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Digital echo visualization and information system (DEVIS) for processing spatially-explicit fisheries acoustic data

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Abstract

Spatially explicit analysis of fisheries acoustic data preserves heterogeneity observed in spatial distributions of fish. A software system — Digital Echo Visualization and Information System (DEVIS) — has been developed to process digital underwater acoustic data for spatially-explicit fisheries acoustic research. This system can be used to obtain spatial and temporal distributions of fish density, fish abnndance, and fish lengths for management applications and for ecological modeling. DEVIS first reads digital data, corrects the data according to the sonar equation, discriminates individual targets, and vertically and horizontally integrates the data into a two-dimensional array of mean volume backscattering strength. Individual target information (TS, spatial location) is meshed with the volume backscattering array, and representative acoustic sizes are estimated in array cells with missing target information. Estimation methods for acoustic sizes and potential biases in abundance estimates are introduced and discussed. The final output is the spatial distribution of numeric density and fish length by length classes and for all fish. Data obtained on Lake Erie in September 1994 and on Chesapeake Bay in July 1995 were processed using DEVIS and are shown graphically. Steps required to process digital data are described and how these data can be applied to fish ecology is shown. Published by Elsevier Science B.V.

Keywords: Fisheries acoustics data processing

1. Introduction

The most common type of fisheries acoustic surveys uses a downward-looking transducer that insonifies the water column from surface to bottom along transects. Traditionally, this type of survey produces estimates of fish density, abundance, and fish lengths for each transect. Investigations using high-resolution acoustic instrumentation have shown that fish distribution is spatially patchy (Nero and Magnuson, 1989; Horne et al., 1996; Petitgas and Levenez, 1996) and that these spatial patterns can be important in ecological processes (Brandt et al., 1992; Brandt and Mason, 1994). Data from fine-scale acoustic surveys result in a two-dimensional (horizontal and vertical) spatially-continuous landscape of fish distribution.

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Survey transects often cross thermal (e.g. thermoclines and thermal bars) and spatial (e.g. nearshore vs. offshore) regimes where discontinuities in species composition, fish lengths, and abundances can occur. Spatially-explicit analysis of fisheries acoustics data can preserve heterogeneous fish distributions by partitioning data into array cells with typical dimensions of 0.5–1 m (vertical) and 50–100 m (horizontal). Each cell has spatially-indexed values of numeric density and fish length and can be referred to the physical environment for quantitative analysis of biological–physical relationships and bioenergetic modeling (Brandt et al., 1992).

The advent of digital echosounders has greatly increased the accuracy and dynamic range of sonar data collected in aquatic systems as well as the overall speed in processing these data on computers. Digital echosounders have several advantages: they eliminate the time consuming step of retrieving analog data, they can facilitate near real-time processing (Powell and Stanton, 1983), and they can be directly processed, visualized, and analyzed on any computer platform. The Digital Echo Visualization and Information System (DEVIS) software system was developed to read, process, analyze, and visualize digital data for spatially-explicit analysis of fisheries acoustic data. DEVIS was written and developed at the Great Lakes Center, SUNY-College at Buffalo for use with the scientific community. The impetus for this software came from the need for higher resolution spatial data for ecological studies of fish (Brandt and Mason, 1994).

In this paper, we describe DEVIS from the perspective of processing fisheries acoustic data for individual target information (spatial location and acoustic scattering size) for two-dimensional arrays of volume scattering, for calculations of numeric density and for data visualization. We give brief descriptions of the SONAR equation and demonstrate the importance of obtaining an accurate estimate of the acoustic size of individual targets for applications to fisheries management and ecological studies. For more detailed descriptions and derivations of the SONAR equation, the reader is directed to Forbes and Nakken (1972), Urick (1975), Clay and Medwin (1977), Greenlaw and Johnson (1983), MacLennan and Simmonds (1992), Misund (1997), and Medwin and Clay (1997).

2. Software overview

DEVIS is a fisheries acoustics research tool that provides a software environment where new and innovative data analysis and visualization ideas can be tested and implemented. DEVIS maintains a constant data format, which increases the efficiency of processing, analyzing, and visualizing the data. Results are the spatial or temporal distribution of fish abundance, fish length, and fish density estimates. These results are crucial for making fisheries management decisions such as stocking strategies for sport fish (Brandt et al., 1991; Brandt, 1996), for monitoring programs, and for ecological studies such as estimating potential grazing rates of planktivorous fish on zooplankton (Luo and Brandt, 1993), spatial modeling (Nero and Magnuson, 1989; Nero et al., 1990; Mason and Patrick, 1993; Luo et al., 1996), and spatially-explicit bioenergetics models (Brandt et al., 1992; Brandt and Kirsch, 1993; Goyke and Brandt, 1993; Mason and Brandt, 1996).

The overall format of DEVIS has been separated into two primary procedures. The first procedure reads the data, then corrects the data for time varied gain (TVG), absorption losses, beampattern effects, echosounder and transducer gains, and calibration parameters (Fig. 1, Digital data processing). We also incorporate algorithms in this step to discriminate individual targets from multiple targets. DEVIS outputs a two-dimensional mean volume backscattering strength array ($\bar{s}_v$) and information on individual targets. The s_v array is vertically intergrated and horizontally averaged echo energy which is proportional to numeric density. The acoustic backscattering cross-section, angles off-axis, and spatial target location are calculated for individual targets.

The second procedure (Fig. 1, Post-processing) meshes the $\bar{s}_v$ array and individual target information into two-dimensional arrays of numeric density, fish length, and acoustic size for statistical analysis and visualization. Acoustic echoes can be converted to fish length (Cushing, 1973; Midttun, 1984; Foote, 1991), and the spatial distribution of numeric density for a number of user defined length-classes can be computed. The reader should note that the conversion of acoustic size to fish length is complicated by the orientation and aspect of fish relative to the transducer, by the elongated shape of fish, and the presence or

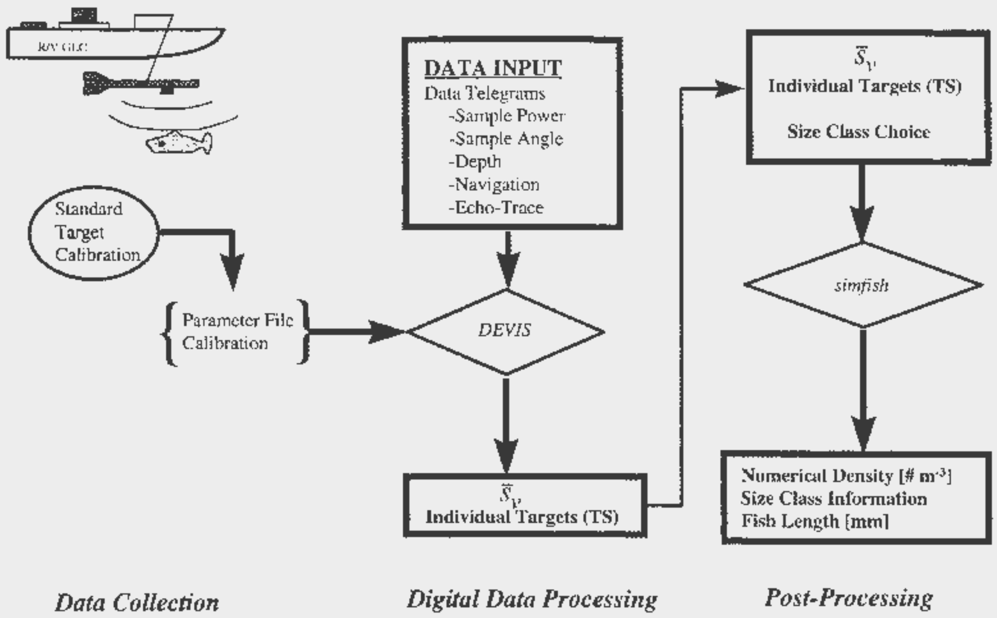

Fig. 1. DEVIS flowchart for processing digital sonar data. The *Digital Data Processing* procedure (left side) reads raw digital sonar signals, parameter values, and calibration information to output $\bar{s}_V$ and acoustic target size information. The *Post-Processing* procedure converts this information into an array of numerical density, fish length, and numerical density of size-classes.

absence of a swimbladder (Nakken and Olsen, 1977). Compensation for these effects is currently an area of study in the fisheries acoustics research community. For mobile fisheries surveys, the vertical dimension is depth, and the horizontal dimension is time or distance along a transect. Time is the common denominator for integrating acoustic data with zooplankton data (Stockwell and Sprules, 1995) and physical data (Nero et al., 1990; Brandt et al., 1996). DEVIS also contains algorithms to integrate Global Positioning System (GPS) data, which is useful for placing the data in a geographic context.

The software is written in Interactive Data Language (IDL) (Research Systems, 1996). IDL software is necessary to run DEVIS and can be run on a variety of platforms, from UNIX workstations to PCs (both Microsoft Windows based and MacIntosh), increasing the portability of the code. Simrad EY500 split-beam echosounder data have been used as a model for DEVIS. Post-processing and visualization procedures are independent of data input and were built on more than 6 years of fisheries and ecological acoustic processing using a variety of other echosounder systems (Kirsch, 1992).

3. Data processing

DEVIS uses "raw" digital data (i.e. gains and corrections have not been applied) allowing greater flexibility to correct misapplied gains during data collection, to determine scales of integration, and to diagnose inconsistencies in the data. A parameter file defines parameters used by DEVIS, and values are changed for the specific environment and echosounder system (Table 1). Parameters are noted in the text when applicable to processing procedures. To enhance processing time, only data in the water column are processed. In addition, near-surface and near-bottom data can be ignored (parameters: transducer depth, blanking distance — "blind spot" distance immediately below the transducer, and off-bottom integration distance). Data processing consists of correcting the signal for transmission losses and echosounder gains, applying calibrations, discriminating individual targets from multiple targets, and creating a two-dimensional $\bar{s}_V$ array.

Acoustic sizes of individual targets are obtained by solving the SONAR equation. For an individual target, the SONAR equation is written in linear form

Table 1
Parameters and default values for processing digital sonar data with DEVIS[a]

Parameter values	
Category	Default value
Sonar frequency (kHz)[b]	120
Vertical bin size (m)	1.0
Horizontal bin size (ping)	20.0
Record depth (m)	20.0
Alpha (dB/km)	10.0
Sound speed (m/s)	1500.0
Max. power output (W)[b]	63.0
Directivity index (dB)[b]	28.2
Transducer efficiency (%)[b]	77.0
Max. angle (degrees)	4.0
Blanking distance (m)	1.0
Min. TS detection (dB)	70.0
Min. echo length	0.8
Max. echo length	1.6
Pulse width (ms)[b]	0.3
Equivalent 2-way beam angle (dB)[b]	20.7
Off bottom integration (m)	0.5
Transducer depth (m)	1.5
Std. target strength (dB)	−40.4
Angle sensitivity alongship[b]	21.0
Angle sensitivity athwartship[b]	21.0
s_v minimum level	100.0
Phase deviation	1.0

[a] These values are changed to reflect the specific echosounder and analysis.
[b] Echosounder specific parameters.

as

$$p_e^2 = D^4\sigma_{bs}\left[\frac{\langle p_0\rangle^2 G_E}{R^4 \times 10^{(4\alpha R/20)}}\right] \quad (1)$$

where p_e is the echo pressure, $\langle p_0\rangle$ the source pressure, D the directional response of the transducer, α the attenuation coefficient (dB m^{-1}), R the range (m) from the transducer to the target, and G_E is the echosounder gain which is presented as a generic term that is echosounder dependent. The acoustic backscattering cross sectional area, σ_{bs} (m^2), is the acoustic size of the target. It is the ability of the target to scatter sound back to the transducer and is the primary variable used throughout all subsequent calculations and conversions to numeric density, fish length, and biomass. A common form of the acoustic size given in fisheries acoustics literature is the logarithmic form of target strength: TS=10 $\log_{10}(\sigma_{bs})$ (dB) (Clay and Medwin, 1977). Terms within brackets in Eq. (1) are used to correct the signal for source level, transmission losses, and echosounder gains. To obtain accurate measurements of σ_{bs}, targets need to be recognized as individuals and compensation for the transducer directional response must be applied.

Individual targets are discriminated from multiple targets using a series of criteria (parameters: min. TS detection, min. and max. echo length, and phase deviation). The first parameter sets the lower limit, in decibels, of target acoustic sizes. For example, if larger fish are wanted, the user can filter out smaller fish and zooplankton by setting a larger minimum TS. The next level of discrimination uses the echo shape to discriminate targets. The parameters min. and max. echo length are a proportion of the pulse width at the −3 dB points (echo width at the half-power points of the peak). The echo waveform is similar to the waveform of the incident pulse, and the width of the echo relative to the pulse width has been used to discriminate individual echoes from overlapping echoes (MacLennan and Simmonds, 1992; Traynor and Ehrenberg, 1979). The final level of individual target discrimination is a phase deviation parameter. We use the "standard deviation discriminator" to compute the standard deviation of phase values within the echo (Soule et al., 1996).

After an echo has been accepted as an individual return, the angular position is computed. Split-beam and dual-beam systems have an advantage over single-beam systems by directly measuring the target's position relative to the acoustic axis. DEVIS calculates the alongship and athwartship angles of the echo peak from the Simrad "sample angle" data telegram. This angular position within the beam is used to compensate for the transducer directional response. The final target filter (parameter: max. angle) eliminates targets if their maximum angular distance is greater than the specified angle. A smaller angle will reduce the number of accepted individual targets, and an angle greater than the beamwidth reduces the certainty of the σ_{bs} calculations for targets outside the main lobe.

The echosounder must be calibrated to quantify acoustic measurements (Foote, 1982). This is accomplished using the standard target technique (MacLennan and Simmonds, 1992) with a tungsten carbide ball (38 mm diameter, TS=−40.4 dB at 120 kHz) (parameter: std. target strength). Calibration results consist of the beampattern and a numerical correction for the difference between the standard target and observed target strengths. The beampattern requires a large number of valid target acquisitions in each quadrant. We obtained excellent results when calibrating a Simrad split-beam echosounder in January 1996 on the frozen Erie Canal using the ice as a stable platform. A two-dimensional polynomial of the 4th degree is fitted with a multiple regression model to create a calibration file that defines the beampattern and numerical TS correction (similar to the "lobe" program by Simrad).

The digital signal is also corrected to obtain volume backscattering strength (s_v) based on the equation

$$s_V(R) = \frac{32\pi^2(\text{Digital Signal }(R))R^2 10^{(2\alpha R/10)}}{\Pi(xdeff)\lambda^2 c\tau\Psi 10^{(\text{DI}/10)}10^{(G_{sv}/10)}} \qquad (2)$$

where digital signal is the digital sample data, Π the maximum power of the Simrad echosounder, *xdeff* the transducer efficiency, λ the acoustic wavelength, c the speed of sound in water, τ the pulse width, DI the directivity index, Ψ the equivalent two-way beam angle, and G_{sv} is the echosounder gain (Table 1). In cases where noise from electrical or mechanical sources is present in the data, the s_v minimum level parameter filters unwanted noise similar to Watkins and Brierley (1996). The corrected s_v's are vertically intergrated and horizontally averaged to give a two-dimensional ($H_n \times V_n$) mean volume backscattering strength ($\bar{s}_v$) array (Fig. 2), where H_n and V_n are the number of cells in the horizontal and vertical dimensions (parameters: horizontal and vertical bin size). For spatially-explicit data processing, $\bar{s}_v$ is volumetric relative density (m^{-3}) in each cell. The $\bar{s}_v$ array and individual target information are passed to the post-processing procedure for estimates of fish density, length, and abundance.

3.1. Spatially-explicit post-processing

Post-processing computes nnmeric densities for all fish, partitions the fish into different length classes, and computes numeric density for each length class (Fig. 1). We used the conceptual framework of MAVAIR (Multi-frequency Acoustic Visualization And Information Retrieval System, Kirsch, 1992). Length-classes are user defined and should reflect

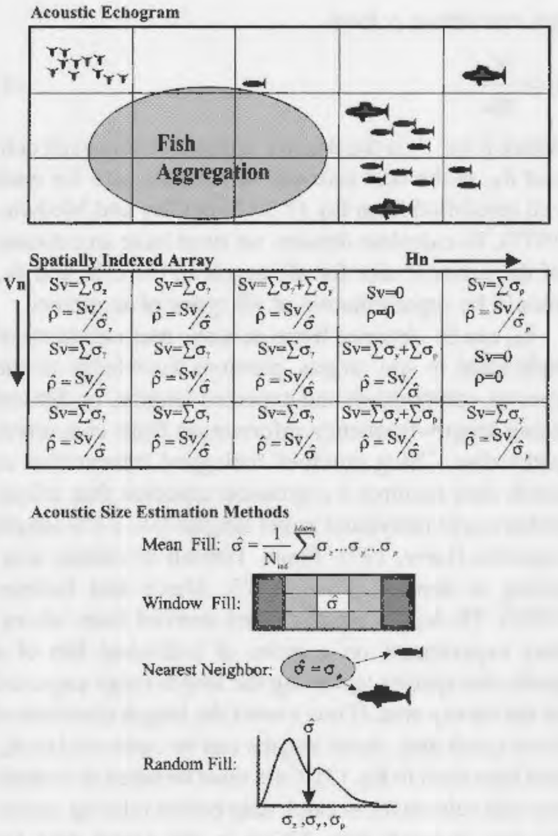

Fig. 2. Visualization of an echogram showing a large fish aggregation (i.e. shoal or school), large individual predators, smaller prey fish, and aggregations of zooplankton. The lower array shows the data array for processing. H_n and V_n are the horizontal and vertical dimensions. s_v is volume scattering, $\hat{\rho}$ is the density estimate (m^{-3}) in each cell, and $\hat{\sigma}_p, \hat{\sigma}_y$, and $\hat{\sigma}_z$ are the estimated acoustic sizes for predators, prey, and zooplankton, respectively. $\hat{\sigma}_?$ are acoustic sizes that must be estimated. The bottom panel shows diagrammatic representations of the four acoustic size estimation methods. The window fill method shows a horizontally elongated window.

the size structure of fish populations in the environment. Acoustic size is converted to fish length using regression equations derived by Love (1971, 1977), Foote (1991), or Fleischer et al. (1997).

To obtain numeric density (ρ) (m^{-3}) in array cells, we use the mean volume backscatter strength array, $\bar{s}_v$, and acoustic sizes, σ_{bs} in each cell. Assuming linearity and incoherent addition of scattering (Foote, 1983), the contribution to volume scattering by individual targets in each cell is proportional to their density, and we can obtain ρ from

$$\hat{\rho} = \frac{\bar{s}_v}{\hat{\sigma}_{bs}} \qquad (3)$$

where ρ (m^{-3}) is the density estimate within each cell, and $\hat{\sigma}_{bs}$ is the best estimate of acoustic size for each cell (modified from Eq. (7.3.13) in Clay and Medwin, 1977). To calculate density, we must have an estimate of the acoustic size for all targets in the cell, and $\hat{\sigma}_{bs}$ should be representative of all types of scatterers.

$\hat{\sigma}_{bs}$ can be obtained from: acoustic measurements of individual in situ targets, previous knowledge of the species composition and expected lengths, or derived using length–frequency information from concurrent catch data. Using previous biological information or catch data requires a regression equation that relates either σ_{bs} to individual target lengths (i.e. a TS–length equation (Love, 1971; Foote, 1980a)) or volume scattering to density (Love, 1975; Massé and Retiere, 1995). TS–length equations are derived from laboratory experiments on a series of individual fish of a particular species, spanning the length range expected in the survey area. If one knows the length distribution from catch data, these lengths can be converted to $\hat{\sigma}_{bs}$ and then used in Eq. (3). Care must be taken to include the size selectivity in catch data before relating acoustic size to catch data. Using in situ target data for estimating a representative acoustic size requires that fish be recognized as individuals. This constraint is due to the processes of multiple scattering and/or acoustic shadowing. An advantage to using in situ targets is that the distribution of acoustic sizes should be representative of the local distribution of fish lengths. However, data must be collected when fish are not schooling or in dense shoals.

Array cells may have at least one target, no individual targets due to a tight aggregation of fish, or low $\bar{s}_v$ and no individual targets (Fig. 2). In cells with individual targets, the weighted mean backscattering cross-section is calculated from the distribution of targets in each cell, and numeric density is computed by Eq. (3). In cases where no individuals are present, $\hat{\sigma}_{bs}$ must be estimated. In cells with no individual targets, but with non-zero volume scattering (e.g. fish aggregations with no resolvable targets), acoustic size can be estimated using (1) a weighted-mean from all in situ targets in the array, (2) a weighted-random choice from all in situ targets in the array, (3) a dynamic local-search window, and (4) a nearest neighbor (Fig. 2).

The first acoustic size estimation method uses a weighted-mean σ_{bs} from all individual targets in the array. This mean acoustic size is placed in all cells with missing targets. The second method uses weighted-random acoustic sizes chosen from the distribution of all individual targets in the array. In this case, the random choice is weighted by the probability of occurrence for each size and is updated for each cell. These methods assume homogeneous fish scattering types or species throughout the array. The third method uses a dynamic local-search window. This window searches for in situ targets by beginning with array elements immediately surrounding a cell and then increasing in size until either a minimum number of targets is found or a maximum window size is reached. Three window parameters: maximum window radius, window shape, and minimum number of targets, define the search pattern and the target distribution used to obtain a representative acoustic size. The search pattern may vary from a symmetric shape to an elongated shape to accommodate different spatial distributions of organisms. Fish species often segregate at thermal fronts (Brandt, 1993), and elliptical search patterns will estimate $\hat{\sigma}_{bs}$ from individuals more representative of spatial distributions of species. A minimum number of targets within the search window provides a distribution of targets for acoustic size estimation and avoids a nearest neighbor search. A maximum window size restricts the search pattern to a local area where similar species are expected, and avoids searching the entire array. When the minimum number of targets is found, the weighted-mean of those targets is used as the representative acoustic size. If the maximum size is reached and no in situ targets are found, cell density is set to zero. The fourth acoustic size estimation method is the nearest neighbor method, where the acoustic size of the nearest target is used as the representative size. If two or more targets are equi-distant, then the weighted-mean of those targets is used as the representative acoustic size.

The methods to estimate $\hat{\sigma}_{bs}$ for calculation of numeric density in length classes are identical to those above but use targets in each length class exclusively. $\bar{s}_v$ in each cell, is proportioned to the number of targets in each length class (a proportion of the number of targets in all length classes in each cell). Numeric density for each length-class is then computed using the proportional cell density and $\hat{\sigma}_{bs}$ in each length class. The proportional number of targets in a length class (η_j) is

$$\eta_j = \frac{N_j}{\sum_{j=1}^{M} N_j} \tag{4}$$

where N_j is the number of targets in the jth size class and M is the number of length classes. We then proportion $\bar{s}_v$ in the cell by

$$\hat{\rho}_j = \frac{\bar{s}_v \eta_j}{\hat{\sigma}_{bsj}} \tag{5}$$

where $\hat{\sigma}_{bsj}$ is the acoustic size of the jth size class. This method assumes that all scattering is due to similar scattering types, and that volume backscattering follows the linearity principle (Foote, 1983). Acoustic data can be collected at night, when fish tend to be dispersed and are less likely to be found in tightly packed schools. Other analytic techniques are required to estimate the density of fish schools (Massé et al., 1996; Misund, 1997).

4. Applications and discussion

One caveat for spatially-explicit acoustic data analysis is that each array cell must have an estimate of an acoustic size. When cell dimensions are small, the probability of detecting individual fish decreases and methods other than using in situ acoustic targets must be used. Conversely, cells that are too large may contain a greater diversity of target types making $\hat{\sigma}_{bs}$ less accurate. Echo statistics and probability density functions (PDFs) can be used to resolve "dense" vs. "loose" aggregations (Stanton, 1985; Stanton and Clay, 1986), and potentially to resolve scatterers of similar or varied types. The acoustic size estimation methods currently implemented use a distribution of targets from either individual cells or the entire array. In addition, with the exception of the nearest-neighbor acoustic size estimation method, the representative acoustic size is calculated by weighting individual targets by their frequency of occurrence. Using weighted distributions should improve estimates of the representative acoustic size and have been applied to zooplankton acoustic data (Hewitt and Demer, 1993).

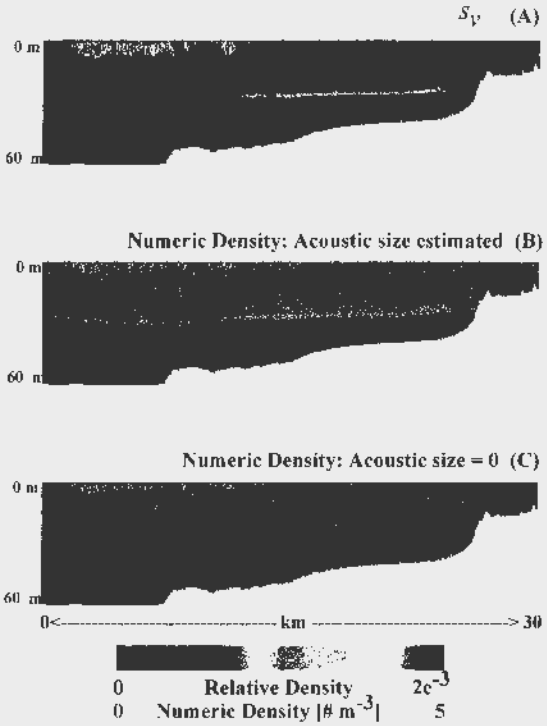

Fig. 3. Acoustic data collected during September 1994 in the eastern basin of Lake Erie used to illustrate the necessity for an accurate estimate of acoustic size. Panel A shows $\bar{s}_v$ at a spatial resolution of 0.5 m vertical and 50 m horizontal. A dense concentration of fish are aggregated at the thermocline (20–25 m depth). In this aggregation, few individual targets were detected. Panel B shows resulting numeric density (m^{-3}) distribution when $\hat{\sigma}_{bs}$ was estimated in cells without individual targets using the weighted-random acoustic size estimation method. Panel C shows numeric density distribution when σ_{bs} was set equal to zero for cells without individual targets. Panel B better represents the original distribution of fish.

Acoustic size estimation methods are necessary to compute numeric density for spatially-explicit data analysis, and as with any estimation technique, can potentially bias estimates. 120 kHz dual-beam (BioSonics model 102) acoustic data collected during September 1994 in the eastern basin of Lake Erie illustrate the necessity for an accurate estimate of $\hat{\sigma}_{bs}$ (Fig. 3). A dense concentration of fish are aggregated in the thermocline at 20–25 m depth (Fig. 3A). In this aggregation, few individual targets were detected. Two estimates of $\hat{\sigma}_{bs}$ are compared. The first method used weighted-random estimates, using the distribution of all targets in the data array, in cells without individual targets (Fig. 3B). The second method conservatively set the density in cells without individual targets to zero (Fig. 3C). The spatial density map with non-zero estimates better represents the original distribution of fish, whereas the distribution of the "zeroed" data does not adequately represent fish density at the thermocline. This example does not factor changes in cell size or the sampling design which may compound the variability in abundance and biomass estimates. These examples are given to show how one component of analyzing acoustic data affects abundance and biomass estimates. Variability in abundance and biomass estimates increases the uncertainty for fisheries managers when stocking or harvest quotas must be set. We would like to note that this is an area of interest in fisheries acoustics, and estimation methods are constantly evolving.

Data collected during July 1995, as part of the Trophic Interactions in Estuarine Systems (TIES) project, graphically represent various results using DEVIS. Data from a representative cross-bay transect, near the middle of Chesapeake Bay, were collected with a Simrad EY-500 split-beam echosounder operating at 120 kHz. Data have been corrected for transmission losses and beampattern effects. The two-dimensional $\bar{s}_V$ array has a resolution of 1 m vertical (V_n) and 20 pings horizontal (H_n) (Fig. 4a).

Numeric density (m^{-3}) for all fish sizes was calculated using the weighted-random $\bar{\sigma}_{bs}$ acoustic size estimation method in cells without individual targets (Fig. 4b). Conversion of acoustic size (σ_{bs}) to fish length was computed using a regression equation derived by Love (1971). Fish lengths in acoustic data correspond well with midwater trawl catches (Fig. 4c), where targets were identified as primarily anchovy (*Anchoa mitchilli*) in the 50–100 mm length range (Edward Houde, personal communication). Fish in the 12–200 mm length class contribute the greatest proportion to overall density (Fig. 4d). Fish biomass was calculated using a length–weight regression for bay anchovy (Luo and Brandt, 1993) and biomass density (g m^{-3}) distributions are presented in Fig. 4e.

In this paper we have not attempted to determine the "best" acoustic size estimation method or TS to length conversions. Methods to convert acoustic information to biologically meaningful numbers, especially the conversion from backscattering cross section to fish length, are continually improving. Backscattering by fish is strongly dependent on the orientation of the swimbladder relative to the transducer (Foote, 1985; Clay and Horne, 1994) which influences conversion to fish length (Foote, 1980b). Currently we use accepted TS–length equations and distributions of targets to compute "weighted" estimates of the representative acoustic size. DEVIS is a fisheries acoustic research tool to provide a convenient software environment for testing new algorithms to improve estimates of fish density, length, and abundance. As a research tool, the software is available for collaborative work.

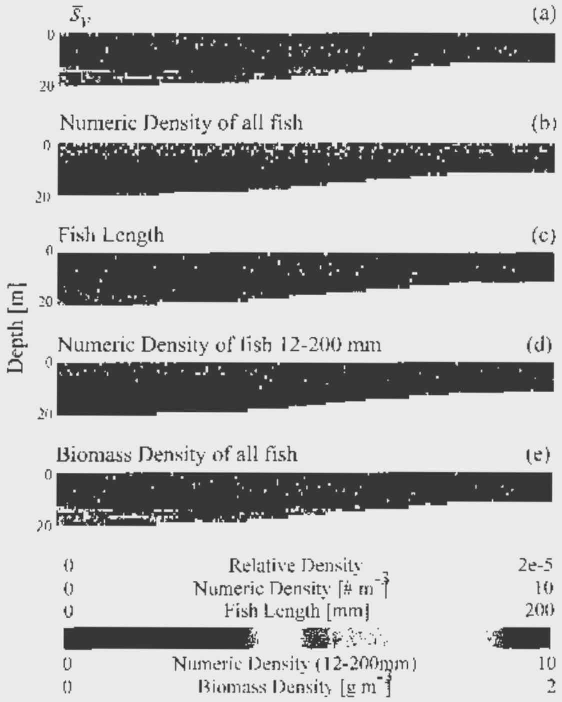

Fig. 4. (a) The s_v array. The color scale represents low (violet) to high (red) values in all echograms. The top of each echogram begins at 2.5 m below the surface (transducer depth is 1.5 m and blanking distance is 1 m) and ends at 1 m above the bottom. The transect is approximately 3.5 km; (b) Numeric density (m^{-3}) for all sizes of fish; (c) The average length of fish in each array cell; (d) Numeric density of fish in the size class 12–200 mm; (e) The biomass density (g m^{-3}) of all fish using an anchovy length–weight relationship. For all panels, the horizontal scale is 3.5 km, vertical resolution is 0.5 m and horizontal resolution is 50 m.

5. Conclusions

Spatially explicit analysis of fisheries acoustic data is desirable because it preserves the heterogeneity ubiquitous in spatial distributions of fish. We have developed a software system — DEVIS — to process, and spatially analyze and visualize fisheries acoustic data. DEVIS provides a software environment to efficiently test and implement fisheries acoustic algorithms. We currently use Simrad echosounder data as a model for processing and visualization, but post-processing, analysis, and visualization are independent of specific data formats. Spatially-explicit data analysis requires an estimation of average acoustic size, or a probability density function of acoustic size, for each array cell. Because acoustic size estimation methods may potentially bias abundance estimates, more research (e.g. sensitivity analysis) is needed for better accuracy and precision of acoustic estimates used in fisheries management and ecology.

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