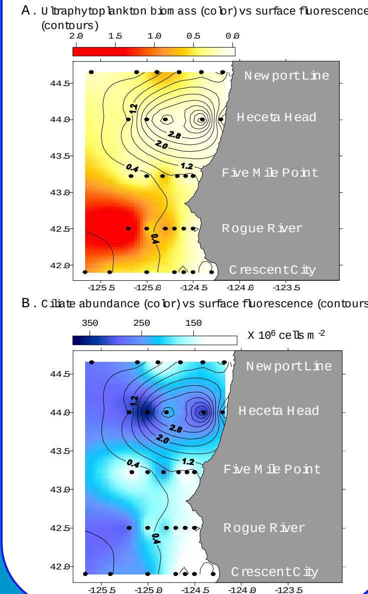


Table 1. Estimate of microzooplankton grazing impact in the upper 70 m of the Newport Line, June 2001: Abundance (cells/ml), average cell size (equivalent spherical diameter, ESD, µm), and biomass (µgC/liter) and grazing impact (% of water volume cleared per day) for ciliates, heterotrophic dinoflagellates, other flagellates, and grazing impact for total microzooplankton. Assumed mean cell-specific clearance rates, based on literature values, were 4.6 µl/cell/hr for ciliates, 0.6 µl/cell/hr for heterotrophic dinoflagellates, and 0.1 µl/cell/hr for other heterotrophic flagellates. Mean value ± one standard deviation, range of values in parentheses.

Parameter	Ciliates	Hetero-dino-flagellates	Other flagellates	Total grazing
Cells/ml	3.5 ± 2.0 (0.5 – 9.2)	17.5 ± 6.5 (8 – 32)	23.3 ± 16.1 (6 – 48)	
Biomass, µg C/liter	2.0 ± 1.7 (0.1 – 4.2)	2.0 ± 1.2 (0.3 – 4.4)	2.3 ± 2.0 (0.4 – 10)	
Equivalent spherical diameter, µm	19.3 ± 5.5 (14 – 29)	11.4 ± 1.6 (9.5 – 16)	11.1 ± 2.1 (9 – 21)	
Clearance, % water volume/day	36.7 ± 22.5% (10 – 42%)	25.2 ± 9.3% (10 – 42%)	5.6 ± 3.9% (1 – 14%)	67.5 ± 27.4% (15 – 136%)

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