

Energy Transfer to Upper Trophic Levels on a Small Offshore Bank

Lewis S. Incze
Aquatic Systems Group
University of Southern Maine
350 Commercial St.
Portland, ME 04101
phone: (207) 228-1676 fax: (207) 228-1689 email: lincze@usm.maine.edu

Scott Kraus
New England Aquarium
Central Wharf
Boston, MA 02110-3399
phone: (617) 973-5457 fax: (617) 973-0242 email: skraus@nea.org

David Fields
Bigelow Laboratory for Ocean Sciences
Box 475 180 McKown Pt. Rd.
West Boothbay Harbor, ME 04575
phone: (207) 633-9600 fax: (207) 633-9641 email: dfields@bigelow.org

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LONG-TERM GOALS

We propose to combine field observations and laboratory experiments to understand the coupling of physical and biological processes that transfer energy from lower to higher trophic levels on a small offshore bank. We focus this study on Platts Bank, in the western Gulf of Maine, and on the relationship between internal waves, patchiness of planktonic organisms (especially euphausiids, *Meganyctiphanes norvegica*), and feeding and residence times of upper trophic level predators (marine and avian, but especially baleen whales, and particularly the abundant humpback whales, *Megaptera novaeangliae*). Observations from Platts Bank and other feeding hotspots in the Gulf of Maine show that they are ephemeral—sometimes very active, often not. Our goals are to understand the factors that drive the “on” and “off” patterns of feeding at features such as Platts Bank, and to gain insights into the foraging strategies and mechanisms employed by highly mobile predators to exploit ephemeral and scattered feeding locations.

OBJECTIVES

1. Quantify patterns of upper trophic level use of Platts Bank over multiple years, extending observations from the original two years of observation that preceded this award.
2. Describe behaviors adapted to feeding on Platts Bank and foraging on networks of scattered feeding sites such as Platts.

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3. Measure and describe the internal wave field, associated velocities, and euphausiid distribution and abundance patterns.
4. Use field and laboratory studies to document and quantify the behavior of euphausiids and the coupled bio-physical processes that affect surface patch formation, in particular testing the hypothesis that internal waves help drive surface aggregations and upper trophic level feeding.

APPROACH

1. Use standard survey methodologies for enumerating large and mobile predators (marine and avian) on Platts Bank.
2. Develop a protocol for documenting predator orientation and behavior.
3. Use acoustic techniques (sound scattering) to survey the internal wave (IW) field and biological sound scattering on and around Platts Bank.
4. Measure at multiple scales the properties of internal waves, including amplitudes, frequency, and water velocities that would affect planktonic organisms. CTDs and a thermistor chain (T-chain) precisely measure vertical displacements and frequencies of IWs. CTDs are deployed in cast and fixed-depth modes. The T-chain consists of 10 rapid-response (2 s, accurate to 0.01 °C) thermistors located every 2 m along a data cable (Precision Measurement Engineering, Carlsbad, CA). Depth of the bottom thermistor is ascertained with a VEMCO internally recording temperature and depth sensor. A 1200 kHz RDI ADCP measures water column velocities at 25 cm vertical resolution down to about 15-17 m, sufficient to study the region of most interest above the seasonal pycnocline and the propagating internal waves. A velocimeter (6 MHz, 3D velocity) measures velocities at 1 cm³ scale at controlled depths.
5. Observe the behavior of euphausiids in the field with underwater video camera supplied with natural or IR light, attempting to do so in swarms and in the presence of internal waves.
6. Observe the behavior of euphausiids in a laboratory flume, using water velocities equal to those measured in the field.
7. Measure the mechanosensory/neurophysiological threshold for euphausiid response to fluid motion by placing microelectrodes into the antennules while the animal is exposed to well-controlled fluid signals created by the flume.

We received extremely valuable advice and assistance with our early acoustic work from Andone Lavery, Timothy Stanton and Peter Wiebe, all at the Woods Hole Oceanographic Institution. A. Lavery served on the MS Committee of a graduate student in L. Incze's laboratory. A joint publication on one aspect of the work is planned.

WORK COMPLETED (2008)

1. Conducted seven day-cruises to Platts Bank and Jeffreys Ledge, with predator counts and behavioral and orientation records.

2. Conducted acoustic transects of the internal wave field patterns on and off the bank.
3. Constructed spars to mount ADCP and camera/velocimeter independently of the research vessel, vastly improving measurements.
4. Obtained measurements of the internal wave field on the bank using the T-chain and small-scale velocity measurements (velocimeter, 1 cm³ volume). 1200 kHz ADCP data down to 15-17 m were collected but not yet analyzed.
5. A small flume (32 L) has been built and calibrated. Flow speeds recorded in the field are within the range of speeds achieved in the flume. Upward velocities were created by moving a perpendicularly mounted cylinder into the flow. The speed of the cylinder was controlled by a linear drive with 25 cm travel. This allowed us to mimic the approach (increasing upward velocity) and passing (downward velocity) of an internal wave.
6. Preliminary data on krill behavior were made in Norway in May 2008. Animals were tethered on a small glass rod and positioned within the flume. Flow measurements were made simultaneously with video observations of krill behavior and analyzed for increased swimming speeds as a function of changes in vertical velocity. Preliminary data (1 animal) show a significant increase in swimming speed and duration of swimming with increased flow speed.

RESULTS

Field measurements: A spar-mounted camera and velocimeter were used to measure the vertical velocity of internal waves passing over Platts Bank (Figs. 1-3). The spars dramatically improved data collection by reducing high-frequency vertical motions. A MgCO₃ source near the velocimeter provided enough particles to measure velocities in a small volume (1 cm³) at high frequency (16 Hz), which was previously a problem in the relatively clear offshore waters. Vertical velocities measured by the velocimeter were on the order of 0.025 m/s, or ~1 body length s⁻¹ for the average euphausiid in our study area. The measurements agree with vertical displacement rates calculated with T-chain data. The advantage to the T-chain is that it records displacements at all depths above approximately 22 m (Fig. 4), and can be deployed all day without interruption. T-chain data recorded a drop in the average depth of a reference isotherm with the onset of slack tide, apparently the cessation of an internal tide on the bank (Fig. 5). This is the best measurement we have of this phenomenon, observed before with acoustic data which are ambiguous about the specific depth of the pycnocline. The depth of the pycnocline has an impact on how the IWs affect surface flows and, we hypothesize, surface plankton aggregations. The change in water column structure is shown with CTD data in Figure 6.

Laboratory measurements: In a small flume (32 L) we were able to mimic the increasing upward velocity and decreasing downward velocity typical of IWs measured in our field site. Preliminary data on krill behavior (1 animal) show a significant increase in swimming speed and duration of swimming with increased flow speed.

IMPACT/APPLICATIONS

We plan to increase knowledge of krill behavior in offshore waters, including vertical distribution, interannual variability in abundance, interactions with internal waves, and mechanisms of patch formation. In addition, we will define thresholds for reactions to flow fields that should have broader

application than just internal waves or Platts Bank. By studying bio-physical mechanisms and upper trophic level behaviors on Platts Bank, we hope to provide insight into the processes that affect good and poor feeding conditions in areas of rapid topographic relief, such as Platts Bank, and the foraging behaviors and strategies that allow highly mobile, upper trophic level predators to exploit scattered and ephemeral feeding areas. This would help to explain vagrancy/residency patterns and movements of animals, including the large whales.

RELATED PROJECTS

This project has a relationship with the Gulf of Maine Area Program of the Census of Marine Life (<http://www.usm.maine.edu/gulfofmaine-census/>), which funded the first two years of observations on Platts Bank and led to the current research program funded by ONR. The Census is focused on defining patterns of biodiversity in the oceans and the processes that shape them. The Gulf of Maine program has the additional aim of describing how that diversity influences the ecosystem, and how diversity and functionality can be maintained. Incze is the lead PI on the program, and Kraus leads the upper trophic level expert group. The census is entering its synthesis period in 2009-2010.

PUBLICATIONS

Stevick, P., L. Incze, S. Kraus, S. Rosen, N. Wolff and A. Baukus. 2008. Trophic relationships and oceanography on a small offshore bank. *Mar. Ecol.-Progr. Ser.* 363: 15-28.

Baukus, A. 2008. Importance of internal waves for the density, distribution and trophic dynamics of euphausiids on a small offshore bank. MS Thesis, University of Southern Maine, Portland, ME. 58 p.



Fig. 1. Spars used for suspending instruments and dampening motion generated by surface waves. Top figure shows two spars in operation, holding the camera/velocimeter package (distant) and a 1200 kHz ADCP. They are tethered and cabled to the boat for real-time data display, but can also be cast free in internal recording mode. Lower left shows the bottom half of a spar with ADCP attached (sensors covered); lower right shows three spars on deck.



Fig. 2. David Fields prepares camera and velocimeter package for deployment. A vane holds the viewing field of the camera and the velocimeter (three-pronged device, in front) toward the current and in undisturbed flow. An innovation employed this year places a source of MgCO_3 above the velocimeter to provide enough particles to measure velocity in the relatively clear waters over Platts Bank.

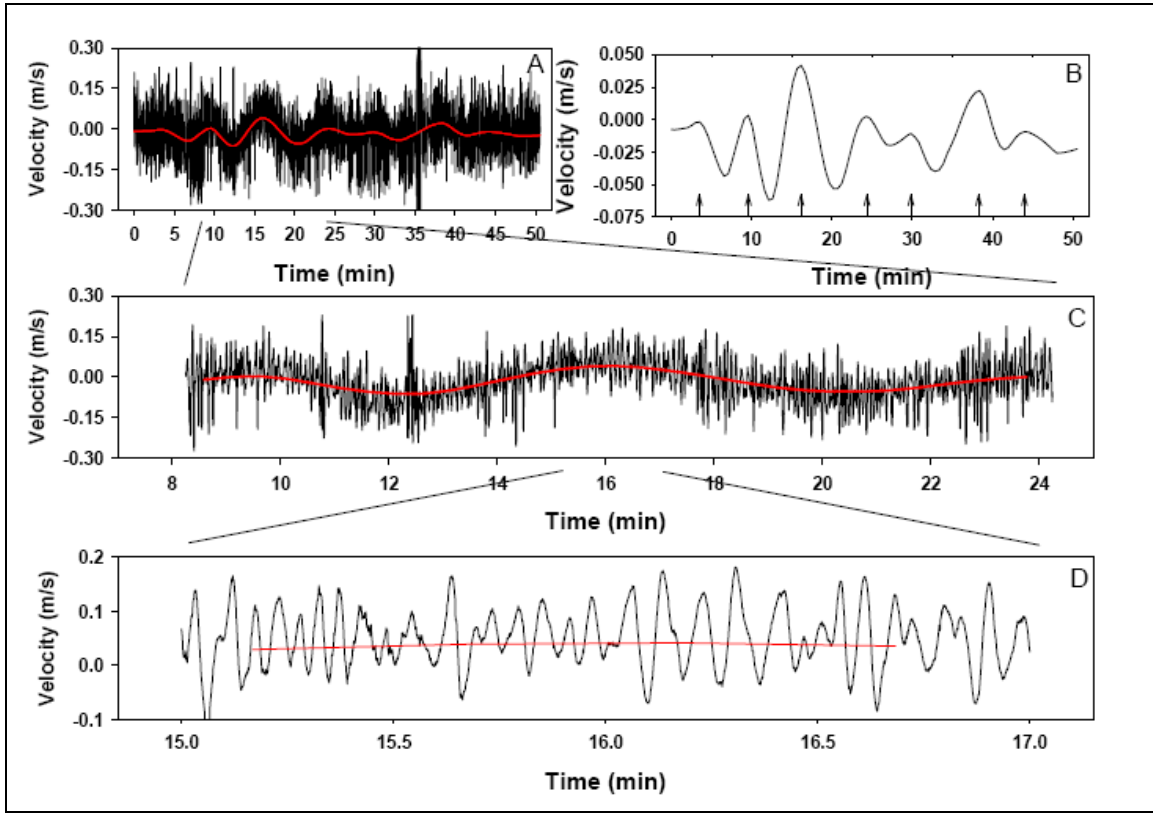


Fig. 3. Velocimeter data at 10 m depth. Upper left, Panel A, shows a 50 minute recording of vertical velocity, in m/s. Data were collected at 16Hz. Black lines are displacements caused by surface waves. The red line is a moving average of the velocity, which is isolated in Panel B with the velocity-scale expanded. Note that the indicated wave periods are 5-8 minutes, which is the internal wave period observed with acoustics (120 kHz), visually at the surface, and with the T-chain. The range of velocities are close to those calculated from T-chain measurements of isotherm displacements (see Figs. 4-6). Panels C and D examine the velocities more closely, showing the ~ 0.025 m/s upward velocity associated with the passing crest at time=16 minutes in the data segment shown in Panel A. This is equivalent to $1 \text{ body length s}^{-1}$ for the average euphausiid (*Meganyctiphanes norvegica*) in our study area.

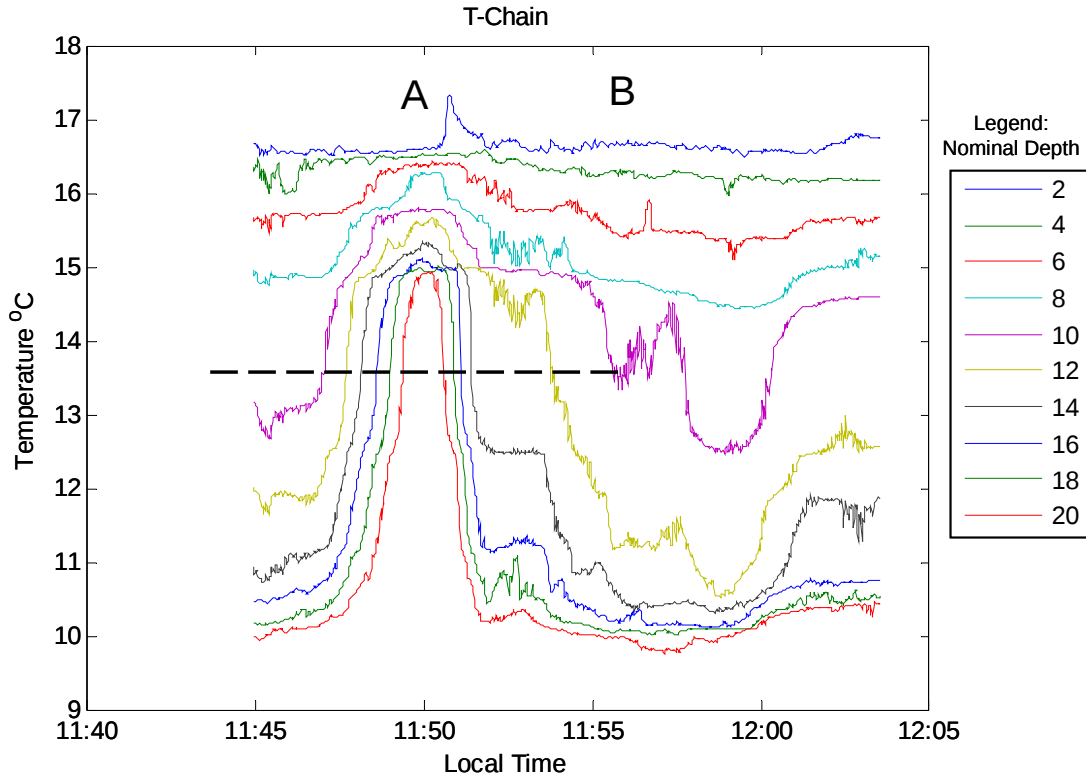


Fig. 4. A short section of T-chain data, showing how temperatures at fixed depths record the passage of an internal wave. The legend at right shows the nominal depths of rapid-response thermistors that are spliced into a conducting cable. Depths are corrected in final data processing using data from a pressure sensor at the end of the chain. “A” and “B” denote downwelling (convergence at the surface) and upwelling periods, respectively. [The wave structure is the inverse of the temperature pattern. Downwelling is indicated by increasing temperatures (y axis) at fixed depths (thermistors), while upwelling is marked by the opposite trend.] The horizontal broken line is drawn for reference: from 11:47 to 11:50 the 13.6 °C isotherm shifts from 10 to 20 m depth and then shallows, indicating an internal wave with amplitude ~10m. The general wave pattern can be rapidly assessed in the field from the real-time display of these data.

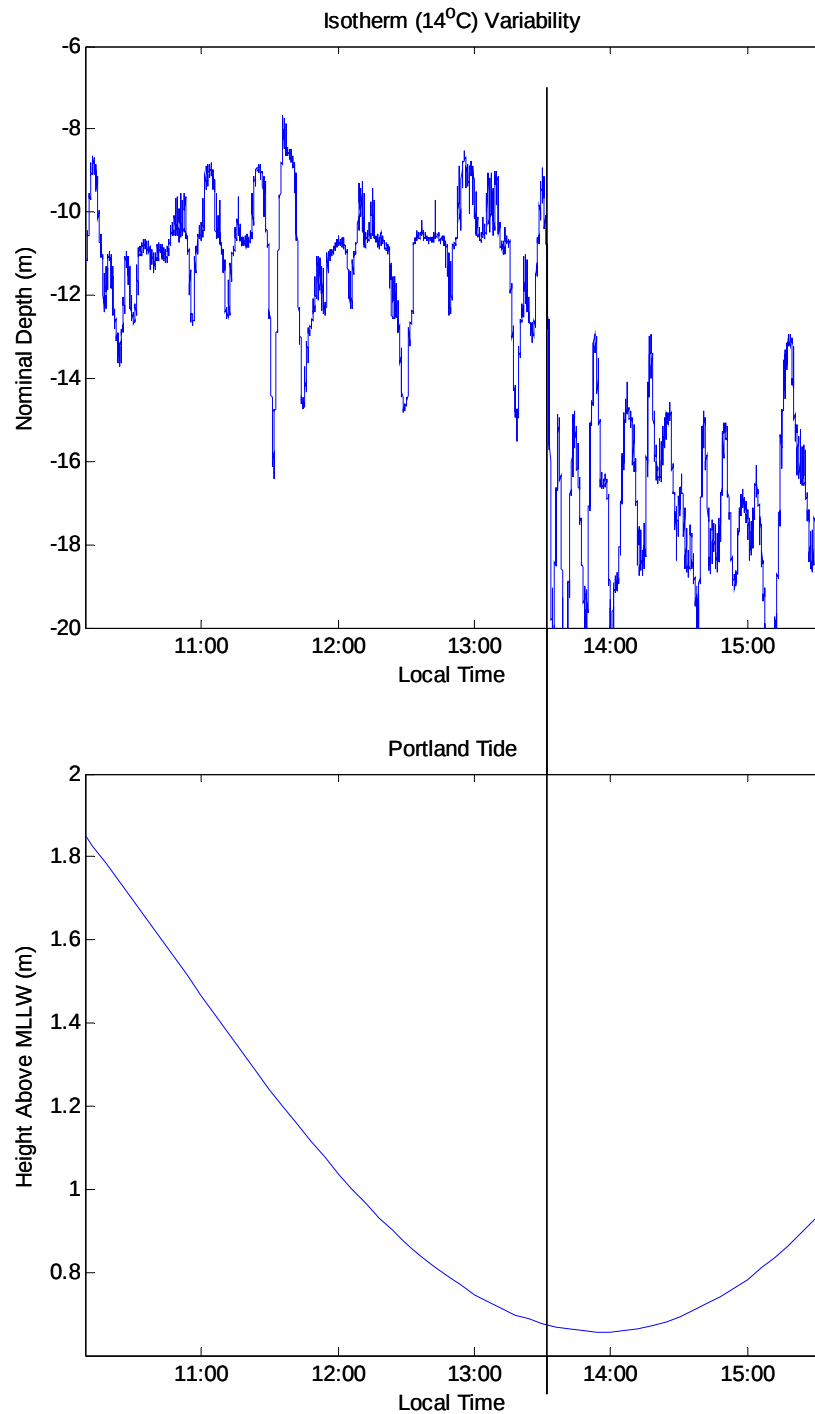


Fig. 5. Changes in the depth of the 14 °C isotherm obtained from T-chain data on September 10, 2008. Sudden deepening of the isotherm at ca. 13:40 was associated with slackening of the tidal stream over the crest of the bank, and indicates the presence of an internal tide while the tide was ebbing (flowing east over the bank). Vertical grey line is for reference. The shallower average depth of the pycnocline (see Fig. 6) brings internal waves closer to the surface, with impacts on euphausiid depths and associated surface flows (Fig. 7) and, we hypothesize, the formation of surface aggregations in the convergence zones.

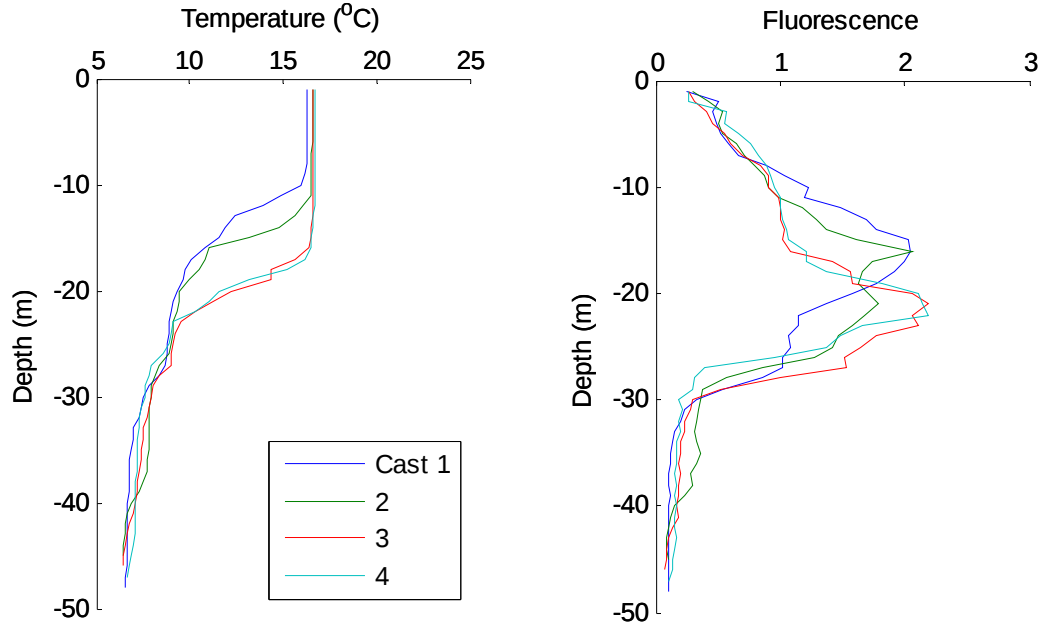


Fig. 6. Temperature and fluorescence profiles accompanying the isotherm data shown in Fig. 5. Casts 1-4 were taken at 09:43, 13:23, 14:03 and 14:57, respectively. The first two casts were taken when an internal tide over the crest of the bank kept the average pycnocline depth shallow; the latter two were taken after the internal tide had relaxed with the slack tide. Tide information is from Portland Harbor and is probably close in time to the local tide, which will be calculated from dGPS drift rates (the ADCP cannot be used for measuring tidal velocity over the bank due to a lack of bottom tracking reference in the deep water).



Fig. 7. The slick in this photograph shows a region of divergence over the crest of an oncoming internal wave (foreground) and a region of convergence (roughened surface) behind it. Internal wave structure is recorded by temperature profiles (T-chain), current profiles (ADCP), small-scale velocities (velocimeter), and acoustics (120 kHz) as the wave passes beneath the research vessel. We are examining plankton behavior, patchiness and upper trophic level feeding patterns and strategies in the presence of these waves, especially as the depth of the wave/pycnocline shallows over topographic features.



Fig. 8. The PIs: Lew Incze (upper left), David Fields (right) and Scott Kraus (lower).