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3D visualization for pelagic fisheries research and assessment

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Traditional acoustic approaches to the estimation of fish biomass have relied upon single-beam echo sounders that sample a relatively small volume of the water column within the survey area. Mean transect values, after bottom removal, are extrapolated to provide an estimate of number or biomass within a survey area. Over the past 20 years, many multibeam sonars have been developed but these systems which are commonly employed to collect detailed bathymetric and seafloor-type data, have been designed to remove mid-water returns. Only recently has a multibeam sonar been developed that allows for continuous digital recording of mid-water returns. For fisheries acoustics, the movement from single-beam to multibeam surveys provides a mechanism to greatly enhance the area and volume of coverage. The large volume of data generated by these systems, however, presents serious challenges for analysis and interpretation. This paper describes initial studies related to the transition from single to multibeam applications including the types of equipment investigated, the limitations of several acoustic systems examined, and how geomatics and 3D visualization can be used to enhance our knowledge of pelagic fish schools. Early results indicate that multibeam sonars, in conjunction with 3D visualization software can be powerful tools for assessing fish stocks, investigating fish school behavior, for exploring habitat preferences and for addressing questions related to vessel avoidance. As the technology improves so will the capability to investigate and to incorporate additional multi-parameter data such as water column properties and bottom type and as calibration techniques are developed for multibeam sonars estimates of biomass may also be possible.

Keywords: fish school dynamics, hydroacoustics, multibeam sonar, 3D visualization.

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Introduction

Scientific surveys in support of fisheries assessment typically consist of standardized field programs involving either stratified trawls and/or acoustic measurements that use relatively narrow-beam vertical-incidence echo sounders. In both cases the precision of biomass estimates is limited by the need to extrapolate from small sample sizes and an uncertain knowledge of the influence of the sampling techniques on the estimates. Furthermore, variations in the natural behavior may bias estimates through changes in availability, i.e. annual, seasonal or even daily changes in the vertical distribution of fish, as well as through changes in organizational structure that effect the ‘‘catchability’’ and/or distribution of the target species (i.e. whether fish are distributed as individuals, patches or schools).

Understanding the impact or effects of active avoidance is critical for stock abundance estimates based on either acoustic or trawl measurements. If fish react to an approaching vessel with either a horizontal or vertical displacement, the estimate of fish density will be biased (Misund, 1997). There are many reported cases of substantial and variable avoidance reactions of pelagic fishes due to boat and trawl noise (Ona and Godo, 1990). Unfortunately, the ability to make quantitative observations beyond the limited spatial coverage of a trawl or single-beam downward looking sonar has greatly limited the investigation of avoidance or behavior-associated bias.

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The need to increase areal coverage without compromising spatial resolution was recognized by several researchers who pioneered the use of multibeam or sector scanning sonars to address the critical issues of fish behavior and vessel avoidance [Bodholt (1982), Misund and Algen (1992), Gerlotto *et al.* (1994), Hafsteinsson and Misund (1995)]. Unfortunately, at the time of these studies, quantitative digital data output was not available for the sonar systems. The approach taken by these investigators was to digitize the video images produced by the sonar and to use these digitized images as the basis for subsequent analysis. In 1997 a multibeam sonar was introduced that permitted the acquisition of the digital data stream for the entire water column to several hundred meters either side of the vessel (the Simrad SM-2000). The transition from digital single-beam data to digital multibeam data also resulted in a tremendous increase in data density, as most modern multibeam sonars produce hundreds of megabytes of digital data per hour. While the volume and density of the data collected with multibeam sonars presents a distinct challenge for data processing, it also opens up a range of new possibilities for using modern data visualization techniques as an aid in analysis and interpretation. Herein we describe an investigation of the use of interactive 3D visualization techniques for the presentation and possible quantification of multibeam sonar data for fisheries research and assessment.

In a collaborative effort involving the sonar manufacturer (Kongsberg-Simrad-Mesotech), the herring fishing industry, the Canadian Department of Fisheries and Oceans, and researchers from the University of New Brunswick's Ocean Mapping Group and the University of New Hampshire's Center for Coastal and Ocean Mapping, a project was undertaken to developed a suite of qualitative and quantitative tools for the analysis and display of data collected with the SM2000 multibeam sonar. While the prototype software toolkit concentrated on the interactive (i.e. real-time or near-real time) 3D visualization of multibeam sonar fisheries data for observation and presentation, it soon became apparent that the technology was capable of far more. The fact that the system produced digital, beam-by-beam amplitude data which could be georeferenced meant that a powerful tool might be available to investigate spatial and behavioral related issues, assuming the system could be calibrated and some editing features combined with the visualization software. This paper provides a general background into multibeam sonars and describes the transition from single to multibeam technology. A description of the approaches taken to date and the current capabilities of the technology (illustrated with actual field data) is presented as well as an outline of the framework for future research activities.

Sonars

In modern times, the ability to explore the oceans has been inextricably linked to the evolution and development of sonar systems. Echo sounders (used both for measurement of depth and for fisheries work) have evolved since the Second World War from primitive instruments that could barely discern a faint echo from the seafloor to sophisticated systems with complex signal processing algorithms that result in extremely high signal-to-noise ratios and target resolution. The earliest echo sounders produced vertical beams that were very broad (typically 30–60°). While the travel time and range (assuming the sound speed is known) to a target could be easily be measured, the lack of angular resolution within the beam meant that the target could be anywhere within the beam footprint (an area with a diameter of 0.6–1.7 times the water depth). To resolve this problem, narrow beam (less than 10°) echo sounders were developed providing much greater lateral resolution but with ensonification of a much smaller volume of water. The ability to achieve both large areal coverage and high lateral resolution (through angular discrimination) came with the development of mechanical sector scanning sonars and then, in the early 1970s, with the development for the military of multibeam sonars.

A multibeam sonar typically uses multiple elements within a single array or orthogonal transmitting and receiving arrays, to produce a transmit pulse that is narrow (1–3°) in one direction (usually the fore-aft direction) and very broad (90–180°) in the opposite direction. Electronic beamforming is then used to produce a number of simultaneous receive beams that are narrow (1–3°) in the athwartships direction and relatively broad (10–20°) in the fore-aft direction. The receive beams intersect the transmit beam to produce 48–128 individual areas of ensonification that are the cross product of the transmit and receive beamwidths. Thus the system has large areal coverage (i.e. the swath width is 7.5 times the water depth in a 150° system) while maintaining the angular resolution of an extremely narrow beam sonar (1–3°). In contrast to a sector scanning sonar which employs incremental steps through an arc, the entire arc of the multibeam sonar's transmit pulse is imaged each time the sonar transmits. This results in complete coverage which at longer ranges, occurs at rates hundreds of times faster than that achieved by a scanning sonar (Figure 1).

Over the past 20 years several manufacturers have introduced multibeam systems working at frequencies from 12 kHz (for deep water) to 455 kHz (for shallow water). However, to reduce the tremendous amount of data produced by these systems and to focus processing efforts on determining the water depth, almost all are designed to record only the returns from the seafloor. Even considering only the seafloor returns, a

Figure 1. Typical geometry of bottom tracking multibeam sonar. A fan-shaped beam that is wide across track and narrow along track is transmitted while many receive beams that are narrow across track and wide along track are formed. The intersection of these beams (yellow boxes) results in many simultaneous depth measurements across the swath, each with excellent lateral resolution.

high-frequency multibeam system working in shallow water can collect more than 15 million soundings in an hour. Many systems also record the backscatter of the return and in shallowest mode can gather more than 400 Mbytes of data an hour. While this data density presents a difficult challenge to the data processor, it also provides tremendous opportunities for modern data visualization tools that can represent the information in new ways with unprecedented detail.

Taking advantage of this data density, a suite of software tools for the real-time processing, analysis, editing, and visualizing (in both 2D and 3D) of multibeam sonar data was developed by researchers at the University of New Brunswick and University of New Hampshire. These tools allow for interactive 3D visualization and exploration of large data sets in a simple and intuitive manner by converting numeric data into high-resolution image fields and taking advantage of the opportunities offered by scientific visualization.

The combination of multibeam sonar systems and visualization techniques have revolutionized the way in which we study the seafloor. No longer is it necessary to present bathymetric data as discrete soundings or interpolated contours. It is now possible to create full digital terrain models and then use color coding, artificial sun illumination, shadow generation and texture to create natural and realistic-looking 3D depictions of the seafloor (Figure 2). Much like the first aerial photographs or satellite images, multibeam sonar data has provided an unprecedented perspective of seafloor topography and thus the potential for new insights into the understanding of seafloor processes. More recent developments in multibeam sonar systems have allowed the simultaneous collection of seafloor backscatter data. These data provide insight into the nature of the seafloor (its roughness and/or composition) and when combined with the detailed bathymetric data collected with multibeam sonars offer the opportunity to present thematic maps of the seafloor. The ability to combine seafloor information with water column data on fish distribution and abundance is a powerful tool in fisheries and habitat assessment and ecological studies.

Applications to fisheries research

The use of multibeam sonar systems to collect, display, and interactively explore detailed bathymetric and seafloor-type data for fisheries applications began with bottom habitat related studies (Mayer *et al.*, 1997). The approach has been used for habitat studies of a number of ground-fish species and in direct support of the scallop fishery. In the case of the scallop fishery, detailed, sun-illuminated digital terrain models have been integrated into shipboard electronic charts allowing scallop rakes to be carefully placed with respect to the bottom structure. This process has been extended to the direct mapping of benthic habitat from integrated sets of multibeam sonar bathymetry, associated geological information, and benthos data (Kostylev *et al.*, 2001). The economic and environmental success of these efforts led to the investigation of whether multibeam sonars could be equally useful for pelagic fish species through the direct mapping and quantification of mid-water targets.

Given the advanced state of geomatics (i.e. the field of study related to the measurement analysis, management,

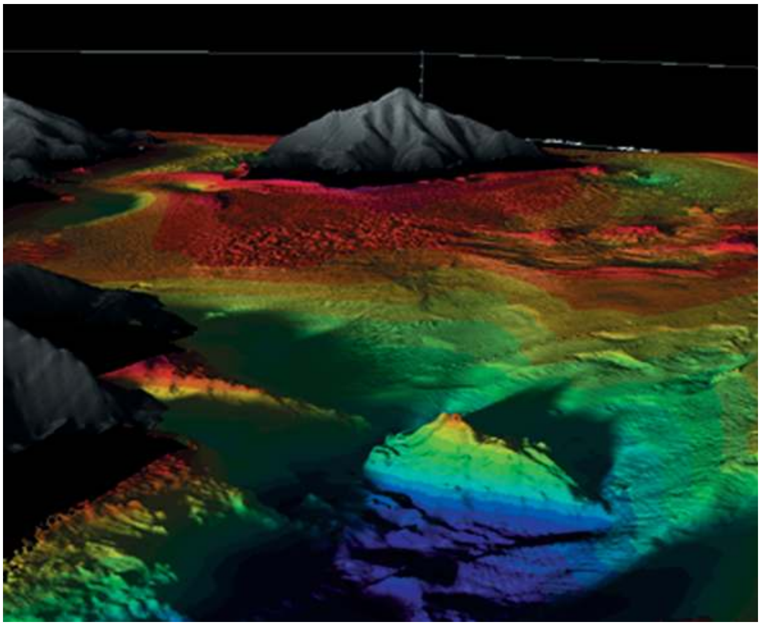

Figure 2. 3D visualization of multibeam sonar data from San Francisco Bay, CA. Data is color coded by depth and artificially sun-illuminated. Gray areas represent land data derived from USGS 30 m digital elevation models. Data courtesy of Jim Gardner, USGS.

storage, and display of spatial data), and concurrent developments in computer graphics hardware, initial efforts concentrated on the visualization and display of mid-water multibeam data to address issues of fish school dynamics and vessel avoidance during acoustic surveys. It was also implicit that as the sonar systems improved, estimates of fish density and volume could eventually lead to direct biomass determinations. Thereafter, efforts are likely to address the question of target discrimination (particularly for demersal fish as multibeam sonars resolve near-seafloor returns much more robustly than vertical incidence echo-sounders) and target classification.

The geometric advantages of a multibeam sonar versus a single beam sonar for pelagic fisheries studies are manifest. A single beam sonar with an 8° beamwidth will ensonify 40 million cubic meters of water per hour at a 200 m range (at a survey speed of 8 knots). A multibeam sounder with a 150° swath and the same 200 m range will ensonify more than 2 billion cubic meters of water per hour at 8 knots. Not only is the volume ensonified greatly increased but this ensonification is done with the ability to discriminate the azimuthal position of targets (to the resolution of the beam width) and with a lateral resolution that reflects the small beamwidth of the individual beams of the multibeam sonar (e.g. 2° for the SM-2000) vs. the larger beamwidth of the single beam sounder.

In searching for a multibeam sonar to investigate mid-water fisheries related issues, it quickly became apparent that most multibeam sonars were designed specifically to remove mid-water returns; modification of these systems would be very difficult and expensive. On the other hand, commercial fishing sonars, which are designed specifically to display mid-water returns, were not typically capable of the digital acquisition and data storage required for visualization. For all practical purposes a multibeam sonar system which met our requirements was not available. In order to resolve this problem a collaborative project with Kongsberg-Simrad-Mesotech (KSM) was initiated. In the short-term, KSM modified an existing sector scanning sonar to allow a digital data stream from which to develop visualization algorithms. In the long-term, a true multibeam sonar was developed to provided digital return data for its entire range setting (i.e. water column and bottom data).

3D visualization

Traditionally, sonar displays have presented a two-dimensional image of relative target strength (often color-coded) vs. range in a vertical plane beneath the vessel or a horizontal scan forward of the vessel (Maclennan and Simmonds, 1992). The advent of omnidirectional and multibeam sonars made possible the display of 2D slices, with many choices of the sector displayed. Data were presented in 2D because such displays are easy to produce in real-time. The presentation is, however, much less than intuitive, as the observer is

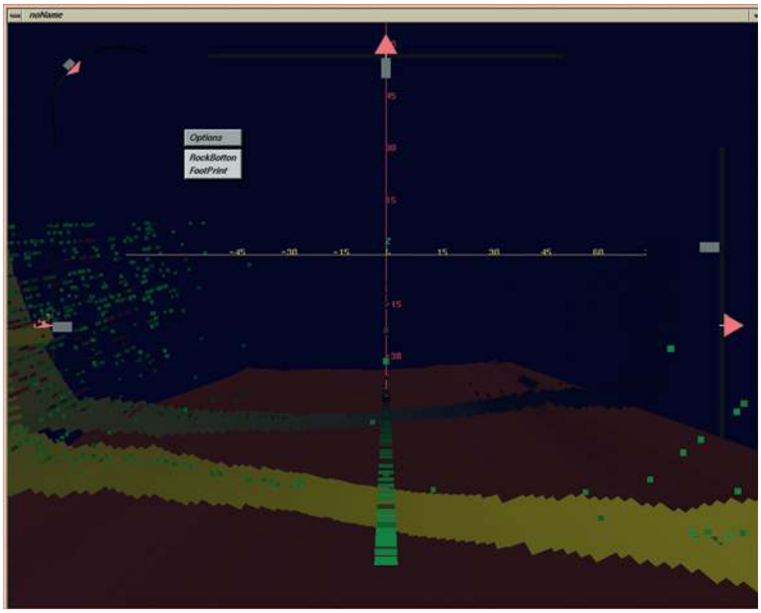

Figure 3. Front-on view of 3D visualization of MS-900 sector scanning sonar and a Biosonics vertical profiler Where the vessel is moving into the page. The brown area represents the seafloor, yellow the footprints of the MS-900 sweeping 75 m to either side of the vessel and green the Biosonics sounder footprint directly below the vessel. A few targets (fish) are discernible in the outer ranges. Due to forward motion of the vessel, only that part of the water column above the yellow footprints are ensonified during a sweep of the sector scanner. Note the vast difference in area of ensonification between the vertical profiler and the sector scanner as well as the unsampled water volume for each system.

forced to attempt to mentally integrate these 2D pictures into the actual 3D distribution of targets. Our approach was to take advantage of recent developments in both sonar technology and graphics hardware as well as our experience with 3D visualization to produce a fully georeferenced 3D display of the acoustic targets. With such an approach, the complete distribution of targets (within the ensonified area) can be visualized in a natural and intuitive way. If the acoustic targets are fish, then visualization can provide direct information on fish behavior, school dynamics, and possible vessel avoidance. With such an approach, researchers would be able to quickly determine if their experimental strategy is appropriate for a given set of circumstances.

Sonar systems and field work

In developing visualization tools a number of sonar systems were evaluated. These included vertical incidence echo-sounders (manufactured by Biosonics and Femto), several commercial fishing sonars, a Simrad-Mesotech MS-900 sector scanning sonar and finally a true multibeam, the Simrad-Mesotech SM-2000. The following briefly describes the nature of the latter two sonars and their modes of deployment then discusses the presentation of data collected from them as true 3D displays; finally approaches to more quantitative studies are discussed.

MS-900 sector scanning sonar

Initial studies revolved around a modified Simrad/Mesotech MS-900 sector scanning sonar. This compact sonar, originally designed for target imaging and pipe-tracking, operates at 330 kHz (5–250 m range) with a 100 msec pulse length, and a $1.9 \times 25°$ beam that scans in 1.3° increments. A complete 180° scan takes between 17 and 34 s. The system was modified to permit the digital logging (at 20 kHz using a custom built multi-channel digitizer) of each return signal, navigation data (from DGPS) and information describing which sector was being ensonified (Cochrane and Melvin, 1997). While the MS-900 provided an initial dataset with which to develop 3D visualization techniques and to demonstrate both the feasibility and advantages of wide-swath coverage for fisheries research, the MS-900 was found to be less than ideal as it leaves much of the water column unensonified. This is due to the slow scanning rate of the sonar (17–34 s per sweep) combined with the forward vessel motion of 6–8 knots (see Figure 3). Thus the need for a true multibeam sonar.

SM-2000 multibeam sonar

In late 1997, KSM introduced the SM-2000, a compact multibeam sonar system operating at a frequency of 200 kHz with a range setting of 5–400 m. A prototype was provided to explore its viability as a tool for mid-water data collection. The prototype formed 128 simultaneous beams with a swath width of 180°. Beams were spaced at 1.4° increments and the sonar footprint was 2.0 × 20° [20° in the fore/aft direction (with − 15 dB sidelobe suppression)]. More recently, a second transmitter has been added to the system (SM-2000P) which provides an across track beamwidth of 1.5 or 3.0° and allows for an along-track beamwidth of 1.5 or 3.0° (selectable) and transmit swath widths of 120 or 150°.

Field programs

The sonar systems were tested in September 1997 and September 1998 as part of a herring survey conducted by the Departmemt of Fisheries and Oceans' research vessel "Teleost" on Brown's and German Bank (well-established herring spawning grounds) off Nova Scotia, Canada. Standard acoustic protocol and survey design was employed with a series of randomly selected transects established for a pre-defined survey area (Melvin *et al.*, 1998). In October 1999 additional surveys were conducted within the confines of a herring weir (fixed trap) containing a known fish biomass.

Except for the weir experiment, the sonar systems were mounted in a tow body and deployed off the starboard side of the vessel at a depth of about 15 m to mitigate problems of propeller wash and to decouple the sonar from vessel motion. Typical survey speeds were 5–7 knots and sonar ping rates were 2–5 pings per second. Along with the MS-900 and SM-2000 records, data was also collected with a calibrated, vertically incident (3 × 3° beamwidth) 120 kHz Biosonics profiler and/or an 11° circular beamwidth, 50 kHz Femto sounder. Both vertically incident sounders were digitized with a Femto digital acquisition system (HDPS version 5.6).

For the weir experiment the SM-2000 sonar head and Femto vertical sounder were mounted on a floating platform in the center of a 1603 m^2 herring weir in 16 m of water off the southwest coast of New Brunswick. A GPS antenna was mounted directly above the transducers and used to monitor the position of the sonars. The sonar heads were oriented vertically with the multibeam sonar set on a 50 m range. This enabled ensonification of the full width of the weir within a single swath. The floating platform with the sonar heads was rotated through 360° providing complete ensonification of the contents of the weir.

Data processing and display

The time-series from each individual scanned sector of the MS-900 was digitized at 20 kHz and stored on disk. For the Biosonics and Femto systems all signals above a set threshold level were recorded for each ping (1/sec). Positional information from each of these systems (from DGPS) was also logged with the data, producing a simple data stream of relative target strength versus range and position subsequent display. For the SM-2000, the only information which could be recorded and played was the raw received amplitude on each transducer element. Algorithms to form the 128 individual beams were therefore developed in order to allow post-processing visualization and analysis.

Once the beams are formed, individual time series representing the echo strength as a function of range for each of the 128 beams (in this case at 1.4° increments) is produced. Data are presented using both the SM-2000 with a single transmit/receive transducer (2.0 × 20° beamwidth) operating with a 180° swath and the SM-2000P with a separate transmitter (2.5 × 3.0° beamwidth). As with the other systems, navigational information from DGPS was logged in the ping header with the sonar data. A fixed setback was used to calculate the position of the tow body relative to the vessel.

Target extraction and position determination

Early work (pre-1998) took advantage of the advances in graphics hardware by using state-of-the-art, Silicon Graphics workstations; however because of technology enhancements (particularly the very rapid development of powerful graphics boards for the computer games market) subsequent applications have been developed on NT-based workstations. Given a time-series of amplitudes as a function of travel-time (which is then converted to range using a measured or assumed sound speed), a known beam width, orientation for the beam, and concurrent positional information for the vessel and the tow body, the position in geo-referenced space of any target in the time-series can be determined. While this can be done for any "target" in the time-series, a thresholding algorithm is applied that identifies the seafloor (consistently the strongest return in the time-series) and then allows a user selectable choice of levels for "significant" targets. The 3D position and target strength for each target above the threshold and for the seafloor is then calculated and sent to an output file for display.

3D display

For any given ping, a ship-centered, three-dimensional coordinate scheme is established within the context of the screen display and the targets are plotted as color coded (based on relative target strength) 2D polygons whose dimensions are a fixed number of sample intervals in their proper location relative to the vessel. The seafloor return is plotted as a smooth, shaded surface. A single ping display would look something like a standard 2D plot provided by most sonar manufacturers (Figure 4).

The true 3D display results from multiple pings combined with vessel motion and the use of a moving window algorithm that provides a visual perspective that

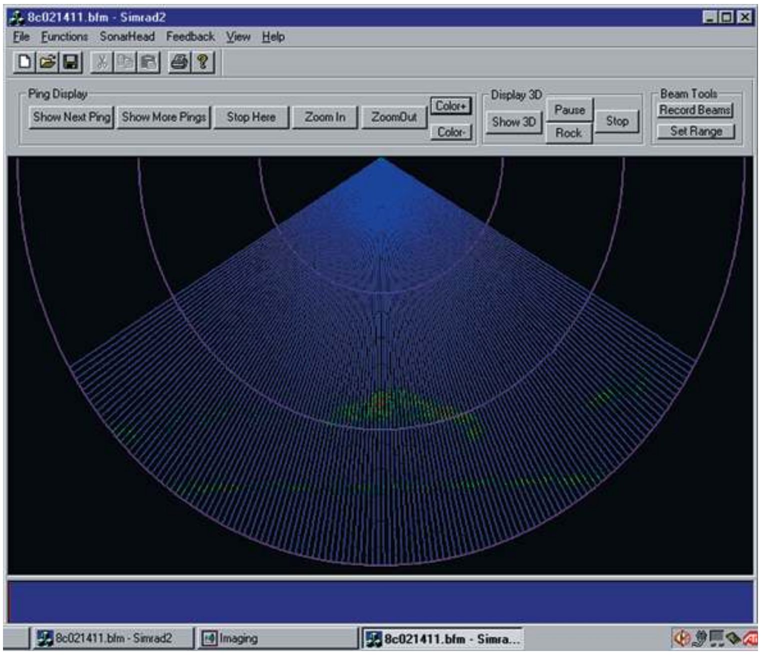

Figure 4. 2D display of herring being ensonified with the SM-2000 in 150° sector mode; range is 200 m. Seafloor is flat return at bottom of display, fish (mid-water targets) are color-coded based on relative target strength.

moves with the vessel. A specified number (typically 60) of pings are displayed within this window representing 0.5–1 minute of vessel transit (depending on ping rate and vessel speed). The display continuously scrolls, keeping up with the vessel's forward motion. The display of multiple ping data is presented in perspective using a number of visual cues to add to the sense of 3D (i.e. color blending which blends colors gradually into the background color as they are further from the viewers perspective). A mouse-controlled interface (widgets) allows the manipulation of the scene with six degree of freedom so that it can be viewed from any perspective. As the vessel transits, the oldest ping data is dropped off the front of the screen and the most recent data is added, producing a continual scrolling scene of the vessel and the targets moving over the seafloor (Figure 5).

While initial 3D visualization work was done off-line on previously collected data, we can now, even with a Pentium II processor and low-end graphics board (ATI-Pro), display 3D data at ranges up to 30 m and repetition rates of up to five pings per second in real time. With a faster processor and high-end graphics boards (e.g. Oxygen GVX), much higher repetition rates and ranges are possible.

Initial observations and future directions

The relative advantage of multibeam data and 3D display are clearly evident in Figures 3 and 5. In Figure 3, a frame from a scrolling 3D visualization collected while simultaneously profiling with a Biosonics vertical incidence profiler and the MS-900 sector scanning profiler is presented, while in Figure 5, data collected simultaneously with the SM-2000 and the Femto sounder are displayed. In Figure 3, the acoustic footprint of the single beam system is indicated by the green boxes intersecting the seafloor; in Figure 5 it is represented by the vertical wall in the middle of the image. The observed difference in volume ensonified is clear as the sector scanner sweeps to 75 m to either side of the vessel versus the very limited volume ensonified by the vertical profiler (Figure 3). On the other hand, the multibeam sonar simultaneously ensonifies more than 100 m to each side of the vessel while the vertical sounder samples only the small volume of the water column directly below the vessel. It is also clear from Figure 5 that the density of fish is highly variable across the vessel's track, a fact that the vertical incidence profiler could not resolve.

It is important to note that the across-track resolution of the sector scanner and the multibeam system is significantly better than that of the vertical profilers (1.9 and 1.5° vs. 3 or 12°). However, in this case the along track resolution of the vertical profiler is significantly better than either the sector scanning or the multibeam sonar. The drawback of the sector scanner in terms of unensonified volume is also evident as much of the water column remains unsampled (Figure 3). With the transition to the true multibeam (SM-2000), the entire water column is sampled (Figure 5) and given the beamwidth

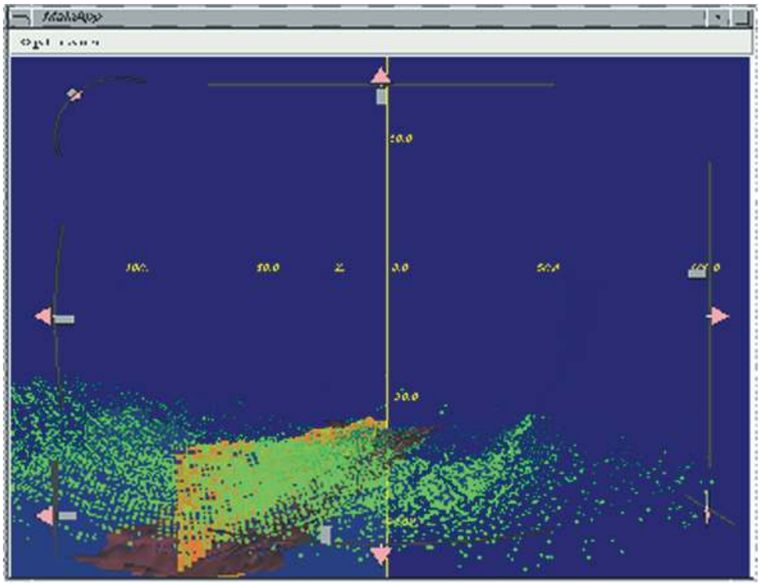

Figure 5. 3D visualization of SM-2000 and Femto vertical profiler data off Chebucto Head, Nova Scotia collecting data over herring school. Area ensonified by Femto profiler is indicated by vertical wall in middle of display. Rest of display is area (100 m to either side of vessel) ensonified by SM-2000. Brown region is seafloor return. Note the variation in density of fish across swath that can not be seen with the vertical sounder.

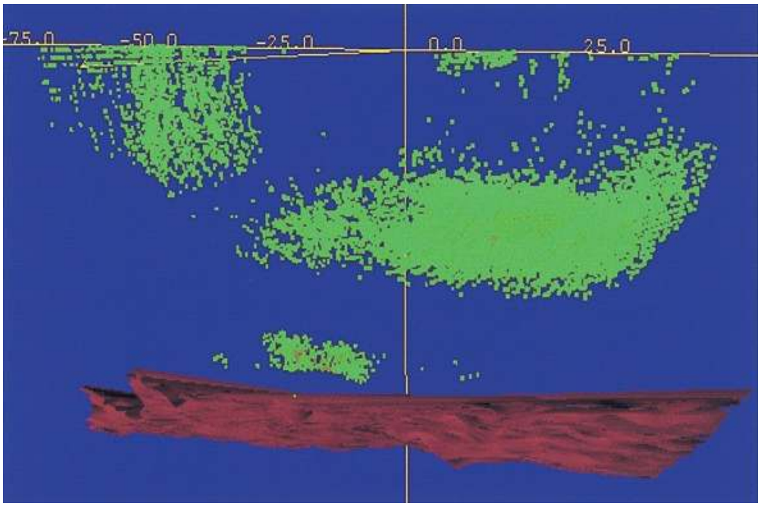

Figure 6. Evidence of avoidance as vessel steams through school of herring. Gap in school is observed directly under path of vessel (into page at 45° angle). Sonar is on 75 m range to either side of vessel; brown surface is seafloor. This behavior is typically observed during night operations when fish are closer to surface.

available with the separate transmitter (SM-2000P), the along-track and across-track resolution is equal to, or better than, that of the vertical incidence sonars.

With 128 individual 1.5 × 1.5° beams covering a sector of 120–180° around the vessel, the behavior of fish schools, if not individual fish, can be monitored. Initial results have often shown avoidance behavior with schools apparently parting and/or diving as the vessel moves over them (Figure 6). Differences in avoidance behavior associated with day/night school depth (avoidance behavior being greater when the school is at shallower depth) as well as seasonal effects, probably associated with spawning behavior, have also been noted. While these initial observations are subjective, the combination of digital data, large areal coverage, and high resolution will allow us to develop tracking

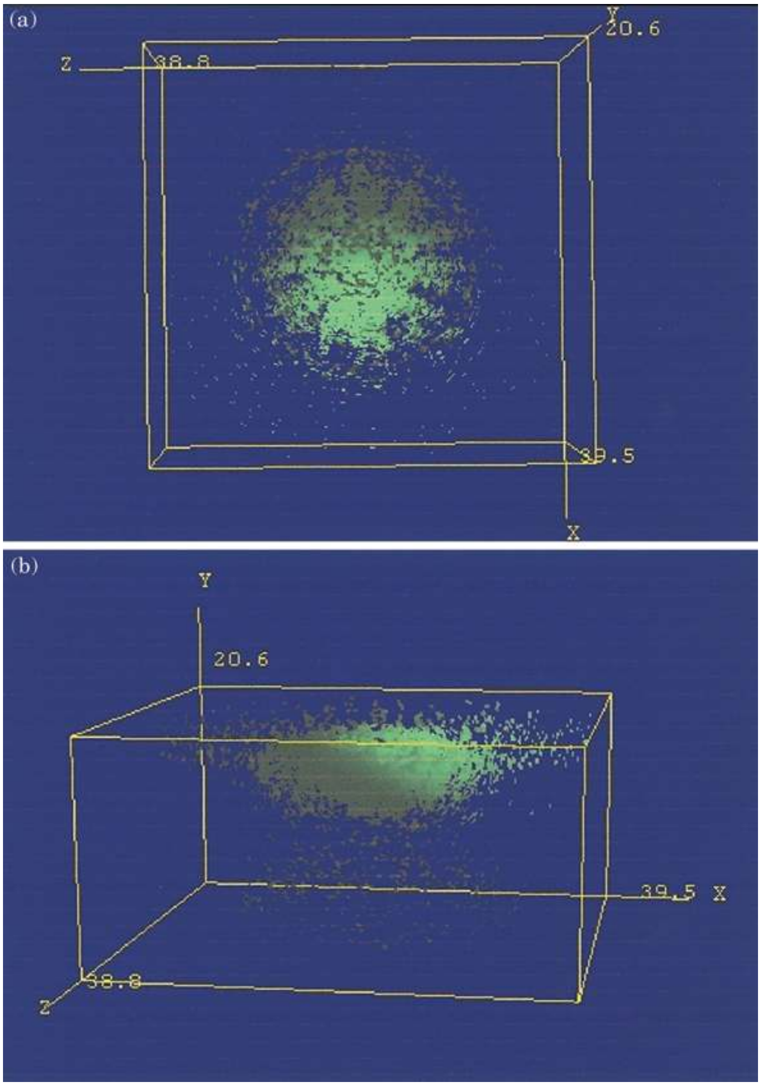

Figure 7. Oriented particle used to produce a 3D image of the contents of a 1603 m^2 weir off the southwest coast of New Brunswick ensonified with SM-2000. (a) top view, (b) side view. Bounding box is for scale and not indicative of bounds of weir.

algorithms that can quantitatively monitor changing behavior. Specifically, an approach is being explored that allows individual returns to be displayed as "oriented particles" a technique that allows the targets to be viewed as individuals but with an orientation that is based on the distance to their neighbors (Li, 1996). This approach allows the shape of the school to be easily discernable while maintaining the targets as discrete individuals (Figure 7).

Through the use of standardized acoustic targets (Foote *et al.*, 1987) we are currently in the process of calibrating the SM2000, a non-trivial task considering the multibeam nature of the sonar. These calibrations will allow for the calculation of volume backscatter for each beam and from this, estimates of density and biomass. Algorithms are also being developed for the cleaning and editing of the data as well as for the counting of individual targets when target density is low.

The combination of large areal coverage with high angular and spatial resolution will also help address the key issue of biomass estimates. The small beam angles of the SM-2000P greatly enhance the chances that targets detected represent individual fish (particularly at close range). In addition, the ability to measure phase differences from discrete contiguous beams presents the opportunity to determine the orientation of the targets (in the across-track direction); the high repetition rate may allow the determination of orientation in the along-track direction. Finally, the ability to capture the entire waveform from multiple, georeferenced, returns, opens up the possibility of statistically robust waveform characterization for target classification.

The experiments conducted in the weir provide the opportunity to "ground truth" the algorithms. Figure 7 shows the ensonified contents of the weir directly before being emptied by seining. Thus both multibeam acoustic measurements as well as absolute measurements of both the biomass and the size distribution of the contents of the weir are available. These "ground truth measurements" will provide an excellent means of calibrating the algorithms developed for biomass and density estimation.

Conclusions

Many of the uncertainties associated with our ability to estimate fish stock abundances can be linked directly to limitations in the spatial coverage of our sampling systems. In order to achieve large areal coverage, traditional hydroacoustic techniques have had limited spatial resolution. Newly developed multibeam sonar technology, however, now allows for large areal coverage while maintaining high spatial resolution. The large volume of data generated by these systems, however, presents serious challenges for analysis and interpretation. We are taking advantage of new developments in graphics hardware, as well as our expertise in handling multibeam sonar data and in visualizing large and complex 3D data sets to develop a suite of software tools that allow the real-time or near real-time interactive 3D display of all acoustic targets in the water column to several hundred meters on either side of a survey vessel. Even during the initial field trials of these tools we have been able to clearly demonstrate the value of ensonifying a large volume of water while maintaining high spatial resolution for monitoring fish behavior, fish school dynamics, and vessel avoidance. As they evolve, these visualization tools will become the basis for further research into quantitative estimates of biomass and target identification.

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