# Zooplankton Aggregations Near Sills

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## LONG-TERM GOALS

The overall goal of this multi-investigator project is to understand the biological and physical mechanisms for producing and maintaining dense aggregations of zooplankton in regions where ocean currents interact with steeply-sloping coastal sills. Field trials combining multi-frequency acoustics, instrumented plankton net tows, and in situ optical techniques will be conducted in FY02 and FY03.

## OBJECTIVES

The objective during this year was to conduct a retrospective study of echo-sounder and other physical oceanographic data collected during the late summer of 1995 in Knight Inlet, B.C. This previous ONR-funded field trial (conducted by D. Farmer, L. Armi, M. Gregg, E. d'Asaro, F. Henyey) was focused on internal hydraulic features and internal waves in tidal flows over a coastal sill, but nevertheless produced a data set rich in information on zooplankton aggregations. This present study was focused on providing a physical oceanographic context and some preliminary ideas about zooplankton distributions that will assist in designing survey strategies for sea-trials planned in this area during November, 2001.

## APPROACH

Raw echo-sounder and other physical oceanographic data, such as CTD, thermistor chains, and micro-structure profiles, were retrieved from archives held by D. Farmer at the Institute of Ocean Sciences and by M. Gregg at the Applied Physics Laboratory, Univ. of Washington. The work of retrieving the data and sending it to this PI was performed by G. Kamitakahara at IOS and J. Klymak at APL/UW, and their assistance is greatly appreciated. Software was developed for display and analysis of the echo-sounder data, which was reviewed for zooplankton occurrence, with emphasis on understanding ebb vs. flood tide and diurnal variations. Some effort was made to identify and review sources of the acoustic scattering. Unfortunately, little quantitative zooplankton information could be gleaned from this data because neither system had been calibrated and no net samples were taken.

## WORK COMPLETED

The entire 15 days of 200kHz echo-sounder data set collected by M. Gregg from the *RV Miller* in late August and September, 1995 was reviewed. This data was collected during daylight hours under both ebb and flood tide conditions. Additionally, some selected portions of 120 kHz echo-sounder data collected by D. Farmer from the *CSS Vector* were retrieved and reviewed, with emphasis on night-time conditions. Attempts were made to produce rough echo-sounder calibrations by assuming typical

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14. ABSTRACT

**The overall goal of this multi-investigator project is to understand the biological and physical mechanisms for producing and maintaining dense aggregations of zooplankton in regions where ocean currents interact with steeply-sloping coastal sills. Field trials combining multi-frequency acoustics, instrumented plankton net tows, and in situ optical techniques will be conducted in FY02 and FY03.**

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values of zooplankton species and densities for deep day-time scattering layers. Several microstructure profiles were compared with co-located echo-sounder data, lending support for hypothesized acoustic scattering from turbulence within near-surface shear layers. A detailed technical report summarizing these findings and making recommendations for future sea-trials was prepared and distributed.

**RESULTS**

The high-resolution vessel-based echo-sounders used in the 1995 surveys produced dramatic images of complex internal hydraulic flows, turbulence, and zooplankton distributions in the vicinity of the Knight Inlet sill. Figure 1 shows an example. The addition of high-resolution *in situ* current (ADCP) and water property (CTD and turbulence) profiles allowed some interpretation of the echo-sounder image features, including assessment of the flow internal hydraulics (see e.g. Farmer and Armi 1999a,b) and identification of acoustic scattering regions attributable to either zooplankton or turbulent microstructure. This present work has found that the general zooplankton distributions were modified only modestly by the turbulent internal hydraulic flows over the sill. The zooplankton retained their classic diurnal migration habits, forming into relatively dense layers at 60 to 120 m depth during the day and dispersing throughout the entire water column at night. This behaviour is suggestive that the zooplankton scattering layers were dominated by Euphausiids, which are common in B.C. coastal inlets such as Knight Inlet. During the day-time on both ebb and flood tides, there was clear evidence that the zooplankton layers were trapped and concentrated by the flow against the upstream side of the sill (which projects above this daytime scattering layer), as shown for example on the right-hand (upstream) side of the sill in Figure 1. At night, and particularly during periods of slack water, the zooplankton and small fish were seen dispersed throughout the water column with seemingly little regard for the internal tidal flows.

A comparison of acoustic scattering with the *in situ* temperature, salinity, and turbulence profiles suggested that microstructure scattering was responsible for the *flow lines* appearing in the strongly stratified near-surface region (upper 20 m). In particular, over the crest of the sill the flow often separated into distinct layers with strong pycnoclines and current shear at the boundaries. These acoustically-imaged flow lines were found to correspond directly to pycnoclines and turbulence maxima observed with the *in situ* profiling devices. Through the use of microstructure scattering models, volume scattering strengths were predicted along these boundaries which were roughly consistent with the acoustic measurements. Outside of the these strongly stratified layers, the predicted microstructure scattering was small or negligible due to either small temperature and salinity gradients or small turbulence dissipation rates, or both. This left only zooplankton (in general) as the source of acoustic scattering throughout the bulk of the deeper waters. This separation by depth is fortunate, as the predicted level and spectral shape of zooplankton and microstructure scattering were found to be similar at these typical echo-sounder frequencies (100 to 200 kHz). Another potential means to distinguish between zooplankton and microstructure scattering is through the use of multiple echo-sounder frequencies. At a minimum two echo-sounder frequencies should be used, one operating in the 20 - 50 kHz range and the other at 100 - 200 kHz. At or below 50 kHz the zooplankton scattering should be greatly reduced relative to the microstructure scattering level.

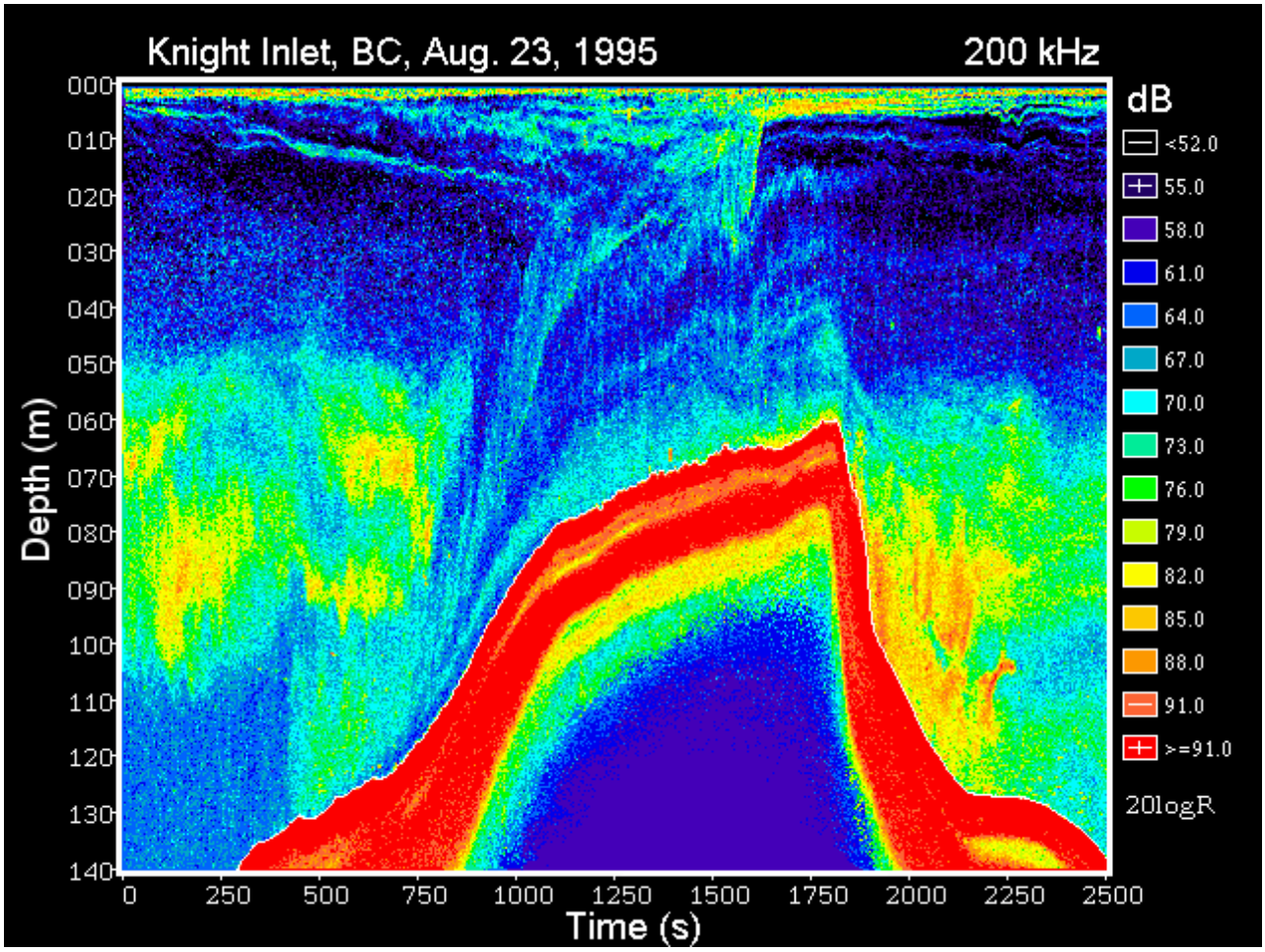


***Figure 1 Raw 200 kHz echo-sounder intensity vs. depth and time (seconds) starting 1715Z Aug. 23rd, 1995 from RV Miller heading from east to west across sill during daytime flood tide. Tidal flow is from right to left (opposite to direction of ship travel), with near-surface scattering layers illuminating a flow bifurcation over the middle of the sill. White line indicates the detected seabed.***

In addition to the obvious requirements for acoustic calibrations and *in situ* zooplankton sampling, this study suggests a number of hypotheses which should be investigated in future field surveys, namely:

1. It was asserted that the zooplankton clouds observed during day-time at 70 to 120 m depth were dominated by Euphausiids (largely *E. pacifica*), with other species making negligible contributions to the acoustic scattering. It was further asserted that zooplankton abundances were low or negligible within the strongly stratified upper layers during the day. Net trawls and in situ sampling are clearly necessary to resolve the species and depth of occurrence.

2. Simple fluid sphere and cylinder models for the zooplankton scattering were proposed, based on previous modeling and measurement work. It was asserted that these low-resolution models were appropriate for measuring average scattering levels over populations with some variation in size and orientation. Clearly, it is necessary to investigate the validity of these models, through both net trawls to establish abundances and animal sizes and through some form of *in situ* monitoring of animal orientation. Acoustic measurements at several frequencies are required.

3. During daylight, it was speculated that some zooplankton from the pool trapped against the upstream slope were caught by the currents and carried up and over the sill, creating the observed near-bottom layer flowing over the sill crest. Both diel and nocturnal advection over the sill would homogenize the zooplankton populations on opposite sides of the sill, which can be verified by net samples. A competing hypothesis is that this near-bottom layer is a result of bottom boundary-layer turbulence, and that zooplankton are not advected over the sill during daytime. Simultaneous net and acoustic surveys overtop of the sill during tidal current maxima would shed light on this.

4. Very high levels of acoustic scattering were observed within the near-surface region (depths <10m), above the main pycnocline and away from zones of high turbulence. This scattering is probably of biological origin, but the exact source is unknown. Near-surface zooplankton samples are necessary.

## IMPACT/APPLICATIONS

It is hoped that this work and subsequent field-trials will provide a better understanding of:

1. the links between zooplankton aggregations and physical oceanographic phenomena

2. demonstrate techniques to distinguish between zooplankton and microstructure-based acoustic scattering, which are often co-located.

## TRANSITIONS

The results from this study will be used by the other co-investigators to design zooplankton sampling strategies for the fall 2001 field trials, and as a framework against which new measurements can be compared.

## RELATED PROJECTS

In FY 02 and 03, ONR-funded collaborative sea trials with D. Mackas from IOS and M. Benfield from Louisiana State Univ. will be conducted at the Knight Inlet sill, and possibly other locations. D. Mackas will coordinate the ship-time on the CCGS Vector and will operate an instrumented BIONESS trawl. Additionally, D. Mackas has worked with the group headed by D. Farmer at IOS to develop and test a 3-frequency calibrated echo-sounder system. M. Benfield will operate an in situ optical zooplankton imager (ZOOVIS).

## REFERENCES

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## PUBLICATIONS

Trevorrow, M., 2001. *Zooplankton aggregations near a coastal sill: an examination of echo-sounder data from August and September 1995 in Knight Inlet, B.C.* DREA Technical Memorandum 2001-119, Defence Research Establishment Atlantic, Dartmouth, NS, 35 pages.