

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

Peter A. Jumars
Darling Marine Center
University of Maine
193 Clark's Cove Road
Walpole, ME 04573-3307
phone: (207) 5563-3146, x.242 fax: (207) 563-3119 email: jumars@maine.edu

Award Number: N00014-03-1-0776
<http://www.marine.maine.edu/~jumars/>

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 our current research 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 and the northwest Atlantic coastal zone more generally. Coastal emergence behaviors appear to differ substantially to the south (Jumars 2007). 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 the Damariscotta River estuary likely is more representative of coastal waters than of an estuary because of its limited freshwater input. It is most accurate to think of it as a shallow fjord.

An additional objective that 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 (Dorgan et al. 2006); flaw detection by acoustic means is a common industrial approach that may now become useful in assessing acoustic properties of muds.

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 2006		2. REPORT TYPE N/A		3. DATES COVERED -	
4. TITLE AND SUBTITLE Vertical and Horizontal Migrations Affect Local and Integrated Water-Column Scattering Strengths				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Darling Marine Center University of Maine 193 Clarks Cove Road Walpole, ME 04573-3307				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU	18. NUMBER OF PAGES 4	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

APPROACH

Our work relies 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. This approach limits us to sites with cabled power and data communications.

The final focus of our TAPS work was to observe events as near to the seabed as we could, while placing them in the context of our prior, up-looking records of emergence. We did so by mounting two TAPS on closely spaced tripods, one looking up and one looking down. Our primary activity for FY07, however, was to continue the publication process with data collected as Mei Sato's M.S. thesis (Sato 2006) and Kelly Dorgan's Ph.D. dissertation (Dorgan, in preparation).

We also continued our efforts to place our work in a broader regional context. We added another field effort at MVCO (Martha's Vineyard Coastal Observatory) during September 2007 to our records for September 2005. We also took emergence trap samples at 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.

Kelly Dorgan, a Ph.D. candidate, led our principal effort this year with burrowing. She completed the first analysis of burrowing forces that explicitly parameterizes and measures the relevant mechanical properties of mud. She also produced a range of transparent materials made of different organic polymers that systematically vary the mechanical properties of mud that control the forces needed to burrow, i.e., Young's modulus and the critical stress intensity factor.

WORK COMPLETED

We obtained two, multiple-week data series in the Damariscotta estuary with the combined up- and down-looking TAPS. We recorded data with one TAPS from MVCO for several weeks in September 2007, but as of this writing have not recovered the instrument. Nor have we done the QAQC needed to tell whether the data are reliable. Using photoelastic stress analysis and quantitative videography, Kelly Dorgan documented differences in polychaete worm burrowing behavior in materials of varying elasticity and fracture toughness.

RESULTS

Our up- and down-looking TAPS data showed distinct seasonal changes in migration behaviors of mysids, shifting from nocturnal in summer to semidiurnal tidal in fall (Sato and Jumars, in review). Our prior work has shown in work in Puget Sound (Kringel et al. 2003) as well as in the Damariscotta River estuary (Taylor et al. 2005) that emerging mysids — in total, vertically integrated biovolume — exceed holoplankton by an order of magnitude. The down-looking TAPS data show that we have seriously *underestimated* the biovolume of mysids, at least for the Damariscotta River estuary, because the majority at any one time stay in the lowermost meter of the water column even during the largest emergence events. This observation has particular relevance to mine hunting and identification.

The observations from MVCO in 2005 showed clear nocturnal emergence of mysids. That result was expected from previously published work (reviewed by Jumars 2007). Emergence traps in 2007, however, were filled with what appear to be ampeliscid amphipods that divers also reported to be in breeding aggregations (clapsed postures) daily in surface waters during mid afternoons. We are eager to see our TAPS acoustic records for comparison with these diver observations.

In the first analysis of worm mechanics that explicitly used the relevant mechanical properties of the burrowing medium, we found that prior estimates of burrowing forces were grossly exaggerated due to poor understanding of the mechanics of burrowing and artifacts of the methods used (Dorgan et al. 2007). Worms showed clear differences in behavior in materials of varying elasticities and fracture toughnesses. In stiffer materials worms widened their cracks to reduce elastic forces on their bodies. In tougher materials worms expanded their bodies to make bigger wedges (Dorgan, in preparation).

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. Thus an understanding that allows prediction of timing and geographic location of emergence events is useful for this naval application. 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.

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). We expect this new knowledge to lead to better understanding of how animals influence mechanical properties of sediments, with applications to areas such as mine burial and shore trafficability.

REFERENCES

- Boudreau, B.P., J. Choi & F. François-Carcaillet. 2001. Diffusion in a lattice-automaton model of bioturbation by small deposit feeders. *J. Mar. Res.* 59: 749-768.
- Choi, J., F. François-Carcaillet & B.P. Boudreau. 2002. Lattice-automaton bioturbation simulator (LABS): Implementation for small deposit feeders. *Computers and Geosciences* 28: 213-222.
- Dorgan, K.M., S.R. Arwade and P.A. Jumars. 2007. Burrowing in marine muds by crack propagation: kinematics and forces. *J. Exp. Biol.*, accepted
- Dorgan, K.M., P.A. Jumars, B.P. Boudreau & B.D. Johnson. 2006. Macrofaunal burrowing: The medium is the message. *Oceanogr. Mar. Biol. — Ann. Rev.* 44: 85-121.

Jumars, P.A. 2007. Habitat coupling by mid-latitude, subtidal, marine mysids: Import-subsidized omnivores. *Oceanogr. Mar. Biol. — Ann. Rev.* **45**: 89-138.

Jumars, P.A., K.M. Dorgan, L.M. Mayer, B.P. Boudreau and B.D. Johnson. 2007. Physical constraints on infaunal lifestyles: May the persistent and strong forces be with you. pp. 442-457. In: W. Miller, III, Ed. *Trace Fossils: Concepts, Problems, Prospects*. Elsevier, Amsterdam.

Kringel, K., P.A. Jumars and D.V. Holliday. 2003. A shallow scattering layer: High-resolution acoustic analysis of nocturnal vertical migration from the seabed. *Limnol. Oceanogr.* **48**: 1223-1234.

Meysman, F., Boudreau, B.P. & Middelburg, J.J. 2003. Relations between local, nonlocal, discrete and continuous models of bioturbation. *J. Mar. Res.* **61**: 391-410.

Sato, M. 2006. Diel and tidal rhythms of emergence events based on acoustics observations in a shallow estuary. M.S. thesis, Univ. of Maine, Orono, ME

Sato, M., and P.A. Jumars. Periods and phases of emergence rhythms dependent on season and depth. *Limnol. Oceanogr.*, in review.

PUBLICATIONS

(all can be downloaded from <http://www.marine.maine.edu/~jumars/>)

Dorgan, K.M., S.R. Arwade and P.A. Jumars. 2007. Burrowing in marine muds by crack propagation: kinematics and forces. *J. Exp. Biol.* [IN PRESS, REFEREED]

Jumars, P.A. 2007. Habitat coupling by mid-latitude, subtidal, marine mysids: Import-subsidized omnivores. *Oceanogr. Mar. Biol. — Ann. Rev.* **45**: 89-138. [PUBLISHED].

Jumars, P.A., K.M. Dorgan, L.M. Mayer, B.P. Boudreau and B.D. Johnson. 2006. Physical constraints on infaunal lifestyles: May the persistent and strong forces be with you. In: W. Miller, III, Ed. *Trace Fossils: Concepts, Problems, Prospects*. Elsevier, [PUBLISHED, REFEREED]

Sato, M., and P.A. Jumars. Periods and phases of emergence rhythms dependent on season and depth. *Limnol. Oceanogr.*, [SUBMITTED]

HONORS/AWARDS/PRIZES

Kelly Dorgan, Ph.D. candidate, received the 2007 American Society of Limnology and Oceanography's Raymond L. Lindeman Award for an outstanding paper written by a young scientist (for her 2005 paper in *Nature*).

Peter A. Jumars was elected to be Chair the Council of Scientific Society Presidents in 2008 (Chair Elect in 2007)