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

PAPER

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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.

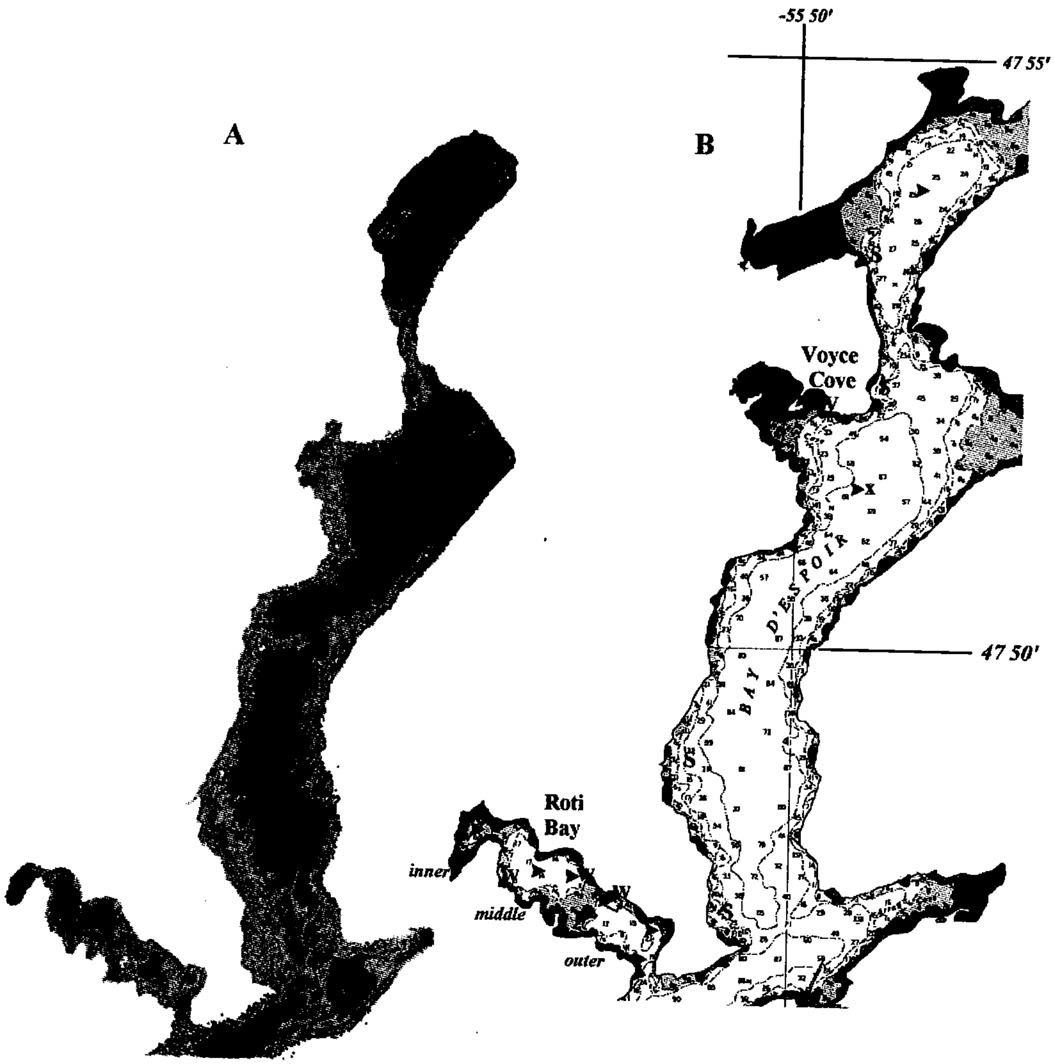
Multibeam bathymetric surveying has the potential to be a valuable tool for monitoring the area below aquaculture sites. This surveying method consists of integrating multiple (30 to 150) simultaneous soundings of water depth and echo intensity to map the bottom topography and sediment characteristics (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).

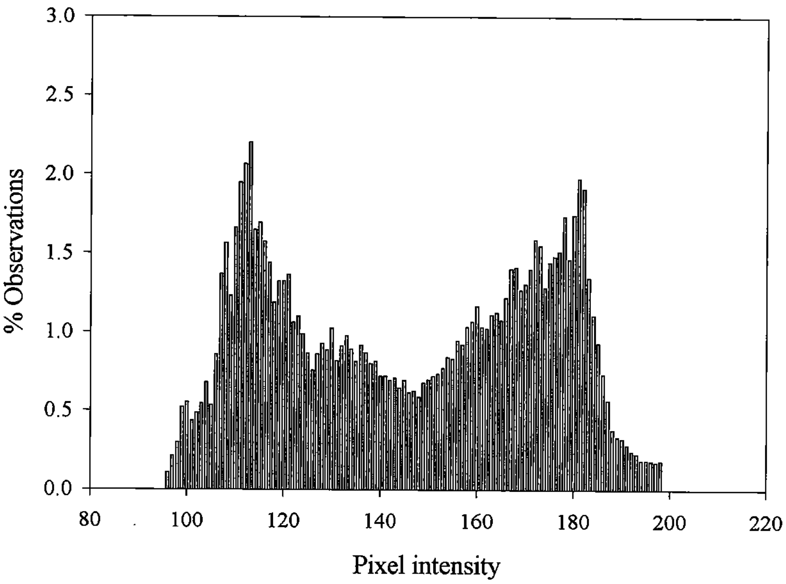
Currently, in Bay d'Espoir, four areas are used for overwintering. The two primary sites include Voyce Cove, which holds the market fish; and Roti Bay (Fig. 2), which holds pre-market fish (Tlusty et al. 1999). Voyce Cove (250,000 m^2) is a wave-cut submerged terrace (Shaw and Forbes 1995) adjacent to 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 ± 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).

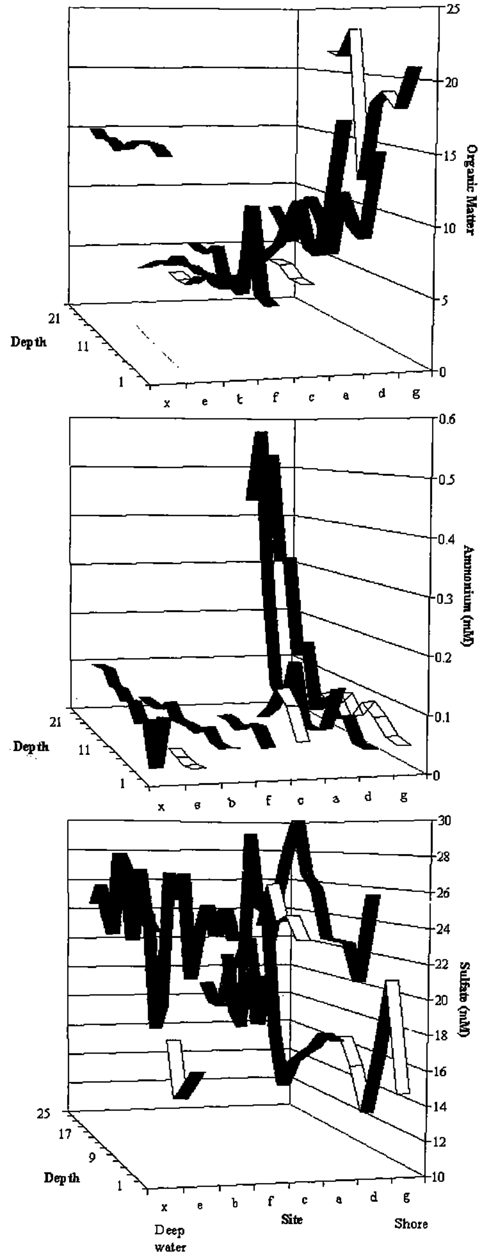
Backscatter data for Bay d'Espoir indicated the overwinter sites for aquaculture tend not to be situated directly over the heaviest accumulation areas as these areas incorporate the deepest parts of the respective basins (Fig 1). Winter aquaculture sites in this fjord were close to shore to minimize 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 ± 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.

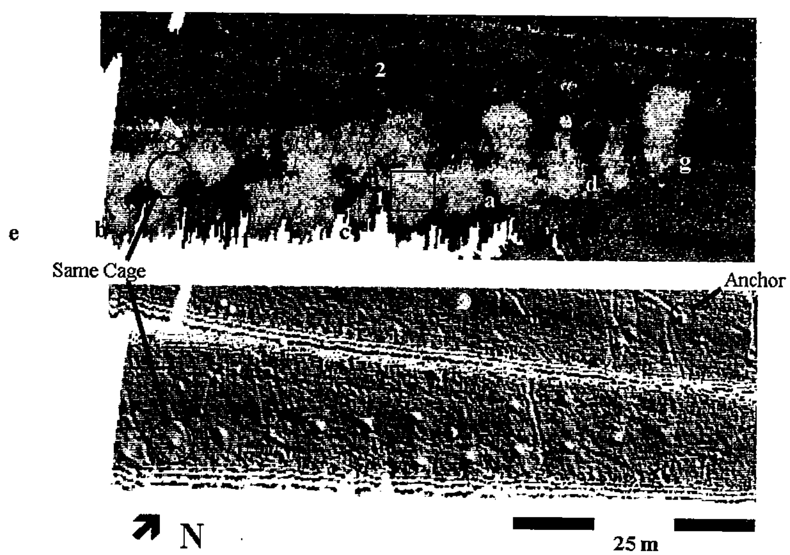


ing more anoxic toward the shore (north) end of the array. Sulfate levels demonstrated no discernable trend except that the northern / shore-most site (g) had the lowest levels (most anoxic).

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

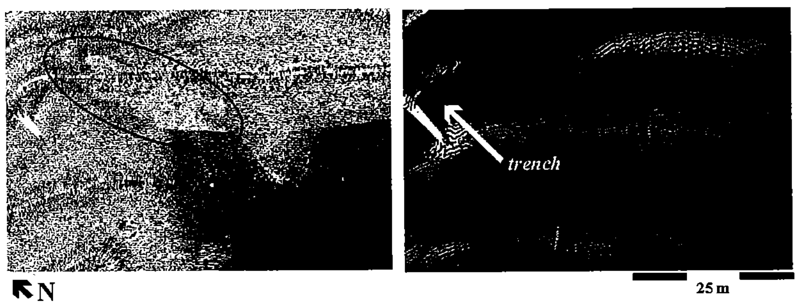
Figure 4. 0.5 m resolution side scan (top) and sun-illuminated (bottom, sun from top right) images from Voyce Cove. This location is beneath a 12 × 2 array of 75-m circumference circular cages in 10–15 m of water. One cage is outlined to facilitate matching the images if they were overlying one another. 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.



in the top 2 cm. The large standard deviation in these data was because four samples were on bare rock, while one sample had 73% organic matter. This sample was obtained from a one to two m wide trench underneath the cage site (Fig 5) that collected a majority of the waste feed and feces from the site (G. Hoskins, Conne River Aquaculture, pers. comm.). It was so localized that samples two m away in any direction were blank (the jaws of the Ekman dredge were blocked by rocks). This trench was barely apparent on the sun-illuminated image, and was not detected via backscatter imagery (Fig. 5).

One final complication of surveying aquaculture sites was if the survey was conducted around active production sites, the signal was degraded (Fig. 6). The interference was from the presence of nets and fish in the nets near the surface of the water. This effectively blocked information on the benthos directly below the cages.

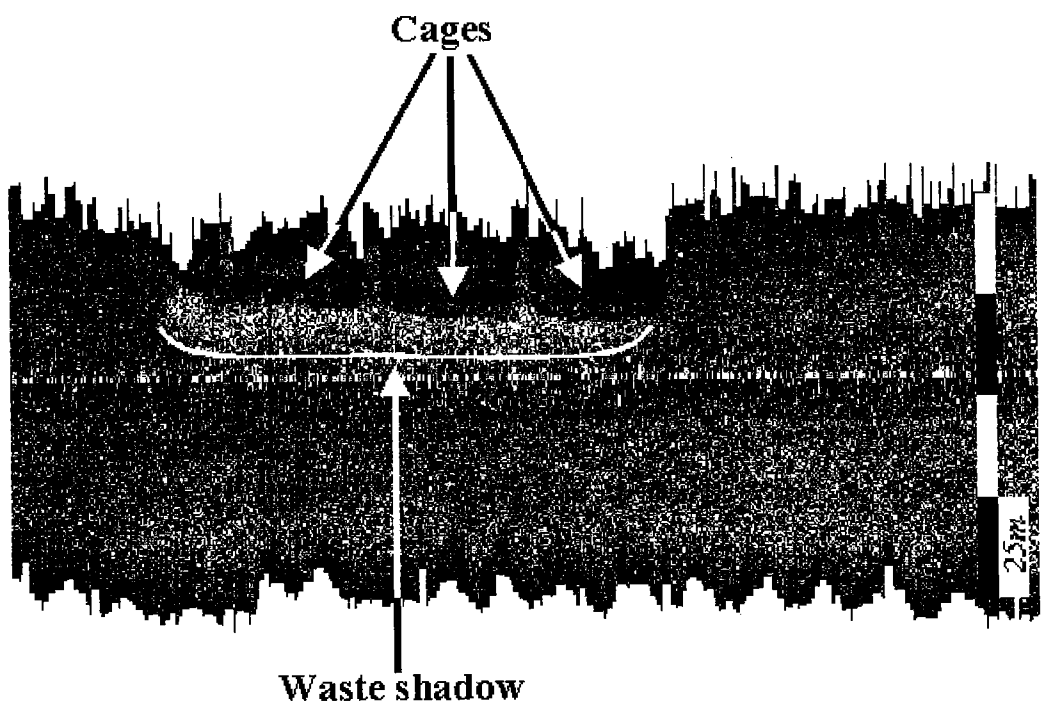
Figure 5. 0.5 m resolution side scan (left) and sun-illuminated (right, sun from top left) images from Roti Bay (see Fig. 1 for location). This location is beneath an 8 × 2 array of cages present in the winter of 1997. This site is in 35 to 40 m of water. The trench beneath the cages is identified.



DISCUSSION

There has been a recent effort to model the deposition of wastes beneath aquaculture operations. These models have found non-symmetrical deposition patterns (Hevia et al. 1996, Chamberlain et al. 1999), and such variation in coverage that make point sampling difficult. While video can survey larger areas than discrete samples (Crawford et al. 1999), the video data are typically reduced to point measures. This is the primary advantage that multibeam sonar surveying has to offer aquaculture, the ability to cover large areas and create maps of bottom topography and sediment characteristics. Shaw et al. (unpublished data) found high backscatter in areas of bark accumulation off a paper mill in Bay of Islands, Newfoundland. Here, a large-scale analysis (EM1000) of Bay d'Espoir demonstrated a positive correlation between backscatter intensity and organic matter content of surficial sediments. This information proved useful in placing how potential and actual impacts from aquaculture fit into the Bay d'Espoir ecosystem. This was beneficial in discussions

Figure 6. 0.5 m resolution side scan imagery from a summer site in which fish in nets were present during surveying. Note the signal attenuation (darkened areas) associated with the presence of the cages.



with both proponents and opponents since it added a degree of objectivity to the interaction. We also found fine-scale surveys (EM3000) beneficial in that they could identify aquaculture waste directly below the cages. However, this identification relied on having an appropriate soft background for the waste to show up. If aquaculture waste fell on a hard bottom, it may be undetected in a backscatter image. Given this suitable bottom environment in Bay d'Espoir, it would be ideal to periodically survey the area to assess cumulative changes to the environment. Subsequent surveys could be digitally analyzed to assess overall changes in the amount of bottom area impacted by the aquaculture operations. By temporally linking surveys, the performance of the cage systems, including the integrity of the anchor system could also be tracked. Some movement of the anchor system in Voyce Cove was detected during this survey. While it was unknown if this occurred post deployment, temporally spaced surveys could be used to track anchor position, and thus indicate system performance.

Given these benefits, we have identified a few problems inherent to sampling aquaculture sites. The first is that when nets and fish are present, the sonar signal attenuates. No data are collected in the area of signal blockage (beneath the cage). Complete coverage at farm sites can only occur when the site is being fallowed or if it has been abandoned. While fallowing is a necessary component of the production cycle in Newfoundland (Tlusty et al., 2000), this is not the case in areas that are experiencing site saturation (e.g. New Brunswick). When sites are not fallowed, monitoring programs may deem it sufficient to use backscatter imagery to determine the total area of impact. At sites which have an area of impact larger than the cage area (Holmer 1991, Findlay et al. 1995, Weston, et al. 1996, Troll and Berg 1997), a multibeam survey would be able to detect the outer limits of fish farm waste. Such a program would preclude any measurement at a low impact site, when the area of waste was smaller than the area of the cages. However, since little information on the degree of impact can be gained from backscatter imagery, any additional information required to assess the scale of impact directly beneath a cage would best be gathered via discrete bottom sampling, and subsequent laboratory analysis.

The second difficulty of multibeam surveying inherent to aquaculture sites is that the aquaculture wastes produce a backscatter characteristic that is light in color (high pixel intensity). This complicates analysis because hard / transport bottoms have a similar signature. The background substrate in Roti Bay was rock, as opposed to a fine sand / clay in Voyce cove. This may lead to the lack of distinction between aquaculture and adjacent areas at the Roti Bay site. However, unlike hard bottoms, the aquaculture wastes are comprised of large amounts of organic matter. Feed is 92% organic matter, while feces ranges from 50 to 88% (Tlusty et al. 1998, Tlusty et al. in press a). The amount of organic matter that settles on the bottom depends on if it originates as feed or feces (Tlusty et al. in press a), depth of water (Gowen and Bradbury 1987, Silvert 1994), current speed (Hevia et al. 1996), variation in bottom topography (Silvert and Sowles 1996), and rate of deposition (Cranston 1994). The sample from Bay d'Espoir with 73% organic matter is not that unusual for aquaculture operations, particularly considering a high degree of feed wastage during the first few years of production at this site (G. Hoskins, Conne River Aquaculture, pers. comm.). Values greater than 65% have been observed in association with other aquaculture operations (Samuelsen et al. 1988, Cornel and Whoriskey 1992). In the case of Bay d'Espoir, large variation between adjacent samples indicated that benthic topography acted to localize areas of accumulation bottoms (Tlusty, et al. submitted). As the wastes are bioprocessed, the amount of organic matter then decreases. In the end, sediment organic matter can be an order of magnitude lower than its feed origin. Control and non-impacted aquaculture sites have an approximate range 2 to 15% organic matter depending on area (Chang and Thonney 1992, Johnsen et al 1993, Krost et al. 1994, Troell and Berg 1997, this study). Given the overall tendency to classify aquaculture sites as transport bottoms using a 4.5 m resolution, there is something inherent in these sediments that cause lighter colored backscatter images.

The other difficulties observed with these multibeam surveys were not inherent to aquaculture per se, but are general drawbacks to this methodology. First, the multibeam surveys could identify gross characteristics, but could not discern variation in sediment characteristics. In Voyce Cove, an impact associated with the cages was observed, and based on the amount of area covered below each cage, the impact appeared to lessen toward the shore. However, organic matter and ammonium profiles of the sediments detected an increase in impacts toward the shore. The sulfate samples were more variable, potentially from bioturbation and a less precise detection method (a colorimeter compared to the spectrophotometer used for the ammonium test). The samples beneath the cages were also lighter in color than the deep reference site, although the organic matter content of the deep reference site was of intermediate value to those from beneath the cages. Thus while the backscatter imagery can identify the area of impact, it does not identify the degree of the impact.

The second general drawback to multibeam surveys was that the depth of water also influenced the resolution of the imagery. This could be for two reasons. First, the increased depth would have allowed the sediments to settle over a larger area yielding a thinner layer. Sonar signals can penetrate very thin overlying layers and transmit data on the underlying bottom (B. Courtney, Geologic Survey Canada, pers. comm.). Second, the resolution of multibeam imagery decreases with increasing water depth. The anchors at the Roti Bay site were not apparent, and there were no light rings beneath the cages compared to the shallower Voyce Cove site. This Roti Bay site had an accumulation feature that collected much of the organic waste from the farm. Unfortunately, this feature was small enough at great enough depth where it was barely recorded with sun-illuminated imagery, and not at all on a backscatter image. Impacts have to be proportionately greater at depth to be recorded in a multibeam survey. It is difficult to say if the visual absence of fish farm wastes in these images are a result of thinner sediments, or lack of resolution because of depth. Each of these difficulties is inherent in the physics of sonar, and will not be corrected without new analysis techniques or technology.

Overall, we found multibeam surveys to be extremely beneficial for a more complete understanding of the impacts below marine aquaculture sites. The visual output was instrumental in describing how aquaculture fits into the whole Bay d'Espoir environment. Individual growers were very interested in the bathymetric maps, and viewing impacts (or lack there of) of their sites. The images also proved useful to demonstrate to concerned citizens the total bottom area being impacted by the aquaculture operations. In Bay d'Espoir it was important to convey the message of background environmental quality and the small deviation aquaculture caused away from the natural state. Finally, the maps were instrumental in steering the biological sampling efforts, particularly since the Bay d'Espoir chart is prone to many errors. While fine scale impacts may go unrecorded, this method is highly recommended as a tool to determine the extent of aquaculture impact on the benthic environment.

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