Groundtruthing Multibeam Bathymetric Surveys of Finfish Aquaculture Sites in the Bay d'Espoir Estuarine Fjord, Newfoundland

PAPER

Michael F. Tlusty
Newfoundland Salmonid Growers Association
At. Alban's, NF
Canada

Present:
New England Aquarium
Boston, MA

John E. Hughes Clark
Ocean Mapping Group
University of New Brunswick
Fredericton, NB
Canada

John Shaw
Geological Survey of Canada (Atlantic)
Bedford Institute of Oceanography
Dartmouth, NS
Canada

Vern A. Pepper
Science Branch
Department of Fisheries and Oceans
St. John's, NF
Canada

M. Robin Anderson
Science Branch
Department of Fisheries and Oceans
St. John's, NF
Canada

ABSTRACT

Current and potential salmonid aquaculture sites in the Bay d'Espoir estuarine fjord on the south coast of Newfoundland were surveyed using multibeam SWATH sonar. In 1997, shallow sites were surveyed using the CSS Puffin *EM3000-POS/MV system, and deeper sites were surveyed in 1998 using the* CCGS Creed *hull mounted EM1000. Sediment cores from representative areas were collected during this period and analyzed for organic matter content, and pore water ammonium and sulfate. We discuss the correlation between the sediment core profiles and the results of the side scan and sun-illuminated bathymetric imagery. Bay d'Espoir is a natural depositional area, and that, coupled with the unique backscatter properties of fish farm wastes, increases the difficulty of interpreting these multibeam sonar images. A fairly accurate broad scale characterization of sediment quality can be made from high-resolution images. However, much of the fine scale detail and inherent variation of sediment characteristics associated with impacts from aquaculture cannot be determined from multibeam imagery.*

INTRODUCTION

A key operating principle for mariculture is to avoid degradation of the environment. This is particularly true for salmonid operations since these species are notoriously insensitive to decreases in water quality (Smart 1981). However, if there is an impact to the environment surrounding an aquaculture sites, it typically occurs in the benthos rather than the water column (Beveridge 1987, Gowen 1990, sources in Ervik et al 1997, Tlusty et al. submitted). Benthic degradation more often causes production problems for the farmer compared to decreases in water quality (O'Connor et al. 1991). A consensus on the relationship between aquaculture activity and physical impacts to the benthos is difficult to reach because impacts to this domain are not always as clear (Silvert and Sowles 1996, Tlusty et al. submitted). Numerous complicating factors exist including variation in biomass production and other natural and anthropogenic sources of loading (Laurén-Määttä et al. 1991), sampling difficulty (Weston 1990), differences in farming practices (Gowen et al. 1991, Johannessen et al. 1994), and environmental variability/patchiness (Gowen et al. 1991, Hevia et al. 1996, Silvert and Sowles 1996, Hargrave et al. 1997). Thus the aquaculture industry faces a great need for efficient methods to monitor and characterize the benthic environment at production sites. Since heavily impacted areas can have a benthic shadow ten (Holmer 1991) to 22 times (Troll and Berg 1997) greater than the area of the cages, monitoring methods that cover large areas are desirable.

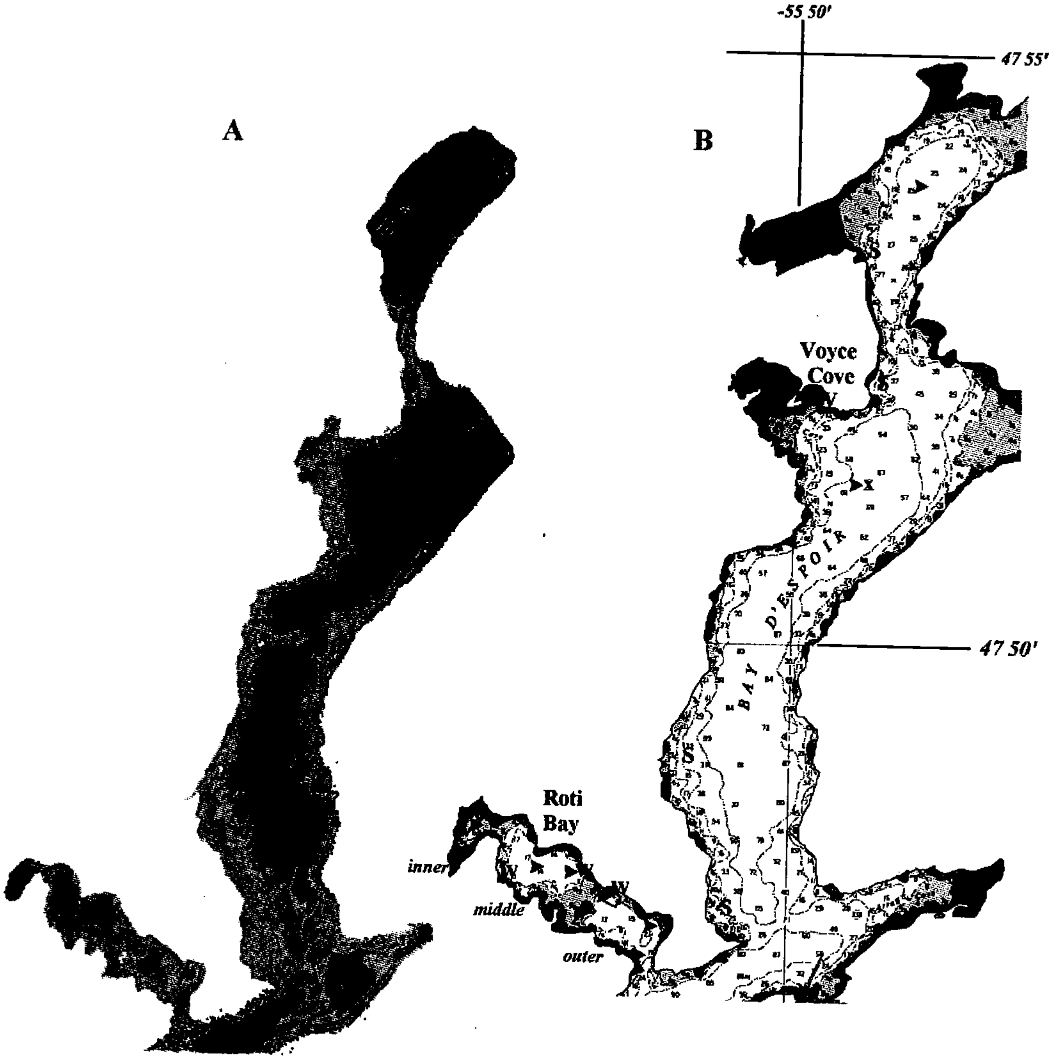
Multibeam bathymetric surveying has the potential to be a valuable tool for monitoring the area below aquaculture sites. This surveying method consists of integrating multiple (30 to 150) simultaneous soundings of water depth and echo intensity to map the bottom topography and sediment characteristics (CSEG 1999). The immense advantage of multibeam bathymetric surveying is that wide areas (4 times water depth, CSEG 1999) can be analyzed in a single pass. The digital data output format allows for rapid analysis and comparison of temporally spaced surveys can be easily made to determine changes in bottom composition over time (Kammerer et al. 1998). While this technology has been used worldwide, new applications of existing technology often present unforeseen challenges. Full utilization of the technology often requires caution, and additional groundtruthing in the new application. For example, impacted sediments under aquaculture operations are of a noticeably different biogeochemical signature than naturally occurring sediments. They are flocculent with a high water content (Holmer 1991, Tlusty 1998), and a higher organic matter content than naturally occurring sediments (Chang and Thoney 1992, Tlusty et al. 1998). The increased organic loading to the benthos (Cranston 1994) creates anoxic surficial sediments characterized by high ammonium and low sulfate levels, and production of hydrogen sulfide and methane (Brown et al.1987, Kemp 1989, Cranston 1994, Black et al. 1996, Hargrave et al. 1997). This can lead to alteration of the benthic infaunal communities, and under severe circumstances, an azoic state (Pearson and Rosenberg 1987, Brown et al. 1987, Gowen et al. 1991, Laurén-Määttä et al. 1991). These properties are likely to produce a different acoustic signal than natural sediments during the multibeam surveys. Here we correlate multibeam data to biogeochemical observations of sediment quality for finfish aquaculture sites in an estuarine fjord on the south coast of Newfoundland.

METHODS

The aquaculture industry in Bay d'Espoir, Newfoundland produces Atlantic salmon (*Salmo salar*), steelhead (*Oncorhynchus mykiss*), and occasionally brooktrout (*Salvelinus fontinalis*). This industry has been operating in the bay for over a decade. Currently, aquaculture in Bay d'Espoir is worth approximately CDN$6 million annually, representing 90% of the province's total aquaculture value. While it is a major player in Newfoundland aquaculture, it is minor compared to the rest of Canada with New Brunswick and British Columbia 18 and 40 times larger respectively (DFO 1999).

Bay d'Espoir is a complex estuarine fjord located on the south coast of the island of Newfoundland (Fig. 1). It is a slow flushed fjord because of 12 sills (submerged moraines) that limit water exchange (Tlusty et al. 1999). Being located at approximately 47° 50′ N, and with the largest freshwater inflow of any small Newfoundland Bay (2.0×10^6 m^3 d^{-1}, MSRL Report 1980), the bay freezes over during the winter making under-ice cage culture a necessary component of the annual production cycle (Tlusty et al., 2000). Before ice-up, cages are moved into protected coves where water remains above -0.7°C, and ice cover is sufficiently stable to prevent catastrophic cage loss

Figure 1. A chart of Bay d'Espoir (B) and the multibeam side scan (backscatter) data (offset, A) at a resolution of 4.5 m. The two main sites, Voyce Cove and Roti Bay are listed, along with other winter (W) and summer (S) production sites. Detailed views of Voyce Cove (Fig. 2), and Roti Bay (Fig. 4) are marked by squares. The X in deep water near Voyce Cove is the location of the deep core (CCG *Matthew* 99-020 core 002). The 11 survey sites referenced in the text are marked ➤ Depths are in fathoms. The difficulty in matching adjacent SWATH lines caused by the positioning error is apparent in the northern most basin (top of A). The chart image was supplied by NDI/CHS, and is not to be used for navigation.



to shifting ice pans. These areas have slow flushing times even during ice-free seasons, and the average current speed is further reduced by the appearance of ice on the bay (Tlusty et al. submitted). The over-winter locations are limiting to the growth of the industry, and hence have been the focus of monitoring and research efforts during the past three years (Tlusty 1998, Tlusty et al. 1998, Tlusty et al. 1999, Tlusty et. al., 2000).

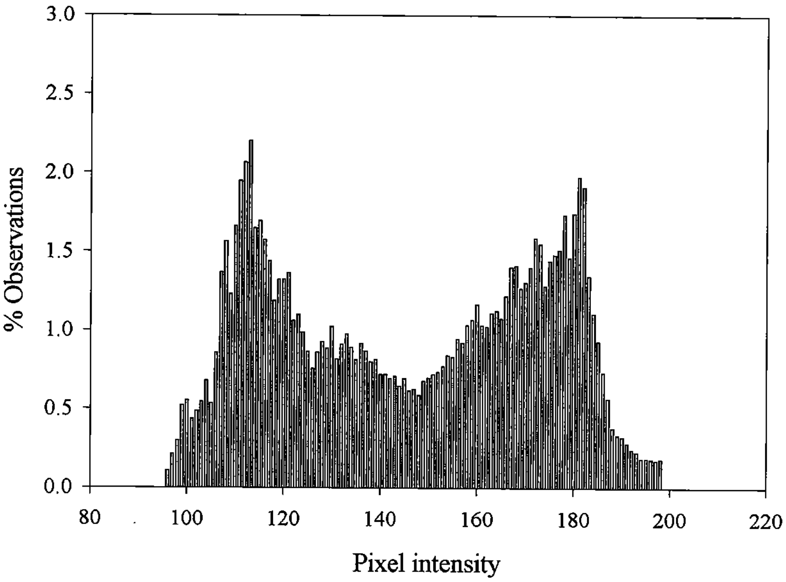
Currently, in Bay d'Espoir, four areas are used for overwintering. The two primary sites include Voyce Cove, which holds the market fish; and Roti Bay (Fig. 2), which holds pre-market fish (Tlusty et al. 1999). Voyce Cove (250,000 m^2) is a wave-cut submerged terrace (Shaw and Forbes 1995) adjacent to a 100m deep basin of the upper Bay d'Espoir system (Fig 1). The flushing time of Voyce Cove has been estimated at 5d (J. Helbig, DFO St. John's, NF pers. comm.). It has been used for winter production of fish for the past decade, and in 1997 carried 850 mt (Tlusty et al. 1999).

Roti Bay (2,662,000 m^2) is a more enclosed bay with a length: width ratio of 4:1 (Fig. 1). It is the major overwinter site as approximately 85% of all pre-market fish are held here. Roti Bay has two useable basins for aquaculture, which are separated by a 10 m deep sill. If considered as a single unit, it has an estimated flushing time of 20d (J. Helbig, DFO St. John's, NF pers. comm). Roti Bay has been used for winter production for the past 7 years, and carried 595 mt in the winter of 1997 (Tlusty et al. 1999).

MULTIBEAM SURVEYS

Bay d'Espoir was surveyed using multibeam systems during the summers of 1997 and 1998. During September 19–22, 1997, aquaculture sites and the shallow fjord edges were surveyed with the *CSS Puffin* EM3000-POS/MV system (Hughes Clark 1999). The deeper sites were surveyed July 25–30, 1998 using a hull mounted EM1000 on the *CCGS Frederick G. Creed* (Shaw et al. 1998). The cages were in their summer locations for the duration of these surveys. During the 1997 survey, there was some difficulty with the digital global positions system (DGPS) system. All the data were degraded due to an operational problem with the positioning system used. During the data processing, the worst errors were removed using both automated and subjective criteria. The initial phase of automatic filtering involved removal of gross outliers. The outliers were selected based on inter-beam slopes and the statistics of neighboring soundings. The second subjective editing phase involved visual examination of the sun-illuminated surfaces, looking for anomalous targets.

Figure 2. A histogram of pixel intensity from the composite backscatter image from the upper Bay d'Espoir system (see offset Fig. 1). The color scale below the x-axis represents the approximate pixel intensity. Lower numbers are darker color and represent accumulation bottoms. Data were truncated by omitting the tails determined by five consecutive intervals with values less than 0.2% of the observations.



When these targets were identified, the sound soundings in the vicinity of the target were interactively imported and examined. The user then manually rejected those solutions that appeared unwarranted. The final terrain model is based on a weighted average of the accepted soundings interpolated onto a rectilinear grid. Even with this cleaning, significant positioning problems still remained, and as a result, most of the data have a positional error > 10 m. This positioning error caused a "mesh"-like pattern in the sidescan imagery. These anomalies are not seabed targets at all, but rather boundaries between the ends and the sides of individual swaths of data. The reason they show up is because of the bad positioning which results in large depth mismatches between the lines causing false topography. Nevertheless the regional bathymetry and local (within swath) detail is preserved.

The backscatter data resulted in a 24-bit gray-scale image of the estuary floor where light coloration represents transport bottoms, and dark coloration represents accumulation bottoms. This image was imported into Optimas image analysis software, and reduced to an eight-bit image. Regions of interest within this image were then analyzed for distribution of pixel intensity using the histogram function. The pixel intensity of the reduced image correlates to acoustic backscatter, and can range from 0 (black, soft bottom) to 255 (white, hard bottom), although the functional range was 90 to 200.

BENTHIC SAMPLING AND ANALYSIS

Sediment cores were collected from the target areas in two ways depending on sediment depth. The first method was to use a 5 cm diameter, 50 cm long KB core sampler for thick sediments. The less profuse sediments were collected with a dredge sampler (5800 cm^3 Ekman dredge weighted with 17.6 kg) and then subsampled with a cut-off 2.7-cm diameter syringe to obtain a mini-piston core (Axler et al. 1996, Tlusty et. al 1998). Irrespective of method, full cores were placed in ice and transported back to the laboratory (minimum of 3 H). In the laboratory, the samples were divided into 2-cm depths, placed into a 50-ml centrifuge tube and frozen ($-20°$ C) until analyzed. Initially, cores were analyzed for % solids (% remaining matter after sample was dried to a constant weight [48H] at 100° C), and organic matter (%LOI_{500} = loss of matter after sample was ignited at 500° C to a constant weight [minimum of 6H], Tlusty et al. 1998). Later cores were analyzed for organic matter, and pore water ammonium and sulfate (Cranston 1994). To obtain pore water, the supernatant was removed after centrifuging the samples at 2,500 rpm for 20 min. Ammonium was determined by end product color determination using the phenate method (APHA 1995, method 4500-F) and subsequent measurement on a Genesys 5 spectrophotometer. Sulfate was determined by precipitate formation via the turbidimetric method (APHA 1995, method 4500-E) and subsequent measurement on a LaMotte Smartcolorimeter. Accuracy was $0.19 \pm 0.17\%$ for % LOI_{500} ($\overline{X} \pm 1$ std. dev., $n = 55$). There was no significant difference between replicate sulfate samples (paired $t_{43} = 4.41$ mM, $p > 0.80$). Ammonium replicate samples differed significantly in their value (paired $t_{49} = -0.058$ mM, $p < 0.005$), but not their magnitude ($r^2 = 0.82$).

RESULTS

Large-Scale Resolution

A composite map of the Bay d'Espoir estuarine fjord (at a resolution of 4.5 m) showed that the interior basins of the estuary (north of 47° 46′ N) form a natural catchment area for organic matter. Darker mapped substrate coloration (Fig 1a) and lower pixel intensity values (Fig. 2) indicate soft, accumulation bottoms. There was a significant negative correlation between the pixel intensity value and organic matter content (%LOI_{500} in upper 2cm vs. backscatter value, $r^2 = -0.74$, $n = 11$, for sample sites see Fig 1) indicating that backscatter analysis is a satisfactory method to categorize bottom type. The backscatter (pixel intensity) values for upper Bay d'Espoir are bimodally-distributed (Fig 2), and 54% of the bottom area of the upper Bay d'Espoir system was classified as an accumulation bottom (Fig 1).

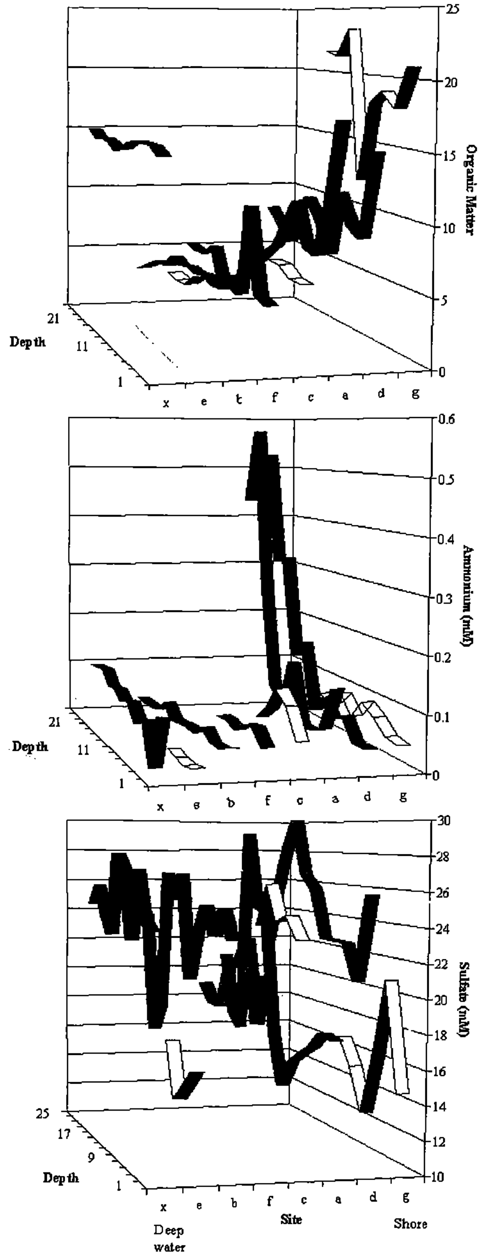
Backscatter data for Bay d'Espoir indicated the overwinter sites for aquaculture tend not to be situated directly over the heaviest accumulation areas as these areas incorporate the deepest parts of the respective basins (Fig 1). Winter aquaculture sites in this fjord were close to shore to minimize the difficulty and costs of deep-water anchors, and to gain safety from moving ice by being close to shore. In addition, there was no correlation between the aquaculture effort and the relative amount of accumulation bottoms. Although the site license in Voyce Cove accounted for 80% of the area and was used for a decade, accumulation bottoms accounted for only 2% of the site (Fig 1). In Roti Bay, used only seven years, the middle and outer basins had 11 and 45% accumulation bottoms (respectively) while site licenses occupied <25% of the area. The inner basin of Roti Bay was 96% accumulation bottom, and never had a farm located there.

FINE-SCALE RESOLUTION

Unfortunately, multibeam backscatter analysis at this resolution did mask some of the benthic impacts and complexities. The main difficulty was that much of the fine scale variation was lost at the 4.5 m resolution. If the backscatter data were considered at a finer resolution (0.5 m), a slightly different picture emerges. A full resolution view of Voyce Cove (9 to 15 m deep) showed that the benthos beneath a cage array had a lighter pixel intensity (Fig 3, square 1, $\overline{X} \pm 95\%$ C.I. $= 165.2 \pm 2.9$) than areas away from the cages (Fig 3, square 2, 72.7 ± 2.0). The light areas were roughly the diameter of a cage indicating the aquaculture wastes spread little, and primarily settle directly beneath the cages.

While backscatter imagery determined these wastes to be of aquaculture origin, the imagery could not distinguish the variation between spatially discrete samples. Each benthic sample of a transect beneath the cages in Voyce Cove had a lighter pixel intensity than a deep reference site (Fig. 1, sample location X). However, the amount of organic matter observed beneath the cages spanned the value observed at the deep reference site (Fig 3). In addition, the light (impacted) area below each cage appeared to become smaller toward the north (shore) side of the cage array suggesting a decreased impact. In actuality the down-core organic matter and ammonium gradients steepened in this direction (Fig 3). This indicated sediments were becom-

Figure 3. Downcore gradients of organic matter (%LOI$_{500}$), ammonium and sulfate for the seven transect sites from Voyce Cove (Fig. 3) and the deep reference site (Fig. 1, site X). Site g is closest to the shore. Depth is down into the sediments in 2-cm intervals.



ing more anoxic toward the shore (north) end of the array. Sulfate levels demonstrated no discernable trend except that the northern / shore-most site (g) had the lowest levels (most anoxic).

The high-resolution sun-illuminated data added to understanding the overall benthic impacts, but again, some fine-scale variation was not recorded. This imagery showed 10 to 50 cm positive depth anomalies beneath a majority of the cages in Voyce Cove (Hughes Clark 1999, Fig 4). In this image, the mounds were broader than the 1 m^3 – 1.8 t cement blocks used to anchor the cages. The sun-illuminated image also showed how one anchor has been dragged from its original position. While this shows where buildup beneath the cages had occurred, it again did not discern any trends in degree of impact as determined with measures of organic matter content or ammonium gradients.

Another difficulty with surveying aquaculture sites is that the loss of detail from multibeam data increases with depth of site (Hughes Clark 1999). Thus fine-scale impacts are less likely to be observed in deeper sites. High resolution images from a farm site in Roti Bay (Fig 5, for location see Fig 1), looked much different than those discussed above for Voyce Cove. This site was in 35 to 40 m of water, and it was difficult to discern the cage imprint on the bottom (Fig 5). Lighter shading was apparent beneath the cages, but not to the degree as in Voyce Cove. While this may have been a function of local oceanographic conditions (e.g. flushing rate) the decrease in resolution was apparent since anchors were not visible (Fig 5). This site also had a different bottom type, as the naturally occurring substrate was bare rock compared to Voyce Cove in which it was clay / extremely fine sand. Ten grab samples from this site indicated that there was 11.0 ± 22.2% organic matter

Figure 4. 0.5 m resolution side scan (top) and sun-illuminated (bottom, sun from top right) images from Voyce Cove. This location is beneath a 12 × 2 array of 75-m circumference circular cages in 10–15 m of water. One cage is outlined to facilitate matching the images if they were overlying one another. The positive bottom anomalies beneath the cages in the sun-illuminated image are an accumulation of fish farm wastes, and one of the nine anchors is also identified. The negative anomaly west of the anchor is a drag mark. The numbered boxes in the top image are areas analyzed for pixel intensity, and the letters refer to the sample locations of the transect.