Vertical and Horizontal Migrations Affect Local and Integrated Water-Column Scattering Strengths

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LONG-TERM GOALS

Our long-term goals are to understand — to an extent that allows quantitative prediction — important interactions among acoustic propagation, marine organisms, particles (including sediments), solutes and moving fluids. The reason for these goals is to allow us to solve interesting forward and inverse problems in the marine environment.

OBJECTIVES

The primary objectives of this work are to develop a predictive understanding of emergence by coastal macrofauna in one region. By emergence we mean leaving the seabed to become part of the plankton or nekton, which typically occurs at night. In high-frequency acoustic records, this emergence appears as a "shallow scattering layer" that typically leaves the seabed after dusk and returns before dawn. Emergence and re-entry (return to the seabed) in shallow water appear to represent an evolutionary solution that avoids visual predation analogously with oceanic "deep scattering layers." In the coastal zone, the water is simply too shallow to provide a holoplanktonic solution.

The region selected for this work is midcoast Maine in the vicinity of the Darling Marine Center, which is located on the lower Damariscotta River. The region was chosen for its diversity of estuarine and coastal environments, including a range of optical properties in river and coastal waters. We emphasize that it likely is more representative of coastal waters than of an estuary because of the small freshwater input. It is most accurate to think of it as a shallow fjord. We have recently expanded our explicit region of interest to include the Martha's Vineyard Coastal Observatory (MVCO) in an attempt to determine whether the observations collected in the Damariscotta estuary resemble phenomena of the open coast.

An additional objective evolved from earlier work with Larry Mayer of the University of Maine and Bernie Boudreau of Dalhousie University is to develop a mechanics-based understanding of burrowing in sediments. Before we chose this objective, no models or measurements of forces or work of burrowing parameterized the relevant physical properties of sediments. Its acoustic relevance has become clearer after we identified crack propagation as the general means of burrowing in muds; flaw detection by acoustic means is a common industrial approach that may now become useful in assessing acoustic properties of muds.

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APPROACH

Our work has relied primarily on measurements with two TAPS-6 (Tracor Acoustic Profiling System with six frequencies) instruments. We operate them in cabled mode at their maximum spatial resolution of 12.5 cm and maximum data rate of one profile per minute. The usual orientation has been up-looking from a bottom-mounted frame. The height of TAPS (70 cm) and near-field problems have limited our observations to the water column > 2 m from the seabed. More recently through the DURIP program we acquired a dual-frequency (420 and 120 kHz), split-beam *DTXU* unit from BioSonics.

Our primary focus for FY08 was to complete the publication process with data collected as Mei Sato's M.S. thesis (Sato 2006) and Kelly Dorgan's Ph.D. dissertation (Dorgan 2007) on the acoustic and bioturbation components of our work, respectively.

We also continued our efforts to place our work in a broader geographic context. We continued analysis of TAPS data collected in September 2005 at the Martha's Vineyard Coastal Observatory (MVCO). In addition we reviewed the world literature on mysid emergence over continental shelves, with particular attention to *Neomysis americana*, the dominant species in our system. In addition, we collected a second set of TAPS data at MVCO in September 2007.

Lastly, we deployed our *DTXU* unit in August and September 2008 after fabricating a bottom tower for mounting it.

WORK COMPLETED

Now entirely published is the work of Mei Sato from her M.S. thesis and of Kelly Dorgan from her Ph.D. dissertation (Sato and Jumars 2008; Dorgan *et al.* 2008).

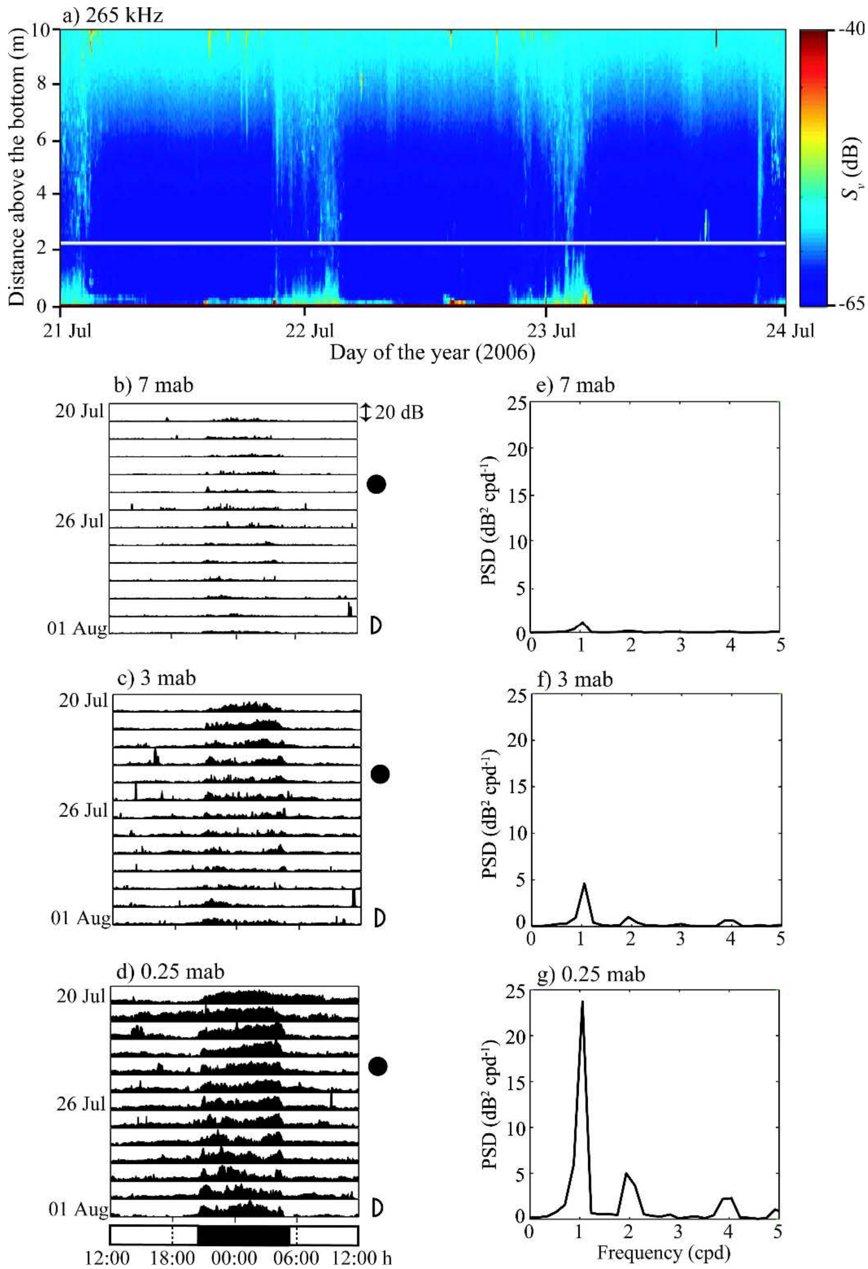

Figure 1. (a) Representative echogram at 265 kHz over a 3-d period from 21 to 23 July 2006. Daily tick marks correspond to midnight. Water depth varied with tidal phase, but the plot was truncated uniformly at 10 mab. Echograms are composited from the upward- (upper part) and downward-looking (lower part) echo sounders. (b–d) Temporal fluctuations in the intensity of volume backscattering strength (Sv) plotted on a 24-h time scale as a waterfall plot at various depths: 260 to 240 dB at 7 mab, 269 to 249 dB at 3 and 0.25 mab. Times of darkness indicated on the abscissa. Moon phases: new moon and last quarter, respectively. (e–g) Power spectral density (PSD) estimates for Sv (dB2 cpd-1) at various depths. Nocturnal emergence dominated, but a substantial fraction of the animals at any one time were found within 1 m of the bottom (Sato and Jumars 2008).

RESULTS

Sato and Jumars (2008) found clear seasonal changes in *Neomysis americana* vertical migration phasing with respect to both daylight and tides. By sampling the lowermost meter of the water column with a down-looking TAPS, we confirmed previous impressions from net sampling (Mauchline 1980) that *N. americana* spreads its vertical distribution (Fig. 1) rather than engaging in wholesale population migration to the surface at night. Thus our general conclusion that mysids dominate biovolume of holoplankton by an order of magnitude (Jumars 2007) is a serious understatement of their actual abundance. Emergent meiofauna evident at higher frequencies emerged predominantly at slack tides and reached surface waters only at low slack.

Dorgan *et al.* (2008) tested simple wedge theory that predicts the shape that a worm should take to move through muds differing in fracture toughness and stiffness. They used various clear polymers to create gels that varied in these parameters. As predicted, worms formed blunter wedges when confronted with tougher materials (Fig. 2). Stiff but not tough materials elicited a side-to-side motion that has been seen many times before (*e.g.,* Hunter *et al.* 1983), but had not been well understood. Based on numerical models of the resultant forces on their bodies, we reinterpret this behavior to be a means of relieving compressive forces on the worm's body through widening of the resulting crack. More generally, this simple wedge theory provides understanding of body shapes of burrowers and provides a promising new approach to evaluate bioturbation consequences of burrowing by crack propagation and feeding in the resulting cracks.

As detailed in our FY07 report, 2005 observations from MVCO showed clear nocturnal emergence of mysids. Mysid emergence was weaker in 2007, but daytime mating emergence by benthic amphipods occurred in dramatic fashion and produced intense fish feeding activity. The new, dual-frequency, split-beam system clearly is better at assessing local fish abundance than is TAPS, but we have not yet optimized it to our satisfaction for mysid abundance and patchiness measurements.

IMPACT/APPLICATIONS

Knowing where and when high-abundance emergence events occur is important with respect to the environment for use of active acoustics for mine detection and identification. Emergence also appears to be closely associated with importance of mysids in fisheries food webs. The most abundant mysids on continental shelves are those that actively emerge, and that emergence is clearly associated with their encounter with, and consumption by, both benthic and pelagic fishes (Jumars 2007). They have been omitted from many model food webs despite their frequent dominance of nocturnal micronektonic and total pelagic biomass.

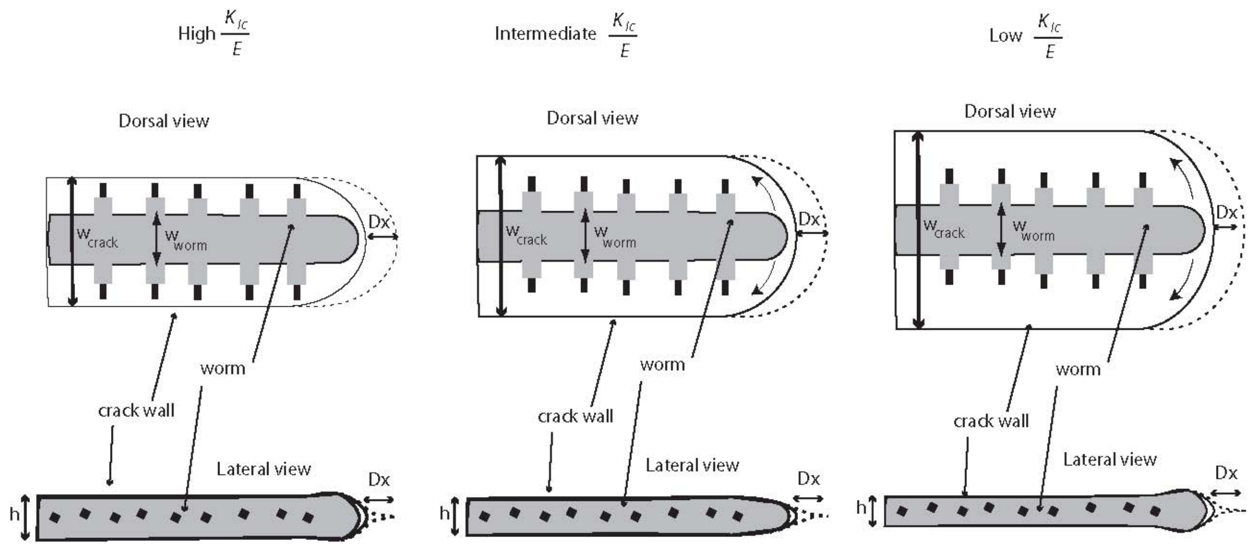

Figure 2. Scheme of differences in burrowing mechanics and worm shape with changing ratios in fracture toughness (KIc) to stiffness (E). Worm width is measured at the 4th setiger. In materials dominated by fracture toughness, the worm presents a blunt wedge. In materials dominated by stiffness (high Young's modulus), worms engage in extensive side-to-side head motion to widen the crack and relieve stresses from elastic rebound.

By better understanding the mechanics of burrowing, we are steadily increasing our ability to specify realistic rules for behavior of burrowers as well as the stratigraphic and biogeochemical consequences of burrowing events. These pieces of information are needed to formulate automaton models (*e.g.*, Boudreau *et al.* 2001; Choi *et al.* 2002) that are sorely needed to replace seriously flawed diffusion models of bioturbation (Meysman *et al.* 2003). Our new understanding also suggests that the earliest burrowers may have operated in sands, where granular mechanics makes shallow burrowing comparatively easy (Jumars *et al.* 2006).

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