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MICROSCALE PLANKTON PATCHINESS IN THE LARVAL ANCHOVY ENVIRONMENT

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Spatial sampling of larval fish food at 20 cm intervals was conducted in the Southern California Bight during periods of maximal and minimal spawning by northern anchovy. Microscale variation of food and non-food organism concentrations consistently exceeded sampling and counting error for one or more organism taxons at all but 1 of 14 sites. Sampling casts were made vertically in the mixed layer and pycnocline, and horizontally in the pycnocline. Both motile and non-motile taxons displayed small-scale patchiness. Microscale variation of their concentrations was greatest in the pycnocline on the vertical axis.

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This report summarizes field measurements to determine if small predators and grazers encounter food patches in excursions of less than 2 m extent. Variation in food supply available to larval fish populations is commonly examined to help determine causes of large interannual fluctuations frequently experienced in the availability of fish to fisheries (cf. Sharp, this volume). Yet concentrations of food of first-feeding northern anchovy (*Engraulis mordax* Girard) seem frequently to be too low for larval survival and growth (Lasker et al., 1970). This may be because conventional sampling with plankton nets, which integrate over depth, distance, and volume, has little relation to the comparatively tiny volumes searched by single larvae (Hunter, 1972). Survival of larvae may, in fact, depend on the existence of food particle patchiness on scales considerably less than 100 m and 1 week (Vlymen, 1977).

Sampling sites considered here were in the Southern California Bight, which occupies the center of the usual distribution of the northern anchovy's central subpopulation and of its spawning distribution (Vrooman and Smith, 1972; Smith, 1972). The 14 sites were in coastal waters (bottom depth ⩽300 m) where standing stocks of food particles are usually highest (Lasker, 1978; and this volume) and have been shown to support larval survival during parts of the anchovy spawning period (Lasker, 1975). Sampling was done in March (peak spawning) and in August and September (minimal spawning).

The Southern California Bight is a region tending to high vertical stability by virtue of characteristically slow flow (reduced shear) and year-round net heat gain (except December) by the ocean's upper layer (Clark et al., 1974). The mixed layer usually is shallow (<20 m) or non-existent. Large temperature gradients that predominate over salinity gradients in determining stability, occur in the upper pycnocline in the absence of steady winds. These characteristics are favorable to the development of small-scale patchiness, but are episodically reversed by storm winds which destroy patches.

Samples to assess microscale patchiness at each site were obtained using the device shown in Figure 1. The micropatch sampler (MPS) sampled either in the mixed layer or in the upper pycnocline in the main chlorophyll maximum layer, as defined by pigment fluorescence in a water stream provided by continuously lowered pump and hose. Clamped vertically or horizontally to the ship's hydro-wire and lowered to the depth desired, the MPS captured water at ten intervals on 20 cm centers in 5 cm i.d. tubes of 600 ml capacity by simultaneous messenger-activated release of lanyards which restrained ball valves from their seats at either end of each sample tube. Replicates

Figure 1. Micropatch sampler (MPS). The array is shown with ball valves open.

were obtained on some casts by strapping another sample tube alongside the original. When sampling vertically, sample tube mouths were oriented by vanes to face a current of ~ 50 cm/sec induced by moving the ship slowly ahead. This minimized vertical mixing of the water by the MPS. When sampling horizontally (tubes vertical), the tubes were closed while raising the array into water disturbed only by the ship's wire. Water thus obtained was aliquoted for various analyses from the well-stirred contents of the MPS tubes upon recovery aboard ship. Samples for microscope analysis were preserved in 5% buffered formalin spiked with strontium chloride. These were counted ashore by the sedimentation method of Utermöhl (1931).

Results of microscope counts are summarized in Table 1 as coefficients of variation, V = 100 · variance/mean, of concentration over the 10 intervals sampled to represent the 1.8 m span. Where replicate samples were counted, average values between replicates were used in the computation. Coefficients are shown for population counts exceeding 10 in at least one of the samples in the set. Trends (i.e., mean gradients) over the 1.8 span are represented by the coefficients, as are variations within the span (i.e., deviations from mean gradients), both sources are taken to indicate microstructure degree because sampling was done in the absence of detectable macrogradients (i.e., in mixed layer and chlorophyll maximum). The V statistic was chosen not because it is necessarily the most appropriate, but because it scales variances for comparability and because it is widely used and understood. A measure of sampling and counting error is provided from counts on four MPS sets each consisting of five replicate sample pairs. The average coefficient of variation between replicates for 15 taxonomic groups counted was 10.9 (range was 4.0–18.5), not including the coefficient for ciliates associated with marine snow at two sites (7703J-MS1, MS2).

Considering interval V-coefficients to indicate a significant degree of microstructure if they exceed replicate V-coefficients by at least a factor of 3, Table 1 shows that:

1) Microscale patchiness is apparent (V ⩾ 33) at all but one of the fourteen Southern California Bight sampling sites for one or (usually) more kinds of organisms enumerated;
2) Most types of organisms suitable as larval anchovy food display significant degrees of microaggregation. Non-food organism types are also aggregated, in many cases to an even greater degree, and not necessarily in the same zones as food organisms (Fig. 2);
3) Vertical profiles in the upper mixed layer (the latter defined by absence of density gradients determined from standard STD casts) showed significant microscale patchiness for 5 of 8 food types and 3 of 8 non-food types at one site or the other, both occupied during the anchovy spawning season under calm wind conditions;

Table 1. Coefficients of variation of organism concentrations sampled at ten 20-cm intervals (interval replicates averaged where obtained) in the mixed layer and upper pycnocline of the coastal shelf of the Southern California Bight.

	Vertical casts in pycnocline at chlorophyll maximum layer								$\bar{V}$	Horizontal casts in pycnocline			$\bar{V}$	Vertical casts in mixed layer		$\bar{V}$
Top depth (m):	22	23	25	29	20	20	14	20		17	18	21		10	10	
Date (year/month):	75/09	75/09	75/09	75/09	76/03	76/03	77/03	77/08		76/03	76/03	76/03		76/03	77'03	
MPS no.:	1	2	4	5	1	5	2	1		3	10	11		2	1	
Food Types																
Exuviaella sp. C					22.7	17.3				27.4	29.1	21.8		12.8	76.6	
Oxytoxum sceptrum						27.7										
Prorocentrum gracile	69.8	52.6	138.4		45.4									37.6		
Peridinium (2 spp.)					50.9						19.2			25.4		
Peridinium minutum					174.1		25.0				35.2			35.5	21.2	
Cochlodinium catenatum	28.4		51.2	44.9				22.0								
Gymnodinium sp. S					22.2											
Torodinium robustum								29.8								
naked flagellate 30x50 μm					67.4			14.5		27.3	21.4	17.3			41.6	
tintinnids						98.6								22.2	34.2	
free ciliates			54.6	44.2	64.1	11.5	63.2			26.2	14.3	24.4		9.9	23.4	
copepod nauplii					32.0	25.4					29.6			10.7	31.8	
$\bar{V}$									49.9				24.5			29.5
Non-Food Types																
Nitzschia seriata					51.8	44.9					35.7			29.2		
Eucampia zoodiacus							115.7							31.0		
Thalassiothrix frauenfeldii														25.1		
Thalassiosira sp.A							27.3									
pennate diatom 30 μm			158.2	92.2												
silicoflagellate			55.3	60.4												
Ceratium kofoidii	39.1				58.4					39.2						
dinoflagellate spp. 5x10 μm					27.9						31.1			27.0		
Pseudoeunotia doliolus	95.7	104.6	56.8													
Thalassiosira sp. B								28.9				37.3				
Skeletonema costatum														40.1		
pollen grain 70x40 μm															65.6	
oikopleurans														52.4		
Noctiluca sp.					29.0	21.2					24.2			21.5		
$\bar{V}$									62.8				33.5			36.5

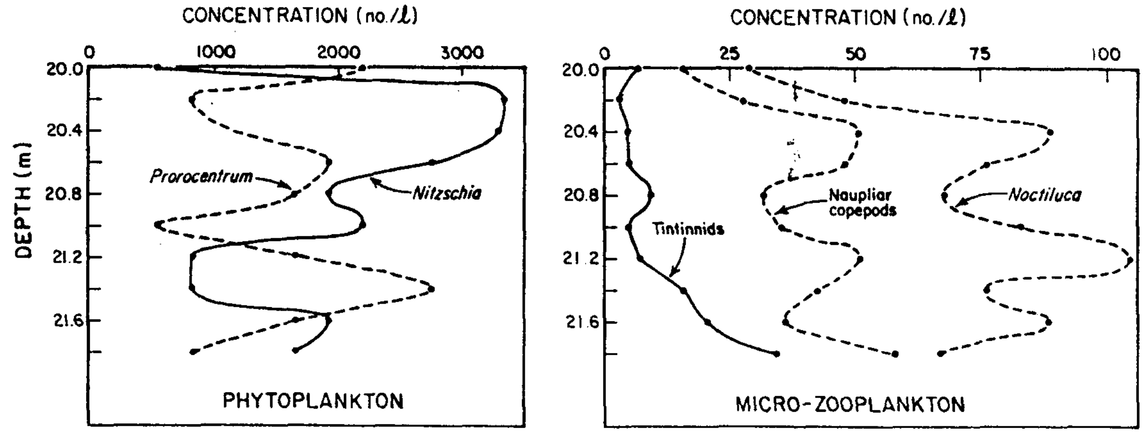

Figure 2. Variation of concentration of microplankton in samples from 20 cm depth intervals in the pycnocline (vic. depth of the main chlorophyll maximum) in March 1976 over the coastal shelf of the Southern California Bight (7603J MS1). *Prorocentrum*, tintinnids and copepod nauplii are larval anchovy food items.

4) Microscale variation was usually greatest in the pycnocline and in the vertical axis for most food and non-food types alike (but see *Exuviaella* sp. C — this flagellate species behaves rather differently on the microscale, being more randomly dispersed vertically than horizontally in the pycnocline and apparently capable of forming small patches in the mixed layer);

5) Horizontal variation was usually less than vertical variation in the pycnocline, indicating (except for *Exuviaella* sp. C) lenticular patching and anisotropic behavioral or physical processes that control patchiness;

6) Non-motile or weakly motile organisms (cf. *Nitzschia*, *Thalassiosira* and pennate diatom categories) may show as much or more patchiness as motile organisms (cf. *Exuviaella*, *Prorocentrum* and ciliate categories);

7) There is no evidence for a difference in degree of microstructure between periods of peak and minimal spawning activity (mean V = 49.9 and 50.1, respectively). This is perhaps partly due to too few comparable categories since species composition changed between the two periods sampled.

Microscale variations reported here are due to two sources beyond sampling and counting error. First, free-living organisms aggregate by active (behavioral) or passive (physical) mechanisms. Second, some food-type organisms associate with macroscopic particle aggregations (Silver et al., 1978; Alldredge, 1972). When such colonized aggregates are large and dispersed *in situ*, they are likely undersampled by the MPS, giving rise to increased variation when they are disintegrated by sample manipulation prior to analysis. Distinction between these two sources of variation is difficult without direct observation, but is important because organisms associated with marine snow are available for grazing by a rather different set of predators than are free-living organisms. In particular, first-feeding anchovy larvae are not known to pick at macroscopic aggregates, and their mouths are too small for complete ingestion of whole aggregates larger in least dimension than 200–250 μm (Hunter, 1977). From this set of samples, presence of large aggregates was detected by uncharacteristically large disparity in counts of ciliates and detritus from replicate samples during March 1977, both in pycnocline (7703 MS2) and mixed layer (7703 MS1).

A second point not apparent from Table 1 is that maximum concentrations of food and non-food organisms do not usually coincide on the microscale. A characteristic experience is shown in Figure 2, taken from a vertical MPS cast in the pycnocline, in the vicinity of the main chlorophyll maximum. This effect may augment the increase in availability of food organisms due to microstructure by local clearing of undesirable strike targets in zones where food organism concentrations are highest. This argument assumes varying degrees of desirability among the food types, as there are no consistent patterns between total food and non-food organism distributions on this scale.

Concentrations of suitable food at one site (7603 MS1) of the 14 reported here exceeded the "critical concentration" criteria of Lasker and Zweifel (1978) for survival and growth of anchovy larvae. This incidence would likely be higher if (1) all food type organisms had been enumerated or if (2) plankton richness had been among criteria for choosing sampling sites.

The observations reported here to date suggest no simple relationship between organism types, but show a large degree of variation on short intervals. Results confirm Vlymen's (1977) postulate that small-scale patchiness (on the order reported here) must necessarily occur to support even the minimum fraction of anchovy larvae surviving to recruitment size. The results also suggest sampling precautions to be taken wherever minimum or maximum plankton concentrations need to be known or where "critical concentrations" need to be detected.

This work may thus be applicable to populations other than that of the northern anchovy. Populations of *Anchoa* and *Achirus* are held to be food-limited at the larval stage (Houde and Schekter, this volume) as well as of North Sea haddock (Jones, this volume). The argument may also extend to such grazers and predators as copepods (e.g., Marshall and Orr, 1955, p. 97).

REFERENCES

Alldredge, A. L. 1972. Abandoned larvacean houses: a unique food source in the pelagic environment. Science 177: 885–887.

Clark, N. E., Eber, L., Laurs, R. M., Renner, J. A. Saur, J. F. T. 1974. Heat exchange between ocean and atmosphere in the eastern North Pacific for 1961–71. NOAA Tech. Rep. NMFS SSRF Fish No. 682: 108 pp.

Houde, E. D., and Schekter, R. L. Functional and development responses of fish larvae to varying prey concentrations (this volume.

Hunter, J. R. 1972. Swimming and feeding behavior of larval anchovy *Engraulis mordax*. Fish. Bull., U. S., 70: 821–838.

Hunter, J. R. 1977. Behavior and survival of northern anchovy *Engraulis mordax* larvae. CalCOFI Repts. 19: 138–146.

Jones, R. Simulation studies of the larval stage and observations on the first two years of life, with particular reference to the haddock (this volume).

Lasker, R. 1975. Field criteria for survival of anchovy larvae: the relation between inshore chlorophyll maximum layers and successful first feeding. Fish. Bull., U. S., 73: 453–462.

Lasker, R. Factors contributing to variable recruitment of the northern anchovy (*Engraulis mordax*) in the California Current: contrasting years, 1975–1978 (this volume).

Lasker, R. 1978. The relation between oceanographic conditions and larval anchovy food in the California Current: identification of factors contributing to recruitment failure. Rapp. P.-v. Réun. Cons. int. Explor. Mer, 173: 212–230.

Lasker, R., Feder, H. M., Theilacker, G. H. and May, R. C. 1970. Feeding, growth, and survival of *Engraulis mordax* larvae reared in the laboratory. Mar. Biol. 5: 345–353.

Lasker, R., and Zweifel, J. R. 1978. Growth and survival of first-feeding northern anchovy larvae (*Engraulis mordax*) in patches containing different proportions of large and small prey, pp. 329–354. *In* Spatial pattern in plankton communities. Ed. by J. Steele. Plenum Press, N. Y. and London, 470 pp.

Marshall, S. M., and Orr, A. P. 1955. The biology of a marine copepod. Oliver and Boyd, Edinburgh, 188 pp.

Sharp, G. D. (this volume). Colonization modes of opportunism in the ocean.

Silver, M. W., Shanks, A. L., and Trent, J. D. 1978. Marine snow: microplankton habitat and source of small-scale patchiness in pelagic populations. Science 201: 371–373.

Smith, P. E. 1972. The increase in spawning biomass of northern anchovy, *Engraulis mordax*. Fish. Bull., U. S., 70: 849–874.

Utermöhl, H. 1931. Neue Wege in der quantitativen Erfassung des Planktons. Verh. Int. Ver. theor. angew. Limnol. 5: 567–596.

Vlymen, W. J. 1977. A mathematical model of the relationship between larval anchovy (*Engraulis mordax*) growth, prey microdistribution and larval behavior. Env. Biol. Fish. 2: 211–233.

Vrooman, A. M., and Smith, P. E. 1972. Biomass of the subpopulation of northern anchovy, *Engraulis mordax* Girard. Calif. Coop. Oceanic Fish. Invest. Rep. 15: 49–51.