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# TURBULENCE-MODIFIED PROFILES OF FEEDING CONDITIONS FOR LARVAL COD (*Gadus morhua*) ON GEORGES BANK DURING SPRING

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Lewis S. Incze*, Peter Aas and Terri Ainaire
Bigelow Laboratory for Ocean Sciences
West Boothbay Harbor, Maine 04575 USA

Internet: lincze@bigelow.org
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# METHODS AND OBJECTIVES

The vertical distribution of copepod nauplii (prey for early feeding larval cod, *Gadus morhua*) and water properties was sampled at well-mixed and stratified sites on Georges Bank using a pumping system, CTD and *in vivo* fluorometer during a four-day period in late May 1992. Approximately 15 l was sampled for nauplii at discrete depths. Data were collected at fixed sites in various locations and following a drifter drogued at 15 m, which was within the thermocline during the cruise (irregularities in some of the salinity data caused us to use the thermocline as a proxy for the pycnocline). Turbulence in the upper mixed layer was estimated from the 6-h average wind velocity prior to sampling using a boundary layer model (Pond and Pickard 1983), and were in close agreement with empirical fits to data (MacKenzie and Leggett 1993). Turbulence in the thermocline and in the bottom layer was taken from turbulence profiling (see Oakey 1988) conducted by Horne et al. (In press) in the northern portion of the bank in 1985 and by N. Oakey and D. Hebert (Unpubl. data) in our study area (southern Georges Bank) in spring 1995. A theoretical encounter rate (Gerritsen and Strickler, 1977) was calculated for cod larvae (0.52 cm SL) preying on copepod nauplii (125 µm TL) with and without turbulence (Rothschild and Osborn 1988; Evans 1989). Details of the calculations are given by Incze et al. (In press; please contact the author).

This poster presents a selection of profiles from the study (**Figure 1**) to contrast mixed vs. stratified areas and to demonstrate the variety of prey distributions possible in stratified waters. We ask the question: "Does consideration of turbulence substantially alter the vertical profile of assumed feeding potential for cod larvae?" We discuss our findings and suggest that the fine-scale vertical patterns of encounter rates in the stratified region are associated with larger-scale areas that may have "patch-like" dimensions and consequences for the feeding ecology of larvae.

# OBSERVATIONS AND DISCUSSION

Well-mixed sites had low concentrations of nauplii, *ca.* 4 $l^{-1}$, and showed little variation of abundance with depth. Stratified sites had from 4-16 times the integrated abundance of nauplii compared to well-mixed sites and showed strong vertical patterns of distribution. Maximum concentrations of nauplii, up to 160 $l^{-1}$ (median = 32.5 $l^{-1}$), were associated with the thermocline/fluoresecence maximum at 7 of the 9 stratified sampling stations (median depth of sampled maximum = 15 m); at the remaining two stations the maximum was in the upper mixed layer. **Table 1** summarizes data from 11 profiles and shows estimated encounter rates based on some constant and simplified assumptions: larval swimming speed (v) = 0.2 cm $s^{-1}$; naupliar swimming speed (u) = 0.0125 cm $s^{-1}$; and encounter radius (R) = 0.26 cm (1/2 body length). Encounter is defined here as physical approach within a spherical volume of the defined radius and is used for comparative purposes only -- not for estimating actual detection or feeding rates which would require much more detailed parameterization (see below).

**Figure 2** shows profiles of temperature and chlorophyll (1 m averaged) and naupliar concentration (~5 m resolution in the upper 20 m). Maximum water column depth was 50 m at the mixed site (13P) and 70-83 m at the other three; thus, the deepest sample is 20 m or more away from bottom. Integrated naupliar abundance down to the deepest sampling depth is shown by $\Sigma$. Stations 11P and 24P show the greatest and least stratification of nauplii, respectively. The naupliar maximum is associated with the thermocline and fluorescence maximum in both cases (and at 25P and others). 25P is added here to illustrate the greatest thermocline concentration of nauplii encountered during the cruise, although the integrated abundance is the same as at 24 P.

The naupliar profiles at 11 and 24P result in very different potential encounter rate profiles, shown in **Figure 3**. Here, encounter rate (C: from the concept of "contact" rate) has been calculated as number of prey per time assuming a constant radius and swimming behavior with no depth-related change. Note that encounter potential in the thermocline (shaded blue region) at 24P is *ca.* 1.5 x the value at 11P, and the estimated rates are entirely different below the thermoclines at the two sites (24 P >> 11P). Under the assumptions employed here, turbulence increases encounter rate by about 20% in the thermocline and 33% in the region shown below it. Turbulent kinetic energy dissipation rate used here (averaged from measurements) is $1 \times 10^{-8}$ W $kg^{-1}$ in the thermocline and $1 \times 10^{-6}$ W $kg^{-1}$ in the tidally mixed water column > 20 m away from the frictional boundary. The larger total increase in encounter rate enhancement due to turbulence in the mixed area is because of the combined effects of wind and tide. The contrast between mixed and stratified areas is lessened by including turbulence, but absolute comparisons between the two must await better parameterization of such things as swimming behavior, shape and volume of the perceptive field, feeding success *vs.* "encounter" (as in the model), and the effects of light and turbulence itself. Satiation feeding levels may constrain interpretation of these differences because turbulence can directly enhance feeding only when static food concentrations are below saturation feeding levels.

The sensitivity of turbulence-modified encounter rates to assumptions about v and R is demonstrated in **Figure 4**, in which the value of each of the parameters is halved independently. This is not meant to imply the likely *direction* of change with further investigation, but only to show the magnitude.

Stations 11 and 25 (Figs. 2 and 3) were sampled approximately 51 h apart at the site of a current meter mooring (Fig. 1). Along-isobath westward drift during this period was roughly 19 km at 45 m depth and 27 km at 15 m (Manning et al. 1995). Thus, there was vertical shear in the water column and within the population of nauplii (Acoustic Doppler Profiling will enable a higher resolution picture when the data are processed). The naupliar data set is too small to examine the length scales of variation with any rigor, but substantial changes were seen at distances of 5-30 km within the stratified area itself, based on drifter, mooring and transect samples. Such spatial complexity must be included when evaluating the feeding ecology of a larval year-class. Such consideration, and an understanding of mechanisms underlying the spatial patterns, will begin to link properties of the small-scale (the vertical, with turbulence effects) to the intermediate-scale (water parcel, temporal change, physical forcing) in order to estimate impacts upon the population.

We have not addressed the upper, wind-mixed layer in this paper because cod larvae are rare at those depths in stratified areas of Georges Bank. Wind-induced turbulence might play a role in other important interactions, however, such as predation on cod eggs (which are numerous in the upper layer), as well as particle-particle interactions and feeding by numerous shallow-layer, neustonic and pleustonic organisms (see Denman and Gargett 1995; Shimeta et al. 1995).