Zooplankton retention in Muchalat Inlet, a fjord basin in Nootka Sound, BC

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Abstract

The distribution of zooplankton populations in response to tidal forcing was studied at Williamson Sill in Muchalat inlet of Nootka Sound, British Columbia, Canada in December 2015. Net tows were taken at four stations surrounding the sill and were analyzed for abundance (organisms m^{-3}) and organism size. Results show a higher accumulation of zooplankton on the outward side of Williamson Sill during ebb and flood tides, suggesting the sill is utilized by zooplankton as a means of avoiding transport out of their preferred habitat.

Introduction

A fjord is a narrow and deep ocean inlet formed from glacial advancement and retreat that carves deep valleys throughout the affected region. As a glacier advances, it pushes sediment along its path and upon its retreat fills the carved valley with water and leaves a shallow ridge near the mouth of the fjord. This results in an accumulation of sediment that creates a sill. The sill acts like a wall between the deep ocean water and deep fjord water, restricting interaction between the two (Geyer 1982.) The sill also sill creates a layer of more stable deep water that often acts as a haven for small biological organisms like zooplankton to avoid transport out of a nutrient-rich fjord.

Nootka Sound is an estuarine fjord system on the western side of Vancouver Island, British Columbia, Canada where there has been minimal planktonic research. However, the commercial fishery industry, some of which is located in Nootka Sound, is a vital economic resource for Canada – in 2015, Canadian exports of fish and seafood equaled over $5.9 billion (Fisheries & Oceans, Canada.) In cold waters, fish must pursue a fatty diet to increase the chance of survival through the winter, ensuring continued existence of the population. Zooplankton, specifically lipid-rich zooplankters like copepods and euphausiids, are key prey for higher trophic levels including commercial fish such as various salmon species in British Columbia (Tommasi 2013 and Gardner 1982.) Zooplankton success is closely related to both environmental conditions (primary production and nutrient availability) and physical forces (currents and mixing rates.) Fjords are often fed by rivers that input vital nutrients to the system necessary for primary production such as NO_3 and NH_4, which are usable forms of nitrogen for many phytoplankton species (Smith 2006.) Muchalat Inlet in Nootka Sound is fed by Gold River, so it may be beneficial for zooplankton to avoid export from the fjord to maintain access to nutrients and a food source.

Scientific literature has established that macro-zooplankton populations often undergo diel vertical migration (DVM) patterns, retreating to deep waters during the day to avoid predation and returning to the surface at night to graze (Shaw 1998.) In a fjord, zooplankton populations may be conserved, or retained, when they avoid the upper photic zone above the sill, where water can be more readily transported out of the fjord during an ebb tide (Gorsky 2000.) Copepods and euphausiids are particularly suited for DVM behavior because of their swimming ability, and research suggests that large zooplankters like *Euphausia pacifica* swim downwards when exposed to small scale velocity increases like those introduced at a sill (Digre 2015.)

This study is an investigation of copepod and euphausiid distribution around the Williamson Sill in Muchalat Inlet and the sill's influence on retention of these key zooplankters. The goal of this research is to better understand how well zooplankters are retained in a fjord basin in regards to tidal forcing and nutrient availability. Accumulation on one side of the sill during ebbing tides is hypothesized as a means of escaping transportation. A deeper understanding of how environmental conditions and physical processes of a fjord system affect zooplankton distribution can lead to more efficient fishing strategies.

Methods

Field Methods

Zooplankton samples were collected aboard the R/V *Thomas G. Thompson* from 10-20 December 2015 during cruise TN334 in Nootka Sound, British Columbia, Canada. Samples were collected at four stations in Muchalat Inlet: (B01) a control site near the mouth of the inlet, (B02) the outward side of Williamson sill, (B03) the inland side of Williamson sill, and (B04) a control site within the inlet (Figure 1.) Samples were taken from each of these sites at various points in the tidal cycle.

The first four samples were obtained with bongo net tows, 0.6-meter diameter drums with 333-micron mesh. These oblique tows captured zooplankton from a depth of 10 meters from the seafloor through the entire water column. Tow speed was 1.5-3 knots, and winch speed of 30 m/minute. This type of tow is more likely to capture net-avoiding euphausiids than vertical tows but does not capture some of the smaller copepods. The bongo net was lost halfway through the cruise, so all following samples were obtained with vertical net tows, 0.5-meter diameter opening with 209-micron mesh. Again, tows were taken through the entire water column from 10m off the seafloor.

Tows 1-4 were conducted during ebb tide using a bongo net, and tows 5-12 were taken during flood tide with a vertical net. A moored ADCP was deployed in Muchalat Inlet at the beginning of the cruise to measure water speed and direction at ten-second intervals. All samples were preserved in 750ml polypropylene jars with 5% buffered formalin or alcohol solution and stored for later analysis.

Water samples were collected with niskin bottles attached to a deployed CTD rosette at stations C04, C07, and C09 (Table 1) to examine $N0_3$ and NH_4 concentration. These samples were collected at five depths throughout the water column. Station C04 was located in the main Nootka Sound basin, outside of Muchalat inlet. C07 and C09 were within Muchalat, one outward of Williamson sill (C07) and one inland of the sill (C09.)

Laboratory Methods

Samples were filtered and diluted in freshwater to a known volume, then 5mL subsamples were taken with a stempel pipette and viewed under a dissecting microscope. Two to three subsamples were taken for each full sample and copepods and euphausiids were counted and sorted into size groups. Organisms too large to be collected in a subsample were removed from the sample, counted, and measured separately. Abundance (organisms m^{-3}) was calculated by taking the number of individuals counted and dividing by the total volume filtered.

Results

Zooplankton abundance was compared to water speed and direction at each station at time of sampling from moored ADCP data. A total of twelve tows were analyzed, but only eight will be used in this report; four bongo net tows during ebb tide (negative average speed measurements) and four vertical net tows during flood tide (positive average speed measurements.)

During ebb tide, station B02 on the outward side of Williamson sill showed abundance of 566.1 org m^{-3} while station B03 showed abundance of 302.0 org m^{-3}

(Fig 2.) For the duration of flood tide, station B01 at the mouth of the inlet had the highest organism abundance of 1087.8 org m^{-3} with decreasing abundance further into the inlet; B02 at 990.3 org m^{-3}, B03 at 836.0 org m^{-3}, and B04 at 514.0 org m^{-3} (Fig 2.)

Nutrient concentrations at station C04 were relatively higher than C07 and C07 (Figs 3 & 4.) Station C04 showed the highest value of NH_4 concentration with a value of 1.07 while C07 and C09 had values of 0.44 and 0.33, respectively.

Discussion

The data shows zooplankton accumulation on the outward side of Williamson sill during ebb tide and decreasing zooplankton abundances from the mouth of Muchalat and inward during flood tide (Fig 2.) These results were unexpected; it was hypothesized that zooplankton would avoid transport out of Muchalat by accumulating on the inward side of Williamson sill. It is possible that zooplankton prefer to stay outside of the fjord because there is a greater convergence of nutrients from the three inlets of Nootka Sound, and therefore more food availability than in Muchalat inlet (Fig 3 & 4.) It is also possible that Gold River input into Muchalat increases sediment mixing and lowers light penetration, consequently limiting phytoplankton growth, outweighing the benefits of nutrient input.

The discrete samples from this research are not in concurrence with acoustic backscatter images produced with an echosounder of Williamson Sill in December of 2014 (Fig 5 & 6.) Data from Digre (2015) shows accumulation of large zooplankton on the inward side of the sill during flood tide, and relatively even distribution of targets (zooplankters) during ebb tide. Future research would benefit from having acoustic backscatter images and discrete samples from the same time period to more holistically understand zooplankton distribution around a sill and the mechanisms involved in zooplankton retention.

Halfway through the cruise, the bongo net was lost and vertical net tows were conducted for the remainder of sampling. The two types of nets have different mesh sizes, and samples can only be compared to other samples collected with the same type of mesh and tow type for consistency. Vertical net tows are not efficient at capturing net avoiders such as euphausiids and some larger copepods due to the increased swimming ability of these zooplankters. Additionally, the smallest mesh size of 209 microns does not capture some of the smallest copepods that may have been present during sampling. Because of these limitations, zooplankton distribution around the sill may not be accurately represented. Four samples from vertical net tows were extremely degraded by the time of lab analysis, and organisms could not be accurately counted or identified. This degradation likely occurred because they were not immediately fixed after sampling. For this reason, the samples were unusable, leaving a small sample size for the remaining data analysis.

Factors such as depth preferences, predation avoidance behavior, and swimming ability should also be considered in future research when investigating the effect of a sill on zooplankton populations. Further studies with more discrete samples using the same net would help generate a more complete picture of a sill's influence of zooplankton distribution. Coupling these samples with acoustic backscatter data that identifies zooplankton in the water column would also be valuable to analyze zooplankton distributions by depth during tidal events. This continued research should be conducted throughout the year and when zooplankton populations are larger, for example following a phytoplankton bloom. If food distribution is not limited, it may be less crucial for zooplankton to avoid transport out of their preferred location.

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Figures & Tables

Table 1. Coordinates of sampling stations with identification of types of data obtained at each.

Station	Latitude	Longitude	Sampling types
B01	49 39.1626 ° N	126 25.9830 ° W	Net tows
B02	49 39.4062 ° N	126 23.3466 ° W	Net tows
B03	49 39.1314 ° N	126 22.6263 ° W	Net tows
B04	49 38.6544 ° N	126 18.6690 ° W	Net tows
C04	49 36.1272° N	126 31.3584° W	$N0_3$, No_4
C07	49 38.9028 ° N	126 22.3416 ° W	$N0_3$, No_4
C09	49 39.5560 ° N	126 13.3518 ° W	$N0_3$, No_4

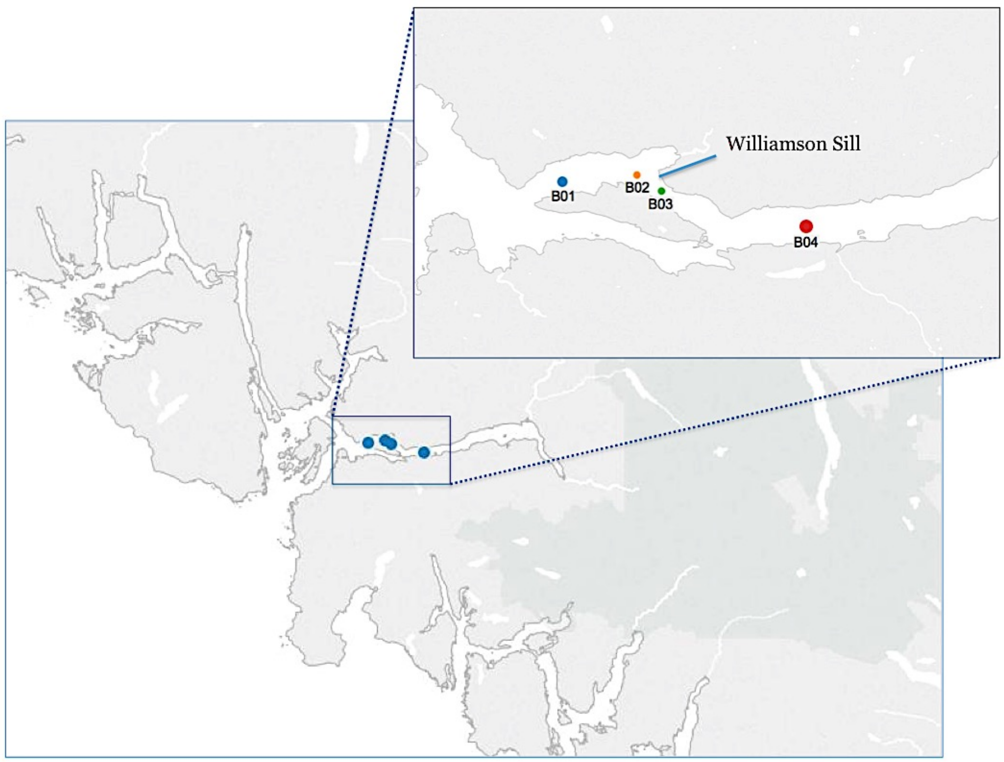

Figure 1. Chart of Nootka Sound, BC, Canada with detail of sampling sites in Muchalat Inlet.

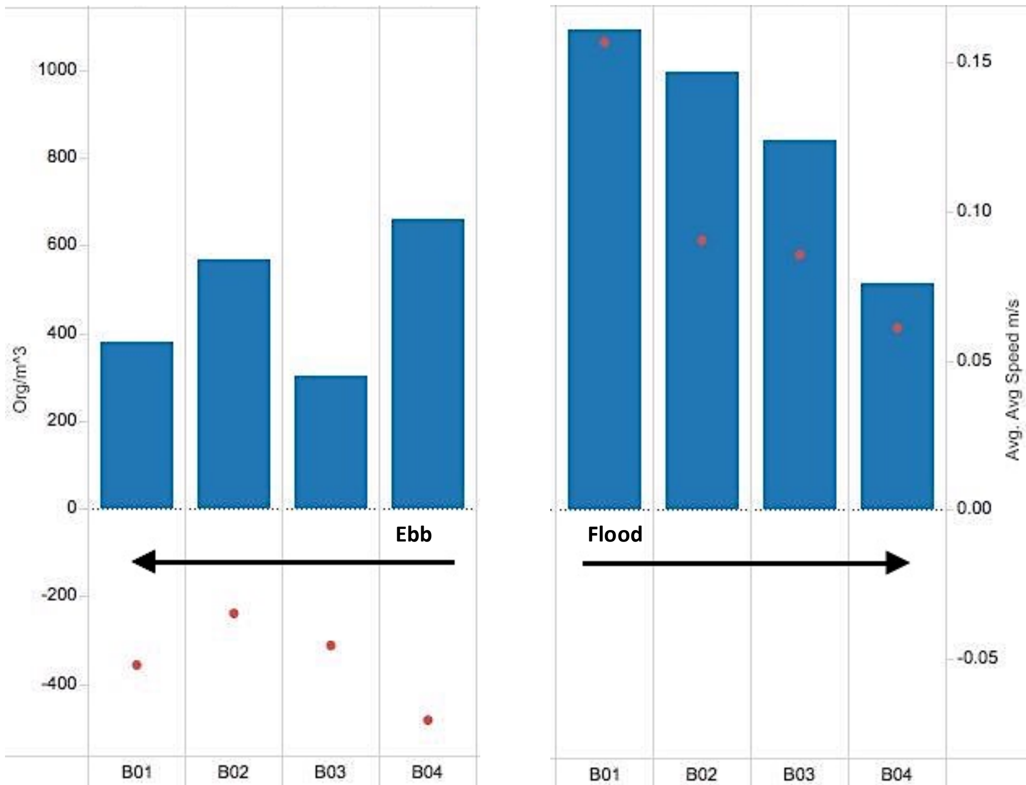

Figure 2. Organism abundance at each station (blue) with average water speed (red) and relative water direction (black arrow.) Ebb tide abundances reflect numbers from bongo tows, and flood tide abundances display numbers from vertical net tows.

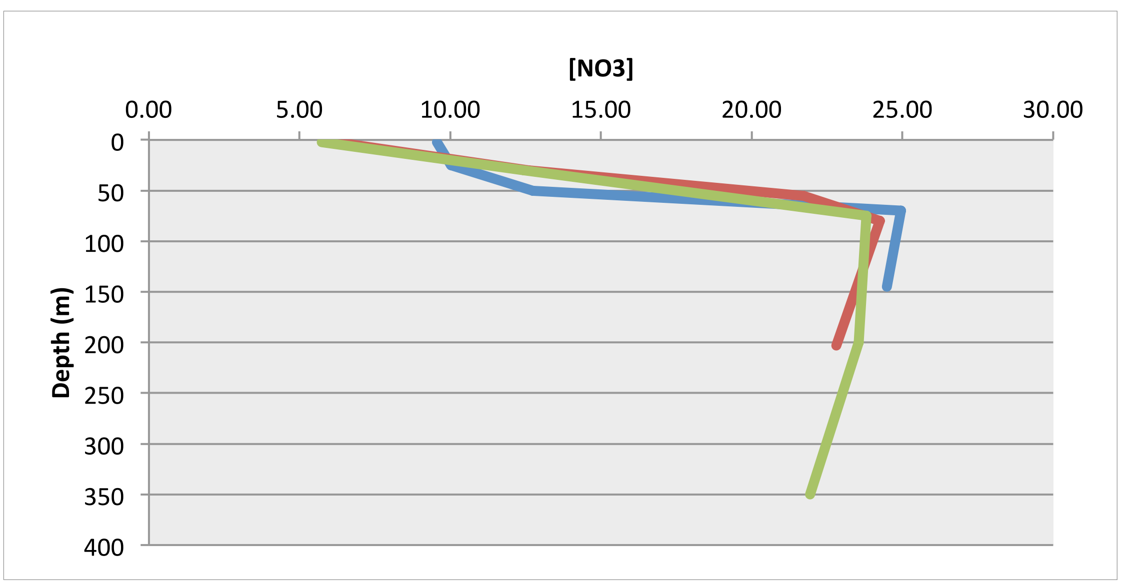

Figure 3. Nutrient profiles of NO_3 at C04 (blue) C07 (red) C09 (green.) Station C04 was located in the main basin of Nootka Sound, and stations C07 and C09 were within Muchalat inlet.

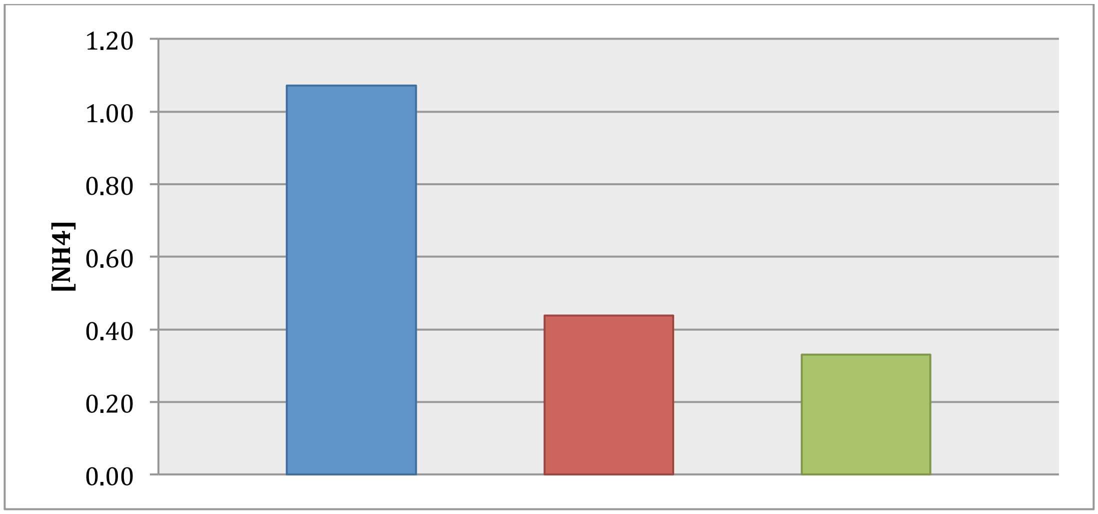

Figure 4. Surface (2 meter depth) measurements of NH_4 concentration. C04 (blue) C07 (red) C09 (green.) Station C04 was located in the main basin of Nootka Sound, and stations C07 and C09 were within Muchalat inlet.

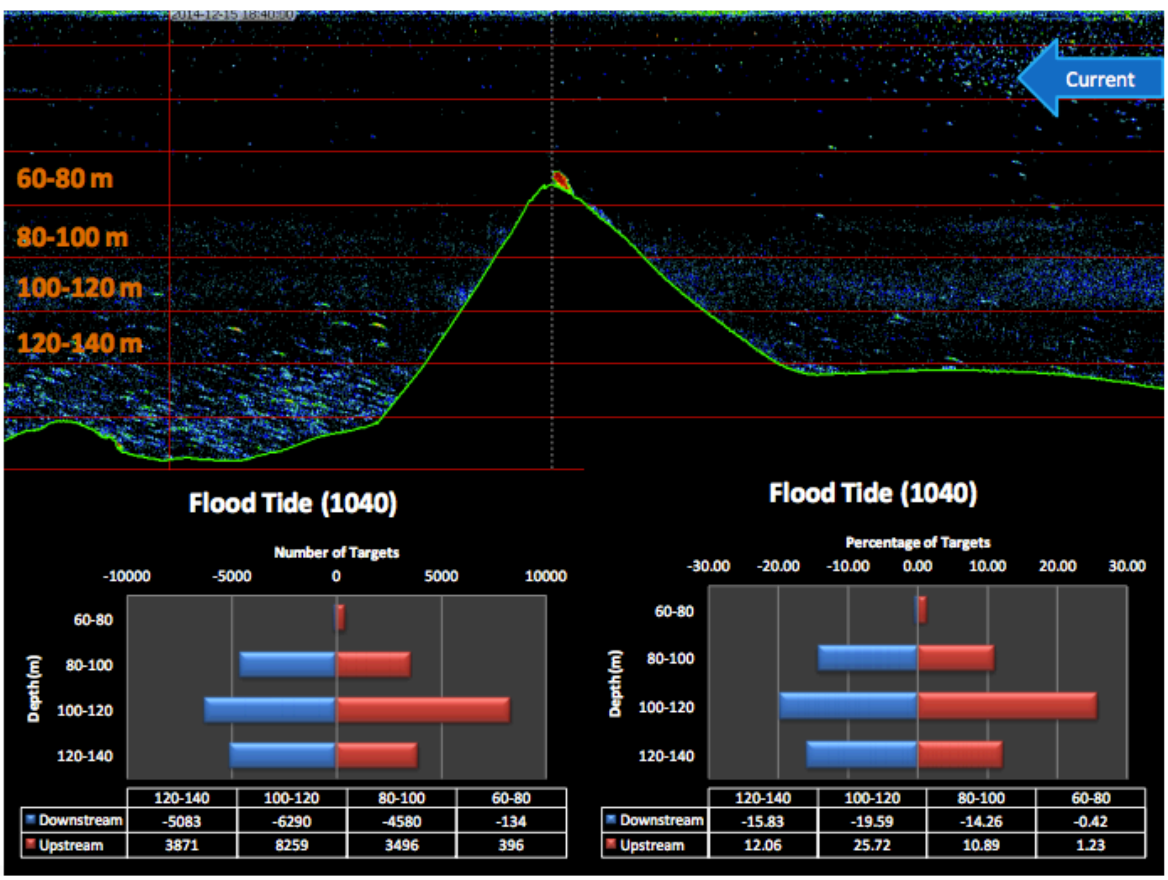

Figure 5. Digre, Sean (2015.) Acoustic backscatter image during flood tide of zooplankton distribution over Williamson Sill. Blue and green dots represent zooplankton, or targets.

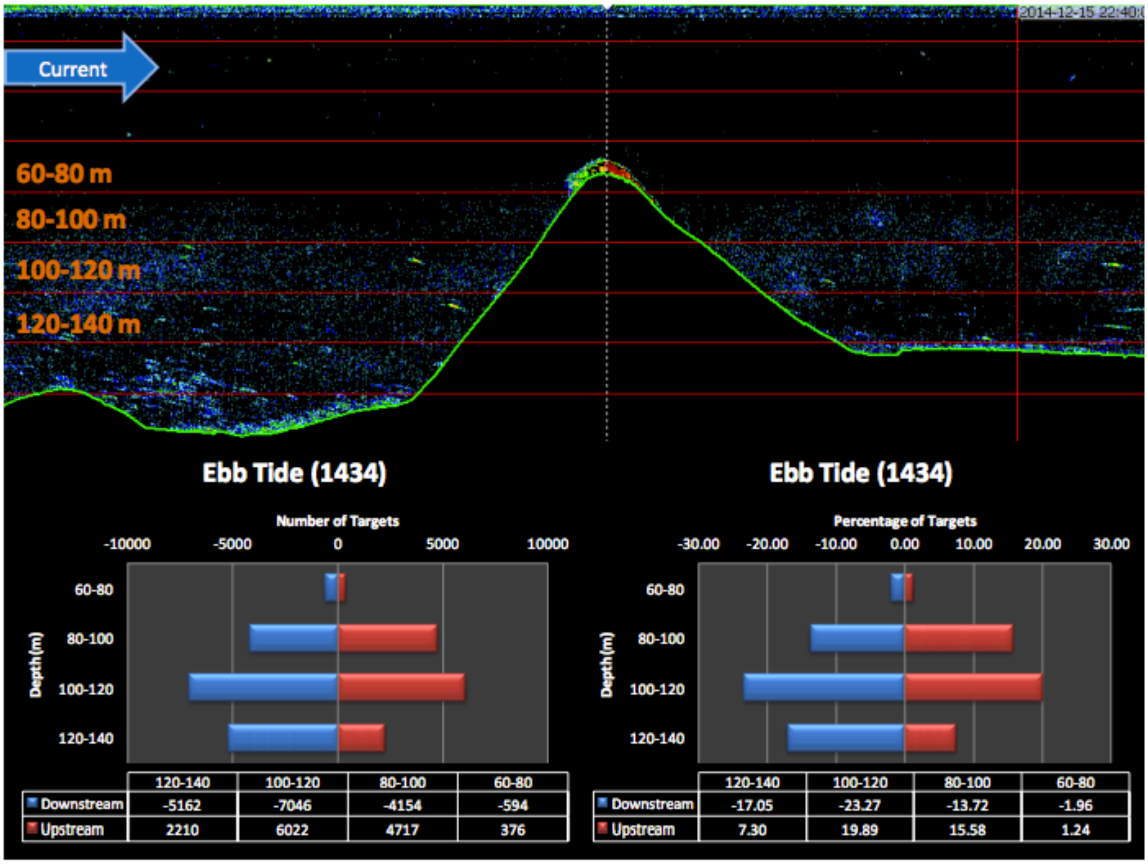

Figure 6. Digre, Sean (2015.) Acoustic backscatter image during ebb tide of zooplankton distribution over Williamson Sill. Blue and green dots represent zooplankton, or targets.