Acoustic Imaging of Salmonid Mariculture Sites

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Abstract

Experimental trials in Letang Harbour, NB, have clearly shown that the build up of organic detritus beneath finfish aquaculture cages can be delineated from both 200 and 300 kHz oblique acoustic backscatter imaging. Repetitive surveying has further indicated that this method could be used to monitor changes in this signature with time. Diver-collected samples allow positive confirmation that sedimentary organic enrichment is the prime reason for these enhanced backscatter signatures.

Although such diver surveys are currently the standard method for mapping, they are expensive, slow and provide only limited areal coverage. The promise of the acoustic imaging method is that both the degree and spatial extent of organic enrichment might be accurately determined remotely, at a reasonable cost per unit area. However, at this time, whilst the areal extent of the deposits can clearly be mapped and monitored acoustically, a reliable method for determining the degree of enrichment is not yet available. This research investigates the feasibility of using variations in the acoustic backscatter signature to empirically estimate the degree of organic enrichment.

Two methods have been employed: a 300 kHz multibeam sonar and a 200 kHz fixed sidescan stave. The multibeam approach requires the use of extremely expensive hardware demanding a high level of operator training. As an alternative, the fixed 200 kHz sidescan geometry has been investigated as it allows the use of significantly cheaper hardware and requires a much lower level of operator training. Unlike the multibeam data, the 200 kHz sidescan imagery, provides no bathymetric information, but does provide higher-resolution acoustic backscatter imagery. However, because the sidescan system employs no elevation angle discrimination, in-water-column targets (mooring lines, nets, subsurface floats and their shadows) much more notably corrupt the image. These echoes overprint and thus distort the backscatter signature of the organic debris.

In order to provide repeatable backscatter strength measurements so that differences may be monitored, both sonar systems must be calibrated as far as is reasonable. Problems encountered with calibration primarily include imperfectly known beam patterns and absolute source levels.

Introduction

Salmon culture in New Brunswick produced 25,000 tonnes in 2000, worth approximately $M190. The industry takes advantage of the sheltered bays and inlets of the Bay of Fundy coastline. Because of the high tidal ranges (~6-8m), conditions for water-column flushing are ideal. This results in rapid redistribution of organic wastes, notably faeces and waste food for most areas. The most favoured sites, however, are those outside the main current streams; thereby saving on expensive mooring hardware. At such locations the sediments are depositional and flushing is markedly reduced, although not enough to be associated with marked water column anoxia.

In protected locations where the sediment environment is net depositional, excess food and excrement builds up beneath the cages. The accumulation leads to organic enrichment which has a strong local effect on the benthic biota (Poole et al, 1978, Pearson and Rosenberg,1978, Pohle et al,2001). In extreme cases (for example directly underneath aquaculture cages) anaerobic bacteria are established which produce gaseous byproducts including nitrogen, hydrogen sulfide and methane. All of these have been identified from anoxic sediments under salmon farms by mass spectrometry (Wildish et al, 1990). It is thus critical that we have a method for monitoring organic enrichment in sediments so that we can prevent toxic buildup.

The standard approach to environmental monitoring of organic enrichment in marine sediments is by macrofaunal sampling of benthic invertebrates with grabs or corers (Pearson and Rosenberg,1978). The objectives are to determine spatial or temporal effects of organic enrichment by reference to the progressive changes of macrofaunal species distribution and abundance (Wildish et al., 2001c). This method of traditional bottom sampling and biological and chemical analysis, however, is both expensive, slow and very limited in is spatial extent (Wildish et al., 1999). In addition, if the analysis is required for active sites, then divers have to be employed rather than grabs or corers and this further increases the cost and is potentially hazardous.

Recent acoustic imaging experiments (Tlusty et al., 2000, Hughes Clarke, 2001) have shown that oblique acoustic backscatter imaging (sidescans) can clearly identify the spatial extent of seabed coated by organically enriched salmon farming waste products even under active sites. More traditional vertical-incidence acoustic methods (Chivers et al., 1990, Heald and Pace, 1996) cannot be brought to bear as these surveys must take place whilst the cages are in place. In this study we demonstrate that this signature is time varying. Thus far, however, these investigations have shown only that we can define the areal extent of these deposits. Before we can quantitatively attempt to use the imaging to define the relationship between acoustic backscatter strength and seabed properties (thereby potentially predicting the level of organic enrichment), we have to fully understand the sonar parameter settings and the imaging geometry.

Sidescan backscatter imaging has long been a tool for qualitative seafloor sediment investigations (Belderson et al., 1972). Interpretation of the data relied upon subjective user interpretations. Automated schemes for sediment classification (Pace and Gao, 1988, Reed and Hussong, 1989, Blondel, 1996) have been routinely frustrated by imperfect knowledge of the sonar source level, pulse lengths, beam widths, and receiver gains. Only with the advent of multibeam sonar systems have many of these settings been routinely measured and recorded (Hughes Clarke et al., 1996).

It is suspected, but not proven at this time, that the main cause of the high acoustic backscatter signature is due to the presence of gas bubbles (Chu et al., 1997) in the organic debris (which in itself is not otherwise high impedance contrast material). If we can quantify the acoustic backscatter measurements we might be able to establish an empirical relationship between the level of gas present and the total organic enrichment of the sediments.

Methods

For most multibeam surveys, reduced backscatter maps are now routinely available (Hughes Clarke et al., 1996). As the multibeam sonars are near calibrated and all sonar parameter settings are automatically taken account of, it is a simple matter to provide the client with a map of surficial backscatter strength. The mean backscatter strength is one of the most robust first order classifiers available (Mitchell and Somers, 1989, Mitchell and Hughes Clarke, 1994, Borgeld et al., 1999) and it’s variation with grazing angle provides significant extra ambiguity resolution (DeMoustier and Alexandrou, 1991, Hughes Clarke, 1994, Dugelay et al., 1996, Hughes Clarke et al., 1997).

Reliance on higher order statistics such as backscatter variance, spectral content, GLCM’s, or fractals (Pace and Gao 1988, Reed and Hussong, 1989, Linnet et al., 1991, Kavli et al., 1993, Blondel 1996), whilst promising, has usually been restricted to a single sonar operated with constant parameter settings (impractical for routine operations where depth is continually changing). If the pole-mounted sidescans data could be reduced to estimates of the surficial backscatter strength (through proper reduction of power level, pulse-lengths, receiver gains and beam patterns) a similar product would be provided for all depth ranges.

Instrumentation Used

The two sonar hardware types used were :

- A 300kHz multibeam sonar (Simrad EM3000)
- A 200 kHz pole mounted sidescan (Knudsen 320B/P with Airmar 0.5º staves).

The Simrad EM3000 uses a transmit beam that is 1.5º wide and each receive beam is as narrow as 1.5º. The beams are spaced out over a sector covering +/- 65º from the vertical. This allows one to examine out to ~ 2X the depth (less the sonar draft which is normally ~1m). Although not used in this project, the system can be mounted in a tilted mode, so that solutions up to and above the horizontal may be obtained.

Bathymetric resolution is of the order 0.5% of the water depth or 10cm vertically and ~ 5-10% of the depth horizontally. Absolute accuracy depends, in addition, on a number of other external factors (orientation, refraction and alignment), but do not significantly affect the tool for the purposes used, herein.

The system measures an estimate of bottom backscatter strength. This measure is based on an estimate of source level, gross beam patterns, pulse-lengths and time varying gains. Absolute values should only be relied on to ~ +/- 5dB, however, as software and hardware upgrades clearly affect the result. However for a single sonar without upgrades repeatability is excellent at the <2dB level.

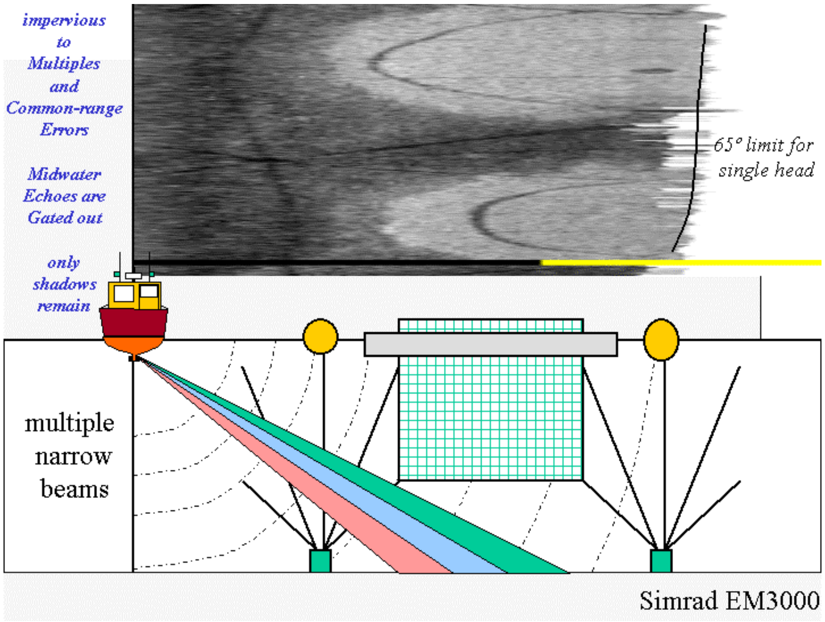


Figure 1: Imaging Geometry, Simrad EM3000 multibeam

Because the sonar discriminates within the elevation plane, the presence of a mid water targets only corrupts the specific beam that points at the masking target Fig. 1) . Thus data collected under the aquaculture hardware is only contaminated by cast shadows. For the same reasons contamination of the bottom backscatter signal by multiples or surface echoes is not an issue.

As the bottom tracking algorithms in the system are specifically designed to track a continuous surface (automatically rejecting solutions that lie away from a near continuous surface, the bathymetric data is extremely clean, even under cages where mid water targets are very common. This allows one to discriminate in detail, the location of bottom mounted hardware such as mooring blocks. It is particularly useful for discrimination the small but resolvable bathymetric expression of the build up of organic debris.

The Knudsen sidescan used 0.5º transmit beam patterns and a single receive beam that is ~ 50º broad in the elevation plane. The sidescan staves were mounted on a fixed pole at a depth of 1m and the main lobe was tilted approximately 30º off the horizontal. For this deployment, although two staves were available, there was only one logging channel. For this survey, the data was logged as an 8bit value proportional to the square root of the linear intensity. Changes in pulse-length, TVG or source level are not reduced from the data. In order to prevent the data from clipping within the limited (8bit) dynamic range it is often necessary to change the sonar settings. Whilst these setting are not currently backed out of the recorded data, those settings are at least recorded as a series of codes by the logger. At this time the absolute source level is unknown and the recorded power and gain steps are only relative. The data presented in this paper are uncorrected, with just a 40logR gain ramp and an empirically estimated residual beam pattern. However, fixed sonar setting were used for all data presented.

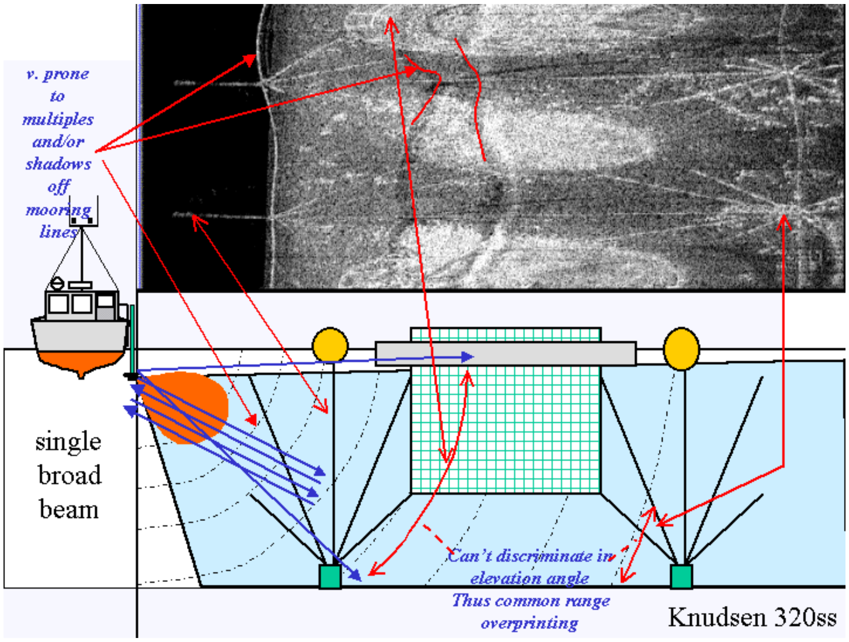


Figure 2: Imaging Geometry, Knudsen 200 kHz sidescans

Because the data are collected from within a single beam that does not discriminate in elevation angle, any mid water targets will show up in the data at their respective slant range (Fig. 2), overprinting any seabed echoes at the same slant range. For the same reason surface echoes and multiples show up and corrupt the data.

One advantage over the vertically mounted EM3000, however is that data are recorded out to significantly lower grazing angles. This allow a greater lateral range to be achieved, normally completely imaging the whole deposit in just one pass.

These two instruments were deployed on different occasions at a common site. The site was and is an active salmon mariculture site. It is located in Limekiln Bay in the Letang Estuary. When first imaged (using just the EM3000) , the sites had been occupied for several years and contained mature salmon. During the second imaging (with just the Knudsen sidescans) 8 months later, the cages had been moved and were full of only very young fish. The results of these two surveys are discussed in more detail below.

November 2000

In November 2000, the first acoustic investigations were carried out as part of a regional mapping exercise for the entire Letang Estuary.

Regional Variation in Visibility of Acoustic Signature.

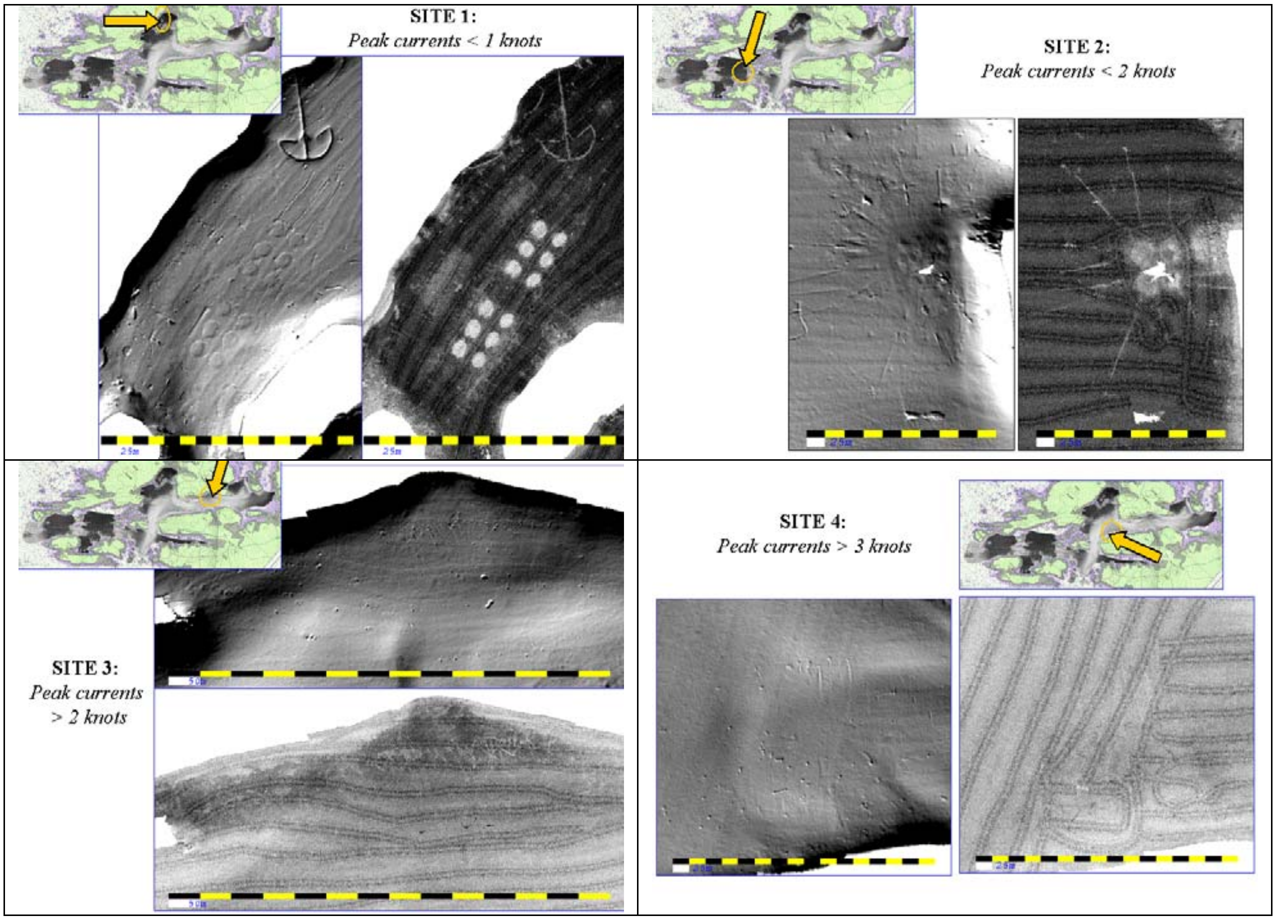


Figure 3 : The four images show sites in progressively higher current regimes. The background sediment backscatter strength is clearly seen to increase dramatically (from ~ -40 to -15 dB) as one moves into the higher current regimes.

In the four figures above, representative aquaculture sites from around the Letang Estuary are presented. In all cases farm cages with nets were on site and actively being used. Duration of occupation and age of fish was not known, however. Each figure includes a sun-illuminated topographic image and a map of bottom backscatter strength (light is high BS). For each site, the sun-illumination direction and vertical exaggeration are the same and the grey scale stretch for each is the same. With all the backscatter images, a gross correction for grazing angle has been applied. Residual ship-track parallel stripes are still however, visible that reflect variations in the shape of the angular response over the average corrector applied.

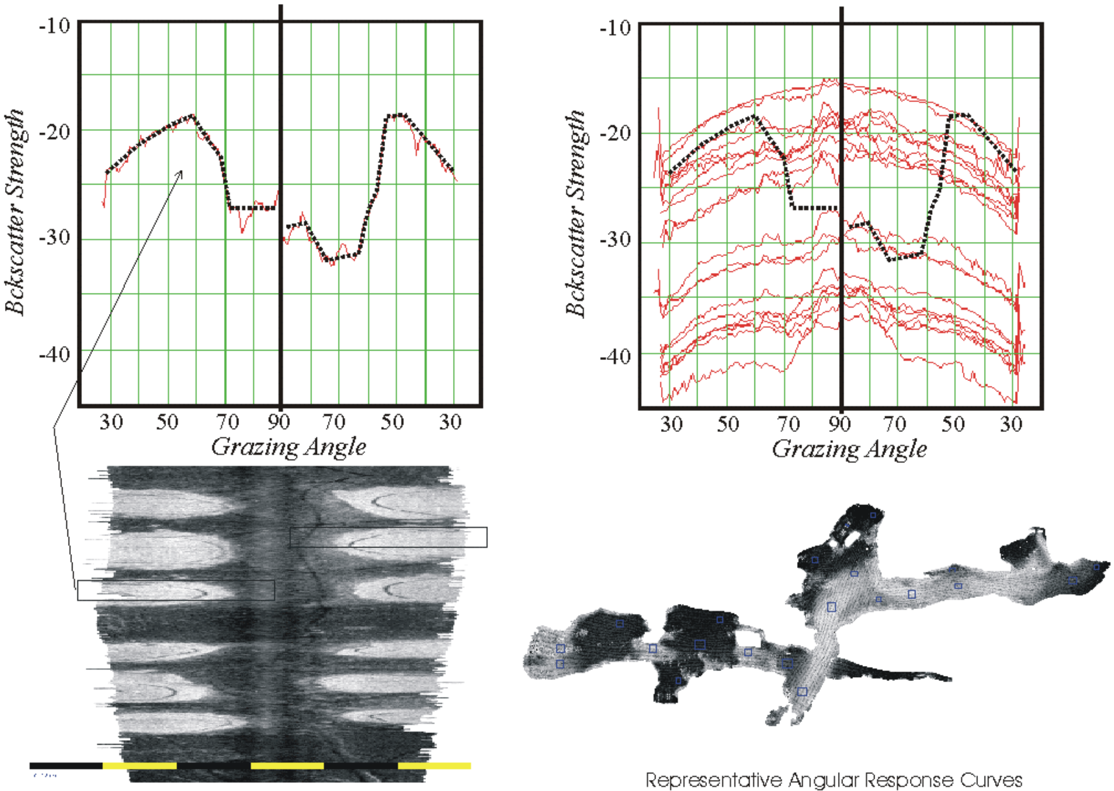
At sites 1 and 2 in Figure 3, a clear topographic signature can be seen of the sediment buildup below the cages (~ 10cm thick). This is notably absent in sites 3 and 4. At all sites one can clearly pick up the location of the mooring blocks and any scour/chafing of the seabed due to the mooring cables.

In the backscatter images the signature of the excess buildup of organic debris is clear. This signature is absent at sites 3 and 4. At sites 3, the regional backscatter strength is not as high as that of the organic debris and thus we assume it is not there. For site 4 the regional backscatter site is about the same as the organic signature (see figure 4). Thus if the material is there it is not visible from this “monochromatic” image. Based on the topographic signature however it is probably not there.

These 4 images clearly suggest that the likelihood of build up of organic debris is inversely related to the peak tidal currents in the area. What is also apparent from these images is that it is hard to confidently map these organic materials in areas of regionally high backscatter. In this case the high backscatter is probably there reflecting the modern current regime. However, other sites often occupy areas of relict high backscatter sediment (glacial tills or bedrock). Availability of grain size data is, currently limited to the regions of finer grained sediment (Milligan et al., 1994).

Measurement of Angular Response Curves Regionally

For areas that exhibit close to the same mean backscatter strength, the shape of the angular response is a potential discriminator. This can be derived from regions where sediment changes only over length-scales wider than a typical swath width. A series of representative example are presented on the right hand side of Figure 4.



Angular response curves obtained, scanning
out under the salmoncages
(note, organic materia is onlypresent at grazing < 60)

Representative Angular Response Curves
from around the Letang Estuary

FIGURE 4: Backscatter angular response curves. On the left, two curves are provided from a 50 ping stack as the EM3000 passes between two lines of salmon rings. Only at grazing angles lower than 60º can one see the effect of the organic enrichment. On the right are a family of angular response curves derived from a wide variety of locations within the Letang Estuary (blue boxes in lower right map). The organic curves are superimposed.

For regional sediment coverage, it is feasible to come up with a robust measure of the mean and angular variation in backscatter strength. Statistics may be derived for a large area, encompassing the full range of grazing angles. Variability in this signature due to speckle and seabed patchiness are averaged out (their contribution is still very useful and can be measured by the variance of the instantaneous signal from this robust mean).

Complications due to small sediment footprint

Unfortunately, as the organically enriched sediment are so limited in extent, no useful angular response information can be acquired. Indeed if one looks at those sites in detail (Figure 7) it is clear that the deposits are extremely patchy (variations of over 10dB) over length-scales at last as short as 5m. As the material is so limited in spatial extent, it is rare to have the deposit extend from nadir out to the far range in a single ping. Even with multiple passes, it is rare to get any response at nadir (as the nets block access to vertical incidence).

A further complication is that the nets and mooring hardware themselves can locally mask and thus potentially corrupt measurements at certain grazing angles. Even the statistical measures are likely to be contaminated as the presence of the mooring hardware can grossly alter those statistics (presence of specular echoes and shadows).

Over the range of grazing angles routinely encountered (~30 to 60º) the angular response lies within the upper part of the natural range of curves due to background sediments (Figure 4 right). Also the angular response curve for the organically enriched sediments is generally parallel to other sediment curves (see figure 4, right). Thus we are left with trying to classify by using just the mean backscatter strength which in itself provides problems. The material does not uniquely separate from other high backscatter material. A commonly expressed concern is that using just this single degree of freedom, gravel pavements and some types of bedrock outcrop are indistinguishable from the organic debris.

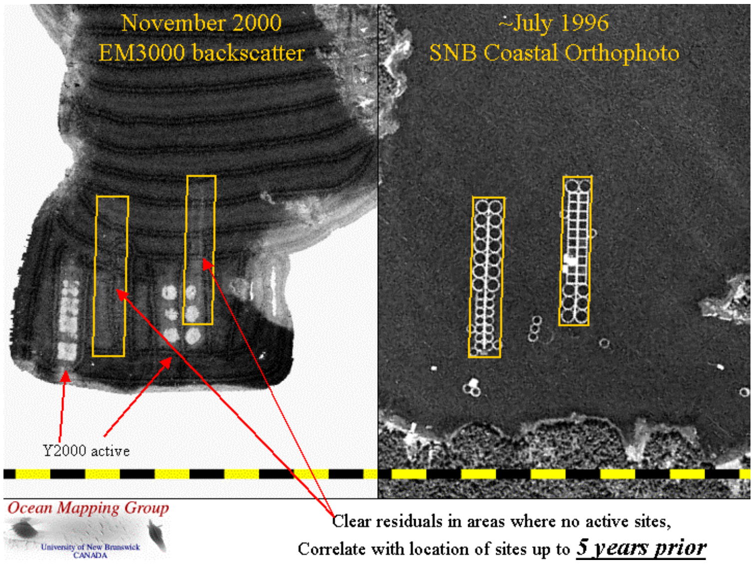
Prior Evidence of Temporal Variability

These organic sediment buildups have always been assumed to be ephemeral. The critical question has always been: “how long does it take for the sediments underneath the cages to return to their natural state after removal of the fish farm?”. Whilst the Nov. 2000 data was the first survey of this area (and thus we couldn’t yet show change in the acoustic signature) the areas has been an active mariculture site for more than 15 years. We would expect that the acoustic imaging would reveal some record of previous activity at sites no longer active. If we could identify these, and date the sites then we could estimate the longevity of these backscatter signatures.

We were fortunate that regional aerial photo study had been undertaken in 1996 as part of a provincial program by Service New Brunswick to create an orthophoto database of all coastal lands (SNB, 2001).

Based on aerial photos taken in 1996 (Figure 5 right), we were able to recognize active aquaculture sites at the time. By coregistering the aerial photography with the November 2000 acoustic imagery (Figure 5 left) it was apparent at several sites that ghost-like acoustic signatures on the seabed, which are not associated with activity in November 2000, match up extremely closely with the cage locations in 1996.

This suggests that the signatures could extend for period, possibly as long as 5 years (at this time we don't know when those sites were deactivated).



Clear residuals in areas where no active sites,
Correlate with location of sites up to *5 years prior*

Figure 5: coregistered 2000 backscatter and 1996 aerial photos

July 2001

In July 2001, a second acoustic survey of the Limekiln Bay was performed. In this case the Knudsen sidescan staves were used (the only available system at that time). The survey was done to coincide with a ground truthing program (Wildish et al., in prep). These used a diver-deployed corer that recovers relatively undisturbed samples.

Preliminary Groundtruth results:

Whilst complete analysis if the bottom samples for benthic fauna and geochemistry remains incomplete, digital photography of the exposed cross-sections of the push cores (Fig. 6), clearly indicate a gross contrast in surficial sediments.

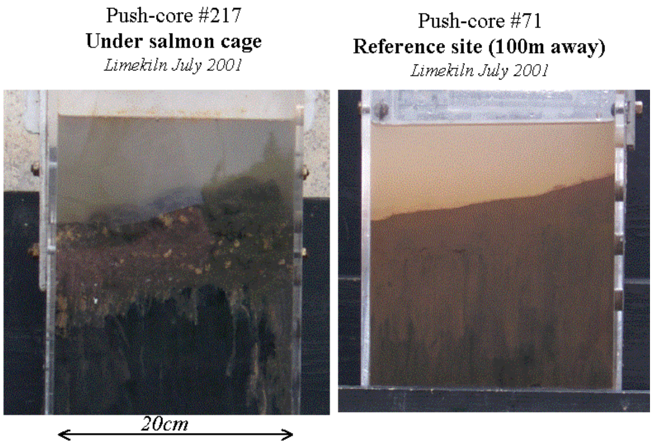


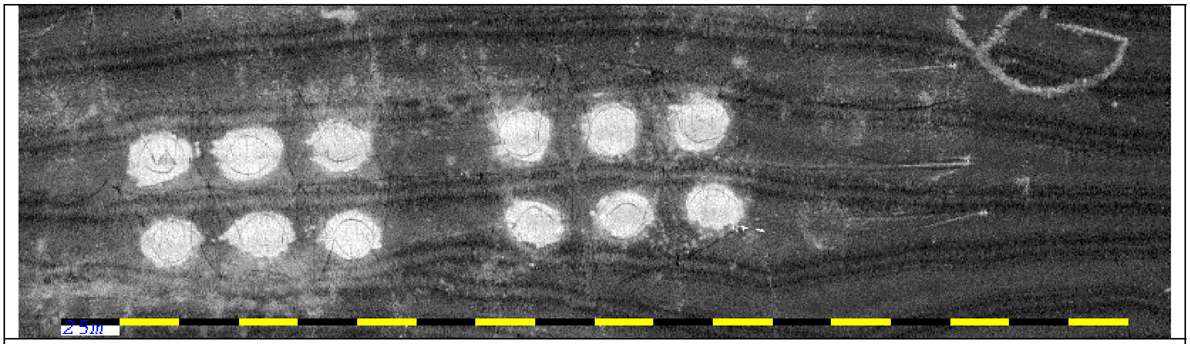
Figure 6: side photos of diver deployed box cores at the Limekiln aquaculture site.

Under the cages, a clear surface layer around 5-10cm thick was found containing waste food pellets and salmon faeces which sits on a black sulfide layer (Fig. 6, left). Few/no animals are found in the under-cage sediments. In contrast the sediment away from the active cages (a reference) shows none of these characteristics.

In contrast to the farm site, at the reference site (Fig.6 right) some 100 m away, there are voids and worms in the reference sediments.

Temporal Variability

Of particular interest with the second survey was to ascertain the extent to which the signature of the previous year would be preserved. The old cages had been emptied of mature fish, and they had then been relocated, in the same general area but at a slightly different orientation and offset.



Simrad EM3000S 300 kHz backscatter mosaic – Limekiln Bay, November 2000

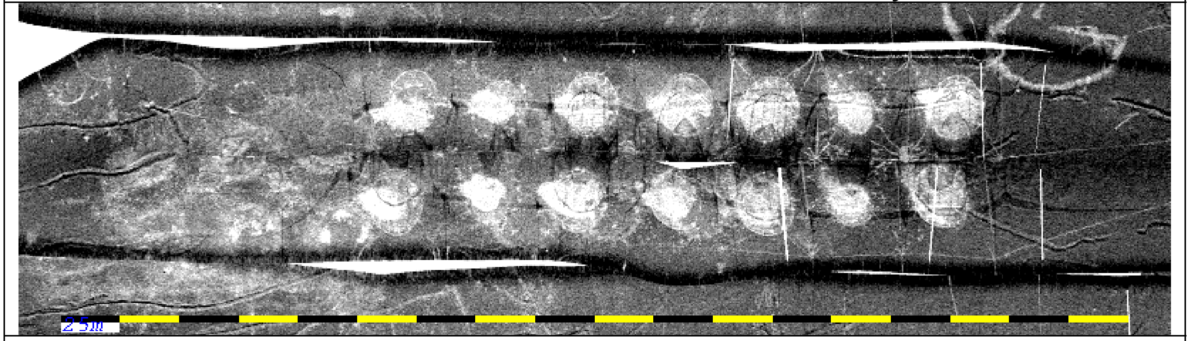


Fig 7 : Knudsen 320B/P 200 kHz sidescan mosaic – Limekiln Bay, July 2001

As can be seen from the comparative imagery in Figure 7 (above), where the old sites were not reoccupied, there is a distinct, if fainter and more spread out, signature of where the older sites were. Similar sub-circular acoustic signatures have quickly been established under new sites. It is notable that these newly established signatures are much more patchy suggesting that they have not yet completely covered all the underlying sediment.

Looking at these two images, which lie over a seabed which has a common signature all around (no natural sedimentary boundaries), it would appear to be a simple matter to use mean backscatter strength as an empirical indicator of enrichment. Of concern however, is the fact that other natural strong scatters in the region which show up with similar mean backscatter strength.

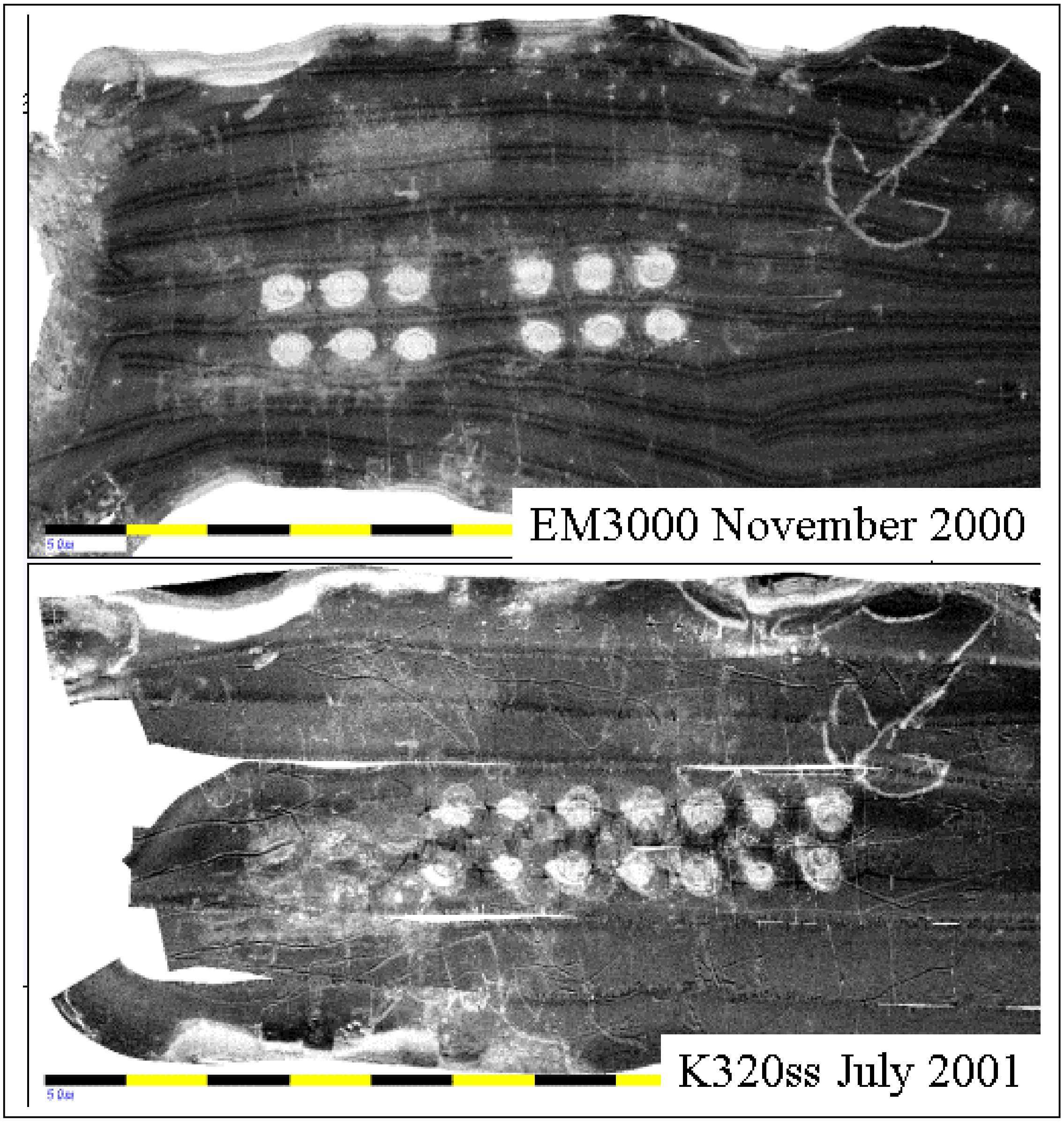


Figure 8: showing the acoustic imaging of the whole of Limekiln Bay, including the aprons of coarser sediment against the coast.

This can be seen in Figure 8 where we examine the entire bay. In the upper (EM3000) image, the signature of two previously abandoned farms can be seen (which are in the 1995 photos just like the example in Figure 5). These older deposits map out to have the same mean backscatter strength as the coarser sediment apron coming off the coastline immediately to the left in the same image. Similarly the high BS of the active organic enrichment is close to that of the gravel pavement along the upper edge of the image.

In contrast to the 300 kHz imagery, at 200 kHz, the backscatter strength of the gravel pavement appears significantly higher than that of the organic enrichment. Thus, inter-frequency intensity ratios may provide an added degree of freedom. To more definitively explore this approach we intend to try this method in the 2002 field season using the two systems collocated on the same survey platform. If the backscatter strength ratios between the two frequencies are different for the organic debris and the gravel pavements this provides a better means of discrimination (equivalent to multi-spectral imaging).

Discussion and Recommendations

Recent results from the Letang Estuary have demonstrated that organically enriched sediments clearly show up with a distinct acoustic facies. Whether this signature is due high roughness due to incompletely broken-up food pellets or the build up of micro bubbles in the sediment is still not known.

What the acoustic tools do clearly provide is a rapid means of measuring the spatial extent of the anomaly (at least in areas of naturally contrasting background sediments). This allows for the first time a quick means of examining the patchiness of the deposit and can be used to design an optimal and minimal ground truth sampling program. Without this step, any sparse grab or push core program risks having aliased results.

Limitation in the method, however, include:

1. Mean backscatter strength provides only one degree of freedom and thus there is ambiguity in classification for areas of high background sediment backscatter strength.
2. Robust angular response measurements cannot be acquired over such small patches.
3. Any attempt to use 2nd order statistics is limited due to signal corruption by the echoes and shadows of the farm hardware itself.

4. Absolute backscatter measurements from the EM3000 are not reliably repeatable after software or hardware reconfiguration
5. The data from the Knudsen sidescan at this time, is dependent on operator settings.

Future research directions are planned which intend to address a number of these deficiencies. They include:

1. Co registered, synoptic multi-frequency imaging to attempt to use inter-frequency ratios (“acoustic colour”).
2. Use a reference site in an area where we believe that no change has happened to try and quantify small changes in the sonar response due to changing hardware or software.
3. Conduct trials through a wide range of sonar settings for the Knudsen in order to quantify : beam patterns, absolute power levels, and pulse length settings.

Acknowledgements

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