

**From plankton to whales:  
Oceanography of a traditional whale feeding ground and  
marine park in the St. Lawrence estuary**

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**ABSTRACT**

The head of the main channel of the eastern Canadian continental shelf is a traditional whale feeding ground that is part of the first Canadian marine park and one of the most intensive whale-watching sites in the world. In mid 1990's, a research program was launched to understand the basic oceanographic processes responsible for this ecosystem hot spot of eastern Canada. Multifrequency acoustics, direct sampling and standard oceanographic measurements were used to map the distribution and abundance of the two whale preys, krill and capelin. Data were interpreted with the help of a high-resolution three-dimensional tidal circulation model of the area. The area was found to be the site of the richest krill aggregation in the Northwest Atlantic. It results from the pumping of waters from the krill-rich intermediate layer by the estuarine circulation and intensive upwelling combined with the negative phototactism of krill. Current structure and hydrodynamic control at the sills determine the mesoscale pattern of the aggregation. Capelin concentrated at the channel head banks and along the slopes. Flooding currents and upwelling were concentrating them at the slopes, and along the fronts that form at the interfaces between water masses. Flooding increased the contact between the two preys. Whales take advantage of the cyclical concentration of capelin at the slopes and of the richest krill concentrations further downstream.

## INTRODUCTION

This paper is a summary of results presented in the series of publications cited in the references and originating from a recent research program conducted in the St. Lawrence Estuary. Its aim was to understand the basic oceanographic processes related to the persistent frequentation of baleen whales at the head of the Laurentian Channel in summer, in the area of Tadoussac and Les Escoumins (Fig. 1). The Basques were hunting whales in this region 450 years ago, and this activity was followed by the whaling industry of the 19<sup>th</sup> century. Nowadays, whales still intensively frequent this area for feeding in summer. In the 1990, it has become one of the most important whale-watching sites of the world visited by more than 400 000 ecotourists every summer. This is at the origin of the creation first Canadian Marine Park, the Saguenay—St. Lawrence Marine Park, which protects a part of the whale feeding ground. Important local oceanographic processes must drive this persistent interest for this area by several species of baleen and toothed whales since centuries. What are they? How does this whole system works? These were the questions addressed by the research program.

## MATERIAL AND METHODS

The research approach was to describe the distribution of the whale preys (krill and capelin) with high resolutions in space and time and interpret the patterns with a high-resolution 3D circulation model of the area (Saucier and Chassé, 2000) and the known behaviours of the organisms. The 3D prey distributions were recorded with echointegration at 38 and 120 kHz along a regular grid of transects (Fig. 1) and then mapped with geostatistic methods (Simard and Lavoie, 1999). The relative signal strength at the two acoustic frequencies was used to sort out capelin from krill (Fig. 2). Prey samples were collected with plankton nets and pelagic trawls. The water mass structure was obtained with standard oceanographic measurements (CTD, transmissiometer, OPC) at a grid of stations (Fig. 1) and along transect lines, sometime in a tow-yo mode. Particular sampling designs were conducted over semidiurnal tidal cycles to study tidal upwelling and frontogenesis at the Channel head (Marchand et al., 1999; Simard et al., 2002). Whales were censused from visual observations from both the ship and an aircraft.

## RESULTS

A dense krill scattering layer, composed of 2-year old adults the two species *Thysanoessa raschi* and *Meganyctiphanes norvegica*, occupies the Laurentian Channel in this segment of the St. Lawrence lower Estuary, sometimes with large vertical extents in the middle of the study area (e.g. Fig. 3) (Simard and Lavoie, 1999). Total biomass estimates indicate that this is the richest krill aggregation area yet documented in the north-west Atlantic, with mesoscale densities similar to those found on the rich Antarctic krill spots (Simard and Lavoie, 1999). Large

fluctuations of total biomass results from exchanges with adjacent downstream segments of the lower Estuary. The two-layer strong estuarine circulation of the St. Lawrence Estuary, the different depth layers occupied by the young and adult krill and the negative phototaxis of the adult krill are responsible for the pumping of 2-year old adults krill from the Gulf of St. Lawrence and its retention in the study area. This large-scale process, largely driven by the St. Lawrence runoff, is responsible for the persistence of the krill aggregation in the area.

The 2D krill distribution in the study area showed different recurrent patterns during neap and spring tides (Fig. 4) (Lavoie et al., 2000). These two distribution modes appear to be related to the control of the circulation by the relative sill dynamics at the three local sills (Lavoie et al. 2000). During neap tides, the sill blocking depth is smaller and less deep-water flows over the two upstream sills (Fig. 5) during flood. The upstream flow at the krill scattering layer depth coming from the northern side of the Laurentian Channel is blocked upstream and diverted towards the south channel entrance, located in the middle of the study area (Fig. 5). Krill then tends to aggregate in this area, all across the Laurentian Channel (e.g. Figs. 3 and 4). When they reach the southern side of the Laurentian Channel they are transported downstream by the flushing circulation of the Estuary (e.g. Fig. 3). This gives a U shape pattern to the aggregation, with a core in the middle of the study area (Fig. 4). During spring tide, more deep-water flows over the upstream sills and the krill aggregation then tends to extend more upstream and take a more elongated shape (Fig. 4). The intense upwelling and downwelling along the slopes combine with the krill behaviour to concentrate them in denser scattering layers (Lavoie et al. 2000).

The other whale prey, the capelin, shows a different distribution pattern (Fig. 6) (Simard et al. 2002). It is concentrated on the upstream shallows and along the margins of the Laurentian Channel. Though its total biomass is only 2% that of krill on average, it is important for those whales found on the intense whale-watching spots, which seem to often target this prey. Capelin total biomass in the study area is correlated with krill total biomass. The distribution of capelin is very dynamic and highly variable over the semidiurnal to monthly periods. During flood, upstream currents appear to force the capelin to concentrate along the slopes, especially in the direction of the sills (Fig. 7). Whales often aggregate along the slopes at this tidal phase (Michaud and Giard, 1998). At maximum flood, they appear to be forced over the sill and shallows (Fig. 7). Capelin also often aggregate along the fronts (Fig. 7) generated at the interface between the upwelled cold waters and the surrounding warmer surface waters, likely in response to their acclimation to a temperature preferendum (Marchand et al. 1999).

Whales generally match the richest concentration of their targeted preys (Fig. 8). The abundance of whales in the study area however did not match the fluctuations of the total biomass of their preys.

## DISCUSSION

Several oceanographic and biological processes acting over several time and space scales appear to be involved in the making of the Saguenay—St. Lawrence Marine Park whale feeding ground. The persistence of this local whale feeding ground for centuries is due to important persistent characteristics of this area. First of all, it is due a main feature of the topography of the continent, the Laurentian Channel, which connects the area to the Gulf of St. Lawrence and the Atlantic, and which abruptly ends in the vicinity of the Saguenay entrance and Tadoussac. Would this deep channel end elsewhere in the St. Lawrence, the whale feeding ground would be found there and not at its present location. Second, the krill production over a large part of the Gulf of St. Lawrence, a productive inland sea that support important fisheries. This krill production is pumped to the head of the Laurentian Channel by a strong and persistent mechanism, the two-layer estuarine circulation of the St. Lawrence Estuary, which drains a large part of the continent. This two-layer circulation acts as a conveyer belt that flushes the shallow-living young stages of krill to the Gulf and brings back the deep-living adults. One cycle appears to take more than one year, which explains why only 2-year old krill of two species are found in the study area. Third, the high tidal energy of the St. Lawrence is involved in concentrating both whale preys in the area, through interaction with the topography and intense upwelling/downwelling.

Among factors involved in the inter-annual fluctuations of total krill biomass on the whale feeding ground are the productivity of the Gulf of St. Lawrence over the previous two-year time period and the intensity of the pumping by the circulation. The intensity of the pumping of krill however depends on the runoff level and on the stratification acting at the sills. The injection of adult krill from the Gulf may likely occur during a critical short period, such as during the Spring freshet, the exact mechanism being still unknown. More research should be dedicated to this question of exchanges with the Gulf.

Another factor that is presently also important is that the dominant krill species (*T. raschi*) is a cold water species that lives in water colder than 2°C (Simard et al. 1986), which corresponds to the cold intermediate water, characteristic of the St. Lawrence system and resulting from winter cooling and advection. In the context of global warming, if this cold water habitat recedes or even disappears, it is likely that the present equilibrium will change. If global warming also affects the St. Lawrence freshwater runoff, as it is predicted, the krill pumping will also be affected. Global warming may also affect the aggregation of capelin at fronts, by reducing the strength of the cold-water barrier that capelin seem to avoid at the upwelling tidal fronts.

Finally, the highly fluctuating capelin total biomass and distribution in the area need more attention. The aggregation dispersion mechanism over a tidal cycle has to be understood with enough comprehension to be able to model it and extract the passive and active components. Similarly, the origin and degree of perennity of this small biomass of capelin compared to the expected total stock biomass of the Gulf of St. Lawrence need further research.

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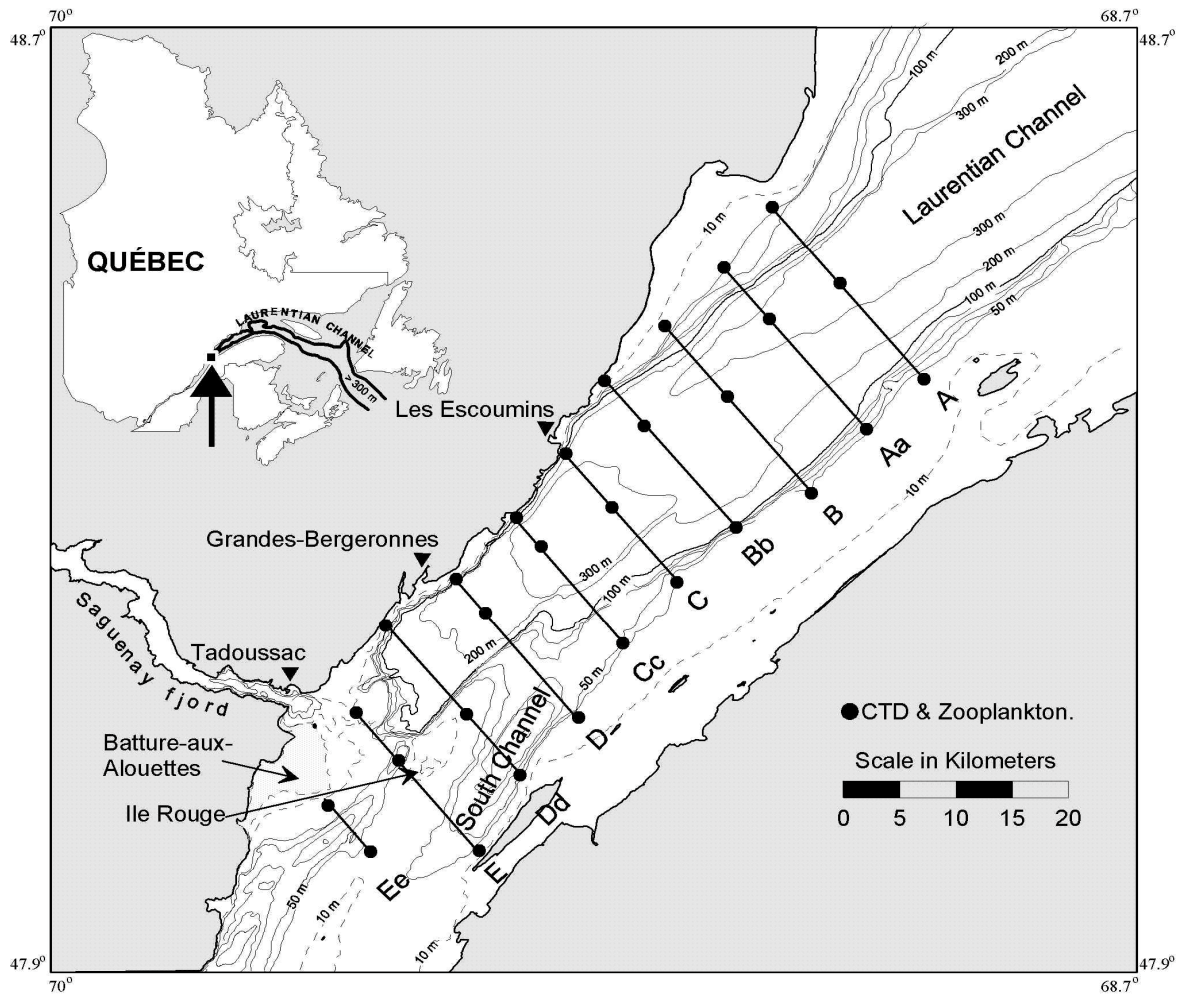


Figure 1. Map of the study area showing the acoustic transects and hydrographic and plankton stations.

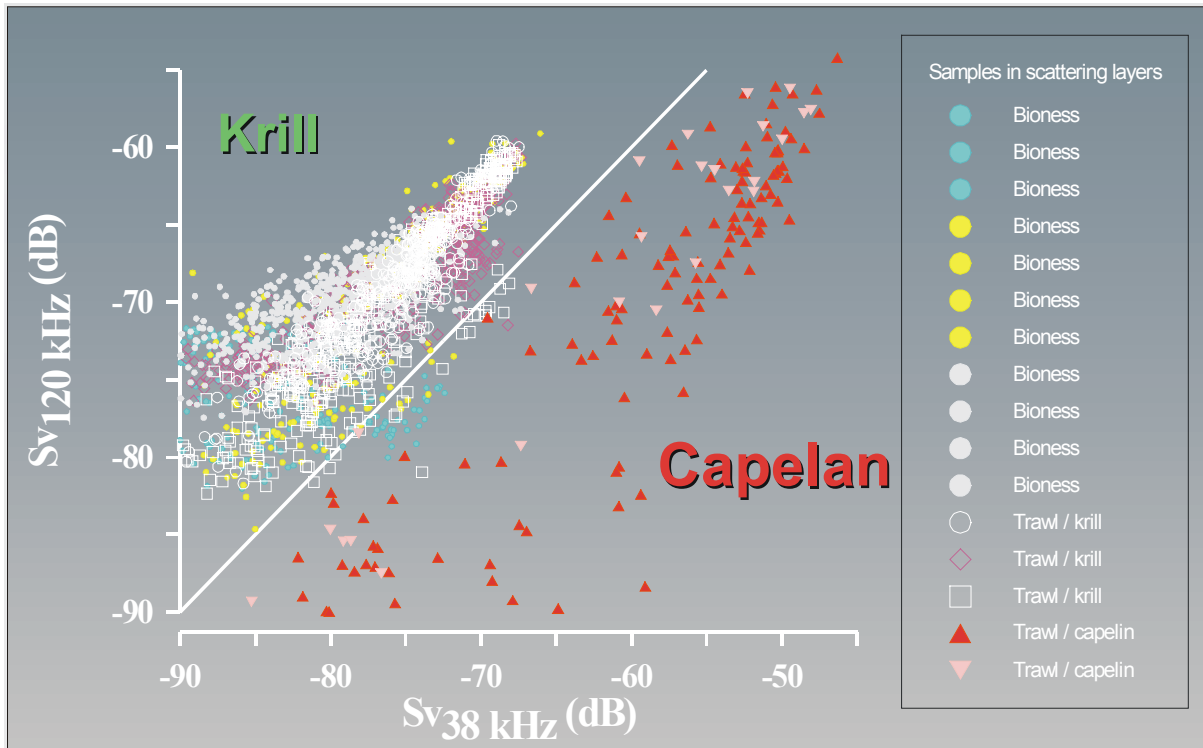


Figure 2. Volume backscattering strength ( $S_v$ ) at 120 kHz versus 38 kHz for krill and capelin corresponding to direct samples collected in the krill sound scattering layers and in capelin schools with the Bioness or a small-mesh pelagic trawl.

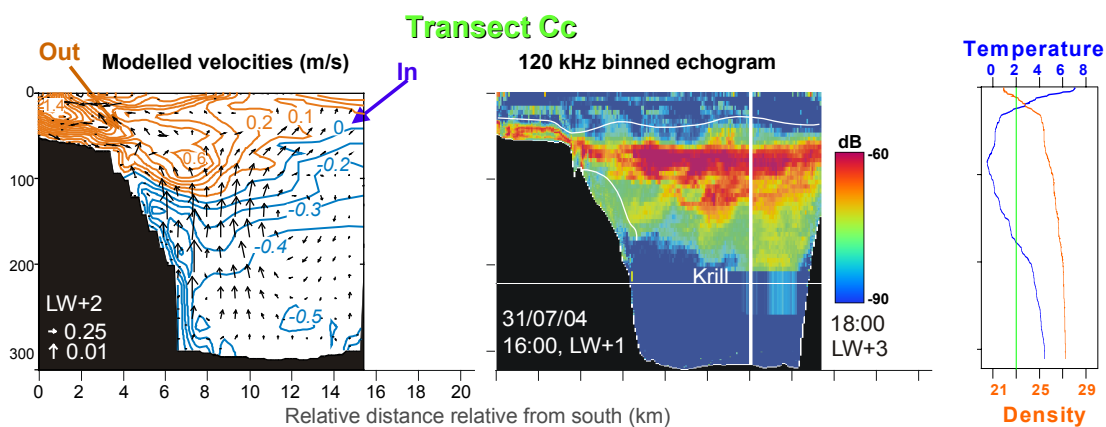


Figure 3. Example of a cross-section of the Laurentian Channel in the middle of the study area on 31 July 1994, showing the  $\sim 150$ -m thick krill scattering layer ( $S_v$ ), the corresponding 2-layer current structure ( $\text{m s}^{-1}$ ) from the model and the temperature and density profiles.

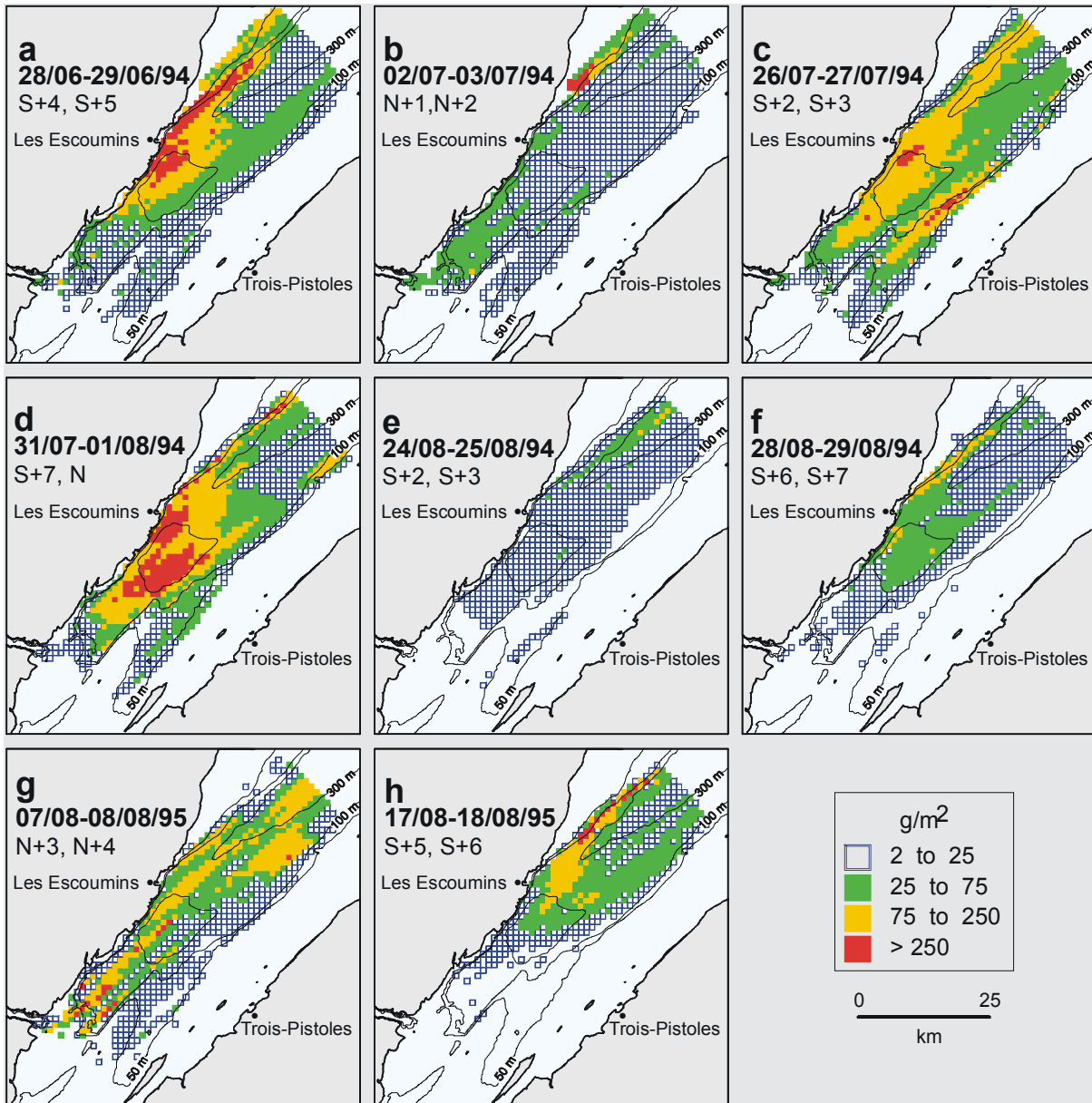


Figure 4. Maps of krill distribution in the study area obtained from kriging the vertically integrated biomass measured along the grid of transects. Note the recurrent U shape pattern around neap tides and the elongated patterns during spring tides.



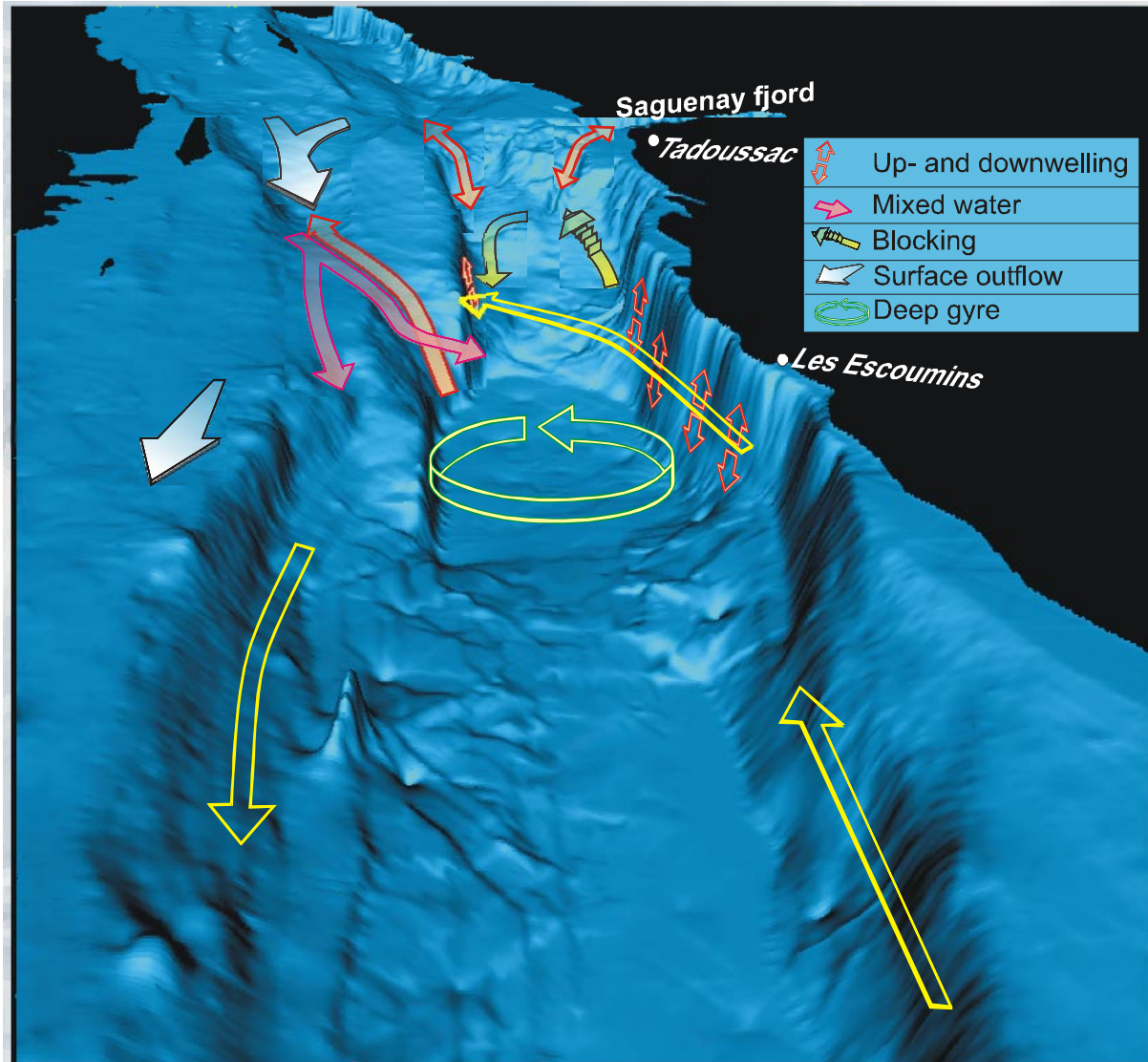


Figure 5. Sketch of the main circulation features involved in the krill concentration and distribution in the study area.

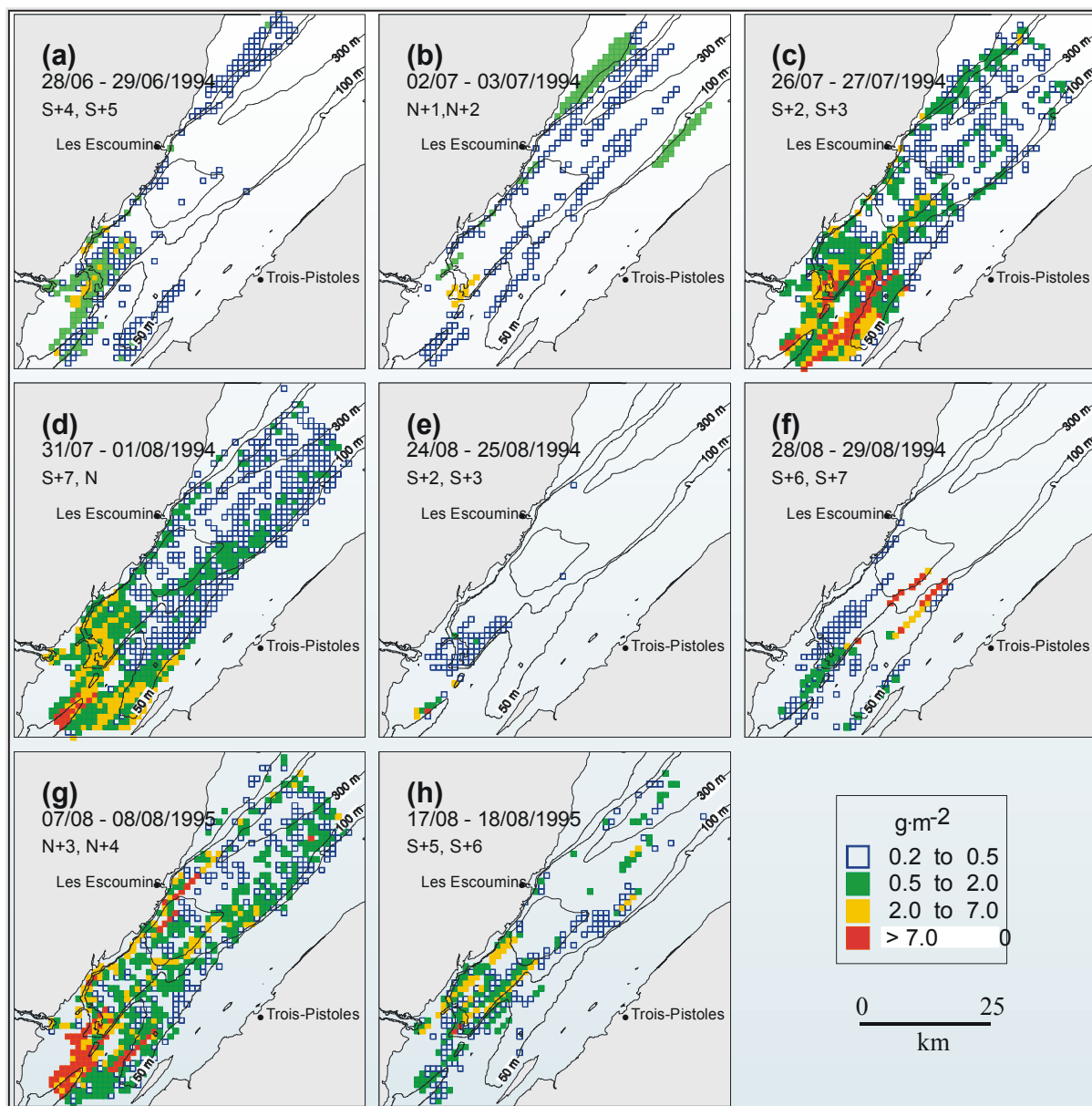


Figure 6. Maps of capelin distribution in the study area obtained from co-kriging the vertically integrated biomass measured along the grid of transects. Note the denser concentrations on the upstream shallows and along the slopes.

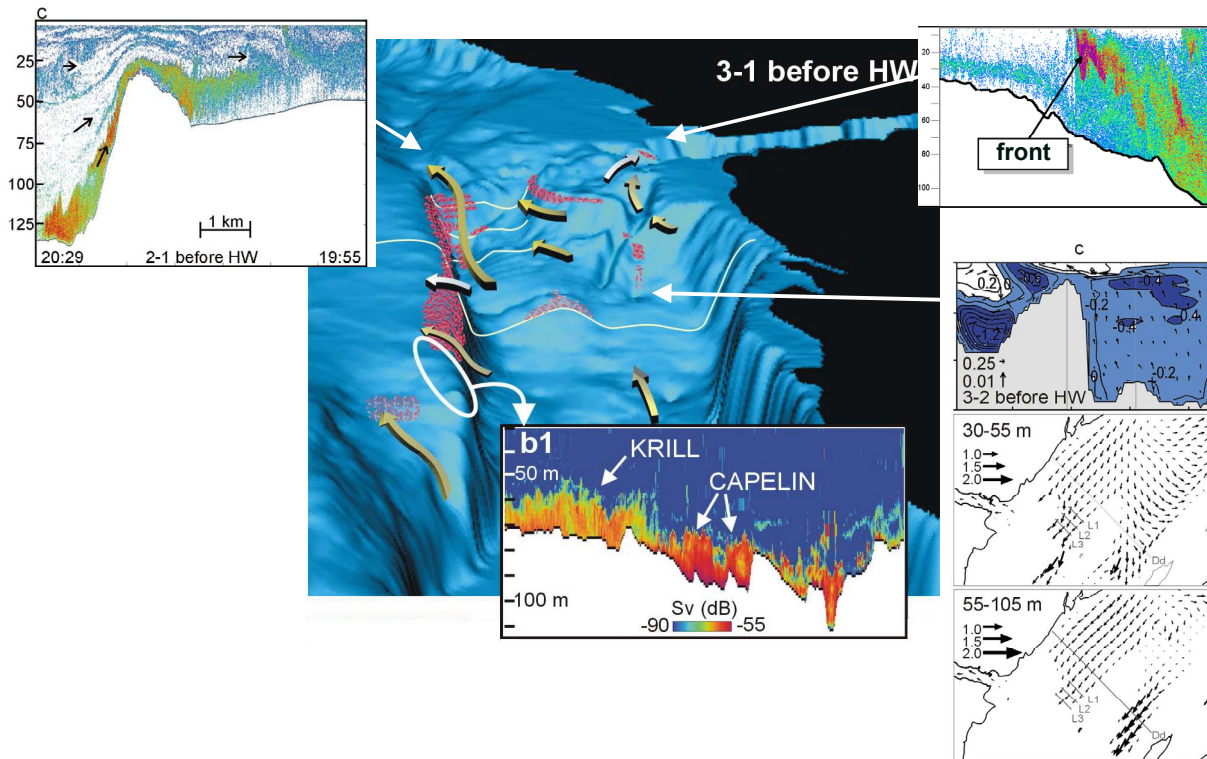


Figure 7. Sketch of the capelin distribution at the head of the Laurentian Channel during advanced flood showing the aggregation of capelin along the slope by the currents converging towards the sills, the upwelling of capelin over the sill and the slopes, and the aggregation of capelin at the frontal boundaries around the different water masses (from the upper Estuary, the Saguenay fjord, and the upwelled cold intermediate waters). The inset panel, b1, is a 4-h 120 kHz binned echogram obtained when tracking a fin whales feeding along the margin of the Channel during the last half of flood.

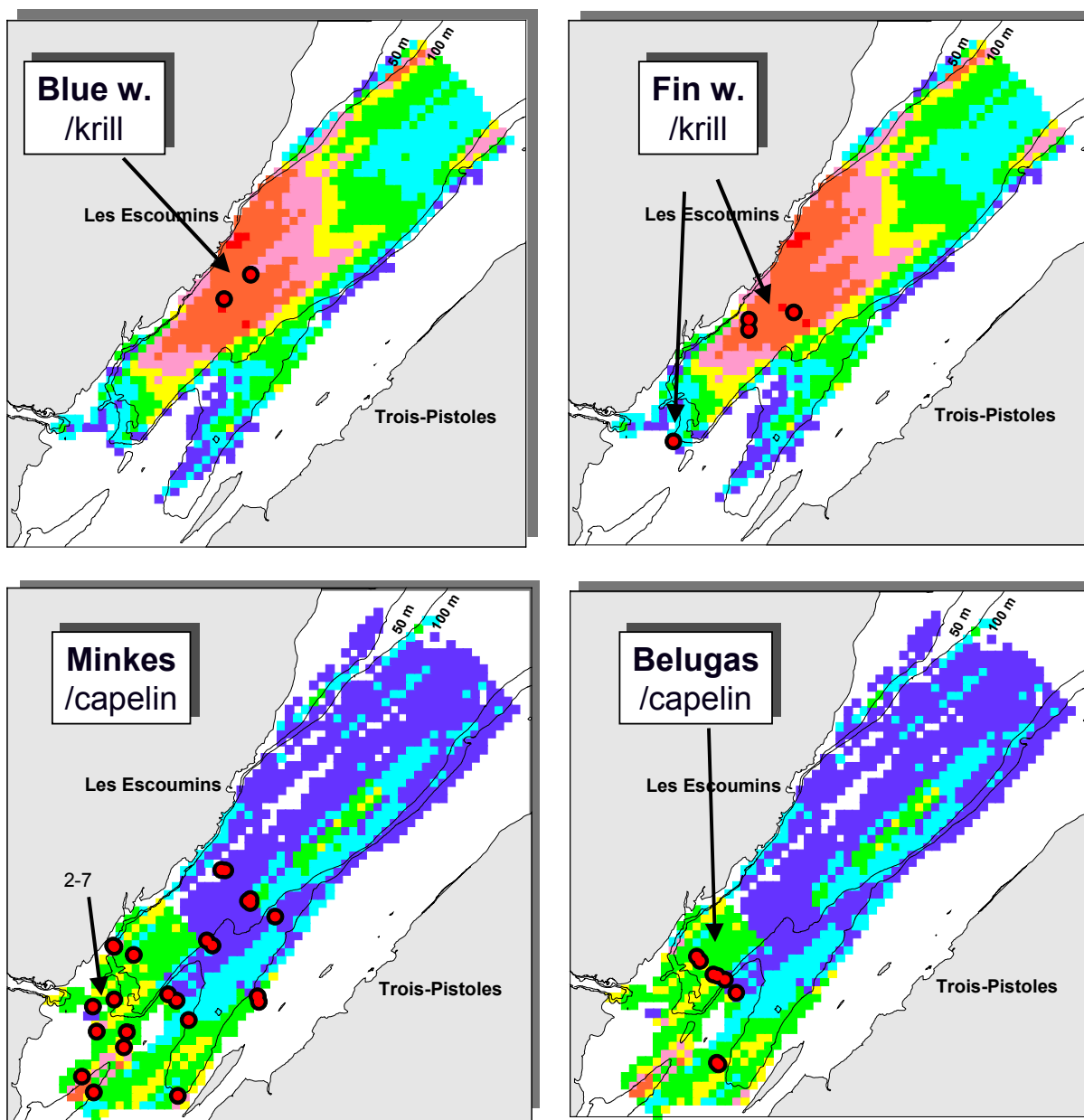


Figure 8. Example of the distribution of group of whales at the end of July 1994 and the correspondence with the prey distribution. Note the different preys targeted by the whales. Unpublished whale data from DFO-MLI (M. Kingsley).